The typology of industrial buildings with reference to the steel trades in Sheffield, 1750-1900

by

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Abstract

In 1900 Sheffield was at its peak as the world's greatest steel-manufacturing city, yet only two centuries earlier it had been a small market town with a speciality in knife-making. This thesis aims to document this dramatic transformation by industry, focusing on the morphology and growth of the town, and the unique building types that emerged there.

Case studies of individual sites are used to explore urban development, with particular attention to its spatial characteristics. Architectural prejudices of the past mean that in most cases little direct evidence survives, and many of the available sources are incomplete or fragmentary. Reconstruction of the working city is therefore a complex task, requiring the assimilation of data recovered from diverse sources.

Following an overview of the growth of the town, considering particularly the effects of geography, communication and land ownership upon its form, the factors conducive to steelmaking are assessed.

The opening case study is presented as a 'model' example, based on a complete recording and analysis of all available sources in order to present a comprehensive reconstruction of the progress of industrial sites over time. Taking as its subject Benjamin Huntsman's invention of the crucible steel process, the study is centred on the outlying village of Attercliffe where the process was first put into commercial production in buildings purpose-designed by Huntsman. Methodologies to interpret the different types of available evidence (including archaeological, documentary, survey and ephemeral) are introduced. Finally, a framework applicable to future studies is established.

Subsequent chapters build on the use of case studies to explore early steelmaking sites, the introduction of steam-power and the development of the heavy steel industries of the Don Valley.

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The typology of industrial buildings with reference to the steel trades in Sheffield, 1750-1900

Volume 1

submitted by

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Abbreviations used in the text

ACM	Arundel Castle Manuscripts
ARCUS	Archaeological Research and Consultancy at the University of Sheffield
BCL	Birmingham Central Library
BP	Boyle Papers (BP WD=work diary)
B&W	Boulton and Watt
CP	Correspondence papers (SCA)
EH	English Heritage
evid.	Minutes of evidence (Royal Inquiry)
FBC	Fairbank Collection (SCA)
FBC FB	Fairbank field book (SCA)
FBC MB	Fairbank miscellaneous book (SCA)
FBC NB	Fairbank note book (SCA)
NBR	National Buildings Record
NCRS	Newspaper cuttings relating to Sheffield (SCL)
OED	Oxford English Dictionary
OS	Ordnance Survey
RB	Rate book (SL / SU=Sheffield lower / upper division)
RCHME	Royal Commission for the Historic Monuments of England
SCA	Sheffield City Archives
SCL	Sheffield City Library
SIMT	Sheffield Industrial Museums Trust
SYCRO	South Yorkshire County Records Office
UGW	Union Grinding Wheel records (SCA)
VB	Valuation book (SCA)
WD	Walker Deeds (SCA)
YWD	Young Wilson Deeds (SCA)

Introduction

The extension of our towns has seldom proceeded according to any previously concerted plan, but by the caprice or convenience of the individual proprietors of the soil. Such was the case at Sheffield.

Joseph Hunter (1819) *Hallamshire*, p. 125.

This thesis has its origins in a long-standing fascination with the industrial buildings and culture of the South Yorkshire metalworking districts, centred on Sheffield which by the nineteenth century had become the pre-eminent seat of steel, tool and cutlery manufacture in Britain, if not the world. Sheffield's success did not arrive suddenly as the result of any specific technology or process, but evolved out of a medieval industry practiced alongside agriculture and animal husbandry (the limited evidence for which is discussed elsewhere) that laid the foundations for the more specialised trades to follow.[1] Adam Smith in his *Inquiry into the Nature and causes of the Wealth of Nations* distinguished such places from those that were established to serve the lucrative but capricious overseas markets in fashionable wares, suggesting that:

In this manner have grown up naturally, and as it were of their own accord, the manufactures of Leeds, Halifax, Sheffield, Birmingham and Wolverhampton. Such manufactures are the offspring of agriculture. In the modern history of Europe, their extension and improvement have generally been posterior to those which were the offspring of foreign commerce...[2]

The local inhabitants, too, assisted by skills brought by European immigrants, acquired a predisposition towards metalworking that was later to encourage the establishment of more complex processes in the town. Patrick Abercrombie, the pioneer of town planning in Britain, had in 1924 described Sheffield as the 'largest example of Mass Heredity in an English town and this must exercise a dominant influence on the continuance of its prosperity'.[3] Perhaps most importantly of all, Sheffield possessed unique geographical advantages in its location at the confluence of five rivers feeding into the Don,[4] and its proximity to the millstone grit and sandstone quarried in the Peak District to the west and plentiful coal measures to the east.

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[1] The best general summaries include Hey (1972) and (1991); Leader (1905) vol. 1, *passim*.
[2] Smith (1776) book 3.
[3] Abercrombie (1924) p. 10. His rather over-simplistic Darwinian reasoning suggested that: 'What has happened in Sheffield is (*a*) a tradition, (*b*) a community obviously fitted to accept and maintain the tradition owing to its natural inherited characters which have intensified because (i) owing to the strenuous and intricate nature of the task the weak or unfitted have been driven away or died without offspring, (ii) the strong and fitted have been drawn in from the outside. These two factors have increased the characteristics of the community—characteristics transmissible by inheritance—for the receiving and maintaining of a tradition, not in itself strictly inherited but handed on by precept and example'.
[4] The smaller rivers that circumscribe Sheffield's site are the Sheaf, the Porter, the Rivelin and the Loxley.

The rivers provided a natural source of power for mechanically-driven grinding mills and forge hammers, the local stone was hewn into grindstones and used in the construction of furnaces, and the coal provided an almost limitless supply of fuel for the forges and hearths.

All of these factors are in evidence at Abbeydale Works just outside Sheffield, a largely intact survival of the early industrial era that has been magnificently preserved and maintained against all odds.[5] [figs. 2.50, 2.51] The visitor is presented with a vivid tableau of the industrial processes that brought the region to global prominence, all performed in buildings almost domestic in scale and construction. Abbeydale's humble appearance belies the important contribution that this and other works like it made to the industrial development of the modern world. Similarly, most present-day visitors to Sheffield are unaware of the great importance of the place before the decline of its heavy industries. Its town centre is surprisingly devoid of the impressive architectural accoutrements of comparable centres such as Manchester or Leeds and as a result has been generally overlooked by historians.[6] While both Second World War bombing and post-war demolition have taken their toll, historic evidence reveals that Sheffield had always suffered from a dearth of investment. As early as 1824, resident author John Holland resignedly commented that:

> *Sheffield cannot boast of much display in public buildings; the establishment of conveniences for religion, charity, business, and amusement, is the certain consequence of the success of commercial enterprise and industry, and although Sheffield like other towns which have risen to importance, has its full share of such conveniences, there has hitherto been rather a deficiency of that public spirit which is necessary to give an appearance of splendour and ornament to its public edifices.*[7]

Priorities lay instead in the establishment and extension of manufactories and steelworks, while the successful industrialist looked to the green suburbs in the west for the laying out of his modest mansion and grounds. Sheffield's architectural interest must therefore be sought out in disparate places: in the narrow streets and cramped yards of the town, the multiplying suburbs that encircled it, and along the river valleys that radiate from it.

The author's involvement with industrial architecture emerged from a wider interest in functional building, particularly the relationship of form, function and culture embodied in the

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[5] Abbeydale Works is the only complete water-powered steel and tool-making premises remaining, its importance magnified with the sole surviving cast steel furnace still in its original state (see chapter 1). The author first visited in 1991, on his arrival in Sheffield.

[6] Until the post-war era, Sheffield could boast few grand public buildings and estates, urban spaces, squares and parks. Since then the situation has improved, and the city is one of the best provided for in terms of recreational parkland and green space in the country, although its urban spaces are still somewhat disappointing. The recently renovated Peace Gardens was the site of an old church and graveyard until the 1920s, as was the cathedral square. Tudor Square was clumsily formed by post-war demolitions, and has struggled to acquire an identity. The Town Hall has no associated public space, occupying an island site. Barker's Pool with its lacklustre war memorial is an incomplete twentieth century rationalisation of a traffic junction. The small Georgian Paradise Square–perhaps Sheffield's only genuine public space–is built on steep incline, and used today as a car park.

[7] Holland (1824) p. 112.

pioneering works of European modernism.[8] Subsequently, the diploma course in architecture at the University of Sheffield provided the opportunity to explore the local industries through a project to house the Hawley tool collection, an internationally important resource acquired for the city by the University and the vehicle for ongoing research. The site chosen was Leah's yard, an original complex of artisan's tenement workshops at the heart of Sheffield city centre, the future of which still hangs in the balance at the time of writing.[9] A concern with the meaning of the buildings' form and arrangement, and how this might inform any future use, prompted systematic research into its past that yielded important generative principles for the ultimate proposal, but also brought up wider issues of the relationship between place, history and design.[10]

Consequently, on beginning research into the present subject, a parallel study of Sheffield's urban development was initiated as a short group project in the diploma school, using the construction of a model of the town in the year 1900 as a vehicle for study.[11] In addition to the fascinating resource of the model, representing a place very different to the Sheffield of everyday experience and making sense of much that is disjointed and jarring in the present city, the insight gained through the supporting research encouraged many students to pursue major design projects based in the town. Being in possession of detailed knowledge of a site's past by no means resulted in historic parodies or an over-conservative approach to surviving fabric, but a more confident approach to the given, even if this resulted (as it occasionally did) in an informed decision to wipe the slate clean and begin again. Working with students over the past five years in the development of projects tackling problems of design within the context of Sheffield's post-industrial landscape has been a source of pleasure, interest and sometimes inspiration, and has no doubt contributed to the final direction of the thesis.

Other activities that augmented and enriched the content of these volumes include a collaboration with ARCUS (Archaeological Research and Consultancy at the University of Sheffield) on a historical survey of the Sheffield inner ring road proposal area, and a pair of exhibitions held at Sheffield's Mappin Art Gallery and City Museum, one exploring the architectural development of the Devonshire Quarter and the other using the 1900 urban study model as the centrepiece of an interconnected social investigation into the town's history.[12]

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[8] In parallel with this thesis, and also under the supervision of Professor Peter Blundell Jones, an exploration of the work of Hugo Häring (in particular his farm of 1923-26 at Garkau, Germany) has resulted in publications and models exhibited at the RIBA in London and various other locations.

[9] On completion of this thesis in summer 2003, the premises lie sadly vacant and boarded-up, having only a few years before been home to trades including a silversmith, upholsterer and stained glass maker, as well as shops to Cambridge Street. A proposal to convert the premises to yet another bar and restaurant has yet to materialise.

[10] The development of urban space through the example of Barker's Pool in Sheffield highlighted the lack of suitable resources available to the architect or town planner interested in the history of a site. Indeed, every year students on the architecture course duplicated research undertaken in previous years on the same streets and districts, unaware of its existence.

[11] The results of the first year of this project were published in an article by Professor Blundell Jones, the author and Dr J Lintonbon (at the time undertaking research into the typology of shops) in *arq*, vol. 3, no. 3 (1999).

[12] For the results of the inner ring road study, see Aitchison (2001). The exhibitions 'Cataclysm and continuity: Designs on the Devonshire Quarter' and 'Remember when...' were held at the Mappin Art Gallery and City Museum in 1999 and 2000 respectively.

The scope of the thesis

Turning to the present body of work, although the absence of any comprehensive appraisal of the architecture of the steel industry could easily justify such a study in its own right, an attempt has been made not to retrace ground covered by earlier studies in different disciplines, including archaeology, economic history and the history of technology. Significant works in these areas include the late Dr K C Barraclough's extensive publications on steelmaking, Crossley's survey of watermills, Beauchamp's thesis on Sheffield's cutlery workshops, Belford's archaeological appraisal of steelworks locations, Simmons' steel industry and estate development in Sheffield, Hey on pre-industrial metalworking, and the economic histories of Tweedale.[13] Special mention must also be made of the late Professor Sidney Pollard's unique contributions to the understanding of the intimately bound social and labour relationships that gave birth to the first Trade Unions.[14]

From an early stage, it was felt preferable to cover a relatively small number of studies in detail and to develop methodologies applicable elsewhere, than to attempt a comprehensive overview of each building type, the latter more the province of the RCHME's National Building Record (NBR), English Heritage, local archaeological organisations and archives. It is hoped that this thesis complements previous work through the careful selection of case studies, while developing lines of inquiry that could be equally applied to better-known examples.

The choice of subject areas was also led by the availability and discovery of primary sources, the in-depth study of Huntsman's steelworks being a case in point, but equally the decision to include Greaves' Sheaf Works, the Cutlers' Company steel furnaces and the Soho Wheel was prompted by access to fresh source material. The sketchy state of knowledge regarding some of the country's largest and best-known manufacturers may come as a surprise to anyone not acquainted with the subject. Secondary works generally reveal little of the built environment and can often be traced to single sources; practice and theory (the latter as expounded in eighteenth and nineteenth century textbooks) seldom appear to coincide. For this reason, the relationship of archetype and type, general and specific, is a thread running through the author's inquiries.

This scarcity of detailed information and accurate contemporary records is generally due to the low estimation in which contemporaries held industrial buildings, rather than to their age. Utilitarian structures were disregarded, thought not to be fitting subjects for the draughtsman, reporter or historian. Thus, the great mid-nineteenth century steelworks of the Don Valley can be as difficult to reconstruct as the smaller proto-industrial sites of over a century earlier. Finding sufficient evidence relating to specific buildings or firms has been a challenging

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[13] Barraclough (1984) 2 vols.; Crossley (1989); Beauchamp (1996); Belford (1997); Simmons (1995); Hey (1972) and (1991); Tweedale (1987) and (1995). Most of the case studies also fall outside of the area and timescale dealt with by the collective urban study project, as described above.

[14] See particularly Pollard (1959) *passim.* and Pollard (1971) introductory essay.

undertaking, and the availability of primary source material has greatly influenced the direction and content of the thesis.

Collections of artefacts made by those who still possess the knowledge of the traditional trades are invaluable in representing facets of manufacture that would be overlooked by scholars. Ken Hawley's collection of tools, for example, includes not only examples of every kind of Sheffield product, but in some cases unfinished specimens at different work stages, as well as the tools and machines used in the *making* of other tools. The ongoing research involved in cataloguing and interpreting the collection recognises that the knowledge of a particular artefact's use and origin is as important as the item itself. For example, the collection contains a number of anvils, all apparently similar, but with small variations that reflect their adaptation to different trades. Similarly, the family of several hundred hand-planes display an almost unlimited variety of forms and uses. It is from such people and their work that the author has attempted to derive something of the complexity and versatility of superficially straightforward trades and processes, and to apply this detailed critical method to the buildings and planning of the town.

A survey of this scope and depth inevitably produces a much greater volume of research than can possibly be presented in a single thesis, although it is hoped that the omitted content has been of benefit to the general understanding of each type.[15]

The aims of the thesis

One of the most urgent conclusions drawn from the author's research in particular and the Sheffield urban study project in general, is that the city is not sufficiently aware of the international significance of its early industry, and that cultural loss as a result of uninformed decision-making continues to date. This may be partly ascribed to the superficially unimpressive appearance of its eighteenth century craft-based methods when compared to the textile mills and blast furnaces that characterised industry elsewhere, and to the sprawling dirtiness of nineteenth century heavy steelmaking which, if not already gone, is mostly derelict and decaying. Fortunately, recent discoveries have raised the national profile of Sheffield's nascent steel industry, and continue to be made at an encouraging rate.[16] It is hoped that the following pages will help to restore the importance of Sheffield's industrial buildings within the modern tradition of architecture and urbanism. Popular histories have been content to promulgate the myth of the 'little mester' and his small workshop; this is to fall into the same

[15] It is the author's intention that much of this surplus material be made available to future scholars through the University of Sheffield and, copyright permitting, on the internet.

[16] From a position of extreme neglect, the study of Sheffield's industrial buildings and their landscape has recently begun to attract more attention. Sheffield's metal working infrastructure was the subject of a recently published English Heritage survey, Wray (2000) and (2001), and Sheffield is to be the subject of a new *Pevsner* city guide. The excavation and identification of John Marshall's mid to late eighteenth century steelworks at Millsands attracted publicity in the national press, see Wainwright (2002) in *The Guardian*, on Radio 4, and will feature in a forthcoming television production alongside recent discoveries at the site of Sheffield's medieval castle. Credit is due to James Symonds at ARCUS and others for their energetic promotion of these significant finds.

trap that Gatty, in his preface to the revised edition of Joseph Hunter's *Hallamshire*, felt had skewed the distinguished antiquarian's account of the town:

> *He [Hunter] liked to contemplate the great lord living in his feudal castle, with the smith at his forge in the little shop under its walls. The noise of the railways, and the great changes passing over the surface of the land for manufacturing accommodation–obliterating many traces of antiquity, and inimical to residential proprietorship–were not in harmony with this scholar's meditations.*

So there is still a tendency to disregard all that is complex, repetitive, impersonal and 'ugly', and to focus instead on the small-scale, homely, carefree world of the journeyman-cutler who inhabits the pages of Joseph Mather's poetry and Samuel Roberts' fiction.[17]

To redress the balance, this study focuses on building types and processes specific to the urban centres of Sheffield and its region, taking advantage of the town's relatively isolated existence before to the arrival of the railways which makes it an ideal closed system for the development and testing of typological hypotheses.[18] What made Sheffield unique was not simply the exclusivity of its steel trades, but the nature of the urban growth which resulted. Unlike most other British industrial towns, a combination of factors led to the development of industry not just in the surrounding countryside and valleys, but also within the town itself. This began in the late seventeenth century with the first establishment of steel furnaces in the town, followed by the proliferation of Huntsman's crucible process from the 1760s onwards, and soon after by the adoption of steam engines to power the grinding and rolling mills hitherto spread out along the five rivers. The extent to which Sheffield's local development interfaced with national and even continental politics and technological advances has also been underestimated, and frequent references to this wider context will be made throughout the text.

The author's research ran approximately in parallel with a major English Heritage appraisal of the surviving buildings of the Sheffield metal trades that has since resulted in the publication of a short report and the deposit of several building surveys with the NMR. In contrast, the present study is directed equally to buildings that no longer exist, and in some cases ones that have not existed for a century or more. This decision was made for a number of reasons.

First, much of what survives in Sheffield (or survived until the recent trauma of industrial collapse) was built in the late Victorian period, by which time the built-up area had already reached its maximum extent and its morphology become fixed. As one of the objectives of this study is to investigate the connection between industrial development and the growth of the town, the earlier instances of site formation are more likely to be fruitful.

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[17] See Mather (1862) and Roberts (1868) *passim*.
[18] The idea of the potential usefulness of a 'closed system' or artificially self-contained selection set in the development of architectural theory is due to Professor Norman Bayldon.

Secondly, many of the surviving buildings are inherently confused. Butcher's works, for example (covered at the end of chapter 2), appears to be a rather chaotic, integrated courtyard works, but is actually the culmination of many decades' change and growth. The same is true of Leah's yard, mentioned above. The complex palimpsest of functions under successive owners that characterises many industrial sites means that only so much can be deduced from the final physical condition of a site. Beyond this, the researcher must turn to archival sources and documentary evidence.

Thirdly, although the last thirty years have seen the wholesale demolition of the town's industrial core, the pattern of industry and methods of production had changed to such a degree by the twentieth century that even before the recent upheavals there would have been little recognisable to an inhabitant of a century or two earlier. For these reasons, the emphasis of the following case studies is on change over time rather than the representation of industry at a particular moment in its history.

Methodology

Fundamentally this study is based on the application of historical method directed toward the assembly of a theoretical framework for the development of the industrial town, using first-hand research from archival sources, archaeological evidence and secondary published material.

Relevant primary sources come in a variety of forms. Most useful in the opening stages of research were early town plans (1736-1832) and more accurate Ordnance Survey maps (especially those surveyed in 1850 and 1889). These enabled a rapid impression of the changing town to be formed, and helped to identify potential targets for more detailed investigation. A particularly comprehensive source of physical data from the late nineteenth century was the collection of Goad fire insurance plans, which show not only site layouts, but also storey heights and specific details such as chimneys, roof-lights, window and door locations, and in some instances even the materials of which buildings were constructed. These plans were used to great advantage by the diploma course students engaged in reconstructing the city of 1900. Their principal drawback for this study was the late date of survey and small area covered, being mainly concentrated on the shops and offices of Sheffield's commercial centre.

General publications and guidebooks from the height of the industrial era also shed light on a broad cross-section of firms and their products.[19] To these must be added the impressive collection of company-specific trade catalogues in the Hawley Collection and the more abstracted listings of the local trade directories (starting in 1774 and published regularly until the late twentieth century), the use of which is discussed later.

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[19] See Pawson & Brailsford (1862); Taylor, Ed. (1879); 'Industries of Sheffield' (1890); Iron Steel and Allied Trades (1905) for a good impression of Sheffield's industrial base from the later nineteenth century.

More specialised resources unique to Sheffield are held by the Sheffield City Archives (SCA) and include the collection of detailed surveys and plans made by the Fairbank firm of surveyors (dating from the mid-eighteenth to mid-nineteenth centuries) and the comprehensive run of Poor Law rate books, maintained for the collection of a tax that was based on the rental value of land and buildings (these will both be examined in greater detail in chapter 1). The process of estate development under the management of Sheffield's major landowner, the Duke of Norfolk, is well represented by the Arundel Castle Manuscripts (ACM), also held at the City Archives.[20] Although much of its graphical content is duplicated by the Fairbank Collection (as the Fairbanks were the Duke's preferred surveyors), it also contains letter books, rental books and plans by other surveyors. Also to be found at the City Archives are resources specific to particular firms, including minute books, ledgers, deeds, letters and plans. These will be referred to throughout the text at the point of use. Unfortunately Sheffield's collection of planning applications dating from the 1860s has been destroyed, save for a small subsection of 'significant' drawings that exist as poor microfilm copies. For some sources such as the Fairbank surveys and rate book evidence it has been necessary to develop specific methodologies over the course of the study, and these too are detailed in the text and the relevant appendices.

Collectively, these sources can be employed at a number of different scales. At the level of the urban quarter, the general character and development of a district can be plotted, as attempted by the groups of students during the urban study project. Zooming in on the individual plot under single ownership, a more specific picture of industrial activity can be reconstructed. Within the plot, individual buildings can be selected as vehicles for detailed study. The case studies that comprise the main body of text embrace this entire range of scales, but are generally centred upon the middle ground of the building plot. It is hoped that by drawing on the specific it is possible to move beyond the abstractions of morphological plot analysis as espoused by Conzen and others, and to arrive at a more complex matrix of evidence.[21] The intention is to present a broadly chronological narrative, based on activities from the scale of the individual to the everyday life of the urban quarter.

Appropriately for a study that originated with a design project, the process of formal reconstruction used throughout could be considered a closely circumscribed extension of the design process. The available historical documentation relating to industrial buildings (and specifically to their spatial arrangement) is limited in its detail and, in the absence of full architectural or survey drawings, cannot be used to reconstruct form directly. In this situation, interpretation and a level of design input is essential, and the term reconstruction may be considered the reverse of critical analysis. The objective is to go through the same sequence of decision making as the original designer, ultimately arriving at the same result for the same reasons. Although this method may appear unscientific to the pure historian, it is a valuable

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[20] Other significant landowners were the Church Burgesses, the Town Trustees and the Earl of Shrewsbury, all represented by documents at the City Archives.
[21] See Conzen (1962), (1966) and (1978) for his unique methods of plan analysis.

tool if employed judiciously and within suitable constraints. Even in the best of cases a high level of contextual understanding is required, and the results must be treated with caution, but under certain conditions it can be surprisingly rewarding.[22] It has even proved possible to reconstruct three-dimensional form from purely textual evidence, using object-oriented computer modelling to assemble groups of elements derived from bills of quantities, a technique that will be expanded upon in the appropriate place.[23]

Many studies, notably those in the fields of economic and social history, attempt to reach general conclusions by the abstraction of large statistical groups, and the identification of patterns and similarities. While to a certain extent this cannot be avoided, and is certainly capable of yielding valid results, it often leads to significant oversights and generalisations and denies the presence of the unique or anomalous. By taking a small number of studies in greater detail, a wider more complex range of parameters can be explored, and their impact assessed in specific terms. Moreover, the results–although connected with specific circumstances–may be transferable to other cases, offering potentially more authoritative conclusions.

It is this combination of the particular and the general along with the ability to identify and examine contextual responses that, in the author's opinion, makes the case study an ideal vehicle for the exploration of urban history and the morphological development of the built environment.

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[22] On more than one occasion the author's 'assumptions' have been confirmed by the subsequent discovery of additional evidence, as in the cases of Huntsman's 1842 steel furnaces (chapter 1) and the Cutlers' Company premises on Scotland Street (chapter 2).

[23] This was employed in the examples of the Cutlers' Company furnaces (chapter 2) and Josiah Fairbank's proposal for a steam-powered grinding wheel (chapter 4).

Chapter 1: The birth of an industry–Benjamin Huntsman and crucible steel

Abstract

The opening case study is intended to be a 'model' example, based on a complete recording and analysis of all available sources. Taking as its subject Benjamin Huntsman's invention of the crucible steel process, the study is centred on the outlying village of Attercliffe, where the process was first put into commercial production in buildings purpose-designed by Huntsman himself. Tracing its progress from the earliest backyard furnaces to the eventual domination of the historic village centre, the study re-evaluates the scholarship to date, and confronts problems of interpretation. The methodologies adopted to interpret the different types of available evidence–including archaeological, documentary, survey and map-based, business ephemera–are introduced, and used to present a comprehensive reconstruction of the firm's progress over time, while also establishing a framework applicable to future studies.

Introduction

During the period covered by this study (1750-1900), Sheffield made the transition from a small market town specialising in cutlery wares and edge tools into the world's greatest steel manufacturing city. The reasons for this dramatic transformation are various and complex, yet had it not been for the invention of a Doncaster clock-maker, the face of the city at the opening of the twentieth century may have been very different.

The clock-maker was Benjamin Huntsman and his invention paved the way not only for all modern steel casting processes, but also the development of the alloy steels without which most of the developments of the last century would have been inconceivable.[1] In 1845 Engels understood the importance of Huntsman's cast steel to the new generation of tools it made possible, which in turn catalysed the industrial development of Britain and the rest of the world.[2]

Although cutlery and steel-making had been practised in Sheffield long before the introduction of Huntsman's process, it was the latter that provided the catalyst for the city's developing steel industry, without which the later heavy industries of the Don Valley–the source of Sheffield's great fortunes–would almost certainly not have developed there.

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[1] Although Huntsman himself did not develop steel alloys, his process was used by Faraday in his pioneering work, as discussed in chapter 3. It is also of interest that the Bessemer converter began its life as a modified crucible furnace, see chapter 5.

[2] Engels (1969) 'Huntsman, a Sheffielder, discovered in 1740 a method for casting steel, by which much labour was saved, and the production of wholly new cheap goods rendered practicable; and through the greater purity of the material placed at its disposal, and the more perfect tools, new machinery and minute division of labour, the metal trade of England now first attained importance'.

Unlike many of the other inventions that transformed Britain's fortunes during the eighteenth century–Watt's rotary steam engine or Arkwright's water frame, for example–Huntsman's crucible process (as it is popularly known) was a deceptively simple idea. In short, it involved bringing pieces of common cementation steel to complete fusion in a clay crucible, or 'pot', placed in a suitably constructed air furnace, before pouring the molten metal into a cast-iron ingot mould. It was the first method by which homogeneous steel ingots could be cast, and their quality precisely controlled; it also allowed the addition other metals to the steel charge, to produce alloys.

The process also had an extremely long lifespan compared to most inventions, remaining in commercial use for over 200 years. Until the 1860s, all steel castings from the smallest ingots to the largest castings of many tons weight were still made of metal poured from individual crucibles, and for applications dependent on special steels its use continued well into the twentieth century. Sheffield almost monopolised the world market for cast steel, and over the two centuries of its production, the bulk of the world's crucible steel came out of Sheffield.

From the beginning, its inventor was largely overlooked, possibly no more so than in Sheffield itself. During Benjamin's lifetime, foreign interest was more pronounced–consequently most of the contemporary evidence comes from European visitors–while at home there was even a certain degree of resistance to his new steel. Even today, in the city that benefited most from Huntsman's invention, there is little recognition of his importance, save an oversized bronze statue of steelworkers that stands awkwardly in the nearby Meadowhall shopping centre.

There has been a similar paucity of research into the subject; the best published account is R A Mott's 1965 article in the *Journal of the Iron and Steel Institute*, and an informative (but sometimes inaccurate) commemorative pamphlet by K C Barraclough was produced for the 200th anniversary of the inventor's death.[3] Certainly, there has been no significant new research on the subject in almost three decades, which had been considered by many to be exhausted.

On the other hand, there is a relative dearth of primary evidence regarding the invention, as is so often the case in the history of industrial developments. Accordingly, the course of this study would have been different had new information not come to light relating to the origins of steel-melting in Sheffield.[4] Consequently, a case study of Huntsman's invention and the birth of the new crucible furnace building type has been used to demonstrate an approach to spatial reconstruction that draws on a variety of sources, both visual and textual.

The study also differs from the others in being outside the town of Sheffield, although still subject to its influence. As an 'ideal' study, closely circumscribed by its locality–the village of

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[3] Mott (1965). Barraclough (1976) the text of which, with minor additions, formed the basis of the first chapter of his book *Steelmaking before Bessemer: Crucible Steel*, Barraclough (1984) vol. 2.
[4] The lack of a coherent background to the development of Sheffield's industrial buildings, and the chance discovery of a number of previously unrecognised sources early in the study period, were the main stimuli to the development of the methodology used throughout the study.

Attercliffe–it is perhaps better suited to illustrate in detail the methodology adopted, before embarking on the larger-scale study of Sheffield.

Due to its length, the study is organised as two chapters, each dealing with a particular area of research. The first deals with the context within which Benjamin Huntsman made his discovery, including a short history of the steel that he set out to imitate. Particular attention is paid to the contemporary scientific understanding of steel and iron, and to the emerging industrial developments at that time. While it is not the intention to give a technical account of Huntsman's steelmaking, a knowledge of the processes involved is essential to the later reconstruction and interpretation of the buildings and landscape that evolved from these developments.[5]

Second is a study of the works themselves, from the first buildings at Handsworth, through the development of the steelworks at Attercliffe, ending in the twentieth century with the final relocation to the Coleridge Road plant.

Although Benjamin, as the originator of the process, has dominated the history of the subject, this study also considers the influence of the succeeding Huntsman generations. Almost from the death of Benjamin onwards, there has been a tendency to confuse his achievements with those of his son, and even his grandson. This may be in part due to the continued use by his son and successor, William, of the name 'B Huntsman'–stamped on the steel ingots, as the name of the business and even as a signature on letters.[6] In addition, most of the oral history relating to Benjamin's life can be ascribed to his grandson, Francis.

In common with most of the other firms addressed by this study, the history of Huntsman firm can be traced over a number of generations; consequently, the recognition and understanding of the development over time of the business and its infrastructure is vital to the study both of industrial buildings and of the industrial town, and constitutes one of the major themes of this thesis.

[5] For a more detailed exploration of the technical aspects of Sheffield steelmaking, see Barraclough (1984) 2 vols.
[6] The 1797 trade directory, for example, lists 'Huntsman William, Attercliffe, marks B. Huntsman'; Robinson (1797). The business was later known as 'B. Huntsman, Ltd'. Also refer to items from SCA PhC 373, Letters book (1757-1808) e.g. 29 September 1791, 13 September 1794. Charles Sanderson, in his essay on steel manufacture, even confuses son with grandson, Sanderson (1855) p. 455.

Part 1: The prehistory of crucible steel

> *There is another sort of Steel, of higher commendations than any of the forgoing sorts. It is call'd* Damascus-steel; *'tis very rare that any comes into* England *unwrought, but the* Turkish-Cymeters *are generally made of it…these* Cymeters *are, by many Workmen, thought to be cast Steel.*
>
> Moxon, *Mechanick Exercises*, 3rd ed. (1703) p. 59.

Steel from Damascus: the first encounters

Since the early Middle Ages, small quantities of a mysterious metal had made its way into Europe by the trade routes from the East. It was known almost universally as 'Damascus steel', apparently after the Syrian city that had become its principal marketplace.[7] It arrived already wrought into fine blades–Turkish scimitars and swords–especially prized for their high polish and the distinctive 'water pattern' upon their surface.[8] [fig. 1.1] Its appearance alone was sufficient to set it apart from the common European steel (at that time little more than a 'steely' iron), but it was in its physical properties that the real differences lay.

The steel goods from Damascus had qualities unlike their western counterparts, an almost unbelievable combination of springiness and strength, sharpness and toughness. Swords made of the metal could be bent double yet instantly spring back to their original form. Compared to the weighty, imperfect steel produced by the European methods of carbonising wrought iron by laborious case-hardening and smithing, or direct from the bloomery (see chapter 2), it must have seemed almost magical–a high performance material of unknown origin.[9]

It seems that steel of this kind had been made since the late classical period. Iron was one of the seven ancient metals (the others being gold, silver, copper, tin, lead, and mercury) and the first steel was probably made directly from certain iron ores rich in trace elements. Curtius Rufus, in his *Life of Alexander the Great*, related that the defeated Indian legation made Alexander a gift of one hundred *Talents* of '*ferrum candidum*', or 'bright iron' thought to be Indian steel.[10] Long before the development of Damascus forged steel, this form of crucible steel was widely employed in India and the Middle East simply as a good homogeneous steel,

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[7] Biringuccio (1540) fol. 19r, calls it 'il Damaschino'; Porta (1658) 'Damask steel'; Boyle (1692) 'Damasco steel'; Moxon (1703) 'Damascus-steel'; Zedler (1744) vol. 7, col. 74, 'Damascener-Eisen'; Diderot *Encyclopédie*, vol. 1, p. 107, 'l'acier de Damas'. Feuerbach (2002) notes that the steel was known as 'Damascus' in Arabic long before its use in Europe, and gives a number of hypotheses for its origin.
[8] Moxon (1703) p. 59, states that "tis very rare that any comes into *England* unwrought, but the *Turkish-Cymeters* are generally made of it'; Giovanni Battista della Porta (1658) described the recycling of steel from broken Damascus swords, indicating the value and scarcity of the material.
[9] Aitchison (1960) vol. 2, pp.350-355; Tylecote (1992) see pp. 75-81 on early medieval iron and steel.
[10] Rufus (1690) p. 364 trans. '100 Talents of Latten', '*ferri candidi talenta C*'; Beckmann (1814) p. 248; Mushet (1840) p. 366.

later to be known as 'wootz'. It has been suggested that tools of this metal were the only ones that could have carved the granite and porphyry of the ancient Egyptian temples.[11] The first detailed description of the production of this steel was that written by Zosimos of Alexandria in the third century, but the method is probably several centuries older.[12]

It was probably during the first crusade that Europeans first encountered Damascus blades. European armour had been developed to withstand heavy, blunt instruments, and the crusaders found themselves quite unprepared for the sharp, light weapons of the Saracens, which must have been devastatingly effective. Consequently, weapons of this steel acquired an almost mythical status, of which the best known is Saladin's fabled sword, the precursor to many of the stories of magical swords from the *Arabian Nights* onwards. Although a fictional account, Sir Walter Scott's *The Talisman* incorporates some of these myths, while evoking the character of Saladin's scimitar of Damascus steel, described as:

> *...a curved and narrow blade, which glittered not like the swords of the Franks, but was, on the contrary, of a dull blue colour, marked with ten millions of meandering lines, which showed how anxiously the metal had been welded by the armourer.*[13]

Although traded at Damascus, the marketplace of the desert, the steel itself came from much further inland, so that both the means of its production and its place of origin were shrouded in mystery.[14] One of the first western travellers to encounter the steel in its native country was Marco Polo who, toward the end of the thirteenth century, gave in his *Travels* some observations of steel and weapon manufacture in Kerman (a city in modem day Iran):

> *In this kingdom...there are also veins producing steel and* ondanique *in great plenty. The inhabitants excel in the manufacture of all the equipment of a mounted warrior–bridles, saddles, spurs, swords, bows, quivers, and every sort of armour according to local usage.*[15]

The 'ondanique' to which he refers, is taken to be the same steel used in the manufacture of the Damascus blades, although not necessarily displaying its characteristic pattern as this was only developed through careful polishing and etching.

In the centuries that followed, few new accounts were published; those that were abounded with rumours and hypotheses as to the manufacture of the steel. One of the earliest

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[11] Mushet (1840) p. 669, cites a letter from J M Heath, who held this belief. Also see Smiles (1863) p. 99 'The Hindoos were especially skilled in the art of making steel, as indeed they are to this day; and it is supposed that the tools with which the Egyptians covered their obelisks and temples of porphyry and syenite with hieroglyphics were made of Indian steel, as probably no other metal was capable of executing such work'.

[12] Lang (1998) p. 10, also cites Berthelot (1888).

[13] Scott (1825) chapter 27. In a test of strength, King Richard cuts through a solid iron bar. Unperturbed, Saladin demonstrates the superiority of his weapon by first bisecting a soft cushion with a single stroke before severing a fine veil allowed to fall onto the blade as a demonstration of its extreme sharpness.

[14] Moxon (1703) p. 59, found that 'no certain Account could be gain'd where it is made.' Biringuccio (1540) fol. 19r, admitted 'I do not know how those people obtain it or whether they make it'.

[15] Polo (1958) p. 62, The term 'Ondanique' is thought to be a corruption of the Persian word 'Hundwaniy', or the high-grade steel later to be known as wootz; also see p. 69, where in Kuh-banan he found similar steel production, including the manufacture of large polished steel mirrors.

publications on metallurgy, Vannoccio Biringuccio's *De la Pirotechnia*, contained the following account:

> *I do not know how those people obtain it or whether they make it, although I was told that they file it, kneed it with certain meal, make little cakes of it, and feed those to geese. They collect the dung of these geese when they wish, shrink it with fire, and convert it into steel. I do not much believe this, but I think they do it by virtue of tempering, if not by virtue of the iron itself.*[16]

Biringuccio's doubts were not unfounded; this is, in fact, a retelling of an episode from the old Norwegian *Thidriks saga* (c.13th century), in which the blacksmith Weland using exactly this method prepared the steel for the sword *Mimung*–allegedly so sharp that it was capable of bisecting from top to bottom a man wearing a helmet.[17] That steel was at some time produced by this method is likely, and the resulting metal would have had many of the characteristics of cementation or case-hardened steel, but there is no evidence to suggest that this was true of Damascus steel.

Agricola's *De re metallica* of 1556, the most celebrated work on metallurgy of its time, paid little attention to steel, being content to recycle Biringuccio's text, but omitting the story of the geese.[18] [fig. 1.2] Likewise, Lazarus Ercker's *Beschreibung allerfürnemsten mineralischen Ertzt* of 1580 barely touches upon ferrous metallurgy, excepting the mysterious suggestion (probably an allusion to cementation) that:

> Iron *may be made (with a long and strong heat, and with hard Coals in a* Secret *glow) without dammage to good* Steel, *and the common* Steel *by* Smith-working *will turn into* Iron *again.*[19]

This limited state of theoretical knowledge persisted until at least the end of the seventeenth century, with most authors content to recycle extracts from Pliny, Agricola and other popular sources.[20] Of the few references in English to Damascus steel, Morden's *Geography Rectified* of 1680 simply paraphrased Polo's text, together with an element of the Weland myth:

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[16] Biringuccio (1540) fol. 19r. '*Laudasi in fra quelli di che ho notitia molto, quel che ha la Fiandra, & in Italia quel di Valchamonicha in Bresciana, & fuor di cristianita il Damaschino, el Chormani, & Lazzimino, & quel degli Agiambi, quali come loro gli habbiano o se gli faccino, non viso dire anchora che mi fusse stato detto, che altro acciaro non hanno che di nostri, & che gli limano & cõ certa farina gli pastano & fan pastelli, & dipoi gli dan mangiare a loche, lo stercho deliquali quando lo par ricogleno con el fuocho lo ristrengano' & conducano in acciaro, ilche nõ credo molto, ma penso bene che tutto quel che fanno se non e per virtu del ferro proprio, sia per virtu di tempera.*'

[17] Ritter-Schaumburg (1999) pp. 64-65, 130-135. '*Velent geht nun zur Schmiede, / und nimmt eine Feile / und zerfeilt dieses Schwert ganz / zu Feilspänen. / Nun nimmt er das Feilicht / und mischt es mit Mehl, / und dann nimmt er Mastvögel / und läßt sie 3 Tage hungern, / und dann nimmt er das Mehl / und gibt es den Vögeln zu fressen. / Dann nimmt er den Vogelkot / und bringt ihn in die Esse / und schmelzt und schneidet nun / aus dem Eisen alles aus, / was noch an Weichem darin war. / Und daraus machte er ein Schwert.*'; 'Wayland now went into the forge and took a file, and filed down the whole sword to filings. Now he took the filings and mixed them with meal, and then he took fattening birds, and left them to starve for three days, and then he took the meal and fed it to the birds. Then he took the birds' excrement and brought it to the hearth, and now melted and cut out of the iron all of the softness that was in it. And from it he made a sword.'

[18] Agricola (1950) pp. 420-426; Carugo (1977) p. xl.

[19] Ercker (1686) book 4, p. 318. Taken from the English translation of almost a century later, by Sir John Pettus.

[20] Pettus (1683) p. 124.

> Kirman *towards the Ocean affords very fine Steel, of which they make Weapons very highly priz'd: For a Scymiter of that Steel will cut through an Helmet with an easie Blow.*[21]

Morden's statement was to be included by Joseph Moxon in his well-known *Mechanick Exercises*,[22] one of the earliest works to differentiate between the various qualities of steel then in use. 'The English-steel', by which he must have meant cementation steel:

> *...is made in several places in England, as in Yorkshire, Gloucestershire, Sussex, the Wild of Kent, &c. But the best is made about the Forrest of Dean, it breaks Fiery, with somewhat a course Grain. But if it be well wrought and proves sound, it makes good Edge-tools, Files and Punches. It will work well at the Forge, and take a good Heat.*

He went on to describe the other steels that were 'in general use here in England', namely 'the Flemish, the Swedish, the Spanish and the Venice-steel', giving examples of the appropriate uses of each, before introducing 'another sort of Steel, of higher commendations than any of the forgoing sorts', namely Damascus-steel.

European smiths found the Damascus steel almost impossible to forge; due largely to its high carbon content along with various impurities such as phosphorus and sulphur, it required temperatures much lower than those to which they were accustomed.[23] Brought to a red heat, as used for most iron and steel, it would literally crumble away under the hammer–in Moxon's words 'It is most difficult of any Steel to Work at the Forge, for you shall scarce be able to strike upon a Blood-heat, but it will *Red-sear*'.[24]

Despite these difficulties, by the seventeenth-century the steel had earned a high reputation among workmen for its hardness, durability and strength. Indeed, for certain critical applications, where the benefits of its hardness and keenness of edge could justify the effort, it had become almost indispensable. Moxon noted that 'when it is wrought, it takes the finest and keeps the strongest Edge of any other Steel. Workmen set almost an inestimable value upon it to make Punches, Cold-punches, *&c.* of.'[25] Similarly, Giovanni Battista della Porta in the thirteenth book of his *Natural Magick*, 'On tempering steel', (1658) related that the rolls and draw-plates used by the silver and gold wire makers were made of steel from broken Damascus swords.[26] That it was a scarce commodity not in everyday use is also apparent. Thus Diderot, in his article 'Acier' from the *Encyclopédie*, while acknowledging the superiority

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[21] Morden (1688) p. 385. The first edition was published in 1680.
[22] Moxon (1703) pp. 57-62, from the chapter 'Smithing' deals with steel, its varieties, annealing, hardening and tempering.
[23] Verhoeven (1998) pp. 58-64, explains the effects of impurities in Damascus steel. Bréant (1824) pp. 267-271, noted that Réaumur had found no Parisian smiths able to forge the steel, blaming this on the workmen. See Holland (1831) p. 254; Comi (1996) *passim*.
[24] Moxon (1703) p. 59, by 'red-sear' means 'red-short', caused by an excess of sulphur in the iron; Porta (1658) p. 312, 'Too much heat makes it crumble, and cold is stubborn'; Verhoeven (1998) dicusses the special forging techniques likely to have been used by the Islamic smiths.
[25] Moxon (1703) p. 59.
[26] Porta (1658) p. 312. Also see p. 305, 'But of all the kindes, the *Seric* Iron bears the Garland, in the next place, the *Parthian*: nor are there any other kindes of Iron tempered of pure Steel: for the rest are mingled'.

of Damascus steel, nevertheless considered it pointless to dwell on the subject due to the extremely limited use of the metal.[27]

It is clear that the emerging disciplines of mechanics and engineering were in increasingly urgent need of an improved steel, and of a more certain supply than the scarce and expensive imported Damascus steel. Unfortunately, the metallurgy of iron belonged to that category of earthy, utilitarian subjects largely ignored by the early scientific community, with its roots in renaissance alchemy and metaphysics. It is therefore unsurprising that one of Britain's most progressive chemists was probably also the first to attempt to discover the secrets of steel, and in particular the manufacture of Damascus steel.

Robert Boyle and the search for refined steel

> *Gold, in comparison of other Metals, is nothing near so great as Alchymists and Usurers imagine. For, as it is true, that Gold is more ponderous, and more fix'd, and perhaps more difficult to be spoiled, than Iron; yet these qualities (whereof the first makes it burthensom, and the two others serve chiefly but to distinguish the true from the counterfeit) are so balanced by the hardness, stiffness, springiness, and other useful qualities of Iron; that if those two Metals I speak of, (Gold and Iron) were equally plentiful in the World, it is scarce to be doubted, but that Men would prefer the more useful before the more splendid, considering how much worse it were for Mankind to want Hatchets, and Knives and Swords, than Coin and Plate?*

Robert Boyle (1678) *Anti-Elixir*, p. 3.

Before the mid-seventeenth century the 'practical arts' were considered subject matter unsuitable for learned enquiry, possibly none more so than the earthy matter of the production of iron and steel. It is no coincidence that Agricola barely touched upon the subject, and most other metallurgical authors concentrated on the more noble gold and silver. There were a few isolated examples of 'philosophers' engaging in the commercial exploitation of industry, but these have (until recently) escaped the attention of historians.[28] One of the earliest formal organisations dedicated to the study of natural history was the Royal Society, established in 1663,[29] which brought together a unique and diverse body of men, including members of the former 'Invisible College'. Robert Boyle was one of the founding members, present at the

[27] Diderot (1751-65) vol. 1, p. 107. 'Il ne faut pas oublier l'acier de Damas, si vanté par les sabres qu'on faisoit: mais il est inutile de s'étendre sur ces aciers, dont l'usage est moins ordinaire ici'.
[28] A notable example was the involvement of the Rosicrucian mystic and philosopher Robert Fludd in an early attempt to establish the commercial production of steel by cementation, see chapter 2.
[29] Thomson (1812) a list of the founding members can be found in appendix IV from p. xxi.

Society's first meeting at which he was elected to the council. His scientific reputation had been established two years earlier with the publication of *The Sceptical Chymist*, still credited as one of the first landmarks of modern chemistry.[30]

Boyle's interest in iron and steel is a subject previously unrecognised, and this thesis takes its lead from a comment in Moxon's *Mechanick Exercises*. Written towards the end of Boyle's life, Moxon suggested that considerable effort had been expended to find the source of Damascus steel and the means by which it was manufactured:

> *We cannot learn where it is made, and yet as I am inform'd, the Honourable Mr.* Boyl *hath been very careful and industrious in that enquiry; giving it in particular charge to some Travellers to* Damascus, *to bring home an Account of it: But when they came thither they heard of none made there, but were sent about 50 Miles into the Country and then they were told about 50 Miles farther than that: So that no certain Account could be gain'd where it is made.*[31]

Steel, and Damascus steel in particular, must have been of particular interest to Boyle, being the hardest and most difficult to melt of all substances known at that time. Although he is generally regarded as the 'father of chemistry',[32] and to have discredited the *tria prima*–the alchemists' doctrine of mercury, sulphur and salt–he was nevertheless a practicing alchemist himself, and his understanding of metals remained largely in accordance with spagyric theory.[33] As early as 1649, at the age of 22, Boyle showed an interest in metallurgy, writing that 'Vulcan has so transported and bewitched me', as to 'make me fancy my laboratory a kind of Elysium'.[34]

A study of Boyle's recently published work-diaries reveals that his interest in steel manufacture went beyond that suggested by Moxon. Although the surviving papers do not record any attempts to create Damascus steel, many of his experiments betray a keen interest in the chemistry of iron and steel, beginning in the 1660s and reaching a peak about twenty years later. The *Sceptical Chymist* concludes with a brief speculation on the tempering of steel, and the effects of heat and cold upon the structure of the metal.[35] Further unpublished notes relate to the conversion of iron into steel, mines of 'native steele' and possible attempts to make steel by the fusion of Swedish iron ore (including the 'double bullet' iron, later to become a staple source material of Sheffield steelmakers).[36]

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[30] Boyle (1661) The book is famous for its definition of elements, which Boyle described as 'certain primitive and simple or perfectly unmingled bodies, which not being made of any other bodies, or of one another, are the ingredients of which all those called perfectly mixed bodies are immediately compounded, and into which they are ultimately resolved'. On this basis, he proposed that none of Aristotle's elements satisfied these requirements.

[31] Moxon (1703) p. 59. Moxon's story was presumably obtained at first-hand through his membership of the Royal Society where he was a close contemporary of Boyle. Thomson (1812) pp. xxi ff., appendix IV, 'List of the Fellows of the Royal Society'.

[32] See Pilkington (1959) *passim*. His book was entitled *Robert Boyle, Father of Chemistry*.

[33] Principe (1998) pp. 35-46, carefully examines the position taken by Boyle in his *Sceptical Chymist* (1661).

[34] *Dictionary of National Biography* (1886) vol. 6, 'Boyle, Hon. Robert', p. 119. Letter of 31 August 1649 to his sister, Lady Ranelagh. Vulcan was the roman god of metalworking and fire.

[35] Boyle (1661) pp. 440-441.

[36] BP 27, p. 63 (WD XXI) entry 380b: 'Mines of Native Steele: An inquisitive visiter of mines answered me that he had founde some that were propperly mines of steele rather then of iron, (of which mettles he had several times <seene>

By the early 1670s he had begun to speculate on the possibility of steel alloys, making an experiment on an alloy of iron and tin:

> *...for ought I know it has not yet been observ'd, what Phænomena, Iron or steele would afford, if it were reduc'd into extreamly minute parts & incorporated with an other Metal. And bec. I knew that thô it be difficult yet 'tis possible without salts or Sulphurs to melt Iron & Tinn into one masse, we caus'd equall weights of them to be melted down together, & causing one part of this masse to be beaten to a fine powder we found that the Loadstone would take up good quantitys of this Dust, as well if not better as if it had been ordinary fileings of meer iron.*[37]

Other work-diary entries include recipes for tempering-baths suitable for steel,[38] and for an intriguing 'flux', which he claimed would prevent steel from rusting:

> *[Take] equal parts of Nitre & the Lapis Hollandi, pulverise & mix them & cement with them your steel, ministring the fire by degrees & at a distance till at length the Crucible be & the contained matter be thorowly red hot and then the Worke will almost if not quite be perfected Tis to make A flux for steel That makes it britil metal but keeps it from rusting.*[39]

On the basis of contemporary theory, Boyle may well have considered the addition of a flux essential to the melting of steel, and perhaps to its subsequent quality–a belief also held by Huntsman, at least in his early trials (see below). This was possibly in consequence of Boyle's experience with gold 'cupelling', where the addition of other chemical substances was made to purify and reduce the melting point of the metal.[40] He also claimed to have had success in the reverse process of converting steel back into iron, using a glassworks-type furnace for the experiment:

> *[Take] peices of Iron steel of a convenient bigness, put them into a Crucible wherein they may be environd to a pretty thickness with Quicklime powderd*

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the Latter turned into the former'. BP 27, p. 155 (WD XXI) entry 746, May 8th 1668 '...the Spring maker told me, that he was wont to weild togather his Venetian Steele 4 or 5 time & forge it out as often, to bring to be fit to make Springs of. Hee likewise confess'd to mee, that he was faine sometimes to cast in cinders of Iron to bring [d] some sorts of Oare to fusion & that of (Swedish) Iron, the bullet Iron which is much the softest, is much fitter to be harden'd into steele than the other harder oare, which rarely or difficultly makes good Steele'.

37 BP 27, p.187 (WD XXIX) entry 215] This also demonstrates the belief that 'salts or Sulphurs' would lower the melting-point of iron.

38 BP 25, p. 68 (WD XXIV) entry 84; BP 27, p. 158 (WD XXI) entry 768. N.B. Biringuccio was of the opinion that the true secret of Damascus steel was in its tempering, and Boyle may well been attempting the same. Other texts of this period to publish recipes for tempering mixtures include Porta (1658) pp. 305-312, book 13, 'Of Tempering Steel', and Gold- und Silber Arbeiter (1708) pp. 175-185.

39 BP 25, p. 60 (Work Diary XXIV) entry 46. The mysterious ingredient 'Lapis Hollandi' might have been 'lapis ollaris' or potstone (steatite = a mixture of silex, iron, magnesia; also known as French chalk or talc). Otherwise, it was perhaps one of Boyle's many code names for substances, see Principe (1998); there was also an alchemist named Holland.

40 See, for example, Boyle (1678?) p.9, 'I put [two Drams of gold] into a new Crucible, first carefully neal'd, and...brought them to fusion by the meer action of the fire, without the help of Borax, or any other Additament, (which course, though somewhat more laborious, than the most usual we took to obviate scruples)...'

close the pot & keep it 8 or 10 hours or much longer in a strong a fire (as That of the glassehouse) to make it Iron againe.[41]

Even towards the end of his life, his inquiries continued,[42] and perhaps more would now be known of Boyle's experiments, had many of his unpublished alchemical papers not been lost at this time.[43] However, a posthumous book based on a compilation of his notes (published under the title *General Heads for the Natural History of a Country*) suggests that, despite his protracted efforts, Boyle never discovered the secret of Damascus steel. In a list of the yet undisclosed mysteries of Turkey, the elusive question remained: 'How their *Damasco* Steel is made'.[44]

Wootz steel and the birth of modern metallurgy

Following Boyle's investigations, the question of cast steel received little attention until Huntsman began his trials, the story of which is covered in part 2. Huntsman's steel furnished the early industrialists and engineers with a peerless material, unlike any previously available, yet even after it had come into general use the interest in Damascus steel remained undiminished.

When some imported cakes of metal from Bombay found their way to the Royal Society in 1795, they immediately became the subject of intense analysis and speculation. An article by Dr George Pearson in the society's *Transactions* announced the discovery by 'Doctor Scott', who had 'sent over specimens of a substance known by the name of wootz; which is considered to be a kind of steel'.[45] Pearson proceeded to make 'an elaborate set of experiments', from which he drew the conclusion that the wootz was 'a species of steel made directly from the ore, without ever having been in the state of soft iron'.[46] Mushet later showed Pearson's conclusions to be flawed, and carried out his own series of experiments, making a number of razors of the steel.[47]

It was not until the publication Francis Buchanan's *A Journey from Madras* of 1807 that a full account of the production of Indian steel became widely available.[48] Buchanan had been commissioned by the Governor General of India to investigate the commercial development of the country, and encountered steelmaking furnaces at a number of locations. He described

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[41] BP 25, p. 60 (WD XXIV) entry 44. Quicklime is calcium oxide, CaO.
[42] In a late series of experiments, the relative densities of accurately-turned iron and steel spheres were measured. BP 21, p. 205 (WD XXXVII) entry 53; BP 21, p. 214 (WD XXXVII) entry 90.
[43] Boyle (1688) single sheet fol., advertised for their safe return, but without success.
[44] Boyle (1692) p. 59.
[45] Pearson's article appeared in the *Philosophical Transactions* (1795) Vol. LXXXV, p. 322. The name wootz is thought to derive from a misprint of 'wook', itself an anglicised form of 'ukku', meaning steel in the south Indian states of Karnataka and Andhra Pradesh. Hadfield (1931) pp. 38-39, printed the symbol for it, as used on the cutler Stodart's business card.
[46] Thomson (1812) p. 497.
[47] Mushet (1840) pp. 650-678, and note B for Mushet's conclusion that Pearson had been in error. In fact, there were several methods of making crucible steel, at least one of which did involve direct production from the ore. See Tylecote (1992) pp. 77-9.
[48] Buchanan (1807) vol. 1, p. 175; vol. 2, pp. 16-22, figs. 40-41.

wootz as made by a method of in-situ carburisation, in small crucibles holding around 1 pound of wrought iron and a suitable organic carbon-rich material, in this case the woody stems and smooth green leaves of certain plants. This was then brought to fusion in a bellows-blown charcoal fire.[49] He also published the first drawings of the furnaces used to manufacture wootz, which show the arrangement of small crucibles stacked above the charcoal hearth.

The resulting product was an ultra-high carbon steel (around 1.5%) with a correspondingly high carbide content (around 20%), largely responsible for its sharp cutting edge. In an unhardened state, the steel displayed extreme ductility and toughness, and made into weapon blades was practically unbreakable. The distinct carbide formations in its structure were also the source of its renowned 'damasked' surface, often confused with pattern-welded steel, in which the more regular waviness is the result of forging together a bundle of twisted iron or steel rods. In true Damascus steel, the patterning was a direct result of the physical structure of the metal, liable to be destroyed by anything but the most careful methods of forging and tempering, and only exposed by grinding away the surface and etching with acid.[50]

Gradually, the fascination with wootz began to pay dividends. The Swedish chemist Torbern Bergman is alleged to have begun his experiments on the nature of steel because of his interest in a Damascus sword blade, which led to the discovery of the role of carbon in steel. In Britain, Michael Faraday's desire to simulate wootz in the laboratory was the key stimulus to his subsequent investigations into steel alloys, using Huntsman's crucible process as a vehicle for the experiments (expanded upon in chapter 3). After performing a careful and thorough chemical analysis of wootz samples, he admitted to being no closer to discovering the secret of its watered appearance:

> *I was desirous, among other researches, to make an experiment, with a view of imitating wootz. In this, however, I have not yet been very successful...*[51]

Faraday's inability to replicate wootz in his experiments did, however, demonstrate that the properties of the steel were not simply a result of the physical addition of chemical substances, or of alloying elements. Faraday's research partner in alloy steels, the cutler Stodart, had begun to use imported wootz commercially, in the manufacture of high-grade surgeon's instruments, razors and other cutlery items.[52]

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[49] Buchanan (1807) vol. 2, chap. 7, p. 20, 'In each [crucible] is put one third part of a wedge of iron, with three Rupees weight (531 grains) of the stem of the *Tayngada* or *Cassia auriculata*, and two green leaves of the *Huginay*, which is no doubt a *Convolvulus*, or an *Ipomea* with a large smooth leaf'; Mott (1965) p. 231; Lang (1998).
[50] Verhoeven (1998) and (2001) *passim*.
[51] Faraday (1819) p. 290. In conclusion, he felt that the substances comprising wootz must 'be either in a more perfect, or in a different state of combination, to what they are in alloys obtained by fusing iron for three or four hours, in contact with wood and the earths'.
[52] Hadfield (1931) pp. 38-39. Describes two of Stodart's trade cards, held at the British Museum. The later example, from about 1820, read: 'J. Stodart, at 401, Strand, London, Surgeon's Instruments, Razors and other Cutlery made from [symbol for wootz] a Steel from India, preferred by Mr. S. to the best steel in Europe after years of comparative trial'.

By the mid-nineteenth century, more was known of the nature of wootz, but the material had all but disappeared from the market.[53] The Sheffield steelmaker Charles Sanderson, in a lecture delivered in 1855, summarised the contemporary state of knowledge:

> *The first steel which may be called cast steel is the celebrated wootz of India; it is produced by mixing rich iron ore with charcoal in small cups or crucibles. These are placed in a furnace, and a high heat is given by a blast. After a certain time this ore melts and receives a dose of carbon from the leaves and charcoal charged with it. The result is a small lump of metal with a radiated surface about the size of a small apple cut in two; it is very difficult to work; nevertheless, swords and other steel implements are manufactured from it in the east; it is not found in England as an article of commerce.*[54]

Although modern chemical analyses have quantified the constituents of wootz and Damascus steel, the traditional arts of forging and tempering practiced by the Islamic sword-smiths have since been lost. Recent experiments suggest that source ores containing trace carbide-forming elements (e.g. Vanadium, Molybdenum, Chromium and Manganese) may have been responsible for the Damascene patterning, and that the depletion of these sources may ultimately have been responsible for the loss of the secret of Damascus steel making.[55] Vanadium in particular seems to have been critical, along with high levels of phosphorus, giving a very hot short ingot that would explain the Western smiths' problems of forging wootz.[56] .

[53] Scoffern (1857) pp. 367-368, also provides a good description, all the more interesting because of its likely authorship by Benjamin Huntsman's grandson (see part 3).
[54] Sanderson (1855) p. 455.
[55] Verhoeven (1998).
[56] The difficulties were described by Bréant (1824) pp. 267-271.

Part 2: Huntsman's invention of crucible steel

The early life and work of Benjamin Huntsman

Thus it fell to a provincial clockmaker and amateur mechanic to find a solution to the problem that had engaged scientific minds for centuries. Huntsman's success was not only a result of his practical background and untiring experimentation; equally important was the context in which his invention took place. It might be said that he lived at the right time and in the right place, as shall be demonstrated later.

Benjamin Huntsman was born in 1704 into a Quaker family living at Epworth in Lincolnshire. His grandparents were previously thought to have been Dutch immigrants, who adopted the suitably English surname 'Huntsman' on their arrival. However, tentative research by the author suggests that they belonged to a distinct family group that had lived in the vicinity of Brantingham in the East Riding of Yorkshire from at least the first half of the seventeenth century, and originally named 'Hunsman', indicative of their North European origins.[57]

As a practising Quaker he never had his portrait made, despite his later renown, and refused to take credit for his achievements.[58] This may also be the reason that so little is known of Benjamin's early life, save that he is said to have shown an uncommon aptitude for mechanical problems, resulting in his apprenticeship at the age of fourteen to an Epworth clock-maker at a premium of £4.[59]

Some time before 1725, Benjamin left the town of his birth to set up business on his own in Doncaster, about 20km to the west, where he quickly became successful as a watch and clockmaker.[60] From 1727 he was charged with the maintenance of the town clock at Butcher Cross, and subsequently of the new clock in 1735 (it is unclear whether he designed the later clock).[61] Both pocket watches and clocks made during this time still survive, and demonstrate the quality and attention to detail that characterised Huntsman's work.[62]

The story of his Anglican marriage in 1729, in breach of Quaker code, and his subsequent disciplining and possibly expulsion from the Society is well known, and covered elsewhere. It need only be said that he had two children, Elizabeth (b. 1730) and William (b. 1733), and that following the split with his wife, his son is thought to have remained with Benjamin in

[57] The evidence is presented in greater detail in appendix 1.2 The story of his parents being German was first published by Smiles (1863), but later disproved by Hulme (1943-45) although it persists in later studies, such as Inkster (1991) p. 51.
[58] Hunter (1869) p. 504. omitted Huntsman from his portraits of Hallamshire Worthies, 'with the expression of regret that a similar woodcut of the features of Benjamin Huntsman could not be procured, as there exists no picture of him'.
[59] Smiles (1863) p. 103. Hulme (1943-45) p. 37.
[60] He was described on his marriage certificate as a watchmaker, Mott (1965) p. 234. Hulme (1943-45) p. 37.
[61] Barraclough (1976) p. 2, note 11; Hulme (1943-45) p. 38. The records are kept in Doncaster Archives, Disbursement Registers.
[62] Hulme (1943-45) pl. II, 'Watch made by "B. Huntsman," c.1725-43', from the Ashmolean Museum, Oxford. A number of larger long-case clocks are also known, see Hulme (1943-45) p. 47; even today, examples occasionally come onto the market, e.g. *www.bgantiqueclocks.com/longcase_pages/clockc98.htm* (November 2002), a clock that belonged to Ferguson family of Walkington, Yorkshire from 1750.

Doncaster, while daughter and mother left for London.[63] By 1739 he was renting a fairly substantial house in the High Street, and bought the freehold two years later for £210.[64] His position as clockmaker and his responsibility for Doncaster's town clock probably allowed him the time and resources to experiment on a small scale, and it is generally believed that around this time he began the first tentative experiments with steel.[65]

What motivated Huntsman to develop an improved type of steel is not known. The most popular theory states that he was dissatisfied with the quality of steel then available for watch-springs, and determined to 'make from cementation steel the springs necessary for his craft which were then usually made of German steel'.[66] This opinion has been so widely published that it now passes for fact, yet there is reason to believe that it represents an over-simplification of the context in which Huntsman made his experiments.

It is true that at this time Huntsman would have been faced with the choice between common cementation or 'blister' steel and German steel. Blister steel was of high quality but lacked homogeneity, and had been made in Britain since the 17th century, although the process probably originated in continental Europe; Newcastle was particularly renowned for its cementation steel, and Sheffield's first furnaces were probably built towards the end of the century, a subject to be revisited in the next chapter.

'German steel', on the other hand, was a term then used for two different products–originally a forged steel derived from pig iron and imported in bars from Westphalia, but later to describe a similar product based on cementation steel (known in England as 'shear steel') which was probably first made around 1750 at Blackhall Mill on the Derwent, by 'Mr Bertram, a native of Remscheid'.[67] Huntsman is more likely to have been acquainted with the former, as half a century earlier, Moxon had noted that 'the Flemish-steel' (i.e. German steel) was the only steel employed in the manufacture of watch springs,[68] and the English variant only became widely available several years after Huntsman's experiments had begun.

His direct descendants noted that 'he had less to do with watches than with clocks, smoke-jacks, roasting-jacks, and other mechanical contrivances', and that his interest in steel was

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[63] Hulme (1943-45) *passim.* The rift between Benjamin and his wife is known only by local tradition. Allegedly, on the birth of William, his wife smuggled the child to an Anglican church in the vicinity of Sheffield in order to be christened, so enraging Benjamin, that he refused to speak to her again. The fact of his wife's burial in the cemetery at Attercliffe (before Huntsman's death) seems to contradict this story.

[64] Hulme (1943-45) p. 38 Leases for Doncaster survive: SCA PhC 445(a) Burden to Huntsman registered 6 Feb. 1741; PhC 445(b) Huntsman to Haigh registered 15 July 1742, according to which the 'messuage or tenement...contains forty one foot in front and the yard or garden at the back of the same contains thirty four feet in breadth within the walls...' (therefore larger than Benjamin's later Attercliffe cottage with its c.27 ft. frontage).

[65] Benjamin Huntsman (the younger) in letter to *The Times*, 3 January 1865; Smiles (1863) p. 104, based on the evidence of clocks made with steel pendulums, claimed 'his first experiments were conducted at Doncaster'.

[66] Mott (1965) p. 234 noted that it was Le Play (1843) who first published this evidence. Smiles (1863) p. 104, elaborated on the earlier account: 'he introduced several improved tools, but was much hindered by the inferior quality of the metal supplied to him, which was common German steel. He also experienced considerable difficulty in finding a material suitable for the springs and pendulums of his clocks'.

[67] Sanderson (1855) pp. 451-453. Angerstein (2001) p. 268. Mott (1965) p. 236, cites Flynn's reference to German steel making at Crowley's Swalwell works in 1754, *Transactions of the Newcomen Society*, 1954-55, 29, p. 259. Le Play (1843) p. 629, also stated its introduction by Crowley to have been 'towards the middle of the 18th Century', trans. Barraclough (1973) part 2, p. 27. Jenkins (1922-23) p. 27, however, speculated that shear steel may have been made at Swalwell as early as 1712.

[68] Moxon (1703) p. 58, '[Flemish Steel] is a tough sort of Steel, and the only Steel us'd for Watch-springs'.

more plausibly the result of scientific curiosity 'for he was a man to whom information on all subjects was welcome'.[69] In any case, Huntsman is unlikely to have been involved in the manufacture of watch springs, as this had become a distinct branch of trade, the springs usually 'made by a Tradesman who does nothing else'.[70]

He was, however, reputed to have been something of a polymath, known in the neighbourhood as a competent medic and oculist, and for his philanthropic use of these skills. In a letter to Huntsman, Matthew Boulton–proprietor of the Soho Works at Birmingham and founder member of the Lunar Society–paid tribute to the inventor's 'philosophick spirit'.[71] The very fact of Huntsman's early correspondence with Boulton, who was later to develop the rotary steam engine with his partner James Watt, places him tantalisingly close to the intellectual hub of the world's pre-eminent industrial centre.

It is also almost certain that Huntsman knew of wootz or Damascus steel, and possibly had first-hand experience of working with it. If so, he would naturally have welcomed a cheaper and more regular supply, and speculated on the possibility of producing the metal in small quantities for his own use.[72] By 1740 or 1742 he was sufficiently convinced of the viability of his ideas that he sold his town centre property, possibly at a loss, in order to move to a remote cottage near the small village of Handsworth where he could dedicate himself to the development of a workable process.[73]

The date of his commitment has been called into question, due to the fact that he took another apprentice in 1743, after his supposed move. However, it is probable that his clock and watch-making business, by then quite successful, continued in parallel with his experiments on steel; indeed, he would have needed extra hands to cover for the time he spent away from the trade. Whatever the case, Huntsman's decision marked the beginning of a lifelong quest, that was soon to lead him away from clock-making and Doncaster, and to have a profound influence on the industrial development of Britain.

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[69] Scoffern (1857) p. 347.
[70] Campbell (1747) p. 251, from chapter 54, 'Of the Watch-maker, and those he employs'. Intriguingly, the *Universal Lexicon* of Zedler (1844) vol. 39, col. 885, makes particular reference to the superiority of 'Englischen Uhrfedern' (English clock-springs). Contrasted with the earlier opinion of Moxon, this may be one of the first references to crucible steel at a time before Huntsman had begun commercial production.
[71] SCL Archives PhC 373, letter from Matthew Boulton, 19 January 1757. At this time the word 'philosophick' was synonymous with 'scientific' or the physical sciences.
[72] Hulme (1943-45) p. 44, was also of the opinion that 'This [wootz or Damascus steel] was the steel that Benjamin Huntsman set himself to imitate'.
[73] Le Play (1843) held the date to be 1740, information gained probably from Jonathan Marshall, nephew of John Marshall the steel caster, Huntsman's contemporary and best-known rival. See the following chapter. Other sources give the date of 1742.

Eighteenth century ideas of steel

The problem Huntsman set out to solve was relatively straightforward: how to create a homogenous steel, possessing similar properties to the scarce and expensive wootz, but in greater quantities and at a cost to compete with the better grades of imported European steel. Less obvious was exactly how these qualities were to be imparted to the steel then available, the production of which was itself something of a mystery. In fact, very little was understood of the chemical or physical composition of metals. That the difference between iron and steel lay in their relative carbon content had yet to be recognised, and the Phlogiston theory of Georg Ernst Stahl still held favour among scientists.[74] In the practical world, the techniques of iron smelting and steel making were more an art than a science, developed in most cases by trial and error.[75] Had Huntsman consulted any of the available scholarship on the subject of steel, he would have found little there to guide him.

He is most likely to have known Réaumur's milestone publication of 1722, *L'art de convertir le fer forgé en acier*, often cited as the first genuinely methodical work on the subject, and credited with significantly improving the understanding of the relationship between iron and steel.[76] Nevertheless, even his tireless experimentation had failed to yield any real practical results in the field of steelmaking, besides which he had come to the conclusion that to melt and cast steel was impractical, if not absolutely impossible.

Other popular theories of steel still reflected the Aristotlean (or perhaps more specifically Heraclitean) view of matter incorporated into Western alchemy: John Wesley, for example, considered fire to be the active principle:

> *As subtile as fire is, we may even by art attach it to other bodies; yea, and keep it prisoner for many years; and that, either in a solid or fluid form. An instance of the first we have in steel; which is made such, only by impacting a large quantity of fire into bars of iron.*[77]

Others held impurities responsible for the degradation of metals from noble to baser forms, iron being one of the lowest, earthiest examples. Thus, Biringuccio believed steel to be a very pure form of iron, a view that persisted well into the eighteenth century.[78] Either theory could

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[74] It was left to Bergman (1781) *passim.* to demonstrate the role of carbon in steel, by which time Lavoisier had also successfully refuted the Phlogiston theory. For a popular account of phlogiston, see Watson (1781-86) vol. 1, essay IV, pp. 165-167.

[75] Brearley (1995) in the preface to his 1933 book *Steel-makers*, suggests that the same was still true (to an extent), defining 'rule of thumb' operations as those led by 'experience, judgement and the ill-defined and unexplainable which guides a workman in producing results'.

[76] Réaumur (1722) dealt with number of topics, including the manufacture of steel by cementation, the 'malleablising' of hard white iron castings as a substitute for more expensive forgings of wrought iron, and an examination of the crystalline structures of steel. Horne (1773) although an admirer of Réaumur, noted that he had never seen any practical benefits come from his writings. See also Tylecote (1992) pp. 453-458.

[77] Wesley (1763) p. 76, part 4, ch. 3, 'Of Meteors'. This view was still prevalent after Huntsman's invention, which did little to contradict it.

[78] Biringuccio (1977) p. xl; *Zedler's Lexicon* (1744) vol. 39, col. 883, describes steel as purified iron, the differences explained in terms of the balance of salt, sulphur and mercury; in *Zedler's Lexicon* (1734) vol. 8, col. 608* iron is said to consist of 'much Salt, little Sulphur, and even less Mercury' ('vielen Saltz, wenig Schwefel und noch weniger Mercurius').

explain why Huntsman's attempts to improve steel were similar in principle to the long-established procedures used to refine precious metals, by melting in a strong furnace to burn out impurities and improve homogeneity and texture.

As a clock and watchmaker, Huntsman's profession demanded a range of mechanical and metallurgical skills. Surviving clocks and watches made while still at Doncaster include skilfully executed work in brass, steel, gold and silver. Huntsman would not necessarily have done all of the work himself, but a good working knowledge of these metals was essential, and he was no doubt familiar with their production, refining and alloying.[79] Gold and silver were still assayed and refined by the centuries old process of cupellation, namely the melting of the impure metal alloyed with a quantity of lead and a flux of various salts in small, porous bone-ash crucibles, or 'cupels'. This flux would react with both the oxidised lead and any other base metals present, before being absorbed by the walls of the crucible, leaving behind a 'button' of the purified precious metals.[80] The temperatures required were easily attainable in a small assaying furnace using charcoal as a fuel, the only limit being the scale of the operation.[81]

That common cementation steel suffered from a lack of homogeneity and unwanted impurities was known in practical terms; during production, the outside of the bar absorbed more carbon than the centre, giving it a more 'steely' character that gradually diminished towards the centre. Its texture also became coarser and more crystalline, the body of the steel peppered with tiny voids and fissures. Although the subsequent forging process gave the steel a more even, condensed character, streaks of slag would always remain, giving a product that was variable in quality and was never totally sound. Huntsman must have felt that if the refining process could be applied to 'impure' cementation steel, that perhaps similar improvements would be effected.

Steel, however, had not previously been brought to temperatures high enough to allow its complete fusion. Neither common cupels, nor the larger clay crucibles used for glass making or brass founding were able to withstand the intense heat required, or the attack of the molten metal on the walls of the vessel. Even if a suitable crucible were found, none of the furnaces then in use could have produce sufficient heat, in a controlled environment, to melt the steel. Huntsman, therefore, needed to develop both a new crucible and a new furnace

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[79] Campbell (1747) pp. 250, 252, makes it clear that by the mid-eighteenth century the watchmaker was usually responsible only for the assembly and finishing of the piece, although apprentices would still learn to make watches by hand: '*The Watch-Maker puts his Name upon the Plate, and is esteemed the Maker, though he has not made in his Shop the smallest Wheel belonging to it. It is supposed, however, that he can make all the Movements, and Apprentices are learned still to cut them by Hand.*'
[80] Alldridge (1789) p. ix.; *Encyclopædia Britannica* (1911) vol. 2, pp. 776-777 'Assaying'. A typical flux was said to contain: sodium bicarbonate 8 parts, potassium carbonate 3, powdered borax 4, flour 1, litharge 9.
[81] Mott (1963) p. 231, noted that the production of carbon monoxide by the combustion of charcoal resulted in the absorption of heat, thus limiting the temperatures attainable by such furnaces.

Development of the furnace

> *Apart from the specially designed building required, the manufacture of cast steel is based on three main factors: the highest quality of steel, which in itself should combine all the properties which are required to make it the best of its kind, a clay with the highest degree of fire resistance for the manufacture of the crucibles in which the above is to be melted, together with a fuel sufficiently powerful and heat generating to attain the intense degree of heat necessary during the melting operation.*[82]

It seems remarkable that a clockmaker with no background in iron- or steelmaking managed to devise a type of furnace that was to remain in service with little alteration over the following two centuries. Huntsman's cast steel furnace belongs to a category now known as the induced draught shaft melting furnace, the first known examples of which date from around the eleventh century. By the time of Huntsman's experiments, furnaces of this type were already in use for glassmaking, and the manufacture of copper and brass; contextual evidence points to the latter as the model upon which the crucible furnace was based.

The brass-making furnace would have ideally suited Huntsman's requirements, but for the problem that steel melts at temperatures over 500°C higher than brass. In order to generate and withstand this considerable heat, significant modifications would need to be made to the design of the furnace. The brass furnace itself was a development of the coal-fired reverberatory furnace for glass-melting,[83] so it is understandable that previous attempts to melt steel had been made in air furnaces resembling a those used in the manufacture of glass (Boyle, for example, used a glasshouse for his experiments on steel). Application of such a furnace to steelmaking was most likely hindered by the lack of a suitable fuel and refractory crucible material. Charcoal was the fuel traditionally used for metallurgical operations, but its use was steadily declining as the forests from which it was sourced were depleted. As an alternative, pit coal was rapidly gaining in popularity, the new coalfields leading to unprecedented change in the industrial landscape of Britain. Coke, a derivative of coal, burnt at higher temperatures still, but had only begun to be used as a metallurgical fuel within the previous few decades, most notably by Abraham Darby I for iron smelting at the Coalbrookdale blast furnaces around 1709.[84]

The lower combustion temperatures of the traditional fuels often necessitated the use of bellows in processes such as brass-making, but the introduction of taller chimneys gradually

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[82] Broling (1812) translation from Barraclough (1984) vol. 2, appendix 3.
[83] Mott (1965) p. 232, cites Mott *Trans. Newcomen Soc.* 1957-58, vol. 31, p. 49; also see Goldsmith & Hulme (1942) pp. 7-9.
[84] Mott (1957-59) p. 49, 62, also notes that its first use in smelting was probably in copper making toward the end 17th century.

removed this need.[85] Chimneys were first introduced simply as a means of conveying the smoke and sulphur dioxide of burning coal out of a building, but were later discovered to produce a draught, the intensity of which could be varied with a damper and concentrated by increasing the height of the stack.[86] Huntsman chose not to use bellows (unlike the ancient Indian steel furnaces) but to adopt the more recent practice of the brass-founders, adapting the design of the building to his requirements.

The similarities are evident in the figure entitled 'A furnace for making brass' from Lazarus Ercker's *Beschreibung allerfürnemsten mineralischen Ertzt*, [fig. 1.3] which bears a strong resemblance to the later crucible furnace with its raised floor, furnace 'hole' with refractory lid, round crucibles and special lifting tongs.[87] Its operating principle was briefly described as follows:

> *When they make* Brass *they make round* Ovens *in the ground, so that the wind may force the fire through the holes below in the Oven, and in one of these Ovens they set 8 pots or pipkins at once...and let them stand 9 hours in a great heat then lift the pots out of the Oven, and pour them (if you will have a piece of Brass) all in one hole.*[88]

Despite the publication in English of Ercker's work in 1683, including the relevant diagrams, it was not until 1702 that furnaces of this kind came into use in Britain.[89] The Bristol area became a notable centre of brass making, using natural draught in place of bellows, although similar furnaces were to be found throughout the country.[90] [figs. 1.5-1.7]

There are, however, significant differences between Huntsman's furnace and that used in brass making: The underground air passages of the brass furnace were enlarged to become cellars, large enough to allow a man or boy to enter in order to tend the furnaces from beneath and to control the flow of air.[91] Each furnace also contained only one pot, as opposed to the eight or nine of a brass furnace, due principally to the higher temperature required to melt the steel.[92] A mass of fuel in a large hole would burn much less efficiently, and the draught would be weaker. Consequently, a number of individual furnaces were used, placed together in rows, their flues converging into a single broad stack (similar to domestic fires) for

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[85] Wraith (1978) p. 44, from editor's introductory note. Antonio Neri (1662) p. 301, 'Of the Furnaces', described the use of bellows in the brass-making process.
[86] Chrysel (1774) published an *Essay on the Draught of Fire in Furnaces, Flues, and Chimnies*, in which he attempted to set out the theory of their operation; most progress, however, was presumably the result of practical experience.
[87] Ercker (1598) fig. 112; see also p. 81, with a figure of a crucible press, much the same as that later used in Huntsman's process.
[88] Ercker (1686) p. 286, published under the title *Fleta Minor*, with additional material by John Pettus. The 'brass oven' is illustrated on p. 288, sculpture XXXV.
[89] Mott (1957-58) *Transactions of the Newcomen Society*, vol. 31, p. 49.
[90] Day (1988) pp. 24-41, gives evidence for the use of glassworks-type cones for draught. The Hatchett diary also notes such works at Birmingham in 1796; Raistrick (1967) pp. 53-55. Also see Angerstein (2001) pp. 38-39, fig. 26, who visited a Birmingham brass-works built to Ercker's pattern in 1754.
[91] The introduction of the bypass flue, allowing the airflow through the furnace to be controlled, is of uncertain date. It is not to be found in any of the early drawings of crucible furnaces, although its omission–especially considering the secrecy surrounding the process–should not be taken as evidence for its absence.
[92] Ercker's furnace contained eight pots, as does the example depicted in the *Encyclopédie*, plates vol. 6. That seen in Birmingham by Angerstein held nine, see fig. 1.8.

efficiency in construction. A linear arrangement allowed a common barrel-vaulted cellar space to be used, while above ground the furnace openings would occupy as little floor area as possible, ranged along one wall of the casting shop.

As shall be seen later, Huntsman had to use the most heat-resistant materials then available, including highly refractory local sandstone for the furnaces themselves, and special clay firebricks for the flues and furnace settings. Even so, at such high operating temperatures, the alternating expansion and contraction of the firebrick flues left them liable to cracking–particularly in the lower portions just above the furnace–resulting in potentially serious structural damage to the stack. In order to minimise this movement, the brickwork was strengthened by the application of several horizontal iron bands pinned to either side of the stack.

The heat not only had structural ramifications, but also created an almost unbearable working environment. Consequently, the windows to the furnace building had no glass, secured instead by iron bars and external shutters, and the roof was liberally punctured by large hatches as traditionally found in iron foundries to let out the heat and smoke.[93]

The greatest technical obstacle to the mass adoption of Huntsman's process lay in the making of the crucibles. When Robsahm visited Huntsman in 1761, he was shown around the works, allowed to see the furnaces and even the finished crucibles, but under no circumstances would Huntsman show him where the crucibles were made, or reveal their composition, not 'even if we offered him fifty pounds'.[94] If indeed the episode of the Walker's espionage did take place, they would have encountered the same difficulty in making suitably refractory crucibles. Even by 1814, the subject was still sensitive enough to be withheld from a German visitor to Sheffield: 'In a steelworks which makes cast steel I was only allowed to see the furnaces and the running of the molten steel. The smelting crucibles were not shown but were kept secret'.[95]

Almost nothing is known of Huntsman's early trials, but what little has come to light suggests that failures were frequent. Buried 'salamanders'–in other words imperfectly fused ingots or failed crucibles–were found by his descendants buried around the grounds of the works, as well as at Handsworth.[96] These failed attempts were by no means all due to the problems involved in crucible manufacture; from the outset experiments were made with a variety of additions to the steel charge, as related by Benct Qvist Andersson, a Swedish industrialist who visited Huntsman in 1767:

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[93] Wortley Top iron forge, in the neighbourhood of Sheffield, has examples of this kind of skylight, both opened and closed by an ingenious mechanism requiring only one rope attached to a lever. Mott (1971) pp 63ff Also see http://www.topforge.co.uk/ (Nov. 2002)
[94] Flinn (1957-59) p. 105. Quotes from Robsahm, J L *Dagbok över en resa i England* (1761) Kungliga Bibliotek, Stockholm, MS M260.
[95] Henderson (1968) p. 153, from *Report on a Journey to England by Factory Commissioner J. G. May in 1814*.
[96] Benjamin Huntsman, letter to *The Times*, 3 January 1865. Scoffern (1857) p. 347 Huntsman's descendants related the discovery of 'many hundredweights of steel, found buried in the earth about the manufactory, in digging foundations for buildings...'

...the first inventor of cast steel was ignorant in the art of melting and did not immediately find the proper way of arranging his experiments. He believed that by mixing various ingredients, not all of which were metallic, he would achieve, with the aid of the fire, his paramount goal, which was to bring about such changes in common steel as would render it perfectly sound. After many years of vain experimenting with mixtures, he hit upon the idea that steel simply by remelting might gain the desired qualities, and he directed his experiments to this end, which indeed succeeded.[97]

Huntsman is known from various sources to have subsequently used a flux of crushed green bottle glass, and a number of independent sources suggest that the use of fluxes was almost universal in eighteenth century steel melting. Indeed, this additive was believed by many, particularly in Europe, to be the true secret of cast steel.[98] In 1765, Gabriel Jars had noted the addition of a flux that was kept a secret, for which every workman claimed to have his own particular recipe.[99] Some later observers were more sceptical, rightly regarding the quality of the steel to be most important.[100]

That a flux was thought to be essential is not surprising; the term 'refined steel', used in the early years of its manufacture, suggests a process of chemical purification, in the same way that precious metals were 'refined' with a suitable flux in crucibles. The flux was also believed by some to reduce the melting point of the steel, as in assaying.

Although modern opinion generally regards fluxes to have been an unnecessary distraction, the addition of green glass does seem to have been of some benefit. The molten vitreous layer, floating on top of the metal, provided an air-tight covering to the steel that reduced the amount of carbon 'burnt off' during melting; it also combined with impurities in the steel to form a quantity of 'scoria' or slag which could be skimmed off the surface before casting.[101] As such, the addition of a flux of green glass continued to be common practice in crucible steel shops into the twentieth century.[102]

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[97] Pipping (1988) p. 96. Andersson also noted the addition of three fingers' breadths of green bottle glass, formerly mixed with one third of powdered lime, p. 97.

[98] Even in England, Brande (1819) p. 237, in his *Manual of Chemistry*, wrote that '*English cast steel* is prepared by fusing blistered steel with a flux composed of carbonaceous and vitrifiable ingredients', while Savigny (1786) pp. 6-7, noted that bar steel 'which has undergone the Process of Fusion, and by being mixed with some well chosen Substances, is very much purified from all drossy Matter, which therefore cannot fail to effect a closer Union of solid Particles'.

[99] Jars (1774) p. 227. 'on les [morceaux d'acier] met dans un creuset, avec un flux dont on fait mystere. On prétend que chaque ouvrier a le sien particulier'. Also see p. 257.

[100] Gustav Broling (1816) who was in England during the years 1797-99 and made specific reference to Huntsman, felt that 'what the steel melter claims regarding the usefulness of the added flux, the quality of the cast steel depends mainly on the blister steel being used, provided that the melting is carried out correctly'.

[101] Mott (1965) p. 236, pointed out that 'much has been made of this secret flux, but Huntsman cast steel not by making it melt at a lower temperature but by producing a high temperature. A flux or addition was required only to make a cinder or slag from the mineral impurities in the cementation steel; glass, rich in soda, was suitable, the slag being absorbed by the crucible or pot. Residual slag was prevented from entering the mould by an assistant to the teemer who used a steel rod tipped with slag'.

[102] Flather (1901-02) pp. 58-60, recommends the addition of an unspecified flux. Pipping (1988) p. 100, note 7, Barraclough recalled the use of green bottle glass in the small high-frequency steel melting furnaces of Sheffield, a continuation of the crucible steelworks practice.

It is also likely that during the first half century of the crucible process, the use of double converted steel (i.e. blister steel that had been cemented for a second time) was considered essential.[103] This may have been to make up for carbon content lost during melting (perhaps oxidised by flux ingredients), but is more likely to have been to reduce the melting point of the steel. [fig. 1.9] The latter reason was alluded to as late as 1812: 'What is called cast steel is nothing else than steel which has undergone the process of steelification twice over, and has become in consequence more fusible than common steel'.[104] The best source of such steel were the 'raw ends' usually cut off bars of cementation steel, where the iron had been closest to the outside of the chest and therefore 'over-converted' (i.e. having a higher carbon content). These also had the advantage of being less expensive than common cementation steel, and were already of an appropriate size for the crucible.[105] It is known that Huntsman purchased quantities of this steel from the 1740s onwards (see appendix 1.1). Another early observer noted the use of old steel files and tools as part of the charge.[106]

The secret: controversy and espionage

After almost a decade of experimentation, Huntsman had achieved a scale and quality of production that was commercially viable. He established his first purpose-built works in 1751 at Attercliffe, closer to Sheffield than Handsworth. His decision to embark upon full-scale production may have been effected in great haste, influenced by events beyond his control. Huntsman's process became one of the most sought after industrial secrets of the eighteenth century, with numerous attempts made to discover it both at home and from abroad.

The theft of Huntsman's secret is represented by two distinct traditions. Of these, the best known is the story popularised by Samuel Smiles in his *Industrial Biography*, but first published in a little known scientific textbook *The Useful Metals and their Alloys*.[107] Smiles claimed to have derived his facts 'from the descendants of the Huntsman family', but quotes verbatim the relevant passage from the earlier anonymous account, leaving the origin of the story unclear.[108]

The narrative opens on a stormy midwinter night: Huntsman's rival, the iron-founder Samuel Walker, approached the furnaces through the snow in the disguise of a tramp, shivering and in search of shelter and warmth. Steel melting was at that time covertly carried out during the hours of darkness, and the kind but gullible furnace-men on duty allowed the pitiful stranger to

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103 A report made in 1770 by Robert Erskine stated that the steel used in Boulton's cast steel furnaces had to be 'twice converted'. Birch (1967) p. 308.
104 Thomson (1812) p. 257, abstracting Frankland's report in *Philosophical Transactions* (1795) vol. 85, p. 296.
105 Pipping (1988) p. 97, quotes Andersson: 'Cut ends of iron bars from the blister steel furnaces are commonly used for making cast steel, because these can be had at good prices and, moreover, the work of cutting up long bars is avoided'.
106 Jars (1774) vol. 1, p. 227. Having observed steel melting in 1765, he noted: 'one takes old files or other old steel items, or cementation steel cut into pieces'. ('... on prend de vieilles limes, ou autres vieux ouvrages en acier, ou de l'acier boursoufflé, coupé en morceaux').
107 Smiles (1863) pp. 99-113; Scoffern (1857) pp. 348-349.
108 Certainly Benjamin's great-grandson and namesake made no mention of this tradition in his letter to *The Times*, 3 January 1865, defending his ancestor's entitlement to the discovery; see below

rest in the warmth of the melting shop. Feigning sleep, the impostor observed the whole process, learning enough that on his departure the following morning he took the secret with him. He immediately set to work building his own furnaces, in which he was soon producing steel to rival Huntsman's.[109]

This oral tradition, almost certainly embellished and romanticised over time, is, however, supported to a certain extent by documentary evidence. In 1750, the Walker's minutes recorded the construction of a 'House and Furnace for refining steel in at Grenoside', taken to be the result of their subterfuge. However, it was not until 1771 that any further furnaces were built, this time at Masbrough near Rotherham, and extended by a further four 'holes' in 1773. Mott took this to imply that the original furnace held only one crucible, and that the Walkers' initial success (and therefore their threat to Huntsman's trade) was limited.[110]

In addition, the date of 1750 or earlier would locate the episode at Handsworth, where the furnaces directly adjoined Huntsman's cottage, making it less likely that such a simple ruse could have succeeded, particularly as the furnace hands had all been 'pledged to inviolable secrecy'.[111]

An additional facet of this story, local to the Grenoside area, identifies the plot to steal Huntsman's idea as a conspiracy between Samuel Walker and Benjamin Tingle, the latter a partner of the Walkers and subsequently a steelmaker on his own account. Shortly after the establishment of the rival works at Grenoside, the two men are said to have parted company, with Tingle retaining possession of the crucible steel furnaces. This version of events would explain the construction of the Walkers' later furnaces at Masbrough, and the origin of the Tingle family of cast steel manufacturers.[112]

There is, however, a lesser-known but more sinister account that portrays Huntsman as the recipient of the secret, in what is almost an inversion of the previous story. It was first made public by Henry Horne, a London cutler, in a short book *Essays on Iron and Steel* of 1773, with further details added in 1786 by Bishop Richard Watson of Llandaff, chemist and Professor of divinities in the University of Cambridge, in his *Chemical Essays*.[113] Horne surprisingly made no mention of Huntsman's name in relation to crucible steel (yet he can hardly have been ignorant of his existence), but instead ascribed the invention to a mysterious individual:

> *It was not a great many years since this discovery was first made, by a gentleman (as I have been informed) residing in the Temple, an acquaintance of*

[109] The story is remarkably similar to the earlier tale of Richard Foley (1580-1657), Mayor of Dudley, known colloquially as 'Fiddler Foley'. In order to learn the secret of slitting metal, he went to Sweden where he gained access to the works by posing as a simpleton and playing his fiddle during the workmen's rest breaks. This way he is said to have acquired sufficient knowledge to establish the first slitting mills in England. See Flinn (1957-59) p. 107

[110] Mott (1965) p. 235

[111] Smiles (1863) p. 107. His source was Scoffern (1857) p. 348

[112] Allison (1946) *passim*. Barraclough (1976) p. 7, note 34, related the same tradition from an independent source (J Beevor). Baker (1945) p. 4, noted that these tales were unconfirmed. However, the Tingles' animosity to the Walkers persisted well into the nineteenth century.

[113] Horne (1773) pp. 165-174; Watson (1781-86) vol 4, p. 147

the late Lord Macclesfield; whose name I could never learn; nor could I ever gain the least information of the means, by which he became possessed of so valuable a secret.[114]

This altruistic 'gentleman' subsequently passed on the secret to 'one who had been employed in flatting of gold and silver wire for the use of the lace-men', in order to make better steel rollers for his trade, which had until then been smuggled from France at great expense and risk. Bishop Watson later identified the gold wire-flatter as 'one *Waller* from London'.[115]

Dissatisfied with success in his own trade, Waller saw the opportunity to put the new steel to other uses, and having melted 'a considerable quantity of steel' contracted a cutler named Humphrys of Covent Garden to manufacture razors of it. Due to the high mirror polish of the steel, the razors proved popular and Waller soon acquired 'a pretty large number of customers at the west end of the town, where he became a considerable hawker'.

His unexpected success alarmed the other razor manufacturers, and a number of them including John Savigny[116] and Humphrys himself approached Horne (presumably behind Waller's back) to build a steel furnace and thus break Waller's monopoly.

Horne took up the challenge and, despite considerable difficulties, he claimed to be soon producing steel 'vastly superior' to Waller's, with which he supplied the London cutlers 'at a very moderate price'.

Faced with this new competition, Waller is said to have left for the North of England with a view to selling the secret at the highest price, and damaging the London trade in the process. Finding no takers at Birmingham, he continued to Sheffield where after several rejections, 'he met at last with some keen friends, who wormed the secret out of him, supplied him with a little money, and sent him back to town; and they, being better skilled in the nature of steel than he was, soon outdid their master'.

It was not long before Horne found his customers turning to Sheffield, where they could purchase steel from eight to ten pence a pound, undercutting his own trade.[117]

With a clear interest in the affair, Horne's version of events cannot be regarded as impartial, and as such has been often discredited: the Victorian metallurgist John Percy considered Horne to have made 'a singular and no doubt entirely erroneous statement'.[118] Horne certainly manufactured cast steel, although there is nothing in his account to suggest a date earlier than 1765, by which time others in Sheffield were also practising the art.[119] However, there

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[114] Horne (1773) pp. 165-6. Lord Macclesfield was President of the Royal Society from 1752 until his death in 1764.
[115] Watson (1781-86) p. 147.
[116] Savigny, the author of *A Treatise on the Use and Management of a Razor* (1786) and *An Essay on the Mystery of Tempering Steel* (1771), described himself as 'Razor-maker to His Majesty, Instrument-Maker to St. George's-hospital, and inventor of the convex-penknives'.
[117] Horne (1773) p. 172, complained that they had acted 'without any regard (which is too common a case) to the trouble and expence, which at their own request I had been at, to serve them under their difficulties'.
[118] Percy (1864) p. 830.
[119] Horne (1773) p. 178, claims to have made cast steel mirrors for 'the very ingenious Dr. Ingenhoust, while he was last in England', by whom he meant Jan Ingenhousz (1730-1799), resident in London between 1765 and 1768.

exists an independent source that corroborates much of Horne's account, but from a different perspective. It consists of a short book dating from 1755 and written by John Waller himself.[120]

Entitled *An Appeal to the Nobility and Gentry In Regard to the Gold and Silver Lace, Brocades, Embroidery, and Gold and Silver Ribbon of this Kingdom*, the text's main purpose was to petition for an Act of Parliament to protect the purity of Gold used in the production of decorative lace for clothing, but alongside this argument Waller makes a strenuous case for the precedence of his invention of cast steel:

> *I must beg leave to assert something in Defence of Truth and myself. About twenty Years ago, I got a violent Sprain of my right Leg, which took me off divers Parts of my Work, as a Gold and Silver Wire-drawer; I then at leasure Times applied myself to study in various Things in Metal, particularly in refining of Steel to make Mills, for the flatting of Gold and Silver Wire, for the making of Lace; and I had more Time upon the Death of the late Queen Caroline, in which Year I finished my Work, which was greatly wanted by several Flatters.*[121]

This would place the invention around the end of 1737, prior to Huntsman. Furthermore, in confirmation of Horne's evidence, Waller declared himself 'the Inventor of the refined Steel Razors, which have been vended in most Parts of Europe with general Satisfaction', and with which he had supplied 'His Majesty and several of the Nobility and Gentry with the same, who can attest their Goodness'.

That Waller had also melted his own steel seems likely, as his testimony betrays a practical appreciation of the problems that would have faced anyone attempting the process, including the identification of the crucible as the key secret.[122] On the other hand, he comes across as a hot-tempered individual with an axe to grind, while some of his claims are ridiculous; at one point he even suggests that he had achieved the transmutation of iron into tiny particles of gold.[123]

Perhaps the most revealing statement is Waller's assertion that 'I have had the Honour to prove these Things to the *Royal-Society*, and Leave to let the World know they approved of

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Likewise, he suggested the use of cast steel for John Bird's 8ft transit of 1773 for the Radcliffe observatory. Museum of the History of Science, Old Ashmolean Building, Oxford, inventory no. 30919.

[120] Waller (1755) *passim*. Discovered by the author in the collection of the British Library.

[121] Waller (1755) p. 6. Queen Caroline died on 20 November 1737. The reference to mills or rolls for flatting wire is of interest as Huntsman's steel was also in great demand for rolls. Matthew Boulton wrote to Huntsman to order rolls for gold leaf and specifically mentioned those used in the flatting of gold wire by the lace-men. Horne (1773) p. 166-167, also made reference to steel rolls (although he could have derived some, but not all, of his information from Waller's pamphlet): 'Prior to this period, the workmen at a very considerable expence, and no small risk, had been obliged to smuggle those implements, or steel-rollers, by which the wire is flatted, from Lyons in France; whereas our melted steel is qualified to form them in a much better manner'.

[122] Waller (1755) p. 7. 'Please to observe that I was obliged to find Matter to make my own Bricks and Pots off; for I could get none to stand my exceeding strong Furnace, for I had tried all Sorts to no Effect...' At this time, most observers believed the flux added to the crucible to be the secret.

[123] Waller (1755) p. 8. '... *in some Operations I made upon Iron ore, I turned it into Steel at once. In others I destroyed* all the Iron, and got little Particles of Gold, about the Bigness of Pins-heads. I might make mention of various other Discoveries, to let the World see I am not that ignorant silly Fellow some wicked People would insinuate, whose Selfishness is more hateful than a Toad or a Snake, as a certain Philosopher saith, for great Good may be got from the above two Animals, but none from Lyars'.

them as Facts'. It will be remembered that Horne's 'gentleman' who passed the secret to Waller was an acquaintance of Lord Macclesfield, an influential Fellow and the President of the society from 1752. This relates to another apocryphal episode in the Huntsman story, concerning the offer of a Fellowship by the Royal Society, 'in acknowledgment of the high merit of his discovery of cast-steel, as well as because of his skill in practical chemistry'.[124] Huntsman is said to have turned down the honour, due, it is said, to his reserved manner and Quaker principles (which forbade him to swear allegiance to the crown), but the offer would hardly have been made without an understanding of Huntsman's process.[125]

The most likely sequence of events incorporates elements of all of these stories. It is probable that the Royal Society, having heard of Huntsman's invention, invited him sometime around 1750 to present his findings, with the possibility of a fellowship.[126] At this stage, some details of the process may have been transmitted in confidence to a small group of Fellows, including the 'gentleman residing in the Temple' who later passed them on to Waller for his own use. Subsequently Waller, realising the value of the process, determined to apply it elsewhere and, in order to conceal the subterfuge, published his own version of its discovery. For the remainder of the story, Horne's account of Waller's actions will suffice, needing only to add that the 'keen friends' who extracted the secret may well have been Huntsman's rivals, the Walkers.

The Cutlers' Company of Sheffield also seems to have become involved, the accounts for 1750 containing the cryptic note: 'By expenses at Jacob Roberts's about Huntsman's, the steel founder's, request, 4s.'[127] The nature of this request is not specified, but as it was made at the height of the controversy, it may be hypothesised that it related to Waller and the London cutlers' trade in cast steel razors, and possibly to the establishment of steel melting by the Walkers.

It is difficult to trust the accounts of Waller and Horne, particularly the claims made by each author. Waller portrays himself as the original inventor of cast steel, as well as a loyal patriot and the champion of truth in a corrupt trade. Horne, while making no claim to the discovery, nevertheless boasts to have reinvented the process independently, and much improved over the original; nor does he miss the opportunity to deprecate the products of Sheffield make, promoting instead his own steel manufactory 'where the best razors, lancets, &c. made by the author, may be had'.[128]

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[124] Smiles (1863) p. 110.
[125] Benjamin Huntsman (the younger) in letter to *The Times*, 3 January 1865. The absence of any record of this offer in the archives of the Royal Society may simply indicate the tentative nature of the exchange.
[126] How the Royal Society came to hear of Huntsman is unknown, although a number of influential Fellows had Sheffield connections, including the Dukes of Norfolk and of Devonshire (both major landowners in the region), and George Savile (later to represent Yorkshire in the House of Commons). Thomson (1812) appendix IV.
[127] Leader (1905) vol. I, pp. 174-5.
[128] Horne (1773) p. 181. 'I last summer took a journey to Sheffield, to try whether it might not be possible to have the steel melted there, upon such terms, as to enable me to reduce the price of my razors, &c. but in this I found myself greatly disappointed, for though I took with me steel of the most excellent quality, converted for the very purpose; though I prepared, and carried with me, a sufficient quantity of my own flux, and had the steel melted under my own immediate inspection, I say, notwithstanding all these precautions, when the steel came to be wrought into razors, and other instruments, by one of the ablest artificers I could procure, they fell so far short of those made from the

If anything certain can be derived from these texts, it is that the controversy over cast steel was real, and that much was at stake. Waller's appeals obviously fell on deaf ears, as Huntsman continued to increase his trade and reputation, while the name of John Waller and the London cutlers faded away. Nevertheless, this version of events found its way into the report of the eminent Swedish scientist Gustav Broling,[129] gaining currency in Europe at least until the publication in 1843 of Frédéric Le Play's important study *Mémoire sur la fabrication de l'acier en Yorkshire* restored Huntsman's claim to the invention.[130]

Even as late as 1864, an anonymous correspondent of *The Times* resurrected Waller's claim to the invention, and provoked a defiant response from Benjamin Huntsman's great-grandson, who claimed that Francis Huntsman (his father), by then 80 years old, had 'no recollection of ever having heard the name Waller mentioned in connexion with the discovery of cast steel'.[131] Since that time, most studies have dismissed the story as a fabrication by Henry Horne.[132] The rediscovery of Waller's text casts new light on an episode previously thought to be unverifiable, and which may now be worthy of further investigation.[133]

Opposition of the Sheffield cutlers

In stark contrast to the excitement over the secret of cast steel manufacture was the distinct lack of enthusiasm reputedly shown by the local cutlers and toolmakers. At this time, most cutlery would have been made of forged cementation steel or imported 'German steel', familiar and readily available materials. Huntsman's steel, made by melting down relatively small quantities of cementation steel, was necessarily much more expensive due to the special skills, time and labour involved in its production. Its higher carbon content meant that it was also harder, and more difficult to work at the forge, besides which it required especially careful tempering.[134] Given the traditional conservatism of the Hallamshire cutlers, and the relatively low prices obtained for their products, there is little surprise that this new material was received so coolly.[135]

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steel I had before melted, and wrought down to proper sizes, at my own manufactory that I could not honestly dispose of them upon any terms'. His steel manufactory was at White-Cross-Alley in Middle Moorfields, London.

[129] G. Broling, *Anteckningar under en Resa i England, 1797-1799*, vol. III, pp. 5-6

[130] Le Play (1843) *passim*. Smiles (1863) p. 102, noted that 'M. Le Play, Professor of Metallurgy in the Royal School of Mines of France, after making careful inquiry and weighing all the evidence on the subject, arrived at the conclusion that the invention fairly belongs to Huntsman'.

[131] Anonymous letter to *The Times*, 21 December 1864; Benjamin Huntsman's reply in *The Times*, 3 January 1865. The denial was not necessarily disingenuous, as much of the firm's early history seems to have been similarly lost to Huntsman's descendants (e.g. the date of his relocation to Attercliffe).

[132] Percy (1864) p. 830; Hadfield (1894) p. 228; Mott (1965) p. 236, thought Horne's book 'pretentious rather than informative'.

[133] No attempt has yet been made to trace Waller's activities in London, nor to verify his claim to have supplied cast steel razors to the nobility, and even King George II. Waller is known to have become the Master of the Worshipful Company of Gold and Silver Wyre-Drawers in 1758. See Stewart (1891) pp. 116-119, 'Gold and Silver Wyre-Drawers Company, List of the Masters'.

[134] Perret (1779) p. 64, expressed the view held by many cutlers in Europe at the time, that 'cast steel is judged unworkable by many forgers, and yet it requires only care and dexterity to master it'. ('L'Acier fondu est jugé intraitable par beaucoup de Forgerons, & cependant très-possible de s'en rendre maître; il ne faut que des attentions & de l'adresse: voici les expédiens convenables').

[135] Campbell (1747) pp. 238-239, chapter 48 'Of the Cutler', observed that the London cutlers' goods 'come to a very great Price, yet do not excel in Goodness the same kind done at *Sheffield* and *Birmingham* at a much lower Price;

Consequently, during the early years of his steel manufacture, much of Huntsman's production was exported to Europe–France in particular–where it could command prices up to ten times those at home.[136] The extremely high cost of the steel reflected both its superiority over the other materials then available and its limited availability, but also meant that its use was limited to special applications where expense was no object, such as the manufacture of precision tools, watch springs and luxury items such as razors.[137]

The trade with Europe was not without its consequences for the other Sheffield manufacturers, who soon began to resent the growing popularity of cast steel. Their response to the threat was an attempt to stifle Huntsman's business, as related by Samuel Smiles:

> *When he had fairly established his business with [France] the Sheffield cutlers became alarmed at the reputation which cast-steel was acquiring abroad; and when they heard of the preference displayed by English as well as French consumers for the cutlery manufactured of that metal, they readily apprehended the serious consequences that must necessarily result to their own trade if cast-steel came into general use. They then appointed a deputation to wait upon Sir George Savile, one of the members for the county of York, and requested him to use his influence with the government to obtain an order to prohibit the exportation of cast-steel. But on learning from the deputation that the Sheffield manufacturers themselves would not make use of the new steel, he positively declined to comply with their request.*[138]

The date of the cutlers' protest is not specified, but it must have fallen between the years 1759, when Savile was elected to the commons, and 1764, when the Cutlers' Company effectively endorsed the use of Huntsman's steel by establishing their own crucible furnaces.[139] Indeed, from 1764 onwards a number of new crucible steel ventures emerged in rapid succession as shall be seen later, indicating the local cutlers' steady, if reluctant, adoption of cast steel.[140] Quite how an export ban would have countered the threat from the

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they are indeed neatly finished and turned out in a workman like Manner, but the Country Goods, though not so taking to the Eye, prove sometimes as good in the Metal as those more expensive, and from these Places most of the Shops are furnished, and frequently Cutlers, who have a great Demand for Goods, have them made in the Country, put their own Marks upon them, and sell them for *London* made'. Also see Berg (1996) p. 217, *passim*.

136 Perret (1779) pp. 7-8 noted that English steel sold for 1 *écu* per pound in barrels, but that some sold it for double that price at 10-12 *livres* a pound (about 4s 5d per kg). Laumont (1809) p. 19, gave the price as 16-18 francs per kilogram (or about 9s), while Barraclough (1976) p. 14 estimated the cost in England at that time to be £70-80 per ton (or 1s 7½d per kg), or almost a tenth of the cost in France.

137 Jars (1774) p. 258, visited Sheffield in 1765, at which time he found cast steel used for 'les meilleurs razoirs, quelques *canifs*, *les plus belles chaînes* d'acier; quelques ressorts de montres & des petites *limes d'horlogers*'. Babbage (1832) in *The Economy of Machinery and Manufactures* demonstrated the insignificance of the cost of raw materials in such cases, as in the example of 'the pendulum spring of a watch [which] costs, at the retail price, twopence, and weighs just 15-100ths of a grain; whilst the retail price of a pound of the best iron costs only twopence. Out of that weight of iron, fifty thousand of such springs are made'; Scoffern (1857) p. 498.

138 Smiles (1863) pp. 106-7.

139 *Dictionary of National Biography*, vol. 50, pp. 364-7, 'Savile, Sir George (1726-1784)'. 'At a by-election in January 1759 he was returned to the House of Commons for Yorkshire, and he continued to represent that county during the whole of his parliamentary career.' He resigned his seat in November 1783 due to illness. See chapter 2 for the Cutlers' Company furnaces.

140 Local Register (1830) p.123, suggests that prejudice against cast steel was still endemic decades later, recording that on 6 April 1810: 'Journeymen scissor makers combine together, and resolve not to work for masters making cast steel scissors'.

London cutlers using their own melted steel is not clear, but is perhaps indicative of the limited success of their product, despite Waller's claim to have exported his razors 'to most parts of Europe'.

The cutlers' opposition to Huntsman's steel may also have been precipitated by technical differences. Crucible steel, just like wootz before it, required much more careful forging and tempering than cementation steel and the European steels to which the Sheffield cutlers were accustomed, no more so than in the process of welding to wrought iron, also known as 'plating' or 'tipping'.[141] This involved the forging of a sharp cutting edge of steel onto a more durable back of iron, combining the advantages of both metals as well as making best use of the expensive steel. Huntsman's steel, however, would disintegrate during forging if brought to the usual welding heat of iron, requiring instead a lower temperature.[142]

Whether as a result of the cutlers' unwillingness to adopt new working methods, or as a deliberate slur upon Huntsman with the intention of damaging his business, the rumour that crucible steel–the most costly of all–could not be welded quickly became widespread. Bishop Watson noted that 'cast steel will not bear more than a red heat, in a welding heat it runs away under the hammer like sand'.[143] Even in France, where cast steel had been most enthusiastically adopted, Jean Jacques Perret wrote in his *Mémoire sur l'Acier* that 'cast steel cannot be used for objects that need to be welded to iron, as it can only be united to other steel and even then care is required if it is to succeed'.[144]

Whatever the motive, the myth persisted for some time, for over 40 years after the establishment of Huntsman's business, the firm of engineers Fourness and Ashworth felt it necessary to clarify the situation in a testimonial entitled *A report on Huntsman's cast steel*, published as a pamphlet that tellingly included both English and French versions of the text. Besides a promotion of the qualities and potential uses of the steel, the report directly addressed Huntsman's detractors:

> *It has often been said, and amongst other incorrect statements it has been asserted that the Huntsman Cast Steel could not be united or welded to any other Steel or forged Iron; but the opinion is a mistaken one, because we can satisfactorily prove to any person that Mr. Huntsman's Cast Steel may be securely united or welded to any other Steel or forged Iron. To elucidate this fact is one part of the design of this testimonial.*[145]

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[141] Mott (1963) p. 236
[142] Savigny (1786) pp. 5-6, a London cutler and early adopter of cast steel, noted the 'extraordinary Care which this Steel particularly requires', believing that the 'Resistance this Steel has against the Hammer, (which those who have work'd it must be convinced of) is a demonstrative Proof of its compactedness, and shews its superiority to all other'.
[143] Watson (1781-86) p. 148.
[144] Perret (1779) p. 28 'On ne peut pas employer l'Acier fondu à des objets où il faut le souder avec du fer; car il ne peut s'allier qu'avec d'autre Acier, encore faut-il des précautions pour y bien réussir'; Perret was a cutler, corresponding member of the *Académie Royale des Sciences* and Honorary Associate of the *Société des Arts de Genève*.
[145] Fourness (1792) privately printed in both English and French, and dated 28 March 1792. Reprinted as an appendix to Hadfield (1894) pp. 224ff., also Barraclough (1976) appendix 2, pp. 14-15.

Following up Fourness and Ashworth's plea to the manufacturers, Sir Thomas Frankland ventured to prove the same to the scientific world, reporting to the Royal Society three years later that 'when iron is heated to a welding heat, and cast steel to a white heat, they may be readily welded together.'[146] This demonstration did not end the debate, but over the succeeding decades the widespread adoption of the technique in practice found its way into the theoretical textbooks, admitting that all but the hardest cast steel (i.e. as used for razor blades) could be securely bonded to iron.[147]

Visits by 'industrial spies'

Word of the new invention quickly spread to Europe, as cast steel began to be adopted by cutlers and instrument makers in France and elsewhere. A French report of 1798 indicates that Huntsman had begun to export steel about the same time as his establishment of the Attercliffe works: 'the English...still remain in exclusive possession of the manufacture throughout Europe of a third type of steel known as *cast steel*, the invention of which does not date to before 1750, and although its use is limited to a certain number of fine instruments and works, still constitutes an invaluable branch of industry'.[148]

Perhaps the most convincing evidence for Benjamin Huntsman's title to the invention is the number of foreign visitors arriving at his Attercliffe steelworks from the 1750s onwards. These encounters could not have been accidental or opportunistic–Sheffield was not, at the time, of particular renown as an industrial centre, and Huntsman's works were difficult to find.[149]

Nevertheless, in August 1754 the Swedish visitor Reinhold Rücker Angerstein entered Sheffield, it seems, with the objective of discovering Huntsman's secret. He was the first of many Scandinavian 'industrial spies', the son of a wealthy ironmaster and Director of Steelworks for the *Jernkontor* (Iron Bureau), on whose behalf he undertook a long tour of Europe and Britain.[150] Between the years 1753 and 1755, his diaries record in considerable detail the industrial development of England and Wales, including many of the latest developments.[151] As such, one would expect him to have been keenly interested in Huntsman's new process; however, his diary entry for Sheffield is unusual, recording his arrival at the town, but omitting to say anything about its trades or character. Angerstein

[146] Thomson (1812) p 500. Cites *Philosophical Transactions* (1795) Vol LXXXV, p. 296. Holland (1831) pp. 320-321, added that 'The steels on which the experiments of the ingenious baronet were made, were Walker's of Rotherham and Huntsman's of Attercliffe'.
[147] Holland (1831) p. 321. John Holland, the Sheffield-based author of the three volumes of Lardner's *Cabinet Cyclopædia* on 'Manufactures in metal', confirmed that '...a considerable quantity of very excellent cast steel is now used in the manufacture of the lighter sorts of edge tools, and especially in plane irons, and even in table knives, in which the disputed facility of welding it to iron is daily and successfully practised'.
[148] Guyton de Morveau (1798) pp. 82-83. 'Cependant les Anglais, qui nous avoient long-temps fourni l'acier de cémentation, restoient encore en possession de fabriquer exclusivement, pour toute l'Europe, une troisième espèce d'acier connue sous le nom d'*acier fondu*, dont l'invention ne remonte pas au-delà de 1750, et dont l'usage, quoique restreint à un certain nombre d'instrumens et d'ouvrages fins, ne laisse pas de former une branche précieuse d'industrie'.
[149] See for, example, Fischer's difficulty in locating Huntsman's works, Schib (1951) pp. 173-174
[150] Flinn (1957-59) p. 103. The article gives a good general overview of the Swedish Engineers to visit Britain during the 18th century.
[151] Flinn (1957-59) Angerstein (2001) *passim*.

stayed in the town for under 24 hours, and it has been reasonably conjectured that he was driven out of Sheffield after showing too much interest in the crucible process.[152] The Swedes were naturally eager to acquire this new technology, particularly as their own iron was the only suitable raw material for cast steel.

The next known attempt was that of Johan Ludvig Robsahm in 1761, also from Sweden, who met with some limited success.[153] His primary aim was to visit Huntsman's works, to which he managed to get an introduction by way of his contact, the wealthy Sheffield-based steel and hardware merchants Oborne and Gunning. Huntsman seems to have been quite generous to his guest, allowing him almost unlimited access to the works. Robsahm saw inside the steel casting shop and also the adjacent horse-driven grinding mill, in which clay for crucibles was pulverised. Although he was allowed to see some finished crucibles, Huntsman would under no circumstances show him where or how they were made, 'even if we offered him fifty pounds', complained the frustrated Robsahm.[154]

Gabriel Jars, the French author of the well-known *Voyages Metallurgiques*, passed through Sheffield in 1765, where he managed to see the manufacture of cast steel.[155] He did not specifically mention Huntsman, but his description has generally been interpreted as a visit to the Attercliffe works.[156] Jars also made reference to a crucible steel venture in Newcastle, which had apparently run into some difficulty. His short account was also the first to enumerate the variety of applications to which crucible steel was applied.

Arguably the first successful attempt was that of Benct Qvist Andersson in 1767, who gathered enough information to enable him, on returning to Sweden, to establish a crucible furnace at Ersta near Stockholm.[157] The resulting report is particularly valuable due to its almost explicit connection to Huntsman's works, providing a detailed observation of the early process and accompanied by the first known drawings of a crucible shop. Although these relate to the furnace designed and built by Andersson, their general dimensions can be taken as representative of the earliest Sheffield works, seen during his visit.

Another Swedish traveller, the engineer Erik Geisler, came to Sheffield in 1772 and, although he did not mention Huntsman by name, can be surmised to have visited his steelworks.[158]

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152 Angerstein (2001) p. xvii, Prof. M. Palmer notes in the introduction that Angerstein used 'all possible means, legal or otherwise, of getting to see what he wanted, and there are several accounts of his being thrown out of workshops where he had no permission to be'. Also see pp. 211, 213, for his curtailed description of Sheffield.
153 Robsahm, J. L. *Dagbok över en resa i England*, 1761, Kungliga Bibliotek, Stockholm, MS M260. Barraclough (1984) vol. 2, pp. 9-13 quoted from a translation by Torsten Berg from which the following extracts are taken. Robsahm was a notary of the *Bergscollegium* (Board of Mines) and a partner in more than one steelworks.
154 Flinn (1957-59) p. 105.
155 Jars (1774-1781) pp. 257-258, 'Acier coulé'. Jars has been described as 'the most perceptive and diligent of spies', well versed in mining and metallurgy and educated at the Ecole des Ponts et Chaussées, Fox (1998-99) p. 185.
156 Mott (1965) p. 234, believed that Jars had visited Huntsman. Also see Hulme (1943-45) p. 40. There were, however, other possible candidates, including the Walkers' furnace (operated by the Tingles) and the more conveniently located Cutlers' Company site in Sheffield.
157 Pipping (1988) pp. 96-101, provides a full English translation of Andersson's report relating to crucible manufacture, and a reproduction of the accompanying drawings.
158 Geisler (1772) *Reseanteckningar*, MS M243, Kungliga Bibliotek, Stockholm.

The drawings he made during his visit are of particular interest, and will be the subject of more detailed attention below.

Apart from Jars (above), the French generally had little luck in gaining access to crucible furnaces; for example, the La Rochefoucauld brothers who visited Sheffield in February 1785, seemed to have overlooked (or been denied access to) crucible steel manufacture entirely, although they visited works at which cementation steel was made.[159] The various tracts on the subject published during the late eighteenth and early nineteenth centuries also indicate that the process remained a mystery to the French, despite their efforts to become self-sufficient in steel.[160]

Even after the 'secret' of cast steel manufacture had become more generally known, and the product widely available as an article of international commerce, the visitors still came to see Huntsman's works, now motivated by a combination of curiosity and reverence. The Attercliffe works had become almost a site of pilgrimage on every foreign industrialist's map of England.

Svedenstierna made his now well-known tour of Britain during 1802-3 observing a wide spectrum of industrial processes. His diaries do not give any account of the crucible process, but not from oversight; he explains:

> *I did in fact have the opportunity in Sheffield of observing the cast-steel process fairly closely in two factories, but it is not my intention either here or anywhere else to give a detailed description of it, partly because the one which we have already possessed for a long time...is in any case adequate for the practitioner, and partly because it may be of some advantage to us to keep this art to ourselves, for the many unsuccessful experiments made in Germany and France prove that this process is still unknown there.*[161]

His last comment demonstrates the extent to which the production of cast steel had become a matter of international importance by this date. Given the difficulties that the French government was still experiencing in securing their own supplies of the metal, the continued caution of the Swedish and British manufacturers was not unwarranted. He did, however, remark that 'the oldest and largest cast-steel works, which has long been famous, is that of Mr. Huntsman in Sheffield. His brand has won general credit throughout Europe, and the products of the other works have only been comparable for a few years'.[162]

Johann Conrad Fischer, probably the most determined tourist of all, first arrived at Huntsman's works in 1814, returning to Sheffield a number of times over the following four decades. He was himself a steelmaker, having independently developed a method of cast

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159 Scarfe (1995) pp. 51-56.
160 Clouet's efforts to produce cast steel are thought to have achieved only a limited success; Guyton de Morveau (1798) pp. 81-97. The Napoleonic wars added to the urgency, as evidenced by Vandermonde (179?) p. 3, 'L'Angleterre et l'Allemagne en fournissoient à la plus grande partie de nos besoins [d'acier]; mais les despotes de l'Angleterre et l'Allemagne ont rompu tout commerce avec nous. Eh bien! faisons notre acier'
161 Svedenstierna (1973) p. 92
162 Svedenstierna (1973) pp. 92-93.

steel manufacture in response to an international competition, and had established a substantial business in his native Switzerland.[163] His journal entry relating to the first visit is particularly fascinating as an insight to the everyday operation of Huntsman's business, the details of which will follow later. For Fischer, seeing the famous steelworks with his own eyes was the ultimate ambition of his European tour; that evening he wrote in his diary 'Now I have achieved everything that I set myself as the object of my journey'.[164]

163 Henderson (1966) *passim*.
164 Schib (1951) p. 175 'Nun hatte ich Alles erlangt, was ich mir als Ziel meiner Reise vorgesetzt hatte'.

Part 3: The development of the works of Benjamin Huntsman & Co.

In contrast to the histories of the wealthy and powerful, evidence of early industrial activities and their environment is relatively scarce. Most of the surviving documentation was made for administrative or legal purposes (valuations and surveys of property for taxation, sale or lease; business accounts, etc.) and is often extremely specific or limited in its detail. Consequently, the following reconstruction is derived from a wide variety of sources, in some cases requiring the development of special methodologies. Of these, two sources warrant particular attention: The Fairbank collection of eighteenth to nineteenth century field surveys and plans, and the contemporaneous and practically complete run of Poor Law rate books for the Sheffield area, both held by the Sheffield Archives. There follows a short description of each, and of the methodology developed for their combined use; the results forming the basis of the remainder of the chapter.

Fairbank field surveys

The plans and surveys made by this Sheffield based family firm of surveyors have been extensively used in previous research. The collection contains a wide range of material, but the bulk of the visual content falls into two major categories, namely field books and scale plans. The field books cover the period 1753-1844 in an almost unbroken series of 360 volumes,[1] and contain the raw survey data, drawn by hand and not to scale, but with the measurements needed to construct the finished plan. The plans themselves are mostly 'working' copies or duplicates made for the firm's own records, as opposed to the fine copy destined for the client, and often display construction work in pencil or the pin-holes made when transferring the drawing to a fine copy. On their acquisition by Sheffield Archives, a catalogue of the plans and field book contents was made, including the cross-referencing of many field surveys to scale drawings. While most plans can be sourced back to the original survey data, many of the surveys represent plans that have since been lost, while others contain additional information not included in the resulting drawing. Therefore, for the purpose of this study it was desirable to develop a method of redrawing these to scale.

The techniques and notation found in the field books bear little semblance to modern practice, being based on seventeenth century principles.[2] In addition, some of the conventions used were non-standard, developed by the Fairbanks for their own use. The task of identifying and interpreting these symbolic and numeric conventions entailed the transcription a large number of surveys, particularly those that represented structures visible on later large-scale OS plans. Each survey was drawn to the original unit scale using CAD software, and the resulting plan

[1] A project to abstract and digitise their contents, including a new index, is being undertaken by the Fairbank Archive Project research group at the University of Sheffield, led by Dr. David Crossley

[2] Richeson (1966) *passim.*; Chilton (1957-59) pp. 111-129, plates 8-11.

tested against any available independent plans. Any discrepancies falling outside of the accepted tolerances (dimensionally and geometrically) were re-examined, and wherever possible appropriate modifications made on the basis of a corrected reading of the survey data. This process yielded a number of newly identified tools and conventions, capable of being applied to most surveys within the Fairbank collection.[3]

Of special interest are the units adopted for different surveys, almost never specified in the field books. For large-scale land surveys, the units of measurement were generally the link, the chain and the furlong, although the Fairbanks also used the rod or pole (one quarter of a chain) and a linear rood of seven yards.[4] Smaller jobs, such as plans of individual buildings or relatively compact urban areas were in the earlier examples measured in a combination of yards, feet and inches. Later, however, a single smaller unit became the standard, based on a decimal system and very close to a centimetre in length. This actually transpired to be a customised use of the yard, subdivided into one hundred units (each equivalent to 9.144mm), allowing the Fairbanks to perform simplified calculations on the raw survey data, yet easily produce finished drawings to an imperial scale.

In the following site analysis, this technique enabled the retrieval of otherwise unavailable spatial information from field book data, contributing to the reconstruction of plans of the early steelworks.

Rate book evidence

Many studies of industrial development have relied heavily upon local rate book information to make up for the deficit in contemporary descriptions or plans.[5] The rate books were ledgers used in the assessment of property for the Poor Law rate (and sometimes other rates, such as window tax) and collected several times each year, depending on the amount needing to be raised. The information recorded was generally minimal, usually comprising the names of owner and occupier, a short descriptive name for each building, its rateable value and the rate payable. Rate assessors and collectors had every reason to be scrupulous and up-to-date in their valuation of property, and consequently the rate books are often the best (and sometimes the only) indication of the scale and content of industrial sites, besides allowing alterations to be dated with some precision.

In common to the previous studies is the method of periodically sampling rate book data, for use as statistical source material, or as an indication of long-term development. This use of a limited sample is due largely to the impracticability of referencing every rate collected over a long period, which would involve hundreds of volumes and the transcription of thousands of

[3] This is expanded upon by the appendix 'Survey techniques used by the Fairbanks'.
[4] One link equals 0.66ft (201.17mm); 100 links=1 chain; 1000 links=1 furlong. 1 rod=16½ ft (5029.2mm). The rood is most commonly a unit of area, but was also a linear measurement between 6-8 ft.
[5] See Timmins (1977); Timmins (1982); Belford (1998); Beauchamp (1996). A relatively complete collection of rate books survives for the Sheffield area, along with many of the original valuation books.

individual records. Although this technique is adequate for broad historical and economic studies, it does, however, exclude certain types of evidence useful to the architectural and urban historian.

The case study format adopted by this thesis enabled particular sites to be targeted, and every rate book to be checked. The feasibility of this task was assisted by the use of continuous microfilm sequences, and by transcribing only the changes or additions made to each successive rate. Used comprehensively, further layers of information were made available, including accurately dated changes in ownership, use and built fabric, in addition to detailed marginal data intended for the use of the rate-collector in calculating new or amended rateable values on the spot.[6]

Although entirely textual, the rate books can also be used as a source of spatial data. It became apparent from a study of early Sheffield rates that the organisation of the addresses listed in the rate books was consistent but not strictly sequential, streets often being split into shorter fragments, recorded many pages apart, and in a seemingly random order. Plotted onto a street plan, a pattern emerges: As a perambulatory activity, the rate collectors would take the most efficient route through the town, breaking off from the main streets to record side lanes, alleys and courts, perhaps later returning along the other side. As well as being easier on the feet, these routes would also have served as a mnemonic, retraced each time to ensure no corners were overlooked. Similarly, when assessing the individual buildings that constituted an industrial site, the rate collectors would often work sequentially around a yard, or from the front of the site to the rear, rather than by more abstract criteria such as value, size or function. Thus, in conjunction with appropriate plan evidence (such as the first edition OS sheets, or field surveys) the spatial and functional arrangement of a site may often be deduced with some certainty.

On the other hand, the rate conventions tended to change frequently, making comparisons over time difficult. The data recorded also varied in quantity and quality, sometimes providing little more than the ratepayer's name and the payment due. Perhaps most misleading of all, particularly relative to spatial reconstruction, was the tendency for properties belonging to the same owner to be grouped together, irrespective of their topographical locations. Despite these caveats, if approached with caution and augmented by the analytical use of marginalia and valuations, rate book evidence can be used to 'flesh out' the raw spatial information in maps and surveys, adding a level of detail otherwise unavailable.

[6] The comprehensive revaluation of building stock was a long and laborious process, undertaken as infrequently as possible and usually in order to standardise rateable values. For example the Fairbanks' valuation of the 1830s dealt only with buildings of the third class (industrial) during a period of great expansion.

Residence and small-scale production at Handsworth: 1742-51

While it is generally thought that Benjamin Huntsman began his experimentation while still at Doncaster, nothing is known of these early trials. The first real evidence of Huntsman's activities comes with his relocation to Handsworth, 25km to the southwest. The actual site chosen by Huntsman is known, and can be seen on Fairbank's *Map of the Parish of Sheffield*, which although drawn half a century later can be taken to represent much the same landscape. [fig. 1.11] Handsworth appears as a relatively remote hamlet, situated on the long established route from Attercliffe to Worksop, and surrounded by fields. Without any obvious geographical advantages, it is difficult to see why he should have chosen such a remote location rather than one of the larger towns in the area.

The decision can be better understood in the context of the requirements of the nascent crucible steel process. Huntsman's principal motivation was almost certainly the ready availability of raw materials for the new process, particularly fuel. Handsworth lies at the heart of the South Yorkshire coalfields, close to the Silkstone and Barnsley seams that were to be so important to the later industrialisation of the region. In Huntsman's case, it was the ability to convert this high-grade pit-coal into cokes that was the real attraction.

Coke was then made at most collieries, generally by the controlled burning of large pieces of coal, formed into a heap on the surface of the ground, not dissimilar to the manufacture of charcoal from wood. For some applications it was also produced in specially designed 'beehive' coking ovens, resulting in a more uniform, hard coke, although the earliest known use of such ovens in Yorkshire postdates Huntsman's invention.[7] Hard cokes burnt at much higher temperatures than charcoal, and while the latter had served well for iron smelting, it could not be satisfactorily applied to the fusion of steel.[8]

There were three potential sources of coking coal in the area, the earliest being Bowden's pit on the Parkgate seam, very close to Sheffield itself, and the subject of a deed of 1737 granting permission to 'coake or make and convert into coakes'. In addition, the Barnsley seam was worked at Attercliffe pit and, since the early 18th century, at Handsworth. Around the time of Huntsman's move, the colliery there was probably better developed than that at Attercliffe and hard cokes would almost certainly have been in production for the malt-making process.[9]

Besides fuel, suitable refractory materials were required for the construction of the furnaces as well as the composition of the crucibles. Not far from Handsworth was the Catcliffe glassworks (a cone of which still survives), at that time using fireclay crucibles made of Bolsterstone clay for the production of glass. From here Huntsman could have obtained

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7 Mott (1936) p. 33, fig. 8.

8 Mott (1965) p. 231, footnote, recorded that under the conditions found in a crucible furnace, wood charcoal produced a bed temperature of 1425°C, coke from Barnsley hards 1530°C, and Beehive coke 1600°C, the latter used for steel melting after c.1805.

9 Mott (1965) pp. 231-232, cites E. Sorby, *Transactions of the Institute of Mining Engineers* (1922-23) 65, p. 90. Also see Leader (1905) p. 83.

crucibles (either for experimental purposes or to grind down as an ingredient of his improved crucible) and also glass for flux. Although crucibles were later to be made of clay from Stourbridge and elsewhere, it is thought that Huntsman would originally have used the dark clay available nearby, to which he added a 'grog' of ground up crucibles.[10]

Also of importance was the Green Moor sandstone, quarried locally to Sheffield and used for blast furnace hearths; similarly, the chests of cementation furnaces had long been made of the quartz sandstone found in the coal measures of South Yorkshire.[11] The local sandstone used in the metalling of roads also produced an unintentional but invaluable by-product, caused by the erosion of its surface by carriage wheels. Combined with a quantity of organic matter, the resulting mud was known as 'ganister', a highly refractory material used first as a covering to the chests of cementation furnaces and later as a lining for crucible furnaces.[12]

As for the supply of steel, by 1740 the route from the Humber to the Don at Rotherham was navigable, cutting the cost of transporting Swedish iron from its major centre of import at Hull. For many decades, this bar iron had been converted into high quality blister steel by the cementation process at both Sheffield and Rotherham, and Huntsman could easily have sourced the relatively small quantities he required from either town. It is known, for example, that he purchased steel from the Fells at Attercliffe in the 1740s while still at Handsworth.[13]

A good summary of the favourable environmental factors upon which the local steel industry depended, and which drew Huntsman to the area, may be found at the opening of the chapter on 'Steel manufacture' in *The Useful Metals and their Alloys*, the description being of particular interest as its anonymous author was almost certainly Benjamin's grandson, Francis Huntsman:

> *Sheffield, with its neighbourhood, is the chief seat of this trade; and owes its first establishment, as well as its unparaleled development, to the possession of a number of natural advantages presented by no other locality in an equal degree. Among these may be named its situation near the south-western margin of the Yorkshire coal-basin, which contains all the varieties of coal for hard and soft coke, and also converting coal, which the different operations require. Between the Abdy coal, near Wath, eleven miles north-east from Sheffield, and the lowest of the beds near the town, there are no less than thirty-one seams of coal in a vertical section of seven hundred yards, sixteen of which seams are of sufficient thickness and commercial value to be wrought in different places....Building-stone, capable of bearing the great heat of the melting and converting furnaces, is got near at hand, and also excellent clay for fire-bricks; within a few miles westward, lying at the bottom of the coal measures, and alternating with*

[10] Hulme (1943-45) p. 46, 'Discussion', quotes Mr. Baker.
[11] Baker (1943-45) p. 113; Le Play (1843) p. 592.
[12] Le Play (1843) pp. 641-642. Barraclough (1984) vol. 2, p. 33, notes that by the 1850s ganister was being commercially produced at Sheffield.
[13] See appendix 1.1 for an abstracted table of Huntsman's early blister steel purchases.

sandstone and shale, is found in several places that peculiar black clay for melting-pots, which is the only kind known which will bear the great heat of the steel-melting furnaces. These advantages would have been insufficient, especially in the earlier ages of its establishment, but for another, which made available and thereby increased the value of all the rest. We refer to the water-power of five small rapid manageable rivers, which, rising on the high lands of the western moors, converge towards the town.[14]

The crucible process depended on all of these qualities, even the water mills that drove the powerful tilt hammers, without which the ingots of cast steel could not have been forged down into bars.

His new premises were almost certainly based around an existing stone cottage, to which Huntsman made the necessary additions. The form of the buildings is known from a surviving photograph and watercolour,[15] [fig. 1.10] from which it is clear that the chosen site afforded a degree of privacy and security that a more urban location would not. The property was one of a short, unassuming row, slightly sunken below the level of the street.[16] Against the right-hand cottage (as seen in the photograph) Huntsman built an extension, concealed from the street by a high, unbroken stone wall and generally believed to have housed his first purpose-built furnaces. Hidden behind this extension, a small court provided the external space essential to even the small-scale experimental working of the process, as a place for coal, coke, ashes and waste. Perhaps most significantly of all, the very rear of the site seems to have been defined by an natural watercourse and pond, clearly indicated by a meandering line on the 1850 OS plan.[17] [fig. 1.12] A later plan of 1892 shows the same, but with the additional label 'D Wells' meaning a draw well.[18] A fresh and abundant supply of water, as it shall be seen below, was of great importance to Huntsman's process.

There is no indication of the scale of production possible at Handsworth, but it is certain that a commercially workable process was first achieved here, as by 1750 the Cutlers' Company were already referring to Huntsman as 'the steel founder'.[19] Le Play later stated that 'in 1740, after several successful trials, he established himself at Handsworth, a village near Sheffield in the middle of a rich coalfield. Here he established the first works where cast steel was regularly made'.[20]

On his departure for Attercliffe, Huntsman would almost certainly have obliterated any recognisable features of his Handsworth furnaces, although those who saw the cottage prior

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[14] Scoffern (1857) p. 334. See below for the attribution to Francis Huntsman.
[15] Photograph in Barraclough (1976) p. 36. The watercolour was reproduced in a local newspaper, SCL Local Studies NCRS 942.74SF, vol. 27, p. 52.
[16] It is unclear whether the adjacent pair of cottages predated Huntsman's–if not, his property would have stood alone, offering even greater privacy. The watercolour was published with the accompanying note: 'one of a pow [sic, read row] built below the level of the road just above Oakley Road.' This is confirmed by spot heights taken from the OS plans
[17] 1850 OS plan Sheet 295 scale 6"-1 mile (1:10560).
[18] 1892 OS plan Sheet 295.10 (1:2500 scale) surveyed in 1890.
[19] Leader (1905) vol. I, pp. 174-175
[20] Le Play (1843) p. 638. Translation from Mott (1965) p. 234.

to its demolition in 1933 reportedly found flue marks displaying the effects of intense heat.[21] If the stack seen in the photograph represents the vestiges of these furnaces, its dimensions suggest that he operated no more than one or two furnaces, each capable of holding a single small crucible. Of interest is the relationship between the furnace outbuilding at Handsworth and the later Attercliffe melting shop (see below). The depth of each plan between the furnace stacks and the opposite wall is almost identical, at just over six yards (c.5.5m), suggesting that Huntsman may have closely modelled his later full-scale furnace building on the prototype Handsworth structure, simply increasing the length of the shop to admit a greater number of furnace 'holes'.

As already demonstrated, around 1750 Huntsman was faced with the serious threat of losing all entitlement to his own invention, as well as any benefits deriving from its success. With no patent protection and competitors in both Sheffield and London beginning to produce cast steel commercially, he was running out of time and options. The next move was to be decisive: he was to dedicate himself to the manufacture of steel, and confront his rivals in the open market. This meant leaving his Handsworth cottage, and the construction of much larger premises specifically designed by himself for the purpose.

Worksop Road: 1751

The location of Huntsman's first commercial works has long been a subject of speculation and debate. Its importance to the history of Sheffield's industrial development combined with a paucity of contemporary evidence has, over time, resulted in the growth of a tissue of myth, encompassing the few known sources, local tradition and hearsay.[22]

It is generally thought that Huntsman left his cottage in Handsworth in 1750 or 1751, to establish the first fully-fledged crucible works near Attercliffe for which various hypothetical sites have been proposed but not positively identified.[23] The latter date also marked the formal beginning of his business, as commemorated by the firm's stationery and advertisements which bore the title 'Established 1751'.[24]

After about two decades of production, around 1770, he is said to have moved once more, this time to the site later known variously as 'Huntsman's Yard' or 'Huntsman's Row' situated on the South side of Attercliffe Green, the heart of the old village, where the business

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[21] Mott (1965) p. 237, gives the date of the cottage's demolition. Hulme (1943-45) p. 46, published the correspondence of Mr. W. E. S. Patrickson, who noted the flue marks. Mott (1965) p. 232, remarked that 'throughout its career the chimney of a crucible-steel furnace was surprisingly similar to that of a house with a fireplace in a cellar', so the furnace flues may simply have been adapted to domestic uses.
[22] To date, the most comprehensive survey of evidence for Huntsman's career is that contained in the pamphlet Barraclough (1976b) with additional material in Barraclough (1984) vol. 2, *passim*.
[23] Mott (1965) pp. 229, 233, plotted the hypothetical location on a map, fig. 1, although this was not intended to indicate any particular site. Barraclough (1976) p. 4, fig. 4. Bayliss (1995) p. 28: 'Site of his first works (c1751) was on E side of Leeds Road and the second (c1770-1899) S of Worksop Road'.
[24] Miller (1949) p. 21, described an advertisement picturing the Wicker Tilt (later tenanted by Huntsman) with the date 1751 on the building. A redrawing of this image is contained in SCL Local Studies, Henry Tatton's sketchbook, vol. 1, p. 109 (110)

remained until the end of the nineteenth century. Consequently, descriptions made by foreign visitors before 1770 (i.e. Jars, Robsahm, Andersson) have been interpreted as being of the earlier works site.

In tracing the development of the crucible furnace as a building type, it was decided to make a fresh attempt to locate these early works sites, and to account for their growth and change over time, a subject that had not been adequately covered by previous studies. This began with the reassessment of all known evidence, followed by an archival search for new material.

The earliest published plan of Huntsman's works is a survey of 1763, to which revisions were added in 1781, along with a note 'now taken to Thos. Gunning'.[25] [fig. 1.13] This has been used to support the theory of a move around 1770, taken to represent the first pre-1770 site, with the implication being that by 1781 Huntsman had left for Attercliffe Green, and his old furnaces reoccupied by Thomas Gunning, one of Sheffield's most successful merchants and steelmakers.[26] Few clues are given as to the location, save that the properties face 'Attercliff Green', and the absence of a north point precludes the identification of which side of the Green the buildings occupied. Barraclough, however, went as far as to propose a location for the furnaces, on the North side of Attercliffe Green, adding that in 1819 the owner of the site was Charles Hancock who occupied 'a steel furnace' and a 'malt-house'.[27]

This plan became the starting point of the investigation. As expected, conventional methods of identification–for instance, matching landowners' names to rate book or directory entries–failed due to the insufficiency of contemporary records.[28] However, no previous attempt had been made to find a topographical fit for the plan, due to the difficulty of working from the Fairbanks' notation. Drawn to scale, the plan did not fit the site postulated by Barraclough, or any combination of neighbouring sites. Due the lack of a definitive target area, and the significant changes in field boundaries since enclosure, it was deemed impractical to check a large area for a geometrical fit. Instead, a search of the Fairbank collection was made for other surveys of the Attercliffe area made at a similar date, in hope of finding matches of land owners' names or building form.

A survey was found of properties fronting the village green.[29] [fig. 1.14] This had probably been made for a plan of the area, also in the Fairbank Archives but badly damaged and missing the area that would have represented the Green. Although Huntsman's name did not appear, adjacent owners' names (Samuel Scholey and Thomas Crapper) matched those of the other survey, and a number of corresponding measurements confirmed that there was an

[25] SCA FBC FB25, p. 38. Survey dated 11 August 1763; revisions 1781.
[26] Holderness (1973) p. 42: 'Thomas Gunning, who in 1772 was described as the second wealthiest commodity merchant in the town.'
[27] Barraclough (1976) p. 5.
[28] Sheffield's first trade directory was published in 1774 (and lists 'Huntsman Benjamin, cast steel maker, Attercliffe, near Sheffield'), while the Attercliffe rate books do not cover the period in question.
[29] SCA FBC FB58 supp., pp. 37-39. The date of the survey is uncertain, but its context suggests c.1783, which date would explain the omission of detail to Huntsman's property, surveyed as recently as 1781.

overlap between the two plans.[30] With this additional information, not only could the pre-1770 site now be placed definitively within the village, but the precise site boundary could be plotted on to the later, more accurate, OS plan. It was found to be exactly that of the later Huntsman's Yard works.

The first implication of this discovery was that the move of 1770 never happened, and that the buildings represented in the 1763 survey were almost certainly the first works established in 1751; certainly the layout corresponded to the earliest known description of ten years later.[31] Compared with the nineteenth century plans, the original steel furnaces and mill occupied the centre of the courtyard, immediately behind Huntsman's cottage. By 1781 a number of extensions had been made, some of which were coincident with structures seen on later plans of the Huntsman's Yard site.[32] [fig. 1.15]

Further evidence was brought to light by a detailed archive search for the Attercliffe site, and in particular material prior to the notional relocation of 1770. The most important document was a survey of 1767 that filled in the gaps left by the 1763 measurements, describing the cottage, yard with a well, and the full perimeter of the furnace block.[33] [fig. 1.16] The property also included the 'croft' extending all the way to the back lane, the whole described as the 'Burgesses Land Held by B. Huntsman under W^{m}. Fullard'.[34]

Also of significance was another Fairbank survey made in 1819 for the re-evaluation of the Attercliffe rate.[35] [fig. 1.17] Just discernible beneath the pen and ink survey is a faint, ruled pencil under-drawing based on the combined measurements of 1763, 1767 and 1781 and used as the basis of the new measurements. This drawing definitively places the earlier site at the centre of the later complex. As it happened, so many changes had been made to the steelworks since 1781, that the surveyor had to abandon this drawing and start again from scratch on the following page.

Given this new evidence for the continuous occupancy of one site over almost 150 years, one must address the question of how the erroneous version of events arose. The confusion can be traced to a pair of sources: Samuel Smiles' biographical essay on Huntsman from his *Industrial Biography* of 1863, and the publication of a notice from the *Retford Gazette* in an article of 1944.[36]

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[30] Huntsman's plot is marked 'Burgesses', in accordance with the survey of 1763 that indicates his cottage and furnaces were built on the 'Burgesses Land'.
[31] Robsahm gave a detailed account of his visit to Huntsman's works, noting many of the features seen in plan such as the horse-powered mill alongside the furnaces.
[32] The buildings identified as 'a Smithy', 'Furnace' and 'Iron House' in the 1781 revisions to FB25, p. 38, occupied the same area as the later steel house and store. See below.
[33] SCA FBC FB33, p. 4; AB4, p. 72. The latter account book confirms the date to be 21 August 1767.
[34] The Twelve Capital Burgesses (or Church Burgesses as they were often known) were one of the major landowners in Sheffield and its environs.
[35] SCA FBC FB153, p. 6
[36] Smiles (1863) pp. 99-113, Hulme (1943-45) p. 39.

Smiles was the first British writer to take an interest in the Huntsman's career, and the short chapter he dedicated to the inventor is largely responsible for having rescued his name from obscurity. The passage in question informs us that:

> *...the demand for Huntsman's steel steadily increased, and in 1770, for the purpose of obtaining greater scope for his operations, he removed to a large new manufactory which he erected at Attercliffe, a little to the north of Sheffield, more conveniently situated for business purposes. There he continued to flourish for six years more, making steel and practising benevolence', until his death in 1776.*[37]

Smiles claimed that his account had 'been furnished by [Huntsman's] lineal representatives', but this statement must be qualified. Much of his information can be traced aforementioned textbook on metallurgy, *The Useful Metals*, published six years earlier, and it was here that the date 1770 first appeared, along with the story of the 'shivering beggar'.[38] Interestingly, neither text makes reference to the earlier move of 1751.

Smiles' version of the story found a wide audience, and soon began to spread. A French translation of the Huntsman chapter–unfortunately often regarded as an independent source, in confirmation of Smiles' facts–appeared towards the end of the nineteenth century under the title *Historique de l'invention de l'acier fondu en 1750 par B. Huntsman à Attercliffe.*[39] The original essay was later used as the main source for Huntsman's entries in the *Dictionary of National Biography* and the *Encyclopædia Britannica*, upon which countless further accounts have been based.[40]

Almost a century later, a notice was discovered in the files of the *Retford Gazette*, stating that Huntsman had left Handsworth for 'larger buildings designed by himself in the Worksop Road'.[41] Hulme concluded that this was a reference to another site, distinct from the later works on Attercliffe Green, despite the fact that during the eighteenth century Worksop Road was the name given to the route from Attercliffe to Worksop, running straight across Attercliffe Green.[42] It was this assumption that gave rise to the dual site theory that has persisted ever since. It is worth noting that none of the sources written before the 1850s refers to a second

[37] Smiles (1863) p. 110. The date of his death is known from his grave, situated in Attercliffe Hill Top Cemetery.
[38] Scoffern (1857) p. 347, wrote: 'It appears that about the year 1770, he removed to Attercliffe, in the parish of Sheffield, where the business has ever since been conducted. This would have been when he was near 70 years of age, and six years before his death in 1776'. The context of this date excludes the possibility of it being a typographical error, so it must be assumed that the origins of the firm were lost to Huntsman's descendants.
[39] 'Historique' (1888) SCL Local Studies: Local Pamphlets vol. 134, no. 11. The British Library catalogue suggests the date 1888.
[40] Goodwin (1891) p. 313, also drew on Le Play (1843); *Encyclopædia Britannica* (1911) New York, vol. 13, p. 955.
[41] Hulme (1943-45) p. 39, commented that this was 'a move not recorded elsewhere'. The notice was found by one 'Maj. Marples'.
[42] At the time of Huntsman's move, the road had not been upgraded to a turnpike (this happened in 1764), and the green was still a common. Therefore Hulme may have perceived the Worksop Road to end before its entry into Attercliffe village. For Sheffield's turnpike roads, see Smith (1997) pp. 70-79.

site; Le Play, for example, simply notes that from Handsworth, Huntsman 'moved his establishment to Attercliffe where his direct descendants continue the same industry'.[43]

The date 1770 has since become entangled with local tradition. The present day 'Britannia Inn', a public house on the Worksop Road, and a short distance from the site of Huntsman's Attercliffe works, is reputed to have been Benjamin's home in the years before his death in 1776. [fig. 1.18] Wrought-iron numerals on the western gable end forming the date '1772' are said to be cast from Huntsman's steel, and the building has been listed, with a plaque on the outside stating the case for its authenticity.[44] An indenture of 1772 relating to the lease of a property consisting of 'all that Cottage Tenement or Dwellinghouse situate standing and being in Attercliffe aforesaid with a Barn Smithy and Garden therein belonging and also the use of a Certain Well in the Backside and Liberty to draw Water there...' has been taken to be a reference to the same property.[45] Unfortunately, contemporary evidence confirms that this building had no connection with the Huntsman works, 150m further down the road.[46] The cottage that became Huntsman's final residence, from 1751 to 1776 was, as shall be seen, demolished along with the works at the end of the nineteenth century.

Huntsman's cottage faced the Green, its frontage aligned with the consensual building line that defined one side of the triangular space, while from the rear there extended a pattern of long burgage-strips or crofts. [fig. 1.19] The tightly knit village structure would have provided an ideal location for somebody concerned about security, and wanting to keep a low profile. Even by the nineteenth century, many of the fields that surrounded the village were undeveloped or subdivided into allotments, still used for the cultivation of food. It is probable that the cottage predated the other buildings erected by Huntsman on the site, a view supported by the piecemeal ownership of the land upon which the works were erected. It was not unusual to find workshops and even small furnaces in the backyards of dwelling houses, and this pattern of development characterised much of the early industry of Sheffield.[47]

The remaining question of Thomas Gunning's apparent occupancy of the site by 1781 can also be explained, and will be expanded upon below.

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[43] Le Play (1843) p. 638. Translation from Mott (1965) p. 234. Even later, Hadfield (1894) pp. 5-6, recorded only one move from Handsworth: 'Finally, he removed to Attercliffe... and his works are still in existence, considerably altered and enlarged, but situated in the street known to this day as "Huntsman's Row"'
[44] Bayliss (1995) p. 28, 'E5 Britannia Inn'. Barraclough (1976) pp. 4-5, fig. 13. Hey (1998) pp. 70-71. West (1998) p. 125 'Grade II listed buildings in Sheffield'.
[45] SCA PhC 445 (c), Tyler to Asline, registered 10 August 1772. See 1767 survey, which shows property belonging to John Tyler (as in the indenture) immediately to the West of Huntsman's cottage, on the site later to become 'Huntsman's Row'.
[46] Even in later years, the rate books do not indicate that the Huntsman family owned this building. Hadfield (1894) p. 6, stated that 'within a few yards of the works is Benjamin Huntsman's house' (at that date still standing) and may have been misinterpreted by later historians.
[47] Lloyd (1913) pp. 12, 161, 201, included illustrations of an 'Old cutler's workshop, near Sheffield' and 'File-cutters' workshops, Sheffield'. Beauchamp (1996) vol. 2, p. 235, plan of Nook Lane Works, Stannington. See also Leah's Yard, chapter 4.

Reconstructing the furnaces

Documents previously thought to represent the first site need to be reassessed with respect to Huntsman's actual movements. A drawing of Huntsman's Attercliffe steelworks by the late Victorian local artist William Topham was assumed to be a copy of a lost picture from the eighteenth century, on the basis of the number '1787' pencilled on the reverse.[48] However, the arrangement depicts a much later phase of the works' development and was certainly sketched by Topham from life.[49] Therefore Geisler's 1772 drawing of a crucible shop [fig. 1.20] does not represent the furnaces seen in the Topham drawing [fig. 1.21] as proposed by Barraclough; if Geisler did base his sketch on Huntsman's works (as implied by the accompanying text) it must be considered in relation to the furnace building recorded in the earlier surveys above.

Although Benct Qvist Andersson had made a drawing of a crucible furnace six years previously, this was of a building to his own design, albeit after careful study of examples from Sheffield. On the other hand, Geisler's sketch is of an actual Sheffield furnace, accompanied by a scale of *alnar*,[50] suggesting that at least rudimentary measurements had been taken. At this time, there were only a handful of furnaces he would have been able to visit. The Walkers' original 'house and furnace for refining steel at Grenoside' of 1750 was small and possibly disused, and not until 1773 did they build any new furnaces. Love and Spear had a small three-hole furnace on a different plan, and it is uncertain whether Marshall was established at Millsands. The Cutlers' Company furnace, as shall be seen later, had only four melting holes and was of a different construction.[51]

The drawing consists of a plan and two sections, depicting a single storey building with a full-depth cellar, along the back wall of which is a row of ten crucible holes. Above ground level, the flues from each furnace combine into three tapering stacks, in a 3-4-3 arrangement, taken some distance above the ridge of the monopitch roof. This early adoption of a simple roof of joists supported on the massive structure of the stacks is an example of the ingenuity often found in industrial buildings, by which multiple functions are often satisfied by one synthetic form, in this case made possible by the union of several flues into a wider combined stack. This form of construction was to become a common feature of later furnace buildings, allowing the use of efficient lightweight, single-storey construction.

A comparison of the three projected views reveals that the plan is actually taken at basement level, omitting the projecting stacks shown in section; in order to assess the similarity of Geisler's and Huntsman's furnaces, the ground plan, including the three stacks, was

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[48] Barraclough (1976) p. 8, fig. 8. Topham's view predates that used in the Huntsman firm's commercial literature, but can date to no earlier than 1850 (note the second coke shed on the furnace building, and the lean-to shed, not shown on the 1850 OS plan, but present by 1889 [dates of survey]).
[49] See below (the '*Useful Metals*' furnaces) for the evidence relating to these buildings.
[50] The Swedish *aln* (pl. *alnar*), also *ell*, is, like many old European measurements, subject to some variation. Berg, in Angerstein (2001) p. xxii, gives a value of 590mm. Pipping (1988) pp. 96-101, takes the *aln* to be two English feet. Also see Darton and Clark (1994) *Dictionary of measurement*, pp. 135-136.
[51] The Walker minutes for May 1772-May 1773 read: 'Enlarged the casting steel furnace for 4 more furnaces & built a new coaking oven', from Mott (1965) p. 235. See chapter 2 for details of other early crucible furnaces.

recreated by the author from the other views. [fig. 1.22] It was not known whether the furnaces had been extended by 1772, so the site plans of both 1767 and 1781 were considered. The latter proved an exact proportional match with Geisler's drawing, giving a value to the *aln* of 720mm, much closer to the *ell* of the Low Countries (27 inches or about 690mm).[52]

In other respects also, the drawings tie in very convincingly with the Attercliffe works. The stair leading up from the cellar neatly occupies the front corner of the shop, adjacent to the roller-mill and clear of the main circulation. The central front door to the melting shop faced the small yard, which led along the side of the cottage, on the other side of which was built a row of dwelling houses for the steelworkers (see below).[53] At the rear of Geisler's drawing, three banks of flues project from the building by the same amount as Huntsman's, although their spacing suggests that the implied symmetry 3-4-3 was in reality 3-3-4, with 4 being the extended portion. The symmetrical layout was perhaps a rationalisation following his visit, or else the understandable result of his not having seen the back of the furnace building.[54]

In this context, it seems fairly certain that Geisler's sketch plan represents the enlarged Huntsman furnaces as seen in 1781, bringing the date of the extensions to the five year period between 1767 (the survey of the unmodified furnaces) and 1772 (the date of Geisler's visit)--before Benjamin's death and contemporary to the emergence of Huntsman's first commercial rivals. It is likely that both the extension of the works and the increased competition were stimulated by a growth in the market for cast steel, perhaps following the cutlers' failed export ban.

Working from these sources, it is possible to reconstruct the earliest plans of the 1760s, quite probably as originally built by Benjamin Huntsman in 1751.[55] [figs. 1.24, 1.25] The two stacks were of equal size, each one wide enough to contain three flues, giving a six-hole furnace. This early scale of production is supported by the contemporary evidence of B Q Andersson, who observed 'there are usually six such furnaces in one house'.[56] In 1761 when Robsahm visited, Huntsman had just three assistants and an output of eight tons of cast steel per annum, but could have produced up to twelve tons had he 'cared to hire' more workers.[57] On the basis of these figures and an early ingot weight of thirteen pounds, Mott concluded that at two melts per day, each hole might produce three tons per annum, and therefore deduces

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[52] One explanation for the proportional accuracy of Geisler's measurements, but the variation in linear measure, would be the use of his arms as a makeshift scale, in the absence of measuring equipment. The *aln* was based on the distance between the elbows with the hands overlapping (or in some countries with the fingertips touching), reflected in the etymological derivation of the words *aln* and *ell* from the Latin *ulna* meaning elbow or forearm.

[53] Part of this terrace can be seen in the early surveys, although its total extent is not clear. By the 1780s, the rate books list a number of dwelling houses owned by Huntsman and contiguous to the steelworks.

[54] It is unlikely that the profile of the stacks, indicated in Geisler's section, would have been readable in the actual interior, where they would have formed a flush vertical wall.

[55] It is, of course, possible that the furnaces had been built as a small three-hole unit, and doubled in size before 1763. There is, however, no archival evidence to suggest this was the case, and the partial records of Huntsman's steel purchases prior to 1763 do not indicate such a jump in capacity.

[56] Pipping (1988) p. 97. Andersson is known to have visited Huntsman, and also decided to build a six-hole furnace of his own design in Ersta, a drawing of which accompanies his report.

[57] Mott (1965) p. 234, cites Flinn & Birch (1954) p. 171. Barraclough (1984) vol. 2, p. 10.

three holes to have been active. Accounting for days lost to repairs, he estimated a five-hole works, remarkably close to the six holes suggested by the survey evidence.

Projecting from the South elevation would have been the annealing stove, essential to the working of the process, and rebuilt in the same relative position when the shop was later extended. In the context of the full site plan, the internal connections between the casting shop and its various outbuildings can also be deduced. The small structure built into the angle between the 'Furnace' and 'Mill House' may have been the pot-room, used for crucible making, and directly accessible from the furnace shop floor. The 'Mill House' and adjoining 'Shed' are un-hatched in the survey notes, a convention often used by the Fairbanks to represent structures partially open to the elements. Horse-powered mills were often covered only by a simple roof structure, or else had low walls to allow adequate ventilation; the shed was almost certainly for the storage of coal and coke, and would also have been open to the yard and accessed externally.

Geisler would have had little reason to remark on these structures. The simple horse-powered edge roller mill was a common machine of this period, adapted to a wide range of uses.[58] In the absence of gearing, the space required for such a mill was determined largely by the radius described by the movement of the horse (or horses) about the central stone; consequently most one-horse mills of this type have similar dimensions, Huntsman's being no exception.[59] [fig. 1.23] For the purposes of reconstruction, a plan based on a closely matching example from Loudon's *Encyclopædia of Cottage, Farm and Villa Architecture* has been adopted.[60]

A day in the life of Huntsman's steelworks

No complete account exists of the process as first practiced by Huntsman, but the details can be recovered from a number of early sources, and interpreted in the light of later practice.[61]

In the context of the above reconstruction, it can be demonstrated that the layout of the site reflects the relationship between the various underlying processes. The yard was the real hub of the works, enclosed by buildings apart from two short stretches of wall at the front and back, both punctuated by gates. The croft or field behind the works, accessible via a short lane alongside the cottage, was also entirely fenced-in.[62] Huntsman is said to have at first

[58] Atkinson (1960-61); Major (1988-89); Harrison (1973).
[59] Based on examples from Angerstein (2001) figs 130, 193, 292, 316; Loudon (1835); contrast this to Markus (1993) pp. 261-262.
[60] Loudon (1835) *passim*
[61] The sources used as a basis for this interpretation include Jars (1774) pp. 257-258, Pipping (1988) pp. 96-101, Broling (1812) vol 3, translation Barraclough (1984) vol. 2, appendix 3; Robsahm (1761) *Dagbok över en resa i England*; and examples of later practice from Brearley (1995) *passim*.; Flather (1901-02) pp. 58-60, partially reprinted in Barraclough (1984) vol. 2, pp. 46-48.
[62] The surveys of 1763 and 1767 indicate that the entire site boundary was fenced. This may again have been a security measure, as other nearby plots of land were left open.

made his own coke, and it was probably here that the relatively large quantities required were made by burning heaps of coal in the open.[63]

Like many early steelworks, the yard was of the 'drive-through' type with gates at both ends, obviating the need for carts to turn in its relatively confined space. Regular deliveries would have included cartloads of raw clay from a number of sources, coal for coking, bars of cementation steel, glass for flux and possibly even crucibles to be pounded up for 'grog' (the latter two items perhaps coming from the nearby glassworks).

Making the crucibles involved completely drying out the clay before grinding it to a powder. 'Grog' from used crucibles would also be ground down and added to the mixture–for this Huntsman had built the horse-powered edge roller mill adjacent to the furnaces.[64] [fig. 1.26] These dry ingredients were then combined and sufficient water added, in this case drawn from the well between the cottage and the works. The mixing was done in a simply constructed trough of timber planks, resulting in a stiff clay that was subsequently trodden by the workmen using their bare feet, in order to detect any remaining lumps which could lead to the failure of the crucible in the furnace.[65]

Huntsman probably made his crucibles in the small room attached to the side of the furnace building: this dedicated 'pot room' became a standard feature of almost every crucible furnace that followed.[66] Traditionally, crucibles had been formed by a simple screw-press, such as the device seen in Ercker's treatise, [fig. 1.4] a modification of which was later widely adopted in Sheffield. Broling's report, on the other hand, illustrated a simple cast-iron mould into which a 'core mould' of hardwood or preferably *lignum vitæ* was driven with a mallet.[67] To keep the thickness of the crucible consistent, the exterior iron mould had a central hole in the base, into which a corresponding iron spike running through the centre of the timber core was located.

A ball of clay of the appropriate size was inserted into the mould, lubricated inside with suitable oil. This was followed by the core, also oiled, which was hammered down, forcing the clay up the sides of the mould until a small amount projected over the lip. After trimming off this excess with a 'strickle', the core would first be removed, followed by the exterior mould. In Huntsman's lifetime, the forrn of the crucible would have been complete, although later practice required the top of the crucible to be turned in, by the application of a tapered 'bonnet' of sheet metal, resulting in the customary barrel shape.[68] [fig. 1.27]

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[63] Benjamin Huntsman [his great grandson] in a letter to *The Times*, 3 January 1865.

[64] In the absence of used crucibles, this grog or 'pot-sherd' could be manufactured by firing cakes of clay in the annealing-stove as described by Broling (1812). This would rarely have been practiced in Sheffield, where used crucibles abounded

[65] Howe (1895) p. 300. By this time the mixing was more commonly done in a mill, although the practice of treading was still used, 'and, it is thought, with better results'. Also see Flinn (1957-59) p. 107.

[66] Unusually, the perspective image of a Sheffield furnace included in Broling's report as pl. 1 shows crucibles being made in the cellar, as there is no evidence that the building adjacent to Huntsman's furnace was the pot-room, Broling's observation may not be discounted. See also the late nineteenth century example of a furnace, built for Spear & Jackson, where the pots were made and dried in the cellar, chapter 2.

[67] Broling (1812) plate 7. In Sheffield, the mould and core were later termed 'flask' and 'plug' respectively.

[68] Early sources generally show the crucible to have straight sides. See, for example, Raistrick (1967) p. 76; Pipping (1988) p. 98; Althin (1971) pp. 32-33, reproduced in Barraclough (1984) vol. 2, fig. 3. Also Howe (1895) p. 300, fig 151 (reproduced from Greenwood).

The finished crucibles were then left to dry slowly, first in the pot room and then on shelves built above the melting holes, assisted by the heat from the brick stacks, usually for at least ten days, if not over one month. The night before their intended use, the next day's crucibles were put into the annealing stove specially designed for the purpose, and brought to a red heat. [fig. 1.28] This process of gradual drying followed by annealing greatly reduced the chance of the crucible cracking in the strong heat of the furnace. In this instance, the stove was built out from the far wall of the furnace building as to leave the area in front of the holes unobstructed.

In the meantime, pieces of broken and graded blister steel for the first 'round' of melts would be weighed into baskets, each containing the precise mix of ingredients, ready for charging the pots–again, either in the small corner room or in the cellar; the internal steps suggest that the cellar was perhaps more important at this stage, as the later convention was for them to be external.[69] The required quantity of flux would also be measured out, although this may have been the responsibility of the head melter or Huntsman himself.

Early in the morning on the day of the melt the furnaces were lit with a small amount of coal before the annealed crucibles, already hot and closed by their lids, were lowered into the furnace 'holes' and surrounded by coke to be preheated.[70] In the earlier generation of crucible steelworks, each furnace hole contained only a single crucible, holding from thirteen to twenty pounds of steel.[71] The draught would then be 'urged' by replacing the firebrick covers to the crucible holes and allowing the maximum flow of air from the cellar to pass through the furnace. On reaching a white heat, each hole was uncovered and the pot lid moved to one side using iron 'lid tongs' designed for the purpose, before carefully placing the charge of steel into the crucible, either with an iron 'charging shovel' or with the help of a funnel. [fig. 1.29]

The addition of the flux to the pots, especially in the early days of the process, was performed with almost a religious reverence, often by the proprietor of the works himself. Huntsman's descendants recalled that 'fifty or sixty years ago "fluxing the pots" was the grand mystery of some steel melters, who, considering themselves a sort of *Adepti*, would not allow their workmen to flux the pots, lest they should obtain possession of the secret, and become *Adepti* also'.[72] Andersson's report confirms that the horse-mill was also used to grind down

[69] The later adoption of external stairs was perhaps a result of the introduction of the bypass flue. By isolating the cellar from the shop floor, the flow of air through the furnaces may have been more easily regulated.
[70] Broling suggested that work begin at 4am, allowing time for three melts in a day, ready for 'teeming' between 7-9, 10-12, and 1-3 respectively. The rest of the day would be used to clean up the furnaces, weigh and mark the steel, etc. Huntsman may initially have made only one or two melts in a day. See Pipping (1988) p. 99, for Andersson's 1769 comment that 'it is scarcely possible to melt more than once a day in a cast steel furnace, as one dares not immediately put the crucible back into so strong a fire as still is burning after the first melting'. This may have been due to the lack of a bypass flue as shown in his drawing, making it impossible to regulate the heat of the furnace.
[71] Scoffern (1857) p. 348, (Francis Huntsman) described the early conditions: 'In his [Benjamin's] time, and many years afterwards, only one crucible was put into the furnace-hole–now two pots are put in; and his pots held only about half as much as those now used'. See chapter 2 for the earliest evidence for the use of two crucibles. Pipping (1988) p. 97. B Q Andersson reported a charge weight of 20lbs in 1767. Jars (1774) vol. 1, p. 257, saw furnaces each holding one 'large' crucible, 9-10 inches tall and 6-7 inches in diameter, probably containing about the same weight of steel.
[72] Scoffern (1857) p. 348, also added that Huntsman 'used a flux said to be of broken bottle-glass, not with the expectation, so far as is known, that it would in any way improve the steel, but only to make it melt more readily'.

the ingredients of the flux: 'It is necessary to have a common roller mill at such a works, a mill consisting of a millstone on edge rolling upon a flat stone, not only for grinding materials for crucibles but also for crushing glass. Such a mill can best be driven by a horse, lacking wind or water power'.[73]

With the crucible's lid back in place, the furnace topped-up with coke and the cover replaced, the process of melting began. If a number of holes were in use, these would be readied in turn, each hole regularly checked for its progress. Extra coke would be added as required (at least twice more during a normal melt) and the temperature maintained at the correct level for around three to five hours.

When the melt was deemed complete, the steel was 'teemed' into cast iron ingot moulds, each made up of two halves split from top to bottom, and forced together with iron bands into which were driven wedges. Before casting, the ingot moulds were prepared by preheating in the annealing stove, and coating their interiors with soot, to assist the later removal of the cooled ingot.[74] The mould was lowered into a casting pit or 'teeming box'–essentially a trough built into the floor–and rested at a slight incline against the side to allow a more convenient and natural posture for pouring or 'teeming' the steel. [fig. 1.30] By partly filling the pit with sand, the height and angle of the mould could be easily adjusted, and its stability improved. Lifting and controlling the white-hot crucible, even at the relatively small early ingot weights of about twenty pounds to which must be added the weight of the crucible and tongs, was a strenuous and potentially dangerous task, so the ergonomics of the casting procedure were critical.[75]

The crucible would remain in the furnace for a few minutes after checking, while the 'puller-out' and 'teemer' prepared themselves by tying several layers of sackcloth saturated in water around their legs. A sleeve of the same material was also placed over the hand and arm closest to the pot, the wet fabric giving vital protection against the heat of the crucible.

The foreman having determined the order in which the pots are to be removed, the puller-out would first lift the crucible from its hole to shop floor level by means of a pair of iron lifting tongs. The pot was then moved over to the mould, where the teemer would grasp it about the middle with a pair of casting tongs before the lid was once again removed by the puller-out. Before casting, the slag floating on the surface of the steel (a result of the flux), could be readily skimmed off by an assistant using an iron rod tipped with a small lump of metal, taking care not to touch the steel itself. With the crucible and tongs balanced upon his knee, the teemer would then pour the steel into the mould in a continuous stream, a demanding task

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[73] Pipping (1988) p. 97
[74] Broling (1812); Pipping (1988) p. 97, quotes Andersson.
[75] The casting pit was another example of the exploitation of one requirement to accommodate a second function. As the shop floor was raised above ground level to allow the creation of openings for air to the vault below, the poché between the floor and the cellar vault opposite the furnaces was excavated to form a pit of the required depth.

rendered more difficult by the necessity of not catching the sides of the mould with the molten steel.[76]

If the pot was to be used for another melt, the lid would be immediately replaced and the pot lowered back into the furnace, to prevent it from cooling down and becoming brittle. A few minutes after casting, the filled moulds were ready to be opened, by knocking off the retaining hoops and releasing the ingot, which would be taken outside to cool. By the early nineteenth century, it was common practice to perform three rounds in a day, reusing the crucibles whenever possible. Due to the corrosive attack of the molten steel and flux on the inside of the crucible at the level of the slag, the size of charge was lowered in each successive melt, to avoid undue weakening of the same part of the crucible each time.[77]

The finished ingots would then be stored in the adjacent warehouse or shed, prior to dispatch to one of the water-powered tilting mills for forging into bars. Over its history, the Huntsman firm hired, leased or owned a number of tilt hammers in the Sheffield area, the best known being the Wicker Tilt at Lady's bridge. At this time, however, Huntsman may have sent his ingots to John Fell's Attercliffe Forge less than half a mile down the road.[78] [fig. 1.31] He is known to have purchased blister steel from them prior to 1751, and the proximity of such a valuable resource was perhaps one of the main attractions of the Attercliffe Green site.

From the tilt, the forged bars would be returned to the works to be stored until their delivery to the merchants or customers. When Fischer visited the Huntsman works in 1814, he was impressed by the quantity and range of stock held on site:

> *There was much steel in the warehouse, particularly rolled sheet. I asked Mr. Huntsman for a price list of his steel, which he keeps around twenty five per cent more expensive than the other manufacturers. After it had made it out, he showed me the sizes of the corresponding samples in little bars from four* Zoll *[inches] in length, all with stamped with his name, from the thinnest round, flat or square sections, up to the thickest of the same kind.*[79]

Finally, the used crucibles, having reached the end of their short lives, would be roughly cleaned of any attached coke debris and stacked on their sides in the yard, ready to be returned to the grinding mill and ground down to 'grog'. Other uses to which old pots were put

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[76] Such a mistake would result in what was termed a 'catched ingot', injuring the steel's homogeneity and containing cracks which caused difficulties in the next stage of tilting or hammering down into bars. An example of such an ingot is illustrated in Perret (1779) Fig. 12, also p. 212 'représente un morceau d'Acier fondu de forme quarrée, il ne s'y est fait qu'une cassure, décrivant un arc', although at this date Perret did not understand the cause of the crack.
[77] Broling (1812) noted that 'The first time a crucible is used, usually 20lb of steel are charged, the second time 15 and the third time only 10 or 12lb, as the sides of the crucible are each time always somewhat eroded'. In addition, Barraclough also states that the heating caused shrinkage of the crucible. Barraclough (1984) vol. 2, p. 48. Also see Howe (1895) p. 298, col. 2.
[78] Crossley (1989) pp. 20-21, although the type and size of hammer available at this time is not indicated by the known sources.
[79] Schib (1951) p. 175. Translated by the author. 'In dem Magazin war viel Stahl vorhanden, besonders gewalzte Bleche. Ich ersuchte Hrn. H—n um eine Preisnote seines Stahls, den er im Durchschnitt um fünfundzwanzig Prozent theurer hält, als die andern Fabrikanten. Nachdem er sie ausgefertigt hatte, zeigte er mir die den Nummern entsprechenden Muster, in Stängelchen von vier Zoll Länge, alle mit seinem Namen gestempelt, von dem dünnsten runden, flachen oder viereckigten, bis zum dicksten gleicher Gattung'.

included the construction of walls, sometimes of considerable height, by close stacking in a honeycomb manner and mortaring the joints.[80]

The extension of the furnaces did not significantly change the basic operation of the works. In plan, the main furnace was simply enlarged by an additional four holes, and even the annealing stove was rebuilt in the same relative position. Structurally, the entire end gable would not have been load-bearing, and could easily have been removed allowing the walls and roof to be extended seamlessly, with no internal obstructions. Behind the casting shop, a row of new buildings was erected, with a narrow yard in between. The 1781 survey additions record these uses as a 'smithy', 'furnace' and 'iron house', the latter confirming that this was a small cementation furnace. The same drawing shows that access to the smaller yard was by a gate alongside the extended cast steel furnaces. [fig. 1.32] Organisationally, these buildings were not immediately connected to the main steel casting side of the works, and could have operated in relative independence. The cementation furnace in particular would have required round-the-clock attendance for over a week at a time, so its relative isolation from the main yard was an advantage.

Workers, domestic accommodation and security

Benjamin Huntsman lived in the cottage on the site of his steelworks, initially with his son, and possibly others. Following the attempts around 1750 to obtain his secret, he would have taken no chances with security: the close proximity of cottage and works allowed round-the-clock surveillance, in case of any further attempts. However, this domestic arrangement of the works also fitted the pattern of industrial development at that time. Factories, especially in Sheffield, were almost unknown, with outwork and backyard manufactories the hallmark of the burgeoning industrial towns. Nevertheless, Huntsman's home was atypical of those built by comparably successful industrialists, in presenting the appearance of a common worker's cottage. For J C Fischer, who visited the works in 1814, this was so far removed from his idea of such a famous manufacturer's residence that he had difficulty in even finding the works.[81]

Huntsman's house also doubled as the works office, as Fischer discovered upon entering the house. In the front room, he found two men smoking pipes and a woman with a small child, adding to his doubt as to whether he had come to the right place.[82] As it happened, steel casting had been finished earlier that day, so the men were probably taking a well-earned rest. Like many of the Sheffield trades, Huntsman's was an erratic and informal working environment, in which fallow periods of leisure contrasted with long shifts at busy times.

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[80] Several examples of such walls survive in Sheffield, see chapter 2. Crucible pots have even been found used as infill under stone setts, only discovered by their subsequent collapse under the weight of modern vehicles

[81] Schib (1951) p. 173. 'Ich hatte zu meiner Verwunderung einige Mühe, die Wohnung von H—n zu erfragen, die, als ich dazu gelangte, ihrem Aeussern nach meiner Erwartung nicht entsprach'

[82] Schib (1951) p. 173. 'Beim Eintritt in das Zimmer ebener Erde war eine Frau mit einem kleinen Kinde, nebst zwei tabakrauchenden Mannspersonen da'. The men were the brothers Francis and John Huntsman, and the woman and child probably Francis' wife Fanny [Hawksworth] (m. 1812) and daughter Ann (b. 24 March 1813). See Hulme (1943-45) p. 43, 'Generation 3'

From Fischer's description, some idea of the plan of the house can be derived. On the ground floor at the front was the living room, behind which was a kitchen leading directly into the yard. It was here that Fischer found the crucible shop with its door open, and the furnace holes still glowing from the day's melt; the warehouse was accessed from the same yard.[83] Given the size of the cottage, the upstairs chambers must have been bedrooms: the front elevation with central doorway, and the relatively high width to depth ratio of the plan, suggests a centre-stair type, with rooms to either side on each floor. [fig. 1.33] Fischer did not comment on the long, narrow extension to the rear, but this probably comprised stabling for the horse(s) with storage above.

In addition to this cottage, the rate books from the 1780s indicate that there were several tenements adjoining the works, probably built in Benjamin's lifetime. These properties may have formed the nucleus of what was later to be known as Huntsman's row, a terrace of two-storey worker's housing built in stages, and partially reconstructed after 1820.[84] [fig. 1.34] The buildings nearest to Attercliffe Green appear on the earliest surveys of the site, although it is not entirely clear when Huntsman's interest in the tenements began.[85]

In form, the row was similar to that still in existence at Abbeydale Works, two storeys high and built of local sandstone. [fig. 1.35] The reason for their construction was also the same–both Abbeydale and Attercliffe were some distance from town, so the accommodation of workers was desirable. Later rate book and census evidence indicates that not all of the occupants of Huntsman's Row were employed at the works, but by this time the firm's property holdings in the area had outgrown their accommodation needs.

Also similar to Abbeydale Works was the relationship of the housing to the works entrance. In both cases, the row of cottages extended from the main road, along the lane leading to the front gates, defining a territory that belonged implicitly to the works. The fronts of the cottages overlooking this route would have greatly improved the security of the site, and acted as a deterrent to any would-be trespassers.

The second phase: William–crisis and consolidation

Benjamin Huntsman naturally looked to his only son, William, to succeed him in the running of the steelworks, which by the time of his death in 1776 was famous throughout Europe.[86] [fig. 1.36] In many ways, the situation inherited by his son was ideal, with an insatiable market and strong links with London, Hull and continental merchants. Even though the father had charged

[83] Schib (1951) p. 174 '...führte er [Huntsman] mich durch die an das Zimmer anstoßende Küche in einen kleinen Hof, worin das offenstehende Schmelzgebäude sich befand, und wo einer der Oefen von der kurz vorher beendigten Schmelzung inwendig noch glühete.'

[84] The rebuilding is indicated by a marked difference in plan forms. From 1850, the tenements were probably on a back-to-back plan, indicated by the underpass or 'ginnell' and narrow passage running along the rear as seen on the OS plan of that date.

[85] As noted above, both the buildings and the entire site of the later Huntsman's Row terrace belonged in 1767 to 'John Tyler', see SCA FBC FB33, p. 4. The indenture SCA PhC 445(c), Tyler to Asline, registered 10 August 1772, to which Huntsman was a party, also refers to the property of 'John Tyler, forgeman, deceased', possibly the same site.

[86] An undated portrait of William Huntsman survives, showing the steelmaker in Quaker clothing. SCL C2.1 216 Main

more for his steel than his early rivals, the reputation of his brand ensured that trade was brisk.

William, however, also had ambitions of his own. During his father's lifetime he was only been a partner in the steelworks, but had also established his own button manufactory in Sheffield, a lucrative and growing trade at the time.[87] This business had been organised as a partnership between William Huntsman and Robert Asline to deal in cutlery and buttons (including those made of metals other than steel), their manufactory being situated in 'John Street' according to the trade directory of 1774.[88] He had also taken a modest residence in Sheffield, at Balm Green on the Southwest edge of the town.[89]

Perhaps William's ambition stemmed from his father's correspondence with Matthew Boulton in Birmingham, probably the largest and most successful manufacturer of decorative metal wares (including buttons, buckles and other 'toys') in the country. He also had the means to supply himself with the best rolls, punches and dies–all of his own steel–used to manufacture these items. Innovations in manufacturing made possible by the harder, more durable cast steel had given rise to new kinds of cheap, mass-produced goods.[90]

As quickly as crucible steel had become central to the Birmingham toy and button-making industries, so William's competitors were forcing down the cost of the raw material, as indicated in a letter from Matthew Boulton in the year of Benjamin Huntsman's death:

> *Now if you wish to sell ten times the quantity of steel you have ever sold you may easily do so by conforming to your neighbour's price of 7d. per pound rolled. This I give you as a friendly hint not from any wish of our own to reduce the price. For our very fine steel buttons we shall buy your steel be the price what it will, but the great consumption is in the common cheap steel buttons. We have some button makers that order 2 or 3 Tons at a time.*[91]

At this time Huntsman's sheet steel as used by the button-makers was sold at ten pence per pound in weight, significantly higher than his competitors', but still affordable for the high value ornamental goods for which Boulton needed it.

Meanwhile, William Huntsman was becoming increasingly absorbed in the merchanting side of his button business. In the same year, he inquired of Matthew Boulton regarding the

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[87] Robsahm, *Dagbok över en resa i England* (1761) cited by Barraclough (1976) p. 9. Also see Smith, D. (1997) p 92.
[88] Timmins (1977) p. 24. The existence of a 'John Street' at this time is not known; however, William's partner, Asline, is listed in the 1787 directory as a button maker based at 'Jehu Lane', of which the name could be a corruption.
[89] SCL Bagshawe 297, p. 20, nos. 15a & b, shows the location of William's property, described as 'A House & some vacant gr[oun]d'.
[90] The *London Chronicle* of 14-16 July 1761, p. 54, col. b, implies that innovations in the production of dies and punches were leading to cheap and attractive products, including 'sword-hilts, watch-chains, buttons, snuff-boxes, dial-plates and many other valuable branches of manufacture'. Barraclough (1976) p. 13, note 23, incorrectly quoted this article, as making reference to 'the recent invention of Huntsman's Crucible Steel' for dies 'which produce excellent pieces'; the actual text mentions only 'this ingenious invention of dies, which strike excellent pieces of workmanship almost instantaneously'.
[91] 25 Jan. 1776, Letter Book G, p. 517. Cited by Barraclough (1984) vol. 2, p. 4.

purchase of gilt buttons for his own trade.[92] In the volatile economic climate of the 1780s, Huntsman and Asline's venture hit trouble. As the firm's extant ledgers postdate this period, the exact nature of the crisis is not known, but its seriousness is confirmed by a short notice that appeared in the *Gentleman's Magazine* of May 1781:

> '*B-NK---TS* [Bankrupts]... *Wm. Hunsman and Robt. Asline, Attercliffe, Yorksh. button-makers.*'[93]

The partners had clearly over-extended themselves, and were declared bankrupt in March 1781.[94] Ironically, this came at a time when Huntsman's steel was more in demand than ever, and before the commercial embargos of the Napoleonic Wars effectively cut off all trade with Europe.

This bankruptcy offers an explanation for the amendments made in 1781 to the aforementioned Fairbank survey, which was made to ascertain the extent and value of the Attercliffe Green premises as an asset to defray the losses sustained by William Huntsman's creditors. One of those creditors was probably Thomas Gunning, of the highly successful merchanting partnership Oborne and Gunning. They were also 'deeply involved in ironmaking on their own account...if on a modest scale',[95] and by 1756 operated at least two cementation furnaces. Huntsman is known to have been on good terms with the firm, as when Robsahm visited Sheffield in 1761 his contact was the firm of Oborne and Gunning who arranged for him to see various works around the town, including Huntsman's in Attercliffe.[96]

The partnership was well known as having 'cash to spare for money-lending and investments in manufacturing firms'[97] and may well have provided financial backing for William's button-making enterprise, or even helped him to recover from bankruptcy. However, the extent to which the steelworks passed into the possession of Gunning has been overstated. If the area of land ascribed to Gunning is plotted to scale on the plan of the works, [fig. 1.38] it will be seen that his holding was limited to the more recent extensions, while the ground containing the main steel furnace block and cottage remained in the ownership of Huntsman's landlords, the Twelve Capital Burgesses. There is no evidence that Gunning had taken over the steelworks, or that Huntsman's occupancy of the site was interrupted.[98]

Luckily, bankruptcy was not ultimately fatal to the business–perhaps some of William's creditors still had faith in the Huntsman name and had extended their loans–and the firm was re-established soon after, this time concentrating on steelmaking and merchanting. Six

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92 Boulton responded in a letter of 7 Dec. 1776, Letter Book G, p. 767. Cited by Barraclough (1984) vol. 2, p. 5.
93 *The Gentleman's Magazine*, May 1781, vol. 51, p. 244.
94 West Yorkshire Archives, Sheepscar Library, Leeds, Bankruptcy Assignments and Deeds of Arrangement, DB215 No. 191
95 Holderness (1973) p. 42.
96 Barraclough (1984) vol. 2, p. 9, cites Robsahm, *Dagbok över en resa i England* (1761) fols. 58, 68-70, 84-86, Kungliga Bibliotek, Stockholm.
97 Holderness (1973) p. 44.
98 See also SCA SheD71S (n.d.), but drawn around 1781 and describing 'Land held by Thos. Gunning . Several steel furnaces, warehouses & some vacant ground', occupying an area of 13 perches, or 393 square yards (329m²). This agrees with the author's scaled CAD plan, which gives an area of 12.93 perches as shown in plan

months later, by the first day of September, 1781, William was back at the Attercliffe steelworks, and attempting to re-establish the lucrative trade with Matthew Boulton's Soho Works. The first line of his letter to Boulton suggests that he had spent some time in the Debtor's Gaol:

> *As I am now at Liberty & beginning my steel manufactory again thought it proper to write to a few friends & Request there orders & there friendship by Recommending my steel to their friends.*[99]

He went on to assure Boulton that 'You are the first person I have wrote to upon this subject nor should I wish to sell steel of the above Quality to any other merchant in Birmingham.' and stated the price to be '£4 4s 0d for 112w'. The appeal may have been unsuccessful, as in 1788 William was again writing to Boulton:

> *...to make an offer of serving with my fine steel for the Manufactory into fine goods the Quality of my steel you are no Stranger to & make no doubt though the price is more than what some other people sell for you'd find it as much superior in its Quality & the goods much better when finish'd.*[100]

By the end of the eighteenth century, Huntsman's steel still commanded a premium; it has already been noted that Fischer found Huntsman's steel 25% dearer than that of his competitors. Broling, writing of his visit between 1797-99, believed that this was due to Huntsman's use of only the highest quality steel, and that 'as evidence that *Huntsman's* steel owes its advantage to this reason, I must mention that, although he keeps his steel a penny a pound more expensive, the largest instrument manufacturers in London still use his cast steel'.[101]

The Huntsman 'brand' had also maintained a high reputation at home: Hatchett, although he did not actually visit Huntsman while in Sheffield, noted in his diary entry for 14 June 1796 that 'Mr. Huntsman at Attercliffe near Sheffield is celebrated for the steel which he makes'.[102] On the other hand, how much this success was due to William Huntsman's efforts is open to question. The anonymous author of the biography in *The Useful Metals* suggested that his contribution to the business had been limited:

> *His [Benjamin's] son and immediate successor attended to so much business as the well-deserved reputation of the steel brought to him, without much exertion on his own part.*[103]

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99 SCL Archives PhC 373, letter to Matthew Boulton, 1 Sept 1781 See appendix 1.3 for transcript.
100 SCL Archives PhC 373, letter to Matthew Boulton, 4 May 1788. See appendix 1.3 for transcript.
101 Broling (1812) translation Barraclough (1984) vol. 2, appendix 3. He claimed that for 30 years Huntsman had used only the marks of Swedish iron from Osterby, Gimo, Leufsta and Akerby. Ashton (1961) p. 45, noted that in 1801 the tool-maker Peter Stubs paid Harrison 80s per cwt and Huntsman as much as 84s per cwt.
102 Raistrick (1967) p. 73.
103 Scoffern (1857) pp. 347-8. If this was indeed written by Francis Huntsman, it gives a fascinating insight into the relationship between father and son, and may explain Francis' complete reorganisation of the business.

Nevertheless, William's management of the business may not have been entirely ineffectual. As seen from the correspondence with Boulton and Watt above, he made protracted efforts to win back trade, and provided the dies for Boulton's coining machinery at Soho and the Royal mint afterwards, used in the manufacture of the infamous 'cartwheel' copper coinage from 1797. [fig. 1.37] Fourness and Ashworth's testimonial credited William Huntsman with having improved the business substantially, and implored potential customers to reward the steelmaker's 'expenditure of time, and his sedulity in contributing to the convenience of the mechanical part of society'.[104]

Under William, there is the first evidence of the Huntsman family having regained the favour of the Cutlers' Company, probably through the button and cutlery venture of Huntsman & Asline. Both men were on the guest list of the 1790 Cutlers' feast, under James Ward the Master Cutler.[105] Another feud also seems to have been resolved by William, as from 1782 he employed a Joshua Tingle to make steel, from the very same family that allegedly conspired with the Walkers to steal his father's secret. In 1792, after nine and a half years, Tingle left Huntsman to make steel for a Sheffield-based competitor, Harrison, who quickly took the opportunity to impress his customers, informing one of them that:

> *We have now got a very good Hand for making cast steel from Mr. Huntsman...[who] says he can make it as good as Huntsman, and as we can try it as nere as any person in the saw way, we have found it very good. I have engag'd him for some years and find him a sober and good workman.*[106]

Four years later, Joshua Tingle left Harrison to set up business on his own account.

The works also continued to grow under William. Samuel Smiles was of the opinion that 'His son [William] continued to carry on the business, and largely extended its operations',[107] and while to a certain extent this is true, the statement must be qualified. During the spring of 1787 he built another cementation furnace (possibly as a replacement to the earlier), bringing a degree of independence from the merchants upon whom he depended for the supply of blister steel.[108] By the end of 1805, another 'Steel Furnace' had been added to Huntsman's rate, although it is unclear whether this was the second converting furnace or a new crucible shop.[109] Compared to the developments in Benjamin's lifetime, these additions cannot really be held to have 'largely extended' the business. Unfortunately, no plans of the site at this time are known, so the overall picture, along with William's claim to posterity, remains a matter of conjecture.

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[104] Fourness (1792) It has, however, been suggested that the engineers had confused the achievements of William with those of his father. This seems unlikely, as Fourness is known to have had an engineering works in Sheffield, and presumably knew William personally.
[105] Leader (1905) vol. 2, p. 64, under 'general guests'.
[106] Ashton (1961) p. 39.
[107] Smiles (1863) p. 110.
[108] *Attercliffe rate* 14 June 1787, distinguishes for the first time between 'Cast steel furnace' and 'Converting furnace'. This cementation furnace must have been smaller than the later examples, and was probably subsequently enlarged.
[109] Attercliffe rate 23 Dec 1805. The furnace was first valued at £4, before appearing consistently at £1 10s 0d (the same value as each of Huntsman's workers' houses). At some point before 1819, a new crucible shop about which little is known had been built towards the rear of the site, and to which the 1805 addition may refer.

The third phase: Francis–expansion and innovation

On William Huntsman's death in 1809 the business passed to his two sons, John and Francis.[110] It has been suggested that William had met with limited success as a steel manufacturer, leaving his sons an estate amounting to £1500, a modest inheritance even if this did not include the value of the steelworks themselves.[111] It is, of course, entirely possible that bankruptcy had taken its toll on William Huntsman's assets, but evidence suggests that he had recovered much of his steel trade and, in addition, made fairly substantial investments in land.[112] His wife Agnes also survived him and was in possession of her own property.[113]

In the decade following the death of their father, the brothers seem to have shared the responsibility of running the business. From December 1801, Francis, the younger of the two, had served a five year apprenticeship in Leicester under the ironmongers and founders James and Benjamin Cort, during which time he must have gained considerable experience of foundry practice.[114] John, on the other hand, may have been more involved in the management of the business, as the enclosure additions of 1811 were made out in his name. Both brothers appear in the rate books and trade directory listings.[115]

Fischer, on his visit to the steelworks in 1814, met the two brothers, both of whom appeared to be actively engaged in the day-to-day running of the business.[116] One of them showed him around the furnaces and stores, while the other took him to visit a cutlery forge where he could get penknives made of their steel in order to compare them to other similar products.[117] However, by the time of the Fairbanks' survey of Attercliffe in 1819, Francis' name appears alone.[118] John seems to have left the business in the previous year, although the reason for this parting of company is unknown.[119]

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[110] The rate book for 30 April 1810 names 'John & Fran' Huntsman' as joint proprietors. An elder son, William Jr. (1766-1803) may have succeeded to the steelworks but for his early death. Hulme (1943-45) p. 43; Ward (1909) p. 9.
[111] Hulme (1943-45) p. 45. Although this was by no means a small sum, it should be compared with the success of Huntsman's competitors. Hulme gives the example of a payment of £200,000 made around 1791 for a fifth share in the Walkers' steel and iron business, established without capital in 1741.
[112] SCA CB1581. From 1807, William had an interest in some nearby land known as the 'Helliwell Sicks', known by an indenture of 12-13 June; he was also the plaintiff in a fine of Trinity Term 47th George III. The rate books also indicate that his land holdings had risen to almost six acres by 1806; see appendix 1.4.
[113] SCA Younge Wilson Deeds YWD1430, 1475. *'Agnes Huntsman widow' was in possession of 2 tenements and 6* houses on Greystones Road, beginning 15 & 16 July 1811. Also see SYCRO 141/B, reel 2, *Valuation of the Township of Ecclesall Bierlow* (1842) Plan no. 296, for the same property (these all still exist).
[114] Hartopp (1933) p. 518, entry for the year 1801 *'Oct. 27. Francis Huntsman, s. of Wm. of Attercliff, co. York, steel manufacturers, p. to Jas. Cort and Benjn. Cort, ironmongers and co-partners, for 5 years from 25 Dec. next.'* It is not known whether these Corts were related to the famous ironmaster of the same name.
[115] Paulus (1907) p. 46 *'Award no. 32'* granted to John Huntsman 0a 0r 29p; also *'Award no. 89'* gained 1a 0r 27p land on Attercliffe Common - *'a strip off Greenland Engine Road'*; also p. 66 land held by John & Francis, 5a 3r 15p.
[116] Schib (1951) pp. 173-177.
[117] Schib (1951) p. 177 'Sein Bruder hatte indeß noch die Gefälligkeit, mich zu einem Messerschmied zu begleiten, da ich recht gute Federmesser von seinem Stahl zu haben wünschte, um einen Vergleich mit andern anstellen zu können'.
[118] From 22 Sept. 1818 onwards, the rate books also omit John's name. Also see SCA CB1581, p. 4, 28-29 Sept 1818 relating to the lease of a plot of land known as the 'Helliwell Sicks'.
[119] It is known that John lived from 1781 to 1843, never marrying; Hulme (1943-45) p. 43. It is possible that he suffered from poor health, as towards the end of his life, the Huntsman account books recorded regular payments by cheque made out simply to 'Asylum'. SCA LD1613 p. 106, *passim*. For example, the payment of a cheque through Rimington & Younge's Bank for £19 5s 9d on 10 June 1842.

The fabric and practices of the steelworks as inherited by Francis had changed little since Benjamin's day, and the layout remained essentially that recorded in the earlier surveys [figs. 1.39-1.41]. The old original furnace block still stood behind the family cottage, although most of its outbuildings (including the horse-mill) had since been pulled down. The adjacent row of workshops had become a steel warehouse, behind which stood two cementation furnaces. Adjoining this row was a large new workshop, probably housing a replacement for the old horse-powered roller mill, with storage on the upper level.

Francis Huntsman clearly had great ambitions for the business, even if this meant a break with family tradition. Almost immediately he began to make changes, of which the first was probably the most radical: After almost seventy years of continued use, Benjamin's original furnaces were demolished. Although still standing in 1819, the original furnace was no longer operative–in the revised Fairbank survey of that year it is shown simply as an un-hatched outline [fig. 1.42]–remaining unrated and therefore derelict.[120] By the time of the final rate plan of the same year, the furnaces had disappeared. [figs. 1.43-1.45]

The family cottage was also abandoned, although it escaped demolition, and a new house was built alongside it.[121] This was a fairly substantial residence, square in plan, and in the bare classical style common to many manufacturers' houses of the late Georgian era. A central doorway faced the street across a large walled garden, laid out in a sober picturesque style. Unusually, the entrance gates were not placed centrally in the perimeter wall, on axis with the house, but instead on the corner oriented towards Sheffield and closest to the works entrance. Access to the works remained alongside the cottage, while coaches entered by a lane on the other side of the new house.

The old cottage was designated the 'lodge', now occupied by Thomas Hawksworth, presumably a relation of Francis Huntsman's wife, Fanny Hawksworth. Francis may have taken him on as a business associate in 1820, as for a brief period the rate on the works is made out in both of their names.[122] Although the reuse of the cottage could be seen as a pragmatic decision, there is an element of the picturesque in the preservation of the ancestral home, set awkwardly alongside the splendid new mansion and its pleasure-gardens. No attempt was made to deny its presence–indeed, the new house was built to respect the old Attercliffe Green building-line, the enclosure additions forming the gardens, at a time when most other new structures were pushed hard up against the line of the turnpike road.[123]

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[120] SCA FBC FB 153, p. 7. Entitled 'F. Huntsman. House'. The original furnace building was demonstrably still present at this time as new measurements were taken from it to augment the earlier ones.
[121] The rate book evidence of this period is sketchy, although a note alongside the entry for 23 August 1819 reads 'New House, 8s 0d', while the following rates are increased by the sum of 8s. The earliest image of the house belongs to a commercial view of the works from the latter half of the nineteenth century, although its architectural features indicate that this was largely as originally built. A comparison of the Fairbanks' surveys to later OS plans confirms that the main building footprint remained unchanged.
[122] SCA Attercliffe rate books, 14 Feb. to 11 Dec. 1820, after which the full rate is listed under Huntsman's name (although Hawksworth is still present as an occupant).
[123] See fig. 1.44, above, no. 320 on plan.

This campaign of rebuilding may have been conditional upon a deal struck by Francis with the Twelve Capital Burgesses, who owned the land upon which the works stood. An abstracted title deed of 28 April 1818 records the 'Valuation by Josiah Fairbank of the Lands and Tenements at Attercliffe proposed as an exchange between the Twelve Capital Burgesses and Francis Huntsman of this date', traded later that year for three fields nearby known as the 'Helliwell Sicks'.[124] The site to be exchanged is not positively identifiable, but the timing suggests that it may have been in preparation for Francis Huntsman's master-plan.

The enclosure additions had other consequences for the urban development of the area. In order to access the works, new roads had to be formed across what was previously the commons. 'Huntsman's Road', otherwise known as Huntsman's Yard or Row, was an extension of the lane leading to the works' entrance, and the land behind the works was served by a separate private carriage road, along which a coach house was later to be built.[125] [fig. 1.46]

Compared to other sites nearby, Huntsman's design of the post-enclosure additions indicates an understanding of the spatial idea of the village, which was unfortunately to be lost beneath the noise of later development. Successive phases of the Huntsman site conformed to this pattern of a consistent built up frontage with long plots behind accessed via narrow lanes. Meanwhile, the works layout progressed from a layout typified by the backyard smithy to one much closer to the early urban courtyard works of the late eighteenth century.

The Weigh House Furnace: 1825

Under Francis Huntsman, the reputation and trade of the works continued to grow: by 1824, a popular guidebook to Sheffield informed the visitor that 'the process of refining steel is carried on [at Attercliffe] to very great perfection by Mr. F. Huntsman'.[126] In the following year, the rate books indicate that Francis had extended his manufactory by the acquisition of furnaces on the Worksop road. Their existence is not immediately evident, as none of the entries under Huntsman's name correspond to their topographical location, the rate-collectors instead listing them concurrently with the works at Huntsman's Row. Only a detailed analysis of marginal notes and additions to Huntsman's rate payments reveals the new addition. Alongside the entry for 23 August 1825 is pencilled in the word 'Furnice', while in the following rate an

[124] SCA CB1581. See appendix 1.4. The Heliwell Sicks had become of less strategic importance to the firm since they were divorced from the main site by the new canal; however, part of the remaining land was to be of significance later, with the construction of Huntsman's wharf (see below). See no. 2 on fig. 1.66.
[125] Paulus (1907) p. 38. The latter is described as 'one other private carriage road 15 feet wide in Attercliffe, from the said Worksop & Attercliffe Turnpike Road across *Attercliffe Green to the lands of Messrs. Huntsman & others*'.
[126] Holland (1824) p. 247.

addition of 4s 9d is made to the total rate.[127] Cross-referencing to earlier rate books confirms the site to have been directly adjacent to the former turnpike road weigh-house and tollbar.[128]

When built, the weigh-house was located on the carriageway, some distance beyond the old building line of Attercliffe Green, but with the enclosure awards came new development, in most cases up to the very limits of the turnpike road. By the early nineteenth century the land immediately behind the weigh-house had been taken by the company of Parker, Parkin & Co., who occupied a 'steel furnace, garden and yard', the furnace in this case being one for the manufacture of cementation steel.[129] When they vacated the site for new premises in Sheffield, the opportunity to extend the Huntsman plant was seized.[130]

It was, however, not so much the furnace that interested Francis, as the opportunity to acquire land practically adjacent to the Attercliffe works, albeit on a piecemeal basis. This is most clearly demonstrated by the fact that Parker and Parkin's old furnace, too small for Francis Huntsman's purposes, was torn down and rebuilt almost immediately, with only the outer shell of the original furnace shed retained.[131] The other existing structures on the site were either demolished or adapted to new uses, the weigh house itself becoming a dwelling house and porter's lodge. [fig. 1.47]

Apart from the cementation furnace, the major addition to the Huntsman plant was a new block of crucible furnaces, designed to occupy the eastern corner of the site at its widest point, opposite the weigh house. Described as a 'Large Cast Steel Furnace', its capacity seems to have been greater than the older Huntsman's Yard furnaces, later valuations indicating by up to fifty percent.[132]

The crucible shop, along with its attendant steel room, pot house and coke shed, opened directly to the yard. From here towards the rear of the site, a range of shops and iron warehouses were constructed, not directly in communication with the furnaces, but accessible from the yard. Between the weigh house and the gable end of the crucible shop, the street frontage was left clear, its central gateway set within a brick wall running flush with the buildings to either side.

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[127] SCA Attercliffe rate books. RB56 23 Aug. 1825, p. 15. A separate topographically correct entry reads 'Furnace - 4s 9d', but is not identified as Huntsman's.

[128] This anomaly demonstrates the caution with which rate valuations must be used. The convention of grouping together different locations under the same owners' name is fairly common. See below for the example of Huntsman's wharf, clearly on the canal, but listed with his works, and confirmed by a comparison of land areas.

[129] SCA CA13-1 (1819) Fairbank 'Survey of Attercliffe cum Darnall for a new Rate', map 12, no. 315, see fig. 1.43, above. The 'weighing house' is listed as no. 316, owned by the 'Worksop Rd. trustees' and occupied by Joseph Rhodes. The plan and related area measurements confirm this to be the site of the later furnace. Baines (1822) *Directory of Sheffield*, lists the firm as steel converters

[130] In the Sheffield Directory of 1822, Parkin, Parker, Potts and Clough are entered as 'merchants, factors, table knives, saws, edge tools, &c. mfrs. & steel converters, Arundel Street'; this is confirmed by survey evidence, see Belford (1998) p. 15; SCA FBC SheS62L, SheS64L.

[131] On 11 Apr. 1826, the marginal note 'empty' appeared alongside the steel furnace; by 6 June this had been replaced by 'took down', with a deduction from Huntsman's rate of 4s 9d. On 20 March 1827 the new building is described as 'Large Steel Furnace' with a rateable value of £7 10s 0d, an increase of almost one third. See below for information relating to the furnace shed.

[132] RB56 20 March 1827; RB379 6 April 1840, p. 27. The old 'Cast Steel Furnace and Pot House' is valued at £12 compared to £18 for the new 'Cast Steel Furnaces and Shed'.

Unlike Huntsman's Yard, the new site afforded little space for non-steelmaking uses, and consequently its layout remained largely unaltered in the coming years. Thus, the first edition Ordnance Survey plan of 1850 differs little from the earlier survey, although it does provide extra detail respecting the internal layout of the works. [fig. 1.48] That the site could be operated as a relatively autonomous unit is reflected by its distinct name, the 'Weigh House Furnace'.[133] Following the convention of the first edition plans, the internal walls of both furnace buildings are shown, allowing the information from the rate book entries to be located in space.

Both ends of the cementation shed were partitioned to form two small rooms–one for each of the furnace's pair of openings–sheltering the furnace-men from the elements during the long firing process, as well as providing temporary accommodation for the quantities of iron bars and coals needed to work the furnace. The outline of the conical furnace itself is not indicated, as was often the case, although its size and location can be estimated with some accuracy. Assuming that the sides of the brick outer cone had been truncated (as suggested by the evidence below), it appears to have been built to a similar size and pattern as the pair at the main site.[134]

The interior of the crucible furnace building was subdivided into four rooms by partition walls arranged in an 'H' formation. The central space facing the yard housed the melting shop itself, while flanking it on both sides were two narrow strips running the full depth of the plan, housing coke shed and steel room. Behind the crucible shop was the pot house. It is not known with certainty how many crucible holes were present, but from the building's value and dimensions, it seems probable that this was an eight-hole shop.[135]

The yard was effectively a substitute for internal circulation space, with only the pot house not having direct access, due to its relationship with the casting shop. Coke brought into the yard on carts would be loaded straight into the coke shed, from where it would be taken back through the yard into the adjacent melting shop as required; the same was true of steel bars and ingots. Ashes from the cellar would be brought directly into the yard, up the external stair at the front. Only the clay, which had to be thoroughly dried in the vicinity of the hot furnace stacks, would be taken straight into the building, bypassing the yard. The space at the back of the yard would have been dominated by the cementation furnace and by the large quantities of coals it required. Facing this was the warehousing, with a well set at the very rear. Even

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[133] This distinction, along with largely non-sequential rate book entries, has almost certainly been responsible for much of the confusion and obscurity regarding the site.

[134] The dimensions of the central portion of the shed would accommodate a furnace of this size; the rateable value is also in accordance, at £18 as compared to £37 for both of the Huntsman's Row furnaces. Upon re-evaluation, the parity is even closer at £25 versus £50. RB389A, *First rate*, May 1859, pp. 93-4.

[135] RB389A, First rate, May 1859, pp. 93-4. A twelve-hole furnace is rated at £31 16s 0d, compared to the Weigh House furnace at exactly £20. See below the dimensional analysis of Huntsman's crucible furnaces. Each hole may still have held only a single crucible, in contrast to the later adoption of double holes. When the method used to calculate the rate was altered in 1859 (see below), the newer twelve-hole furnace was valued at 10s per double hole, while the overall value of the Weigh House furnace was increased from £18 to £20, equating to either four double holes, or eight single.

with such a small site, this hierarchical distribution of functions was not unusual, following a pattern that came to characterise most Sheffield steelworks, as shall be seen later.

Perhaps due to its subservient relationship to the main steelworks, the Weigh House site never appeared in any of the firm's literature or advertising, and no contemporary drawings or photographs are known to exist. Apart from the more general maps of the area, only one other document relating to the furnace has been found, a planning application of 1954.[136] [fig. 1.49] By this time the works were occupied by tool-makers, and the furnaces were no longer in use. Nevertheless, the drawings indicate that many of the buildings were then still in existence, and provide some additional detail of the construction and fenestration of the old crucible shop.

A recent site survey revealed that much of the furnace buildings' basic structure has survived, despite the significant change of use and consequent modifications.[137] From the street the gable end of the crucible shop can still be seen, as well as a portion of the brick perimeter wall and the dwelling house, now used as offices. [fig. 1.50] The crucible shop of 1826-27 has lost its original roof and, in common with other known conversions of crucible shops, the cellars have been filled in with no traces of the flues remaining. The ground floor walls, however, still reflect its previous use, and correspond well to the earlier planning drawings.

The building that housed the cementation furnace has been shortened, but its brickwork–different to that of the crucible shop and of a lower quality and unusual 'Sheffield bond' technique[138]–suggests that this may well date back to the earlier Parker, Parkin & Co. steelworks, within which Francis built the larger furnace. A cast iron tie-plate belonging to the iron ties typical of these furnaces can be seen on the southeast wall, and probably indicates the location of the conical furnace shell itself. To save on both space and masonry, it was common practice to truncate the sides of the cone, giving a form capable of being built in rows or accommodated within a standard orthogonal shed. As this resulted in the weakening of the shell, iron ties were introduced across the furnace to counteract the outward thrust.

Insufficient evidence exists to enable a reconstruction of the interior of the Weigh House crucible furnace, but it is likely to have conformed to one of two distinct furnace types. The first type would place the stacks laterally along the long rear wall of the casting shop, their hot rear wall facing the pot room (and 'clay place', see later). The alternative would involve a pair of transverse stacks occupying both of the short side walls of the space, dividing the casting shop from the coke shed (right) and steel room (left). Either plan is physically possible,

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[136] SCA CA206/42965 'Proposed Warehouse in Worksop Road for Messrs. Qualcut Tools Ltd.', granted 17 June 1954.

[137] First visited by the author in 2000. At the time of writing, the entire site is in use as metal-spraying workshops, although the recent construction of an adjacent residential estate may threaten its long-term viability as light industrial premises.

[138] Beauchamp (1996) applies this general term to the irregular but cost-effective brick bonding commonly found at workshops in the Sheffield area.

although in the context of the later furnace building (see below), a hypothetical plan of the latter type, housing eight individual holes arranged in two stacks, seems likely.[139]

The *Useful Metals* furnaces: 1842

Between 1825 and 1842, the greater part of Huntsman's steel melting capacity was based at the Weigh House site, while Huntsman's Row was still home to two of the three cementation furnaces, as well as much of the warehousing.[140] The two sites, their gates only 100m apart, must have been strongly interdependent, and can barely be considered an example of multi-site operation (see chapters 2, 3).

The rate book entry for 28 April 1842 notes that the 'cast steel furnaces and pothouse' at Huntsman's Row had been 'taken down'. Six months later, the furnaces reappear, but at a new estimated rental value of £32 6s 8d, or three times that of the previous buildings.[141] Other hints of building activity can be found in the firm's accounts, with additional purchases of bricks and (furnace) shovels.[142]

A comparison of the 1832 Sheffield town plan and the Ordnance Survey sheet of 1850 revealed little change in the basic footprint of the furnaces. [fig. 1.51] The irregular outline of the earlier building could conceivably have been consolidated to form the later rectangular plan.

Just as in the case of the Weigh House Furnace, the detail provided by the 1850 OS plan was the starting point for a reconstruction of the interior. The façade of what is clearly the cast steel furnace in the later views of the works, [fig. 1.52] reflects the rhythm of internal partitions seen in plan, with the two largest spaces at the front corresponding to the melting shops, with their central doors and symmetrical windows. To one side is what appears to be a coke shed, while a narrow space between the melting shops relates to another opening in the facade. Along the rear of the plan, unseen in either view, is another sequence of slightly more shallow rooms on a different rhythm.

While there is only contextual evidence for the different uses within the building, a basic similarity may be noted between this layout and the plan of a furnace building illustrated in the article on steel in *The Useful Metals and their Alloys*.[143] [figs. 1.53-1.55] This latter ideal furnace is also arranged on a bipartite principle, with the 'furnace floor', 'coke shed' and 'clay place' at the front of the building while the 'pot room' and 'steel room' occupy the rear. Upon

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139 Additionally, a lateral plan would require the stack to run directly along the ridgeline (with a gap to either side), a form that has no known precedent in Sheffield furnaces.

140 Based on an assessment of rate book evidence combined with the available plans of the works.

141 Attercliffe rate, 18 Oct. 1842. Their value is later reduced to £27 (10 Feb 1843). The value of £75 given in entries from RB385 (5 May 1849) pp. 33-34, represents the sum of: cast steel furnaces £27, converting furnaces, steel warehouse, counting house £40, workshop £5, cow house & stable £3. The latter values remain unaltered from before the construction of the new furnace.

142 SCA LD1613 p. 116, 'N & R Dodge... by brick acct', total of £40 9s 3d p. 90 'Thos. Dudley & Son, Norbriggs. 1842 Aug. by ½ doz. shovels'.

143 Scoffern (1857) pp. 350 355, figs. 4-6.

closer examination, further associations emerge: several of the dimensions of Huntsman's furnace equate to those given for the corresponding spaces of the ideal plan, although the overall proportions of the plan differ.[144] The accompanying sectional drawings show the stacks to run parallel to the main roof trusses, as in the Huntsman furnace–a relatively unusual format at the time. It is also of note that in the *Useful Metals* drawings, the ancillary spaces to the rear of the plan are entirely omitted from the short section, the roof structure shown instead to neatly accommodate the three wide furnace stacks.

Superimposed upon the OS plan, it becomes clear that the illustrations are not generic examples, but relate closely to the actual furnaces at Huntsman's Yard. They are not a literal representation of Francis Huntsman's 1842 furnaces, but an idealisation based on the dimensions and organisation of this building. Intended as an exemplar of the type, the 'ideal' plan incorporates a number of improvements on its model. In the real building, the furnaces are divided unequally between two casting shops, whereas the ideal plan combines the three stacks in one continuous row, occupying the full depth of the building. The ancillary spaces along the back are reduced in size while the coke shed is moved to the other side of the remaining casting shop, providing less ancillary space per hole, but a more generous furnace floor area.[145] Another clue to the drawings' origins may be detected in their overall accuracy, as if traced off architectural plans, but with distortions in the extended areas, such as at the end of the row of crucible holes where the rhythm visibly breaks down.

How the drawings came to be made is also of some interest. It is known that the anonymous author of the *Useful Metals* chapter had access to the Huntsman family history, and it has been suggested earlier in this thesis that the chapter's contributor was Francis Huntsman himself.[146] In a lecture of 1944, E. Wyndham Hulme came to the same conclusion, although he did not state his source.[147] Given the writer's intimate knowledge of the crucible process, and on the evidence of the accompanying engravings, Hulme's assertion appears to be correct.

Sufficient detail is present in the *Useful Metals* drawings, along with the Ordnance plans and topographical views, to enable an accurate reconstruction of the archetype. The depth of the casting shop admits four crucible holes plus an annealing grate, the five flues converging into a single stack that neatly negotiates the timber roof trusses and rises to a height of 33 feet above ground level. Three such stacks, which would give a total of twelve holes, correspond to the number seen in Topham's drawing, [figs. 1.56, 1.21] with the wider of the two casting

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144 The widths of the furnace, clay place, coke shed and pot room match those in the corresponding locations on the O.S. plan. The depths, however, do not, nor are the number of spaces the same.

145 The area of total floor area per hole is 15.4m² in the ideal plan versus 19.0m² in the real, making the ideal plan more efficient; whereas furnace floor area per hole is 5.3m² (ideal) versus 4.6m² (real)

146 Scoffern (1857) p. 380, noted that the article was written 'by a pen intimately acquainted with the subject; and we feel assured, although the papers are anonymous, every one interested in the subject will see that an able and practical hand has guided the pen, in communicating a mass of knowledge, such as is rarely laid before the public'

147 Hulme (1943-45) p. 41. Barraclough's suggestion that the article's author was William Clay is not credible, as his name appears in connection with chapter 16 (the manipulation of wrought iron in large masses), yet it was stated that the author of the chapter on steel 'wishes to remain unknown'. Barraclough (1984) vol. 1, caption to plate 7; Scoffern (1857) pp. vii-viii.

shops containing a symmetrical pair. The external stair appears to have served both cellars, and can be seen on both OS plans, located unobtrusively at the very end of the building.

Although the number of cast steel furnaces in Sheffield at this time had reached the hundreds, no drawings are known to survive of comparable furnaces, so the arrangement recovered from these closely related sources is of particular interest. The furnace building itself appears to have been very similar to that at the Weigh House site, the scale drawings from the *Useful Metals* being a very close dimensional match to the 1957 planning drawings (especially in terms of roof pitch, eaves height and wall thickness).

In planning the location of the furnace building, the opportunity to reuse the cellars belonging to the earlier furnaces seems to have been of some importance, as excavation was one of the most costly and time-consuming parts of the construction process.[148] The format of the earlier furnace shop is not known in detail, but the location of its cellars may be calculated from the relatively small footprint of the earliest plans of the 1820s. Later plans (e.g. the 1832 town plan) show piecemeal additions to have been erected about this core, which occupied the same site area as the 1842 furnace cellars.

A further innovation was the adoption of furnaces capable of holding two crucibles instead of one, or 'double holes'. This had been a relatively recent development, attested to by the author of the *Useful Metals* chapter: 'In [Benjamin's] time, and many years afterwards, only one crucible was put into the furnace-hole–now two are put in; and his pots held about half as much as those now used'.[149] Consequently, the relatively modest sounding twelve-hole furnace was larger than almost any of the previous generation, accommodating twenty-four large crucibles each holding around 60 pounds of steel.

A fortunate confirmation of the reconstructed plan was discovered in the rate of May 1859, due to a significant change in the assessment criteria.[150] At this time, furnaces were re-evaluated to include the number of crucible holes in addition to the value of the built fabric, and for two rates only, a note alongside the Huntsman's Yard furnace reads '12 holes at 10/- a hole', or a total addition of £6 to the gross estimated rental value. The same is unfortunately not true of the Weigh House furnace entry, given as £20 altogether; it is unlikely that this reflects the old £18 value plus £2, giving only four holes (although eight single holes may have also been rated at this value). At the same time, the Weigh House cementation furnace increased in value to £25, achieving parity with those on the main site, possibly indicating another rebuild.

The timing of this significant investment is perhaps best explained with reference to the leases held on the land. Up to this point, Francis Huntsman held much of his property on lease from the Church Burgesses for periods of fourteen years, the leases in question due to

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148 See SCA FBC FB230, pp. 16, 75, for the costs of 'Cellar digging for the Messrs. Potts, Baxter & Brumby's Steel Furnace' and 'for Robt. Sorby's Milling Furnace in Carver Street', both in Sheffield, at the (standard?) price of '7¼d per yard', also that of the Cutlers Company in chapter 2

149 Scoffern (1857) p. 348. See also Naylor and Sanderson's early furnaces, chapter 3.

150 SCA RB389(A) May 1859, October 1863

expire at Michaelmas 1842 (29 September, see appendix 1.4), the date of the furnaces' completion.[151] As almost all leases on building land, particularly for industrial uses, were subject to unfavourable conditions of reversion, it would not have been wise to invest large sums in infrastructure shortly before renewal, so Francis may have been waiting some years for the opportunity to invest in larger, more modern steelmaking plant.[152]

Francis Huntsman is said to have introduced many new and innovative techniques to the crucible process, and the new buildings support this claim. In use, the plan was designed around the flow of people and materials, while carrying over many of the fundamental features first seen in the original furnace. The coke shed was still accessible only from the yard, with fuel taken in through the front doors of the furnaces. Clay, on the other hand, was fed in to the narrow 'clay place' sandwiched between the furnace stacks, and retrieved from the pot rooms behind the melting shops. The finished crucibles could then be taken straight to the shelves above the holes, without ever having to leave the building. Likewise, steel was stored in rooms at the back of the building, allowing the charge to be broken up and weighed in close proximity to the corresponding furnaces.

The separation of routes meant that these discrete activities could also be carried out simultaneously, with minimal disruption to the others. [fig. 1.57] Clear and efficient circulation was not only desirable in such a working environment, but also potentially life saving, so the casting areas themselves were capable of being served at either end without workers needing to walk behind the holes.

Other developments: the wharf, housing and land

Although the crucible furnaces of 1842 represented the final significant addition to the Huntsman's Row site, beyond the works' boundaries other developments were taking place. The extension in 1819 of the canal from Tinsley to Sheffield[153] had passed just to the east of Attercliffe village, crossing the Worksop Road on the three arch Darnall aqueduct, and enabled the delivery of imported iron from Hull directly to Sheffield itself. Many of the larger firms had acquired land adjacent to the canal, to construct their own private wharves, saving time and money on the storage and transportation of the heavy raw materials. Perhaps the relatively modest scale of Huntsman's business did not, at first, warrant such an investment, offset against the costs of road haulage to and from the main canal basin in Sheffield.

By June 1840 the new addition of a 'Wharf' was made to Huntsman's rate, although once again the entry is grouped with the other steelworks buildings, giving little idea to its

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151 SCA MB422, 'Sketches of part of the Estates of the 12 Capital Burgesses', p. 15.

152 Usually, both the land and all the buildings erected upon it would revert to the landowner. In some cases, the lessee was even obliged to demolish and remove at their own expense any buildings erected during the term of the lease. In the context of the later indentures relating to Francis' land holdings, he may have attempted to purchase outright any land belonging to the manufactory; see SCA CB1579-1585, also appendix 1.4.

153 Linton (1956) p. 165. The canal basin to the east of Sheffield town centre became for a time the principal interchange for the transportation of bar iron and steel.

location.[154] Referring to the 1850 OS plan, the most likely candidate is a wharf just down the road from the Attercliffe works, occupying a large, irregular plot of land rising from street to canal level. Confirmation of this site can be made by a study of land areas, the wharf having been built on a plot of land identified as 'Narrow Field' in an undated survey of the lands of the Twelve Capital Burgesses (see appendix 1.4).[155] [fig. 1.58] Huntsman's trade in steel must have been increasing at this time, leading also to the construction of the new furnaces.

A warehouse was built directly alongside the wharf in 1843, enabling the storage of bar iron off-site and easing pressure on the recently extended Huntsman's Yard works.[156] The wharf continued to be used until 1860, when the route of the proposed railway line resulted in its purchase by the South Yorkshire Railway Company (SYRC, ultimately part of the Great Central) and its eventual demolition, later becoming the site of Attercliffe Station.[157] Transactions indicating Huntsman's interest in the SYRC can be found in the steel firm's ledgers between 1853 and 1866.[158]

In addition to the steelworks and Huntsman's Row, by 1868 Francis owned 24 of the 27 houses at the adjacent Swallow Row (and by 1880 had acquired the whole building, along with most of the south side of Worksop Road) and almost all of the Town Well Yard.[159] [fig. 1.59] His son, Benjamin, owned 32 houses (25 on Broughton Lane, the others at Cricket) and also paid rates for a wharf, office, machinery and premises at Effingham Road, on land belonging to the Earl Fitzwilliam, and a brickyard on lease from the Duke of Norfolk. He had made substantial investments in coal, as the proprietor by 1869 of the 'New Winnings Colliery' (later the Nunnery colliery).[160] Meanwhile, the steelworks rate remained constant, reflecting this recent shift in focus of the business.[161] On the steelmaking side, the works were now running almost like clockwork, and continued to do so through the succeeding decades, with very few changes of any note made to the structure of the works.

The self-sufficient works

With the later detailed valuations, a more complete picture of the site and its operation emerges (see appendix 1.5). [fig. 1.60] Alongside the steel furnaces and warehousing, the

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[154] Attercliffe rate, 21 June 1840, p. 27.
[155] SCA CB1634 'Reference to the Plan of the Estates of the 12 Capital Burgesses' (no clear date given, but probably early nineteenth century). 'Narrow Field' is the land occupied by Huntsman's wharf, which can be identified in the 1859-60 rate books as the 'Grass field' of extent 0a 3r 24¾p (only 0.17% difference). Before the addition of the wharf, Huntsman's was rated on land amounting to 5a 3r 9p, increasing on the following rate by 0a 3r 25p, almost exactly the area of the 'Narrow Field'.
[156] See Attercliffe rate of 4 August 1843.
[157] See Attercliffe rate RB389(B) October 1860, with the subtraction of 0a 3r 24¾p of land, from 4a 2r 25¾p as listed in April 1860, leaving 3a 3r 1p (see below 'Bradley Nook' in 1859). Also Simmons (1995) p. 79, fig. 5.5. Work began on the Sheffield extension in 1861 and it opened in August 1864. It seems that in its place a new wharf was built on the canal just to the southwest of the old site. See 1889 OS Yorkshire Sheet 295.01. See fig. 1.70.
[158] SCA LD1613, pp. 212, 220, 270, 297.
[159] Attercliffe rate, giving a total gross estimated rental of £166 6s 8d.
[160] SCA RB392, Attercliffe rate, p. 130, 1 May 1869, New Winnings colliery gross estimated rental of £2566, by 22 June 1872, £3180 + £32; Nunnery colliery rateable value £1925 + £32.
[161] From 1 May 1874, the rate actually dropped from £18 14s 1d to £16 0s 7½d, although with no reduction in the works value, so presumably resulting from a decrease in land area.

complex contained some unexpected structures. At the very back of the site was a cow-house and other ancillary buildings related to animal husbandry, while closer to the main house was a hen roost and poultry cages. Buildings such as these were not, however, unprecedented in nineteenth century steelworks, and shall be expanded upon in later chapters (chapter 3, Globe works). Steelmaking was not a continuous process, and during inactive periods the workmen would have had time to look after the animals and tend the nearby allotment gardens. The cows' milk would have been used daily at the works, and the vegetables and other produce as a valuable supplement the workers' diets, and even incomes.[162]

The large house also had its attendant gardens: the pleasure gardens, planted with shrubs and flowers are easily identifiable in plan, with their symmetrical network of paths, leading to a small brick summerhouse at the very end. Immediately adjacent to the large house was the 'kitchen garden', part of which can be seen (complete with a bed of rhubarb plants) in the foreground of the cementation furnace photograph. [fig. 1.61] The layout of both the gardens and the works was largely determined by the earlier field boundaries, their long, narrow forms still evident in the later landscaping. [fig. 1.62] Also within the grounds were a vine house, fruit walls and hotbeds, the trappings of a successful manufacturer's suburban residence.

A panoramic engraving of the Attercliffe works, produced towards the end of the nineteenth century, [fig. 1.63] shows the complex in its heyday, the liberally smoking chimneys symbolising industry and prosperity.[163] This view is interesting not only for its detailed representation of the buildings and activities, but also in its revealing symbolic content. The site layout corresponds closely with the OS plans, the foreground dominated by Francis Huntsman's foursquare mansion house set in its restrained picturesque grounds. Behind the house, arranged about the perimeter of an exaggeratedly spacious yard, are the various steelworks buildings, including the immediately recognisable furnace buildings.

Looking more closely, however, a number of anomalies can be found: Three cementation furnaces rise to the left of the view, as opposed to two in plan; the number of stacks emerging from the roof of the crucible shop has increased from three to four; and to the south a tall, octagonal chimney punctuates the horizon. These differences have been ascribed to the enthusiastic 'puffing' of the engraver, a common tendency in commercial topographical views, where the addition of imaginary plant, tweaking of symmetry, and the scaling-up of buildings in comparison to miniature pedestrians were all part of the engraver's art.[164]

In this case, these changes can be shown to have another meaning, as they signify an attempt to encapsulate Huntsman's entire business in one view. The Weigh House Furnace is represented by the appearance of the third conical cementation furnace, slightly detached

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[162] An important study of the everyday life of a Sheffield cutler was researched and published by Le Play in his monumental work *Les ouvriers Européens* (1855) pp. 194-199. There is no reason to believe that the diet of a steelworker would have differed significantly.
[163] The view was included in a catalogue of Benjamin Huntsman Ltd. Photograph at SCL local studies photo G1 67 Main
[164] Barraclough (1976) p. 1, caption to fig. 1. Hudson (1977) pp. 357-368.

from the other two, almost as if the space between the two sites had been obliterated. The off-site crucible holes are also here in the form of an extra stack, neatly inserted at the front of the main furnace block and occupying the full depth of the building. The tall steam-engine chimney is that of the Wicker Tilt (no longer dependent upon waterpower) as if transplanted from its site by Lady's Bridge in Sheffield to one on the canal just behind the works.[165]

The doctored image is not so much an attempt to embellish the truth–no additional capacity has been added that cannot be accounted for–as an idealisation, bringing together the disparate parts of the Huntsman empire. It may also be read as a reflection of the preference for large, integrated sites during the latter part of the nineteenth century (see chapter 5).

It is finally worth noting the cottage in the right foreground, a squat, insignificant structure that could easily have been omitted by the engraver yet was given an unusually prominent position. In fact, this cottage was the last tangible evidence of Huntsman's heritage: the ancestral home from which Benjamin had begun his steelworks over a century before. Since then, everything else about the works had changed except for the elder Huntsman's house, kept as an ever-present reminder of the firm's origins.

This acknowledgement of the past has a direct parallel in the diminutive timber *Stammhaus* (ancestral home) that marked the origin and centre of Krupp's Essen works. As the steelworks grew around it, the cottage remained, preserved on the ground upon which it was built, and over time attaining an almost mythical status. It appeared frequently in views and photographs of the works, dwarfed by the furnaces and chimneys that came to surround it. [figs. 1.64] Also mirroring Huntsman's development, when in 1844 a new, larger house was felt necessary it was built immediately alongside the original, retaining the strong connection with the works. [fig. 1.65]

Coleridge Road: 1898

By the time Francis Huntsman died in 1879,[166] he had earned for himself the popular title of 'The Steel King of Attercliffe'.[167] This was not simply in recognition of the fame of the Huntsman works, but also that over his life he had come to own the greater part of what was once the village of Attercliffe, in addition to large areas of land in the vicinity. [fig. 1.66]

Benjamin Huntsman had branched out into coal mining, but still maintained some interest in the steelmaking side of the company. However, the business had by no means kept pace with the latest developments in steel manufacture, preferring to concentrate on its traditional market of high quality crucible steel. By contrast, other firms in the area, including Brown Bayley's and Sandersons', had embraced the latest techniques and, in the process, grown to many times the size of Huntsman's works. [fig. 1.67] Despite this, the Attercliffe works

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[165] It is worth noting that the Wicker Tilt did have such an octagonal chimney.
[166] Hulme (1943-45) p. 43. His obituary can be read in *The Times* of 27 Feb. 1879.
[167] Vine (1936).

continued to operate in much the same way as they had for decades, their profitability maintained by the reputation for quality with which the Huntsman name was still associated.

It was probably Benjamin Huntsman's death in 1893 that marked the end of the strong family connection with Attercliffe. He was of the last generation to be born and raised at the house alongside the steelworks, and still felt a strong connection to his family's heritage, evident in his spirited letter to *The Times*. Later in life, he had moved away from Attercliffe to West Retford Hall in Nottinghamshire, but his business remained in the Sheffield area. In the immediate aftermath of his death the opportunity was taken to reorganise the business, the most significant outcome of which was the decision to close the Attercliffe works after almost 150 years of production, and to relocate to smaller, modern premises. The move mirrored the management's changing priorities, and an employee at the works later recalled how 'the partners at that time, having many other business interests, were able to devote only a limited time to steelmaking.'[168] Apart from the marginalisation of the steel side of the business, there were almost certainly financial motives behind the decision.[169] In recent years, Attercliffe's industrial base had grown beyond recognition, the landscape dominated by enormous steelworks and heavy industries. Land such as that upon which Huntsman's works stood would have been in great demand, badly needed for workers' housing to support the very works that had eclipsed Huntsman's in scale if not reputation. The pressure of urban growth was even mcre pronounced in Sheffield, where the Wicker Tilt and an adjacent warehouse and goods-yard, also owned by the Huntsman firm, were disposed of at the same time, to be redeveloped at a much higher density.[170] [figs. 1.68, 1.69]

By 1900, most of Francis Huntsman's empire had been replaced by rows of terraced housing along new streets.[171] [fig. 1.70] A new school had already built to serve the new district, named 'Huntsman's Gardens School' in recognition of its location in the fields behind the works.[172] Of the previous works, only the Weigh House furnace site remained in Huntsman's occupation, with its crucible holes, workshops, and possibly one surviving cementation furnace.[173] The retention of this portion of the works must have been of some significance, and resulted in the disruption of the new street pattern around it.

The new site was not far from the last, lying about 500 metres northeast, adjacent to the 'Pothouse Bridge' over the Sheffield to Tinsley canal. [fig. 1.71] The plot was then undeveloped, defined only by the perpendicular boundaries of Coleridge Road and a steep escarpment leading down to the canal. Opposite the canal boundary, and leading off

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[168] Mr. W. E. S. Patrickson, chairman and managing director of the company until 1940, quoted in Hulme (1943-45) p. 46.

[169] In the absence of a complete set of deeds for the Huntsman's Yard site, it is not certain that the firm owned the freehold outright. If the land had continued to be held on 14-year leases from the Burgesses, the last would have expired at the end of 1898, at which time the works were finally closed down.

[170] The buildings were redeveloped by a Sheffield veterinary surgeon, including multi-storey stabling, etc. For more detail see SCL sale plans, Wicker Tilt; also see Sheffield urban study file D5.

[171] These were named Titterton, Britnall, Beall, Bodmin and Chippingham Streets. See the 1903 OS plan for Attercliffe, Yorkshire sheet 295.01.

[172] Built over a decade earlier in 1888. The school's records are held by Sheffield City Archives.

[173] SCA Attercliffe rate book, 10 April 1901, 1st rate, part 2, p. 250. Unfortunately, the entry lists only 'B. Huntsman' as owner and occupier of a 'House' and 'Works & Premises' on Worksop Road, at £9 5s rateable value.

Coleridge road, a new smaller road was created, technically an extension of the existing Tinsley Park Road. Thus, the site area was effectively determined by its rear boundary, forming a rectangular plot of around 205 by 185 feet (c.63m x 56m), or almost twice the area of the previous Huntsman's Yard site.[174] The landscape today is much as it was then, a ragged, slightly windswept terrain of utilitarian sheds and disused plots, quite different to the lower lying Attercliffe village. [fig. 1.72]

It is fortunate that the original architect's drawings were recorded on microfilm, prior to their disposal along with most of Sheffield's early planning documents.[175] The buildings were designed by the Sheffield based architects Fowler and Marshall, and although very different in appearance, in their basic arrangement the new works shared many of the characteristics of the old. [fig. 1.73]

The internal layout of the crucible furnaces and attendant structures was almost identical, despite the furnace stacks now running lengthways instead of the transverse stacks of the old works. Coke sheds still flanked the building at both ends, with the steel house and pot house to the rear, partitioned from the main casting shop by the bulk of the stacks, and from each other by a short wall. A central break in the stacks provided the only means of communication between the two zones. A large ingot store was located centrally to the front elevation, directly opposite wide opening in the stacks, so as to minimise the loss of daylight to the shop interior. To either side of the ingot store, an external stair led down to the large, undivided cellar space, where the furnaces' ash pits were located. Like many of the new works of the late nineteenth century, Coleridge Road no longer included on-site cementation furnaces, relying instead on dedicated suppliers of blister steel, or direct carburisation in the crucible by the addition of charcoal.[176]

The building turned its back to the street, forming an inwardly focused courtyard space with the other perimeter structures. Among these was a large steam-powered hammer shed built along the rear of the site, and intended as a replacement for the Wicker tilt. [fig. 1.74]

The main office and weigh office were either side of the covered entranceway, a window from the weigh office overlooking the passageway where the weighing machine was located. The warehouse was lit by five tall arched windows on the street side, but could only be accessed from the yard itself. Both the warehouse and ingot shed had large drive-in cart openings.

The actual works frontage ran along the smaller cul-de-sac extension to Tinsley Park Road, where the entrance passage was located, so that on entering one would have seen the furnace building to the right, warehouse and hammer shop to the left, while the rear of the site

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[174] This comparison is to the Huntsman's Yard site alone, and does not include the Weigh House Furnace area, wharf, or other adjoining land. The area of the Wicker Tilt is also omitted. Approximate areas taken from scanned CAD plans: Huntsman's Yard 1970m²; Weigh House 875m², Coleridge Road 3510m².
[175] SCA: CA206/03779 (22 July 1898) Coleridge Road, CA206/32887 (8 July 1953) Tinsley Park Road
[176] See chapter 5 for the patent of Tom Vickers

was initially unoccupied, with views over the canal beyond. However, it was the strong symmetry of the casting shop that dominated the site, establishing an axis running perpendicular to this entrance, and reflecting the order of the steelmaking process itself, from the arrival of the raw materials through to the warehousing of the finished forged bars.

The works were still designed to accommodate a porter, who would live on the premises day and night. His small tenement was planned to face the smaller street, immediately adjacent to the main site entrance and close to both the warehouse and the steel furnaces. Even in 1900, the single room deep plan with central stair was a curious anachronism, but the stretched-out plan helped to form a complete courtyard edge. The dwelling terminated with a small kitchen, opening on to its own private yard and WC.[177] Altogether, the dwelling house managed to retain a sense of self-containment and privacy, while remaining fully integrated with the works it served.

The site lacked the solidarity of the village frontage as at Attercliffe, so the location of the porter's dwelling was much more explicitly based on surveillance requirements. Perhaps the location was not prominent enough, as the initial planning application was revised to include a more conventional dwelling house at the junction of Coleridge road and Tinsley Park road, projecting beyond the intended site extents. [fig. 1.75]

A new complex of geometrically planned buildings, further to the north-east on Broughton Lane and identified as 'Huntsman's buildings' on the 1905 OS plan (surveyed 1901-03) [fig. 1.71], was reportedly built for Benjamin Huntsman's colliery workers at Tinsley Park.[178] It cannot be confirmed whether any of the employees at Coleridge Road lived here, but the development was located within easy walking distance of the works, halfway down Tinsley Park Road and across the Broughton Lane Bridge over the canal.[179]

The buildings at Coleridge road are the best recorded of the Huntsman works, but have attracted the least attention.[180] The working interiors are recorded in series of photographs from the early 1900s, [figs. 1.76-1.78] and published in a company brochure. The pictures illustrate the entire range of activities in the melting furnace from crucible making through to the casting of steel ingots. A traditional approach to crucible steelmaking characterised the firm's final years, using proven techniques and equipment; the works were said to have still included a roller-mill for crushing crucibles until at least 1910.[181] Ironically, as the market for crucible steel dwindled, eclipsed by the introduction of bulk steelmaking processes, Huntsman became once again a leading name in the small-scale production of special steels. In terms of steel output, however, the firm was no longer a major contender. The relatively small scale of

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[177] This belonged to the same row as the works WCs, separated from the other cubicles by a short wall.
[178] Trevor Lodge's note to the Godfrey reprint of the 1905 Attercliffe OS plan (Yorkshire sheet 295 01) states that these houses were built for Benjamin's colliery.
[179] 'Huntsman's row' and the other houses in Attercliffe village had been demolished along with the works.
[180] The results of a recent RCHME survey of the site were published in the English Heritage draft document of *One great workshop*, but did not feature in the final publication of the same name, Wray (2001).
[181] Pipping (1988) p. 100, note 7. Barraclough related that this was the case, although it is unfortunately not recorded on any of the surviving plans.

his operations compared to those of neighbouring steelmaker Brown Bayley is highlighted by their respective rateable values: in 1901, the gross estimated rental of Huntsman's Coleridge Road property amounted to £292, while Brown Bayley's works reached almost 25 times that amount, at £7100.[182]

Epilogue

Much of the early twentieth century premises has survived, subject to a series of minor extensions undertaken since 1917 including modest alterations to the administrative buildings and the erection of lightweight sheds and outbuildings on the canal side of the yard.

The crucible shop still stands, but in a dilapidated state [fig. 1.80], having lost one of its stacks and most of its peripheral structures. As in the older works, iron straps are still in evidence to strengthen the flues, and iron bars instead of glass can be seen in the windows to the main shop. Likewise, external stairs still lead down to the brick vaulted cellar, little different in design to the earliest furnaces. Roof hatches provided ventilation for smoke and heat from what was essentially still a monopitch roof structure over the main shop floor, abutted against the massive stacks, just like Huntsman's first furnace of 150 years earlier. The warehouse and offices, dwelling house (extended) and later corner house remain largely unaltered. [fig. 1.79]

In place of the first Huntsman site, occupied continuously from 1751 to 1899, were built new streets of terraced housing for the workers at Attercliffe's larger steelworks. Ultimately, these too were demolished, leaving an area of featureless parkland until the development in 2001 of the 'Attercliffe Village' housing scheme. Unfortunately, this was planned and constructed in ignorance of the earlier premises, and the opportunity to investigate the site was missed. Archaeological remains most likely survived the 1900s housing, falling in the zone between rows of cellars. This includes the site of the original 1751 furnaces, now situated beneath a cycle path and offering the best opportunity of remains, as the deep cellars of cast steel furnaces are often found to be intact below a certain depth (as found at Millsands, see chapter 2).

The village of Attercliffe has all but ceased to exist, now dominated by the Don Valley sports stadium, and few signs remain of the impact that the Huntsman family made upon this community.

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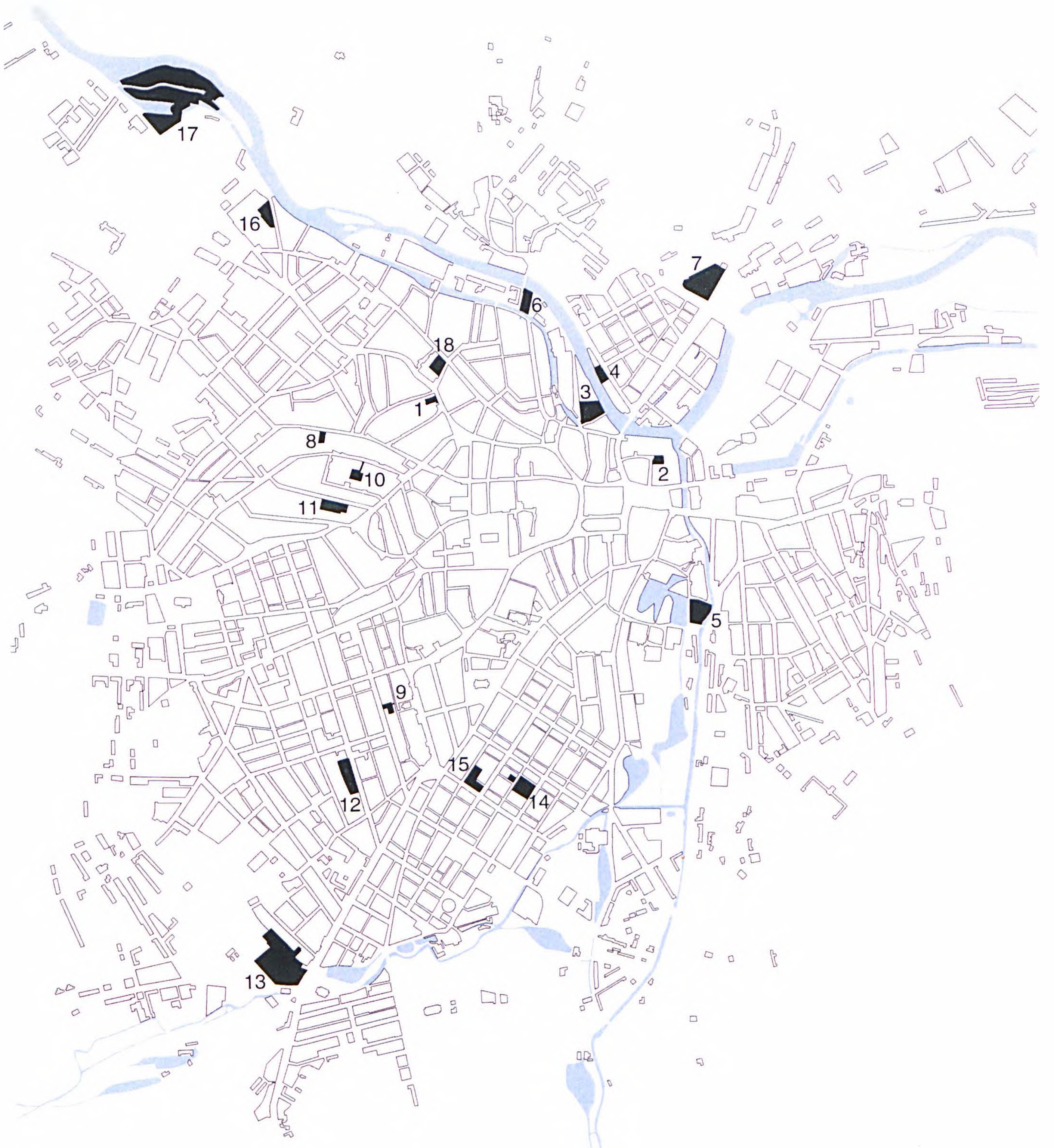
[182] SCA Attercliffe rate book, part 1, 1st rate, 10 April 1901, p. 141



Key to case studies in chapter 2. Scale 1:15,000.

Chapter 2: Location of case study sites

scale 1:15,000

key:

1	Samuel Shore, Furnace Hill
2	Castle Hill steel furnace
3	John Marshall, Millsands steelworks
4	Cocker Bros., Nursery Street wire mills
5	Marsh Bros. & Co., Pond Forge steelworks
6	Naylor Vickers, Millsands steel furnaces
7	John Walker (later Walker & Eaton), Wicker steelworks
8	Cutlers' Company cast steel furnace, Scotland Street
9	Alfred Ward, Backfields / Carver Street steelworks
10	William Parkin, Pea Croft steelworks
11	Kenyon, Hollis Croft steelworks
12	William Stayley; Maw & Tyzack; Earl & Co., Rockingham Street
13	Samuel Newbould, Bridgefield Works, South Street
14	W & S Butcher, Eyre Lane / Arundel Street works
15	W & S Butcher, Furnival Street works
16	W & S Butcher, Globe Works (part)
17	W & S Butcher, Philadelphia Works
18	Thomas Turton, Spring Works, Bower Spring

Chapter 2: Urban steel furnaces in Sheffield

Abstract:

Following the successful establishment of Huntsman's process, this chapter assesses its implications in the development of Sheffield's industrial centre. The extent of early (pre-Huntsman) cementation steelmaking in the town is outlined, and in particular the location and construction of furnaces up to the mid-eighteenth century. Examples include pictorial and survey evidence of the earliest known steelmaking site in Sheffield (namely Samuel Shore's furnaces at the bottom of what became known as Furnace Hill) and the location of small furnaces throughout the town centre and on the site of the ruined castle.

A short summary of the first of Huntsman's competitors deals with the introduction of crucible steel melting to the town and its neighbourhood. The steelworks of Jonathan Marshall at Millsands, probably the first to combine cementation furnaces and crucible steel manufacture on the same site, is examined in the light of the recent archaeological discoveries.

The early cast steel furnace type is explored in greater detail through the little-known venture of the Cutlers' Company. Using newly discovered survey drawings and bills of quantities, the buildings and history of this short-lived enterprise are reconsidered, as is its significance to later developments.

The constraints imposed by urban sites meant that expanding firms were often compelled to seek other locations in order to meet their needs. Consequently, many steel manufacturers operated from a number of distinct sites, sometimes in close proximity but often in different parts of the town. This practice of multiple-site working may be seen as a natural extension of the outworking system, on which most of the Sheffield trades depended, and was often the only option available to firms during periods of rapid expansion. The example of steel- and tool-makers W & S Butcher demonstrates how piecemeal acquisition was used to their advantage, reorganising their works in a series of phased developments that ultimately resulted in an efficient and successful distribution of functions across the town.

Part 1: Cementation steel

> *It is a mystery, this change of substance, that I don't yet really understand. I know that the means of changing iron into steel is to harden those parts that were soft, to give it phlogistic, or elementary, fire, but what phlogistic is and how it is instilled into iron I have no idea.*
>
> François de La Rochefoucauld's journal, Sheffield, 28 Feb. 1785.[1]

Before the development of Huntsman's steel Sheffield was already well known for its cutlery, not only in Britain, but also in Europe.[2] Like its German counterpart Solingen, Sheffield had gradually put in place the infrastructure required for the manufacture of steel-edged products, including the mechanically-driven tilt hammers and grinding wheels powered by its five rivers (chapter 4) and the numerous smithies and forges to be found in the courts and back yards of the town.

The better grades of steel were at first only available as an imported product, and not made in Britain until the seventeenth century. When the technology did arrive it settled in the established ironmaking districts, and the material was brought to manufacturing towns such as Sheffield as finished bars of steel. The Northeast and Gloucestershire in particular became renowned for the quality of their cementation or 'blister' steel, as noted by Moxon who termed it 'English-steel'.[3] As the bar iron used to make blister steel was itself imported, and constituted the majority of the cost of the steel made from it, any incentive to reduce overheads by producing steel locally was outweighed by the substantial initial cost of constructing dedicated steel furnaces.

Cementation steel was a very different product to the varieties of iron that had been produced in Britain for centuries by a number of methods that it will serve to give a brief outline of. One of the earliest forms of iron-smelting furnace was the small bellows-blown bloomery, a precursor to the blast furnace, in which iron ore and charcoal would be heated to around 1000°C to form a spongy mass of iron and slag (the 'bloom').[4] Once hammered to consolidate the metal and reduce the slag content, the resulting low-carbon product was a kind of wrought iron that could be forged into blades and tools. These were not steel in the modern sense, but by the absorption of sufficient carbon in the smith's hearth could be hardened by quenching.

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1 Translation from Scarfe (1995) p. 55.
2 Zedler (1743) vol. 37, col. 803. 'Sheffield... war vor Zeiten wegen ihres Handels mit allerley Eisen-Waaren, insonderheit mit Messern und Klingen, berühmt'.
3 Moxon (1703) p. 57: 'The *English-steel* is made in several places in *England*, as in *Yorkshire, Gloucestershire, Sussex*, the *Wild of Kent*, &c. But the best is made about the *Forrest of Dean*'. Blister steel was so named because of the raised excrescences that usually appeared upon the surface of the product, the result of impurities in the bar iron.
4 See Tylecote (1992) pp. 75-76; Aitchison (1960) vol. 2, pp. 434-441; Barraclough (1976) pp. 10-11. The following description of the early processes is mostly abstracted from these sources.

In the iron blast furnace a very different reaction took place, probably first discovered by the accidental overheating of bloomery-type furnaces. At higher temperatures (1200°C and above) the ore began to absorb carbon, lowering its melting point and resulting in molten iron running to the bottom of the furnace. With suitable modifications, the iron could be tapped and run into moulds formed in a bed of sand, leaving behind much of the slag. The carbon content of these so-called 'pigs', at around four percent, was much higher than that of bloomery iron and made the metal brittle and unforgeable. In compensation, it could be re-melted and cast with relative ease for applications where the lack of malleability and tensile strength was not an issue.

From cast iron, malleable steel could be produced in the 'finery', by remelting in a bed of charcoal subjected to a strong air blast. As the carbon was burnt away, so the melting point rose and the iron solidified into a mass of metal and slag not unlike the earlier 'bloom', which was similarly hammered and forged to a more homogeneous consistency, producing wrought iron. By arresting the finery process before the bloom was reduced to wrought iron a crude form of steel might be arrived at, but this was highly unpredictable and labour-intensive, and was restricted to the production of manageable masses. It was into this context that the more reliable and certain process of cementation was introduced around the beginning of the seventeenth century.

Cementation steel, on the other hand, was made from wrought iron by a process that was in essence scaled-up version of the much older technique known as case-hardening, described by Moxon and known to Biringuccio and Agricola in the sixteenth century.[5] The application of case-hardening was confined to small iron articles, which were enveloped in a pulverised mixture of carbon-rich material (cow's horns and hoofs with salt and wine vinegar in Moxon's example) and covered in loam or sand to render the parcel airtight. When dry, this was heated in an ordinary smith's hearth and held at around 900°C for several hours, depending on the degree of 'steeliness' required, before quenching the red-hot iron in water. The main difficulty lay in judging the degree and duration of the heat, and good results could not be guaranteed; mistakes were costly, as the items to be case-hardened had generally been forged and worked on beforehand.

By scaling up the process, and heating whole bars of steel in receptacles of consistent size and construction, the cementation furnace provided a reproducible means of regulating the amount of carbon taken up by the iron, which could afterwards be sorted into grades suitable for different tasks. The vessels were probably first made of clay and heated in a furnace similar to that used for pottery or glass, but it soon evolved into a distinct furnace type with long chests or 'pots' made of sandstone slabs or refractory brick.[6] The increased size also meant that each 'heat' would be maintained for up to a week, followed by several days in

[5] Aitchison (1960) vol. 2, p. 441. Biringuccio (1540) fols. 18r-19r; Agricola (1556) book 9; Hoover and Hoover (eds.) (1950) pp. 423-426

[6] 'Pots' was a term used colloquially for both sandstone cementation chests and steel melting crucibles. The former were also known as 'coffins' due to their similar size and proportions. See glossary.

which the furnace was allowed to slowly cool. It was most important to exclude air from the chest during a heat, which if accidentally admitted would have the negative effect of oxidisation. This was done by carefully luting the joints of the chests and by covering their open tops with a layer of refractory sand (in Sheffield this was usually ganister collected from the surface of 'metalled' stone roads or 'wheelswarf' a by-product of the cutlers' grinding wheels, see chapter 4 and glossary).

The cementation process of steelmaking may have come to England by an unlikely route. Robert Fludd, the alchemist and mystic, is known to have embarked upon the manufacture of steel around 1618, in breach of the Royal monopoly patent.[7] Fludd had imported a skilled operator from France, John Rochier, who claimed to be 'the inventor of transmuting iron into steel', and established steel furnaces.[8] In 1620 he appealed to James I to consider his steel on its own merits, promising:

> *to make a good steele as anie is made in forraine parts, and to vent the same at easier and cheaper rates than the outlandish steele; that they will waste noe wood but only make it of pitt coale.*[9]

An additional offer of one-third of all profits to the Crown may have helped to secure Fludd and Rochier's patent, at the expense of the original holders who had first complained of Fludd's encroachment and saw their own patent revoked. Little else has come to light concerning the progress of Fludd's process, but it would seem to provide the missing link between the continental origins of cementation steel and its establishment in Britain. Furthermore, the involvement of a philosopher of Fludd's calibre anticipates Boyle's interest in steelmaking, illuminating a largely neglected aspect of early science.[10]

Development of cementation in Sheffield

In Sheffield, the first steelmakers were generally practical men with some commercial experience, although not necessarily in the metal trades. John Love, founding partner of Love & Manson was also a linen draper and began in the steel business with a capital of £500.[11] Others were already established as factors or merchants (see chapter 3), and appear to have seen the production of steel as a profitable sideline, hiring local steelmakers to run their privately financed furnaces.[12]

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[7] Huffman (1988) pp. 23-24, 46-48.
[8] Hist. MSS Com. series, report XII, appendix I, p. 197. Huffman overlooked this evidence.
[9] Huffman (1988) p. 24. The reference to pit coal suggests that this was indeed the predecessor of the cementation process as was to be practised throughout England.
[10] Aitchison (1960) p. 426, commented that 'the genuine chemists of the seventeenth century–as opposed to the alchemists alongside them–were not particularly interested in metals as such'. More recently, the hard distinction between chemists and hermetic philosophers has been questioned through the research of Principe and others; likewise, the segregation of theory and practice may be misleading.
[11] Timmins (1977) pp. 5, 33, 44. The succeeding partnership of Love & Spear operated both crucible and cementation furnaces.
[12] Note, for example, the case of Oborne and Gunning, outlined in chapter 1. John Love was also described as a factor and merchant in Robinson (1797).

It is uncertain as to why cementation steelmaking did not flourish in Sheffield at an earlier date, particularly as the locality satisfied many of the conditions essential to its eventual success: good coal supplies, sufficient timber for charcoal and a ready market for the end product. What it lacked, however, was a convenient source of the imported Swedish bar iron so important to the quality of the resultant steel, which had to be brought from the nearest major port, Hull. Poor roads and the lack of suitable navigation were certainly a serious impediment, and put Sheffield at a disadvantage to locations closer to the main seaports.[13] Perhaps an even greater impediment was the monopoly held by the Hull merchants on the output of Swedish iron producers, allowing prices to be fixed. Even by the nineteenth century a small core of Hull suppliers furnished Sheffield with the bulk of its bar iron.

It is not until the early 1700s that the first evidence for local conversion of bar iron into blister steel emerges. It is widely believed that the first furnaces were to be found in rural settings, located in the district of Hallamshire.[14] While this is likely, the limited evidence for steelmaking in the country around Sheffield does not definitively predate records of comparable urban sites. At the small village of Darnall, near Attercliffe, it is recorded that 'George Steer first began to lay iron in ffurnace [*sic*] to make steel' in May 1719, clearly a reference to cementation steel.[15] Another early eighteenth century site in the countryside near Rotherham, and owned by the Fells (of Attercliffe Forge–see chapter 1), was similarly described as '...all that steele ffurnace with the smythy and tenting house thereto belonging', suggesting that on-site preparation of the steel (possibly drawing it out into bars or rods) may have taken place.[16] Within the town, two furnace sites are known to have been in operation by 1716, belonging to Thomas Parkin at Blind Lane in the south and Samuel Shore on what became known as Furnace Hill to the north (see below).

The process of cementing steel in these earlier times was, in principle, no different to that used over the following two centuries; William Brande's *Manual of Chemistry* (1819) provides a succinct summary of the basic method as it came to be practised in Sheffield:

> *Iron is converted into steel by a process called* cementation, *which consists in heating bars of the purest iron in contact with charcoal; it absorbs carbon and increases in weight, at the same time acquiring a* blistered *surface. This, when drawn into smaller bars and beaten, forms* tilted steel; *and this broken up, heated, welded, and again drawn out into bars, forms* shear steel.[17]

Further folding and forging gave rise to 'double shear' and still higher grades of steel.

[13] Before 1722 the river Don ceased to be navigable near Doncaster, and only upon the completion of the Don Navigation in 1751 did vessels even come as close as Tinsley. Until the 1730s, much of Sheffield's raw materials and produce were hauled by packhorse to Bawtry, about 20 miles away, to be shipped down the rivers Idle and Trent to Hull. Hey (1972) p. 15.
[14] See Belford (1998) p. 13; Hey (1991).
[15] Ward (1909) p. 237, from a memorandum transcribed by Ward in his dairy. The original source has not been identified.
[16] SCA Wheat collection 1966.
[17] Brande (1819) p. 237.

Behind this veil of apparent simplicity the real-world praxis was an unpredictable, hit-and-miss affair, of a chemical complexity little understood until after the process had become effectively obsolete, and for which every manufacturer had rules and procedures of their own.[18] Some adulterated the charcoal with other substances, few of which had any real effect; others swore by particular marks of iron.[19] Furthermore, the temperature and duration of a heat could also be varied, giving countless permutations. It is hardly surprising that steelmakers with a good reputation were in very great demand.[20]

The basic stages of a cementation furnace heat as perfected in Sheffield were relatively straightforward, and remained relatively constant over two centuries of practice.[21] [fig. 2.1] A long stone chest, or more usually a pair of chests [1], was built above a firegrate [2] running the length of the furnace with an ashpit [3] beneath accessed by steps. From the grate, firebrick flues [4] ran beneath and up the sides of the chests to direct the flame more evenly over their entire surface, emerging into a groined vault [5] that covered the whole and reverberated the flame upon the chests beneath. A number of short chimneys [6] (usually six in number) emerged from the springing of the vault, drawing air up and out of the furnace proper, into the space of the conical 'shell' [7] that gave the cementation furnace its distinctive external form.

The first stage involved loading the furnace with wrought iron bars, about three inches by five-eighths of an inch in section and up to twelve feet long. A man outside the furnace would pass bars through an opening above the chests [8] to his colleague inside, who laid them in rows upon a bed of charcoal, continuing to alternate layers of iron and charcoal until the chest was almost full.[22] The central arched opening at each end [9] was just large enough to admit a person, and the vault high enough so that when both chests were full the workman inside could still stoop to perform his task. [figs. 2.2, 2.5] For ease of access in loading the furnace, timber boards were laid over the pit and stairs used during the firing phase. Having filled the chests, finishing with three inches of charcoal, a four-inch topping of 'wheelswarf' was spread over the entire surface to seal it from the air outside and the charging holes bricked-up and sealed with clay. [fig. 2.3] At this point, a coal fire was lit on the central grate and over a day or two the furnace raised to a red heat (around 1100°C), at which temperature it would be

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[18] This is what Harry Brearley termed the 'rule of thumb' element of steel manufacture, still very much in evidence when he was writing in the early twentieth century; see Brearley (1995). The confusion of François de La Rochefoucauld (above), a visitor to Sheffield in 1785, sums up the poor state of theoretical knowledge at that time.
[19] Most additives were in any case carbon-rich organic matter (such as animal hoofs, hair, bones) and performed much the same function as the charcoal (but with less effect); similar recipes were used for case-hardening and tempering of steel. 'Gold- und Silber- Arbeiter' (1708) pp. 175-186. The adherence to particular brands of Swedish iron was more reasonable, having been recognised by Huntsman in the eighteenth century.
[20] The making of iron and steel had always been a process subject to superstition and ritual practice, and there is every reason to believe that Sheffield generated many of its own. One example (also found elsewhere in Britain) was the taboo of presenting someone with a knife or sharp instrument without receiving symbolic payment of a sliver penny or small coin in return, in order to avoid accidents. For steel and iron myths in other cultures see Eliade (1978) *passim*.; Frazer (1922) chapter 21, section 2, 'Iron tabooed'.
[21] Le Play (1843) pp. 583-626, offered a detailed description of the process, on which much of the following paragraphs is based.
[22] Le Play (1843) p. 593, stated that each chest contained 36% total volume of iron, the rest being made up with charcoal. In Sheffield, the common practice was to allow one-third of the volume to be iron. Barraclough (1973) part 1, p. 10

maintained for around a week. [fig. 2.4] Throughout the firing period the furnace demanded constant attention, with furnacemen working in shifts to stoke both ends of the grate at intervals of around two hours. When the time was judged to be right, the fire was allowed to burn out and the furnace left to slowly cool. In later practice, a test bar would be left projecting through a hole in one end of the chest [10], to be withdrawn during the heat as a guide to the progress of conversion. After several days of cooling the temperature of the furnace allowed the bricked-up apertures to be opened and the vitrified crust of wheelswarf (known as 'crozzle' in its baked state, and sometimes set aside as a low-grade construction material, see chapters 2, 3) broken away from the top of the chests. [fig. 2.7] Finally, the bars of cemented blister steel were passed back out of the furnace and their surfaces cleaned of charcoal residue ready for hammering.

When they emerged from the furnace, not all of the blister steel bars would be converted to the same degree, and it took a practiced eye to discern the various qualities. Bars would be graded by breaking off a portion at one end to judge the grain (and therefore steeliness) of the metal, enabling the material to be put to best use.[23] [fig. 2.6] With a heat taking from two and a half to three weeks from start to finish, and accounting for repairs and maintenance, no more than twenty batches of steel could be expected from a single furnace in a year.

While cutlers had used blister steel for the best cutting edges long before the arrival of Huntsman's crucible process, it was the mass adoption of cast steel that proved the greatest stimulus to the development of cementation steelmaking in Sheffield. From the earliest years of Huntsman's experiments, one of the major ingredients of the steel charge had been the leftover 'raw ends' of bars and over-converted blister steel. These were an inevitable by-product of the unevenness of temperature within the furnace chests: in order for bars in the centre to receive an adequate dose of carbon, some of those closest to the fire would become overcharged, or 'burnt'. Unwanted by the cutlers, these high-carbon remainders were ideal for making cast steel, and could be obtained (initially, at least) at a much lower cost. By adding scrap steel to the mix, the final carbon content of the resultant ingot could be controlled, producing homogeneous steel from relatively cheap ingredients. Some outsiders even believed this abundance of scrap steel gave the town its competitive edge; in Bishop Watson's opinion:

> *...the business is carried on at Sheffield with greater advantage, than at most other places, for their manufactures furnish them with great abundance of broken tools, and these bits of old steel they purchase at a penny a pound and melt*

[23] The relationship between grain and carbon content of the steel was first recognised in print by Réaumur (1722). Classification was still performed in this way in the twentieth century, Sexton and Primrose (1912) pp. 231-233, fig. 114

them, and on that account they can afford their cast steel cheaper than where it is made altogether from fresh bars of steel.[24]

Even so, small but significant quantities of cementation steel were produced in Sheffield some decades before Huntsman's steel went into commercial production in 1751. Moreover, the early development of infrastructure for working the raw bars of blister steel into more homogeneous rods and sections for the cutlery trades (namely the town's water-powered tilts and forges), was instrumental to the successful establishment of crucible steelmaking in the locality. For over a century, the two processes were to operate symbiotically, each thriving on the presence of the other.

Samuel Shore: Furnace Hill

Sheffield's first known steel furnace was situated on the northwest edge of the town, owned and operated by Samuel Shore whose family was prominent locally as merchants and later in connection with the local savings bank Parker, Shore & Co.[25] The precise date of the steelworks' establishment is not known, but in 1716 Shore was found to be in possession of a 'steele house', and by 1737–the date of Thomas Oughtibridge's topographical engraving of the town–two conical furnace shells could be seen bordering the fields to the north of the town.[26] [fig. 2.8] The key accompanying Oughtibridge's view testifies to the relative novelty of such furnaces in Sheffield at this time, designating them simply 'The Steel Furnaces'.[27]

However, Shore was not the only steel converter in Sheffield when Oughtibridge made his view. The rate book of 1716 also records a furnace operated by Thomas Parkin, described in his will (1729) as '...my Steelhouse scituate in the Blind Lane in Sheffield, with all the Buildings and Ground to the same belonging...'[28] Blind Lane lay towards the southern end of the town, close to the public space and reservoir known as Barker's Pool; this would not have been visible from Oughtibridge's vantage point and consequently does not feature in his view. Parkin's furnace seems to have ceased to operate by the 1750s, and no contemporary map or plan makes reference to its location.[29]

Meanwhile, Samuel Shore's steel business prospered, taken over after his death in 1751 by his namesake son who is said to have added a third cementation furnace in the 1760s. It is unclear whether this third furnace was an extension of the original building or erected on a

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[24] Watson (1781-86) vol. 4, essay III, p. 148.
[25] Hey (1972) p. 52
[26] Hey (1991) p. 191. 'Steel house' was a term used to describe both the structure of a single cementation furnace and also a building that housed one or more cementation furnaces. Therefore, from this description it is uncertain whether Shore was operating one or two furnaces at this time.
[27] Leader (1875) ch. 4, reported an agreement of 1709 between Samuel Shore, 'ironmonger', and Henry Ball, steel maker, which implies that Ball had been cementing steel for Shore previously. It appears that Ball was paid six shillings a week for his duties, and was bound to supply steel only to a select group of Sheffield filecutters.
[28] Hunter (1869) p. 322; Hey (1991) p. 193.
[29] It does, however, remain a possibility that Young's cementation furnaces on Holly Street were a modification of Parkin's furnaces, see below

different site, but blister steel continued to be made at Furnace Hill until at least 1779, eventually to be eclipsed by Shore junior's banking interests.

Neither the precise location nor any plans of Shore's furnaces have previously been identified,[30] but plans of the furnace site dating from the second half of the eighteenth century do exist, discovered during the Sheffield urban study project (see introduction).[31] [fig. 2.9] The furnaces are shown to have been located at the junction of Gibraltar Street (also known as West Bar Green) and the steep lane known as Furnace Hill, the name of the latter clearly derived from Shore's buildings.[32] The building was L-shaped in plan, with the long range to the rear housing the furnaces and facing a small steelyard accessed from Gibraltar Street. The block facing Gibraltar Street is not labelled, but may have been a dwelling or an associated iron warehouse.

Although the plans provide no internal detail, the layout of the interior may be deduced from external features and dimensions. The façade to the steelyard featured four piers or buttresses in equally spaced pairs. These would have strengthened the outer walls of the furnace building where the conical shells of the furnaces were at their weakest, due to their subtractive intersection with the vertical wall of the shed. In later examples this was achieved solely by the use of iron ties, but in the earliest surviving buildings such as Derwentcote furnace (c.1733) raking external buttresses were employed instead.[33] [figs. 2.10, 2.11] Two furnace cones would have occupied the main space of the shed, consistent with those seen Oughtibridge's view, between which a gateway opened on to the yard, large enough to allow iron bars to be carried in and out of the furnaces.

Oral history suggests that Shore's cementation furnace may have contained only one large chest or 'pot' containing around ten tons of steel, an arrangement found in other early examples (see Marshall's Millsands works, below). The story relates that the furnace was overheated by accident, causing its contents to melt and subsequently to solidify in the chest, forming 'one huge solid block of steel'. Following its extraction from the furnace, this giant 'salamander' lay in the furnace yard for many years before being used as landfill during the raising of the level of Gibraltar Street where it met Furnace Hill.[34] Such accidents, although

[30] Belford (1998) p. 11, suggested a location near 'Steelhouse Lane', opposite Lambert Street. Rate book entries are vague, combining the furnace rate with Shore's other properties, for example SCA RB32 (5 Feb. 1787) p. 82 'Irish Cross Jno Shore 9d, Land in Red Croft 8d, 3 Steel Furnaces 1s 0d.'
[31] For example, SCA SheS 1525, drawn in 1775 by William Fairbank. The plans were located by diploma students Savill, Williamson, Tapp, Jackson and Magill (A5) and identified by the author.
[32] Shore's steel furnaces predate the formation of the street, as demonstrated by the 1775 plan SheS 1525 produced for the setting-out of an 'Intended new Street [i.e. Furnace Hill] which will open a Communication betwixt Gibraltar and Scotland Street', see also FB47 (1775) p. 17; Leader (1875). The contributor, Leighton, recalled that 'Furnace hill was formerly called "t' Cock Tail;" I haven't the remotest notion why'.
[33] Cranstone (1997), Malaws (1999) notes that 'the exterior structure is very largely original and as such is by far the earliest known cementation furnace in Britain, if not the world'. Note that at Furnace Hill, one of the end piers was flush with the level of the front building,
[34] Leader (1875). The narrator, Twiss, noted that 'The tradition has been handed down by very old men, and if there be any truth in it the steel is still there, waiting to astonish some antiquaries of the future'. Whether true or not, the story conveys the uncertainty of early cementation steel manufacture in Sheffield

rare, could prove be very costly and often necessitated the complete demolition and rebuilding of the furnace.[35]

A superimposition of the Derwentcote furnace plan (about the same capacity but with two chests) upon the Fairbank survey of Shore's building yields a plausible hypothesis for the internal layout, the dimensions of shed and piers similar in both cases. [fig. 2.12] With a limited number of available archetypes, there was an understandable conformity to early furnace design as each built on the success of established forms. The short return along Gibraltar Street was probably a later extension, planned in sympathy with the encroaching town, and is unlikely to have housed the third furnace.

Although demolished towards the end of the 18th century, a residual footprint of the building and yard is still clearly visible on the 1850 and 1889 OS plans.[36] [fig. 2.13] Even with the raising of Gibraltar Street, the steep gradient of the site is still evident today, so at least one of the furnaces must have been either built up or bedded into the slope, more likely the latter for reasons of structural stability as at Derwentcote. [figs. 2.14, 2.15] No trace of the original fabric is now visible above ground, but based on experience elsewhere in the town the likelihood of some subsurface remains surviving is high.

[35] The bar iron with which the furnaces were loaded melted at a substantially lower temperature than steel, so the risk was greater at the beginning of the 'heat', before a protective layer of steel had formed. A similar accident may have occurred at the Cutlers' Company cementation furnace on Scotland Street, below.
[36] See 1850 OS plan, sheet 20. The furnaces had clearly been demolished, but the front buildings may have survived in an altered form.

Typology of the cementation furnace

Development of the furnace

Not all cementation furnaces were built to the pattern adopted by Shore. Early visitors to Sheffield made reference to other types, often lacking the superimposed conical shell, and containing different numbers of chests.

One of the largest, the Castle Hill furnace, was built to a square plan on the prominence at the confluence of the rivers Sheaf and Don, once occupied by Sheffield castle.[37] Unusually, it contained two pairs of chests, one holding sixteen tons each and the other thirteen tons, with twin openings at ground level for firing.[38] It may be reasonably assumed that inside the outer cone the furnaces were built to a conventional plan, effectively two furnaces sharing one overarching shell, as it was noted that only two chests were fired at a time. Like the Derwentcote furnace, it passed through the hands of a number of steelmakers, usually augmenting cementation steel production on their main premises.[39]

Nineteenth century images show a large brick cone that dominated the neighbourhood (as must have the smoke given off during a heat), [figs. 2.16, 2.17] but a photograph taken on its demolition reveals that the base was of heavy stone construction.[40] The brick cone had already gone, leaving the lower part with its quoined corners and openings, one spanned with a pointed arch; above each opening can be seen the tie-plates of the iron rods that reinforced the structure. [fig. 2.18] Like Huntsman's Attercliffe Green furnaces, it appears that the upper section of a formerly all-stone shell had been upgraded to a taller brick cone, retaining the relatively costly foundations of the older furnace. Given its date and location, there is a possibility that stone from the ruined castle was used in its construction, and may even have influenced the choice of site.[41]

Unusually, at the end of its life the furnace shell was reused as a storage shed, probably due to its uncommon size. [fig. 2.19] The adaptation of furnace shells to other uses was not common, offering few economic or functional benefits; more often, the abandoned furnace would be left in place being too expensive and difficult to demolish. By this process, a pair of 1830s converting furnaces that had fallen out of use at Bower Spring (now a scheduled

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[37] On nineteenth century plans, the site appears to be relatively constricted, although when first built, the green may have been undeveloped. Sheffield's castle had been besieged and destroyed during the Civil War, and some of the stone reused for building purposes.

[38] SCA FBC NB31 (1834) pp. 7-8, 'Castle Hill, Furniss & Co.'

[39] Occupants included Walker and Wilde, who had established steelworks on the Wicker in the eighteenth century, and Naylor & Co. By 1834, when the Fairbanks made their rate assessment, it was owned by Furniss & Co. See Belford (1998) p. 13.

[40] The photograph, with the caption 'Furnace, Sheffield's oldest' is at SCL Photo G1 274 Main Arkell.

[41] Smith (1865) p. 6, noted that after the fall of the castle in 1644, 'Four years later, [therefore in 1648] parliament ordered that this famous stronghold should be "sleighted and demolished." And the demolition then formally commenced, has long since been so effectually carried on that at the present day not a single stone remains to attest that a monument of such local and historical importance ever stood on "Castle Hill."' Excavations begun in 2001 have revealed that substantial parts of the walls did survive.

monument) survived until the demolition of the surrounding buildings, when they were identified and demolition halted (see below). Similar traces of furnace

At Snowhill near Birmingham, the Swedish investigator Angerstein described a three-chest furnace, similar in appearance to the Castle Hill structure and owing a debt to the form of the bottle-shaped Midlands pottery kilns. [fig. 2.20] Its total capacity was about seven tons, using sixteen tons of coal over six days of firing; another furnace on the same premises was said to have 'only one fireplace and two boxes'.[42]

Alongside these larger examples, by the late eighteenth century Sheffield also contained a number of single-chest furnaces, apparently unique to the locality and allowing the cementation of steel in smaller quantities. Gabriel Jars produced detailed drawings of a trial furnace based on the Sheffield examples he had seen in 1765, and published in his *Voyages Metallurgiques*.[43] [figs. 2.23, 2.24] Even at this early date, Jars was able to state that:

> *In the town of Sheffield and its neighbourhood, they convert a very great quantity of iron into steel. Many of the furnaces of which they make use are similar to those at Newcastle, but are smaller and convert less iron at a time...*[44]

His drawings depict a furnace intended to convert just three to four hundredweight of iron at a time, and by using a shorter chest than usual allowed a single fire-grate at one end.[45] At this time, Sheffield's furnaces more commonly held between three and five tons of iron in their single chest, striking a balance between economy of scale and the realities of a developing industrial economy. In Jars' opinion, the popularity of the smaller furnaces–more common than the large examples found at Newcastle [fig. 2.25]–was due to their lower construction cost and more efficient use of fuel.[46]

Remains of what may have been a furnace similar in form and scale to that described by Jars were unearthed at Wortley Top Forge in 1977, probably fired at one end with a vertical flue at the other, built against the gable end of the foundry.[47]

On a visit to John Marshall's Millsands steelworks in 1796, Charles Hatchett made a thumbnail sketch of a visibly different form of single-chest furnace covered with a tall bottle kiln-like structure, [fig. 2.26] accompanied by the following explanatory text:

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[42] Angerstein (2001) pp. 37-38, fig. 25.
[43] Jars (1774) vol. 1, pp. 221-226, 256-258, 361-365, plate 8 (reproduced in Vandermonde (1793?) as plate 1; also adapted by Hassenfratz (1812) vol. 4, pp. 260-261, plate 61)
[44] Jars (1774) vol. 1, p. 256. 'Dans la ville de *Sheffield* et dans ses environs on convertit une très-grande quantité de fer en acier. Plusieurs des fourneaux dont on fait usage, sont semblables à ceux de Newcastle, mais ils y sont plus petits, *et on y convertit moins de fer à la fois...*' A guide to the scale of Newcastle's furnaces in the mid-eighteenth century is provided by Angerstein's 1754 drawings of cementation works at Blackhall Mill, see Angerstein (2001) pp.267-272, figs. 254a, 257a. Reproduced here as figs. 2.21 and 2.22.
[45] This, however, meant that the standard iron bar of around ten feet long had to be cut to length, impractical for commercial production but acceptable for large-scale trials as intended by Jars (and, he claimed, more economical in fuel). The accompanying text indicates that Sheffield's steelmakers used full-length bars.
[46] Jars (1774) vol. 1, p. 256, stated that the smaller furnaces were 'beaucoup plus communs... vraisemblablement parce qu'ils coûtent moins à construire; ils sont faits sur les mêmes principes'.
[47] Barraclough (1977) pp. 88-89, figs. 1, 2.

Tuesday June 14th [1796]. In the morning we went with Mr. Curr to see a Steel Work (or where the Iron is converted into blister'd Bar Steel) belonging to a Mr. Marshall. The form of these furnaces is like the annexed sketch and the height with the chimney etc. perhaps 30 or 40 feet.

The Bars are of various sizes and are about 12 feet long–they are placed horizontally in the chest so as not to touch each other on a stratum of powdered charcoal and between each layer of Bars a stratum of the charcoal is placed, and when the chest is thus filled, the whole is covered with a stratum of charcoal and this again well covered with Sand to prevent the combustion of the charcoal. The aperture by which the people entered to arrange the Iron is then well closed up and then the fire kindled (the Fuel is Pit coal) and the Red Heat is kept up e.g. from Sunday Eveng. till Saturday following. There is a small aperture in the side by which a Bar may be occasionally taken out, and also the degree of heat seen. This forms Blistered Bar Steel (NB here about 6 Tons are made in each Furnace. The Blisters are hollow).[48]

This is of particular interest in relation to the recent archaeological investigation of the site, which uncovered the remains of a single-chest furnace, possibly the same one described by Hatchett, but in any case unique among surviving examples.[49] Whether visitors were always taken to the same furnaces, or many similar examples existed is not known. The description in François de La Rochefoucauld's 1785 travel journal is of interest, made from the perspective of a layman. He saw a furnace 'shaped like an oven' and 'constructed with doubly thick walls, the first of brick, the outer one by [sic] stone clamped by bands of iron, and the flames are so violent that the outer stone wall is calcinated. A lot of the brick is constantly reduced to cinders'.[50] That the firing took six days, with four days to cool afterwards, confirms this to be a relatively small furnace, like Jars'.

Gustav Broling also recorded a cementation furnace he had encountered at London, unusual in having no shell, but only two tall flues or chimneys connected directly to the firebrick vault around the chests. In addition, he mentioned that 'in Yorkshire there are steel furnaces which have four chimneys, two at each end of the furnace', a type not recorded elsewhere.[51] [fig. 2.27]

Outside Britain, practice and furnace design varied considerably, no more so than in a Swedish example of 1862 which appears to have little in common with British models, either

48 Raistrick (1967) pp 72-73.
49 See the *Guardian* article Wainwright (2002).
50 Scarfe (1995) p. 55.
51 Broling (1812) p. 25, plate 16. Reproduced with accompanying English translation in Barraclough (1984) vol. 1, p. 267. It would be difficult to surmise the existence of such furnaces in Sheffield from the limited plan evidence, as unlike the characteristic footprint of the conical furnace shell, a rectilinear superstructure would be easily lost in the clutter of outbuildings.

in appearance or organisation. Here, the basic furnace design was radically altered to allow the use of local wood as a fuel, with a pair of three-chest furnaces fired by a central gas producer and draught provided by two tall stacks.[52] Elsewhere in Sweden, cementation was carried out in furnaces closer to the Sheffield pattern.

Taking into account other documented examples, this evidence suggests that the definitive two-chest furnace with its conical shell only became the dominant type in the early nineteenth century. The different forms of chimney or shell, or in some cases its very absence, suggests a continuing development of the furnace structure and the crossover of technology from other industries, notably glassmaking and the potteries. It is therefore likely that many of the characteristic features of the Sheffield pattern cementation furnace evolved locally, rather than being imported as a *fait accompli*.

Site and context

As exemplified by the case of Huntsman's works, it was not unusual for early metal industries to develop in a domestic setting; equally, the appropriation of domestic and agricultural building types to industrial purposes was a natural extension of this tradition.

In its early form, the furnace was either freestanding or housed in a building resembling a simple storage shed. Considerable storage space for fuel and waste was needed externally, but iron and charcoal were better stored inside. For this reason, as well as to reduce the impact of smoke and heat on the local environment, cementation furnaces tended to be located in open spaces.

A survey of the locations of eighteenth century steel furnaces yields some interesting results: cementation steel was being produced in small furnaces close to the centre of town–on High Street, Fargate, Paradise Square, Barker's Pool, Townhead Cross, Hartshead and even immediately behind the parish church (now cathedral).[53] At the time of their construction, only some of these furnaces were peripheral to the town; all appear to have been small 'backyard' examples, and most did not survive beyond 1800.

While the expansion of the town centre and the increasing value of land for shops and services tended to push the steel industry to the fringes, some urban sites persisted. In these cases, often what had begun as a small backyard enterprise provided the seed for the development of larger steelworks. An example of the 'seeding' of urban works can be seen at

[52] Barraclough (1984) vol. 1, plate 7: 23. The furnaces were designed by Swedish engineer Lundin, and are depicted in drawings sourced from C. Sahlin (1931) 'Svenskt Stal', *Med Hammare och Fackla*, vol. 3, p. 100. See also plate 5: 9, plate 6: 16, 20, 21, for Swedish furnaces closer to the Sheffield pattern.
[53] Oborne was based on High Street in the 1760s. In 1766 John Brookes had a [cementation] steel furnace and steel warehouse on Barker's Pool, FBC FB31 (20 June 1766) p. 12; SCA Sheffield rate book RB32 (5 Feb. 1787) p. 45 'Down Barker Pool. Jno. Brooks' paid rates on a 'Steel House' and 'Casting Furnace'; John Turner is described as a steel converter of Hartshead, FBC FB13 (1758) pp. 102-103, FB55supp. (1781) p. 46, reproduced in Hall (1932) pp 60-61. From the 1787 trade directory it can be confirmed that Loftus, Brightmore & Co. were converting steel at Townhead Cross (see FB109 p. 22, FB143 p. 79) Jacob Gehrwin at Paradise Square, and the Roebucks at Church Lane. Even on the 1850 OS plan, sheet 20, the telltale outline of a cementation furnace can be made out immediately behind the churchyard on North Church Street.

the improbably located Queen Steel Works of the later nineteenth century, derived from the earlier Holly Street furnaces of Simon Younge, and perhaps ultimately the Blind Lane 'steelhouse' of Parkin.[54] [figs. 2.28, 2.29]

Furnace groups

As demand for blister steel grew, the larger steel manufacturers began to build arrays of multiple furnaces, for operating a number of smaller units offered distinct benefits over a single furnace of greater capacity. First, an increase in sectional area of the chest was accompanied by extended conversion time and lower fuel economy, although up to a point the resulting steel quality was more controllable. This imposed a practical limit on chest size, attained by the early to mid-nineteenth century; for the same reason, multiple chests quickly superseded single chest furnaces.[55] Secondly, several furnaces of different size enabled the cementation of only as much iron as was required for a particular order, reducing waste (of fuel, heating a half-empty furnace, or of iron, converting more than necessary); furnaces constructed with more than two chests were also more difficult to heat. Thirdly, all cementation furnaces required periodic renewal of their stone chests and other repairs, rendering them unusable for several weeks in the year. By running more than one furnace, continuity of production could be maintained, less prone to disruption by regular maintenance and unforeseen accidents. In economic terms also, the working of one furnace did not justify the employment of two full-time workmen, whereas a pair of furnaces could be managed by three permanent employees and a part-time assistant, giving employers an incentive to invest in multiples of two.[56]

Consequently, medium-sized Sheffield steelworks would often be found with two or more cementation furnaces of different capacity. In 1842 Professor Frédéric Le Play observed that typically:

> *A steelworks of average size consists of three furnaces designed to receive different weights of charges, say 12-15 tons, 15-18 tons and 18-22 tons, such that the annual production of the three furnaces can rise to 1000 tons.*[57]

This variation in size, although on a much smaller scale, was also to be found at early sites such as John Marshall's Millsands steelworks and the Cutlers' Company Scotland Street furnaces (below).[58] Where demand was more certain, groups of identical furnaces were built to share common attendant structures, often with 'intersecting' conical shells to counteract the

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[54] Blind Lane was the earlier name of Holly Street; three of the six Queen Steel Works furnaces existed in 1850, the pair on Holly Street corresponding to the watercolour drawing

[55] Increasing the length of chest was also restricted by the necessity of access to fire grates at either end. Examples such as Jessop's 24-foot chests (to hold two standard lengths of bar iron see chapter 3) seem to represent the upper limit.

[56] Le Play (1843) p. 613.

[57] Le Play (1843) p. 621.

[58] Le Play (1843) p. 591, refers to 'The old furnaces, in which less than 5 tons of iron were treated during one operation. ' His information was derived from 'Mr. Marshall', nephew of John Marshall, the founder of Millsands Works, p. 628, note 1.

outward thrust of the truncated cone.[59] At the site of the Nursery Street wire mills of Cocker Brothers the embedded brickwork of a furnace cone (originally one of a pair enclosed by an iron-house) can be seen in the adjoining building, giving some sense of the overall furnace dimensions.[60] [figs. 2.30, 2.31] A similar hyperbolic trace with iron tie-plates may be seen at the Bower Spring furnace site, bonded to the rear wall of the largely demolished iron-house. [figs. 2.32, 2.33]

Groups of four were relatively common, paired within a common iron-house as at Marsh Brothers & Co.'s Pond Forge steelworks (c.1853).[61] [fig. 2.34] At the Millsands site of Naylor, Vickers & Co., (see chapter 5) four cementation furnaces were built in a row spanning between the Don and the Town Mill goit (later to be culverted for the widening of Bridge Street), and to which a fifth furnace was later added. [fig. 2.35] The furnaces were built in the open, sandwiched between two long sheds–one wider than the other to accommodate iron bars and coals–providing shelter to their firing-holes. These furnaces were almost certainly the subjects of an engraving found in a turn of the century textbook, intended to represent a generic group of cementation cones, the arriving horse-drawn coal dray and propped-up iron bars demonstrating the function of the larger iron-house.[62] [fig. 2.36] From the street, the conical furnace shells towered above the high perimeter wall, and can be seen as the backdrop to a posed photograph of unknown origin.[63] [fig. 2.37]

The cementation furnace found its most sophisticated architectural expression at the Holmes Works, Rotherham. In format it was derived from earlier multi-furnace arrays (for example Ponds Forge, above, and Sandersons, chapter 3), but executed in a neoclassical idiom that extended to the furnace cones themselves to give a balanced and integral whole.[64] [fig. 2.38]

Two banks of three cones were arranged on both sides of a large central iron-house in traditional fashion, although in this case coal, charcoal and iron were delivered on railway trucks that passed through the space to other parts of the works. A pair of smaller sheds with through openings (but no rails) covered the far firing holes of both ranges.

All of the classic cementation furnace elements could be seen at the Holmes Works, but creatively enhanced–truncated cones joined at their parabolic cuts and buttressed by the outer walls, here articulated by pilasters; stone coping to the chimney tops, but finished with

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[59] As furnace chests became longer, the ground area required for the established conical shell grew disproportionately to furnace size. In order to reduce the footprint to a reasonable size, while retaining the volume of cone above the internal furnace structure, sections were cut away from either side, leaving a hyperbolic section of vertical brickwork. To counteract the thrust of the cone, iron ties were built into the shell and additional buttressing often provided by the furnace shed or adjoining buildings.
[60] The site is undergoing redevelopment as of summer 2003, and the status of the remaining brickwork is unknown to the author.
[61] Pollard (1954) pp. 30-31. plate 14. The architect's drawing of Pond Forge was made in April 1864 by H D Lomas For variants on the group of four, see also Naylor Sanderson's West Street steelworks, Greaves' Sheaf Works and Ibbotson's Globe Works, all chapter 3.
[62] Sexton and Primrose (1912) p. 231, fig. 113. The five-furnace array is sufficiently uncommon to suggest that the engraving was based on an actual example.
[63] Photograph from SCL local studies, reprinted in Olive (1994) p. 123.
[64] Allison (1936) fig. 7.

classical mouldings. [fig. 2.39] It is tempting to draw comparisons with Ledoux's proposal for a cannon foundry, where the furnace coverings were expressed as pure four-sided pyramids at each corner of a formalised square plan.[65] [fig. 2.40]

The survival of the Holmes Works until 1968 means that they were better recorded than many later furnace groups on a similar pattern, most notably at the larger Don Valley works where arrays of four and six furnaces were commonplace (see chapter 5).[66] Larger groups allowed the employment of fewer men working a number of furnaces alternately, some cooling down while others were being fired or repaired. In other respects also, the Holmes Works may be seen as a precursor of the Don Valley railway-centred works, although superior in terms of architectural ambition and detail.

In conclusion, the manufacture of cementation steel in the town was well established in the neighbourhood of Sheffield long before the general introduction of Huntsman's crucible process, and was a decisive factor in the success of the later industry. Bars of blister steel were certainly still imported from Newcastle and elsewhere, but by 1750 local producers had gone some way to making the town self-sufficient in the material. Conversely, the success of cast steel proved to be the greatest stimulus to development, before which the number and size of furnaces had been relatively small. Much of the growth of Sheffield's cementation steel capacity, particularly in the urban area, must therefore be considered a direct response of the demand generated by cast-steel manufacturers.

[65] Ledoux (1804) pp. 235-240, plates 124, 125. It is, however, unlikely that the architects of the Holmes furnace block were acquainted with Ledoux's project, and probably relied upon local models for the planning and stock catalogues for the detail

[66] In the case of the Holmes furnaces, a survey was made shortly before their demolition by the Department of Economic History of Sheffield University. Redrawn plans and sections of a single furnace were published by Barraclough (1984) vol. 1, plate 6. 19.

Part 2: The crucible furnace

> *But certainly, the discovery of this affair at Sheffield hath turned out of great service to that large and populous seat of manufacturers; which wears, as I have been well informed, at present, a very different aspect from what it did not many years since, before it was in possession of this new and valuable branch of commerce.*
>
> Henry Horne (1773) *Essays concerning iron and steel*, pp. 172-3.

In the decades following the establishment of cast steel manufacture at Attercliffe, Sheffield's trade and connections began to grow: the first stagecoach service to London began in 1760 from the Angel Inn, while a further indicator of the town's increasing prosperity came with the opening of a coffee room at the same premises in 1765.[67] Still, in 1770 Young remarked in his *Tour Through the North of England* that: 'From *Rotherham* to *Sheffield* the road is execrably bad, very stony, and excessively full of holes'.[68]

The archaeology and morphology of Sheffield's crucible furnaces (until 1850) have already been the subjects of a general study by Paul Belford,[69] so it is not intended here to present a comprehensive chronology of the type. Where previous appraisals have concentrated on rate book evidence (Timmins, Belford), surviving steelworks (Ledbetter) and technical metallurgy (Barraclough),[70] this thesis restricts its scope to the small urban steelworks, its buildings and context. Taking Huntsman's buildings as the archetype, the development of a well-defined functional building type is explored through the available architectural evidence.

Huntsman's first imitators

According to tradition, it was the Walkers of nearby Rotherham who established the first cast steel furnaces based on Huntsman's Handsworth prototype (see chapter 1).[71] The Walkers may ultimately have been more successful in their secrecy than Huntsman, as no account of their earliest works or furnaces is known. On the other hand, there is no evidence that their first attempt at making cast steel was a commercial success, and it is possible that they only acquired the 'secret' many years later when they erected further melting furnaces, first at the

[67] Holland (1824) p. 60. The stagecoach was operated 'by Mr. Samuel Glanville, of the Angel Inn', and the coffee house by 'Mr. Holland'. There is, however, evidence for an earlier 'Coffy House' in Sheffield–although it also served ale–referred to a number of times from 1687-1732. Leader (1905) vol. 1, pp. 153, 231.
[68] Young (1770) vol. 1, pp. 131-132.
[69] Belford (1997) unpublished MA thesis; see also Belford (1998) *passim*.
[70] Timmins (1977); Belford (1997); Ledbetter (1972); Barraclough (1984) vol. 2. Also 'Distribution of crucible' (1971) *passim*.
[71] For the origins of the Walkers' career as ironmasters, see Hey (1972) p. 49.

Yellands in 1765-66 and later at Masbrough.[72] Buildings dating from the 1770s (after the alleged split with Benjamin Tingle who retained possession of the secret) were therefore not necessarily modelled directly on Huntsman's works, but may have been built to a different plan based on one of a number of furnaces in operation by this date.

A further development of the Walkers' involvement in steelmaking arose when John Walker, son of Aaron Walker (a partner in the original business of Samuel Walker & Co.), left the family business in 1783 to establish his own steelworks at the Wicker in Sheffield, operating as John Walker & Co.[73] At this date the Wicker was on the edge of Sheffield's built-up area and Walker's construction of furnaces there was something of a novelty, although the proximity of the Wicker Tilt and Wheel must have compensated for its relatively isolated location.[74]

Already by 1778 John Walker had begun to diversify his interests, forming a partnership with Thomas Wilde and operating a cementation furnace on farmland owned by the Earl of Surrey.[75] Six years later, Walker's name appears in a Fairbank field survey of the Wicker site, alongside the memorandum: 'Additional ground to be taken for a long lease with the steel furnace &c. near Hall Car by John Walker, 5/5/1784', and a full survey of the extended site was made during 1790-91.[76] Following its early growth, the arrangement of the Wicker steelworks remained much the same until 1832 when a short but intense boom period prompted the construction of two new cementation furnaces in place of the old one, as well as steam-powered workshops and an iron and brass foundry.[77] By this time, Walker's steelworks had been joined in the Wicker by others: Peter Cadman (see below) with two converting furnaces and a cast steel shop, and the Tingles (descendants of the Walkers' former co-conspirator, chapter 1) with a small crucible steel works at Blonk Street. Although the Walkers continued in the cast steel trade, it was as ironmasters that the family made its mark (and its fortune), even John Walker eventually moving into foundry work at his Wicker premises.

Meanwhile, in Sheffield newcomers to steel melting began to exert influence. Of the early adopters, it was John Marshall who was destined to become Huntsman's main rival, particularly on the continental market where by the 1770s 'Marshall steel' had become a byword for high quality. The Swiss cutler Perret asserted that cast steel came in two varieties, and that 'one tells them apart by the name of the maker: one is punched with the name B.

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[72] Allison (1946) pp. 3-6; Baker (1945) pp. 17-21. Masbrough is at Rotherham. The fact that the Tingles were not included in later trade directories may be due to their location outside of Sheffield parish at Grenoside.
[73] Mott (1965) p. 235. The firm is first listed in the Sheffield trade directory of 1787. According to Belford (1998) p. 12, the firm's name was Walker and Wilde in 1790, although Wilde's association with the business seems to predate this change.
[74] The Wicker Tilt was built around 1748 by Joseph Wilson, leased to Blonk & Co. from 1785, see Crossley (1989) pp. 16-17. Access to the Attercliffe forges was also more convenient from the other side of Lady's Bridge.
[75] SCA FBC FB52, p. 12, survey of 'A close belonging to the Earl of Surry lately held by Wm. Binks now by John Walker and Thos. Wilde 21/7/1778'. The furnace itself was 36 links square in plan (7.3m) with an adjoining iron house.
[76] SCA FBC FB60 p. 17, 'Additional ground to be taken for a long lease with the steel furnace &c. near Hall Car by John Walker, 5/5/1784'; FB69 (1790-1) p. 10, 'John Walker's Steel Furnace measured 8/9 10th 1790 & 14 2nd 1791'.
[77] Brightside rate book (1832-33) vol. 3, p. 12. Timmins (1977) pp. 100, 169, table 3:8, cites SCA WD634 [John Fowler notebook] p. 1.

HUTHMANT, the other MARTIAL'; in addition, Marshall's ingots had their ends cut off cleanly.[78]

Marshall was at Millsands from at least 1765, and it was here that 'converting and refining' were brought together in the same premises for probably the first time.[79] Located on sedimentary ground to the west of the River Don close to the medieval town corn mill (hence the name Millsands), the site was separated from the town by the system of goits serving the mill which could be crossed only by footbridge or ford (for vehicles). Once again, the steel furnaces were constructed at the edge of the developed urban area, on land owned by the Town Trustees, to which was added Marshall's own property including workshops, houses and gardens (leased from the Duke of Norfolk).[80] [fig. 2.42]

It is even possible that Marshall was Sheffield's first native cast steel manufacturer: Robsahm, who had visited Huntsman's steelworks in 1761, also had the opportunity during his stay in Sheffield to examine an unidentified steelworks in the town.[81] Unlike Huntsman's works, this site included both crucible melting and cementation, and was managed by an otherwise anonymous 'Mr Smith'. The crucible steel shop was smaller than Huntsman's with only three holes, although Robsahm did not make a detailed study of these, having already seen Huntsman's shop, as he was more interested in the pair of differently formed cementation furnaces. Of these, the larger was a two-chest furnace built within a large chimney structure or cone. Robsahm deduced from the length of the iron bars used that the internal plan of the furnace was a square of nine feet side (2.7m), each chest being two feet square (0.6m) in section. Six flues exhausted heat and smoke from the vault of the furnace proper into the larger space of the outer vault, sixteen feet square in plan (4.9m). The smaller furnace consisted of only a single chest, capable of converting two tons of iron at a time; a masonry chimneystack built on top of the arched vault provided the necessary draught. The description is remarkably similar to that of a Sheffield furnace given four years later by Gabriel Jars, above. From the context, this otherwise unknown location could well be the progenitor of Jonathan Marshall's Millsands steelworks. Although Robsahm's visit predates the earliest references to Marshall's works, the fact that John Marshall was brought in by the Cutlers' Company as a steel converter in 1759 (and furthermore was succeeded by a 'John Smith' from 1760, see below) suggests that he had already gained considerable expertise in the steel trade.

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[78] Perret (1779) pp. 5-8 'On en voit de deux Fabriques, & on les distingue par le nom de l'Auteur, l'un est poinsonné du nom de B. HUTHMANT, & l'autre MARTIAL...ceux [barreaux] de Martial sont cassés net, & ni l'un ni l'autre sont trempés'. This may shed some light on the origin of the 'dozzle', a small preheated cylinder placed in the mouth of the ingot at the end of teeming and topped up with steel to prevent the formation of cavities within the bar by shrinkage of the metal. The surplus steel was later broken off with a hammer-blow, leaving a solid ingot. For the development of the dozzle, see Barraclough (1984) vol. 2.
[79] Belford (1998) p. 14, refers to SCA Sheffield rate book SL (1765). By the early 19th century Marshall had built four cementation furnaces and forty crucible holes at Millsands.
[80] SCA ACM SheS 1495L (1781) 'A plan of Millsands in Sheffield'
[81] Barraclough (1984) vol. 1, pp. 82-83, published a translation of the relevant passages from the Swedish, made by Torsten Berg.

The correspondence of Hatchett's description with the steel furnace remains excavated at the site has already been discussed. Aside from these fragments, little is known of Marshall's activities or the development of his steelworks until the outset of Naylor Vickers' tenure in 1829 (see chapter 5). However, the steel business inherited by his nephew Jonathan Marshall may have been the largest producer of crucible steel in the eighteenth century.[82] An 1802 survey of the bar iron consumed by Sheffield steelmakers, made in support of the construction of a canal from Tinsley to the town centre, places Marshall at the top of the list, his annual total of 800 tons some way in excess of Walker and Wilde's 500 tons, and dwarfing Huntsman's 75 tons per annum.[83]

Alongside Marshall, only a handful of pioneers emerged in the 1760s. By 1764 the Cutlers' Company had established cast steel furnaces at Scotland Street, examined in more detail below. Nearby, Love and Manson (the antecedents of Spear & Jackson, see chapter 5) had begun to melt steel in 1766, with a small three-hole furnace on Gibraltar Street, typical of the early scale of production.[84] The spirit of the nascent craft is captured by the guild-like wording of their partnership documents, declaring John Love and Thomas Manson 'co-partners and joint dealers in the Art, Trade, Mystery and Business of Running and Casting Steel...'[85]

Outside Sheffield, an unsuccessful attempt at steel melting in the Newcastle area was reported Gabriel Jars in 1765; unfortunately nothing is known of either the originator or the cause of failure.[86] More successful was Matthew Boulton's adoption of Huntsman's process at Birmingham, with furnaces built at the famous Soho Works before 1770.[87] A plan of the Soho Works dated 1788 shows the location of the casting shop, a relatively small unit but sufficient for Boulton's requirements. [fig. 2.41] Within the structure labelled 'Furnaces or Casting Shop' off the rear courtyard, 'twice converted' blister steel was broken up and 'put into a crucible about five inches diameter and fifteen inches high. The crucible is placed in a furnace of live coake cinders', several of which were built in a row and terminating in a thirty-foot high stack. It seems that in Boulton's case, control of the process was more important than cost: he had been a customer of Huntsman since before 1757, but had experienced difficulties in obtaining steel bars of a consistently high standard for his coining dies. He was also said to recycle the

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[82] Leader (1875).
[83] SCA Dunn papers, MD1740: 21. By comparison, Love and Spear's 50 tons was the smallest quantity given; more usual were Cadman at 150 tons, Kenyon at 160 and Young & Co. at 150.
[84] SCA CB1634, 'Ref. to the Plan of the Estates of the 12 Cap. Burgesses' contains the following abstract of John Love's leasehold premises: 'TRINITY ST. [lease:] 1 April 1767 (commenced 1 May 1766) [term:] 800 [orig. lessee:] John Love [quantity sq. yd.:] 410 [rent:] 1,5,7 [no. on plan:] 358 [Tenant:] Ebenezer Elliott – Furnace Workshops & Yard'.
[85] SCA Tibbits Collection, 200. Belford (1998) p. 8, suggests that 'this strange mixture of words well describes the nature of steelmaking at a time when the knowledge of its making was more or less the intuitive skill of a handful of men'.
[86] Jars (1774) vol. 1, p. 227, 'Un particulier avoit entrepris cette opération, à deux miles de cette ville [Newcastle]; mais il a mal fait ses affaires'.
[87] The furnaces were described by Robert Erskine in a letter to Mr. R. Atkinson (11 Oct. 1770), Erskine MSS, Library of the New Jersey Historical Society, Newark, NJ. They were possibly built around 1765-66, and James Watt's *Memoir* of Boulton noted Boulton's steel melting activities as early as 1767. Birch (1967) p. 307-308, note 42. Also cited by Barraclough (1984) vol. 2, p. 7, note 29.

scrap iron and steel from the Soho Works, re-cementing them before casting into ingots. As an enterprising and progressive industrialist, Boulton was clearly aware of the revolutionary potential of cast steel, and as such may even have been behind the rumoured invitation extended to Huntsman to set up a steelworks at Birmingham (chapter 1).

Trade directories from the eighteenth century shed some light on the increasing number of cast steel makers in Sheffield, although due to the inconsistency of compilation not all firms were listed, so the figures below are intended for representative purposes only. The first directory of 1774 lists three such firms from a total of seven steelmakers.[88] By 1787, six confirmed steel 'refiners' appear among the twenty listed steelmaking firms.[89] A decade later, twelve can be identified; this doubling in number every decade was almost matched over the succeeding half-century (although growth was sporadic and affected by trade depressions), so that by 1850 over 140 sites associated with crucible steel furnaces can be identified.[90]

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[88] Sketchley (1774). In this list, John Marshall is described as 'cast & blister steel maker & watch-steel forger', of interest in connection with Huntsman's background as a watchmaker. See also the abstracted numbers in Timmins (1977) p. 11, table 1:1.
[89] From Gales & Martin (1889). The refiners include Hague & Parkin, William Houlden; Huntsman & Asline; Love & Spear; Townrow, Burdekin & Tingle; Walker, Booth & Crawshaw. To this list might also be added Peter Cadman who was certainly operating the old Cutlers' Company crucible furnaces at this date, see below.
[90] Belford (1997) made a thorough investigation of the archaeological potential of these sites in and around Sheffield.

The Cutlers' Company furnaces: Scotland Street

Phase 1: Cementation steel (1759)

As early as 1730, the Cutler's Company had made extensive investigations into the possibility of producing blister steel for the use of its own members. This was not the first time that the Company had embarked on a profit-making venture, and for a time it sold grindstones from its own Peak District quarries to local cutlers.[91] The manufacture of steel, however, was much more involved: steelmakers operated outside of the jurisdiction of the Cutlers' Company, and were therefore free to fix their own prices and meet the requirements of selected customers. Perhaps due to the complexity and cost of establishing cementation furnaces, no action was taken following these first discussions.

The project lay dormant until the emergence of Huntsman's improved steel; it has already been noted that the Cutlers' Company engaged in early talks with Huntsman, potentially concerning the use of cast steel by Sheffield's cutlers (see chapter 1). Nothing seems to have come of this meeting, but within the decade the Company had revived its steelmaking aspirations, and formalised the intention to produce:

> *...steel [that] shall be disposed of amongst members of the Corporation [of Cutlers] equally and impartially at the rate or price directed which rate or price shall if possible be something below the common market and yet to bring a gain to the Company something more than equal to answer the expenses of the Trust and the Interest of the Capital Stock or Fund appropriate or set apart to that end.*

In 1759 the Cutlers' Company had 'taken' a cementation furnace in Scotland Street in order to satisfy the need for steel within the Corporation.[92] At this time Scotland Street was a diverse area on the northwest edge of town, made up of modest dwellings, beerhouses and workshops.[93] The resident community operated almost as a small village, exemplified by the 'Scotland Feast'–an eighteenth century urban tradition performed each year on the 29th of May, characterised by the ritual planting of trees in front of every house.[94]

Although managed by Joseph Ibberson, Master Cutler in 1759, the actual operating of the furnaces was initially contracted out to steelmaker John Marshall, almost certainly the same Marshall who was to establish the successful Millsands cementation and crucible steelworks (see above). Later payments for these services (1760-1763) were made out to 'John Smith'.

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[91] Cutlers' Company (1973) p. xvi. Leader (1905) vol. 1, p. 174.
[92] Leader (1905) vol. 1, pp. 174-175. His choice of words implies that the Cutlers' Company had acquired a pre-existing site and furnace. Barraclough (1973) p. 24, to the contrary, stated the furnace to have been 'erected at a cost of £550', although no contemporary sources make explicit reference to the construction of a furnace.
[93] For an extended description of Scotland Street and the 'Crofts' district, see Belford (2001) *passim*.
[94] Smith (1865) p. 25: 'The adjacent Scotland-street may be mentioned here, not indeed for its rural name, but for its former sylvan aspect at one season of the year. "Scotland Feast," as it is called, the street was planted with trees in the front of most of the houses from end to end. The havoc made in the neighbouring woods and plantations by the "conveyancers" of these trees on the one hand; with the intervention of the surveyors of the highways on the other, has partially put a stop to this once popular *rus in urbe*'.

The accounts for the first heat in 1759 included additional items required for loading and stoking the furnaces, as would be expected of a new venture:

		£	s	d
'Decm^{r}. 26th Cash P^{d}. for Carring [sic] *Steel out*		–	3	6
a spaide 1/6 Candles 1/4 Candle Stick 4d	}			
3 Baskett and Kiddles 1/10	}	–	5	–[95]

Payments for subsequent heats are preserved in the relatively complete records lodged in the Cutlers' Company archives, from which the operating costs and profits of the furnace have been calculated.[96] Ibberson had raised the funds for the enterprise by borrowing from a number of sources, and a statement of 1762 summarised the financial situation:

'Steel Furnace		£	s	d
By Cash Owing to Mr. Newton		400	"	"
D^{o}. to the Cock Clubb		50	"	"
D^{o}. to the Company		100	"	"
D^{o}. to Mr. Law & Mr. Jackson for Rent ab^{t}.		5	"	"
NB. Mr. Ibberson stands D^{r}. to Mr. Bell of Hull	}			
for which he thinks he should be Indempnified [sic]	}	"	"	"
by the Comp^{y}.	}			
He do's not know of any thing more that he stands	}	"	"	"
Indebted to on the Company's Acco^{t}.	}			
By profits gain'd to the Company by carrying	}			
on the Steel Trade for 3 years and three months	}	212	6	11
all Demands & Charges being paid	}			
		767	6	11'

Soon after, in February 1763, changes were made in the management of the furnace, with the current Master Cutler taking direct charge.[97] Ibberson's debt to an iron supplier in Hull may have been the stimulus to reorganise, and new rules drawn up for the operation of the furnace proposed:

> *That a Skillfull and carefull Agent or Workman shall from time to time as occasion shall require be appointed by the said Committee or the major part of them to manage the Furnace and the conversion of Iron into Steel and the same person or some proper person to assist him shall keep a Book wherein he or they shall enter the Weight and quantity of Iron from time to time put into the*

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[95] Cutlers' Company (1973) pl 126.
[96] See Barraclough (1973) pp. 24-28.
[97] The Masters Cutler and furnace superintendents over the period were George Greaves (1763), Joseph Hancock (1763-64), Samuel Bates (1764-65) and Joseph Bower (1765-66). The following Master, William Birks, managed the furnace from 1766-69, and was succeeded by Thomas Beely, under whose management the cementation business turned largely to 'hire converting'. In 1772 direct management finally came to an end, the furnace leased to its major customer, the firm of Watson, Raynor and Turner.

Furnace to be converted and the weight or quantity drawn out when the Heat is over.[98]

Other local businesses also contributed to the maintenance of the furnace. Periodic repairs to, and replacement of, the old 'pots' or chests were also necessary. In April 1761 the stonemason John Morton was paid for 'new pots', and later that year in November the Company lent him a further £5 'towards his next pot making'.

For the ten months following November 1763, activity at the cementation furnace ceased, as did the supply of steel until April of the following year, when it was stated to be brought from Darnall (near Attercliffe). A stocktaking of 1 October 1764 suggests that there had been an accident at the original steel furnace, reporting that there was over 68 hundredweight (3500kg) of 'Steel now remaining in the furnace at Scotland', approximately the full capacity of the furnace.[99] When operations recommenced, the average capacity had increased to over 4.5 tons (4600kg) indicating that the furnace had effectively been rebuilt, probably the result of a disastrous overheating and subsequent fusion of the iron load.

Jonathan Makin, who later became steelmaker to the Cutlers' Company (and was at this time involved in their other steel project, see below), had connections with the Fell's steelworks at Darnall, and it was probably from here that the replacement supply for the Cutlers' customers was sourced. Another major rebuilding was undertaken during 1767-8, and the furnace capacity enlarged further.

Phase 2: Cast steel (1763)

With the reorganisation of the venture, the Cutlers' Company also seem to have been intent on expanding its scope, and although not officially minuted at the 'Meeting of the Master Wardens' of February 1763, a new project was conceived about this time.[100]

The first details begin to emerge during the summer. A survey made by the Fairbank firm, dated 20 June 1763, described a plot of 'Land in Scotland [Street] on which the Corporation of Cutlers intend to erect a Steel Furnace'.[101] [fig. 2.43] In the same month, the Cutlers' Company made a payment to Jonathan Makin, a local builder and stonemason, for two plans of the new furnace (Makin was later cementation steelmaker and mason to the furnace superintendents Birks and Beely in 1766-67).[102]

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[98] Cutlers' Company (1973) pl. 124, facsimile of minutes of 'a Meeting of the Master Wardens .. 26th day of February 1763'.

[99] Barraclough (1984) vol. 1, p. 82, calculated the capacity of the Cutlers' Company cementation furnace at around 3¾ tons, confirmed by a note in vol. 48 of the Cutlers' records reading 'Steel in furnace, 25.10.62, T3. 16cwt 3q 4lb'

[100] Its absence from the official records could be taken to indicate a certain degree of secrecy surrounding the venture

[101] SCA FBC FB25 (1763) p. 12; a copy of the resulting scale plan has also survived, indicating 'Ground contracted for by the Corporation of Cutlers, 529 [square] yards' (442m²), on the south side of the 'street called Scotland'. SheS 1045S. Leader (1905) vol. 1, p. 174, stated that the land was leased from Matthew Lambert (after who Lambert Croft was named) for 800 years at £1 2s 0d, confirmed by the Cutlers' Company records.

[102] Cutlers' Company records, 13 October 1766, 'paid Jonathn. Makin for the first heat of Steel [as per Bill] No. 1.-£1 11s 6d', followed by two further identifiable payments for cementation heats, as well as miscellaneous bills totalling

The site as set out in the survey was near-rectangular in plan, located on the south side of Scotland Street. Redrawn to scale, the resulting plan allows the precise location to be identified on later maps, its form and extents surviving later redevelopments.[103] At the time of the construction of the furnace, the street had not yet been extended into the fields to the west, therefore placing the Cutlers' site at the very edge of the built up urban area.[104] [fig. 2.44]

The Fairbanks acted as surveyors to the Company, both for the initial site survey and later for the quantities, required at designated work stages in order to release payments to the builder.[105] Although Makin's design drawings are lost, the survival of both site survey and detailed bills of quantities allow the reconstruction of the building.[106] [figs. 2.45, 2.46]

The site rose by over three metres from front to back, or a gradient of around one in eleven; this meant that preparatory site works were expensive, the cost of levelling the yard exceeding that of excavating the cellars.[107] Subsequent building-up of the land behind increased the difference in height, the boundary today defined by a sheer stone retaining wall at around five metres tall. [fig. 2.47] It was here, at the very back of the site, that the furnace building was located.[108]

The absence of building at the front of the yard is confirmed by the Fairbank town plan of 1771; this plan is unique among pre-Ordnance Survey plans of Sheffield in representing the built frontages to practically all of the streets, drawing upon the Fairbanks' substantial collection of survey data to show walls, buildings and open space. [fig. 2.49] This type of site layout later became the standard for small urban steelworks, allowing the movement and storage of materials to take place at the front, close to the gates, leaving the space around the steel furnaces relatively clear.[109]

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over £12 (probably repairs / building work). Also see SCA FBC FB24 p. 110, survey of 'Middlewood forge mason work by Jon^{n}. Makin'.

[103] This geometrical match may be confirmed by the location of the building given in later rate books, although several successive changes to the street numbering present an obstacle to this method. See RB31 (3 Dec 1785) U/L p. 24. See appendix 2.2. Barraclough (1984) vol. 1, pp. 83, 85 footnote 77, suggested that the Cutlers' crucible furnace could have been at Millsands, operated by Mr Smith, but the evidence contradicts this view.

[104] See the Fairbank town plan of 1771. No occupant's name is given for the land to the west on SheS 1045S. Also see below for circumstantial survey evidence suggesting unlevelled (and possibly undeveloped) land immediately to the west, in contrast to the land to the east occupied by Ralph Pattison.

[105] Ayres (1998) pp. 35-36, describes these stages, with payments usually on completion of the first floor, on reaching the level of the pole plate, and on completion of the roof. Builders were expected to fund work from their own capital during the interim. This explains Fairbank's categorisation of masonry, cellars, furnaces, etc. separately from roof construction and timberwork.

[106] The author's methodology is an extension of the Fairbank survey reconstruction techniques described in the appendix 'Survey techniques used by the Fairbanks'.

[107] By 'levelling', the surveyor almost certainly meant the reduction, or evening-out of the gradient, as opposed to the flattening of the entire plot to a common level. The remaining slope is indicated by the two 'ramps' built into the western fence wall to accommodate the rising ground.

[108] A comparison of survey and quantities reveals the south site boundary and the rear wall of the furnace building to be of the same dimension. Due to the irregularity of the plot, the measurements of the perimeter fence walling and the furnace building's walls allow only one configuration of the site.

[109] This plan arrangement is visible on the Fairbank town plan of 1771, and corroborated by the north and east fence wall measurements; see appendix 2.1.

Slating, brickwork for walls, 'fence walls' and the furnaces was undertaken by G. Blagdin (elsewhere Blagden), a local builder whose name appears on other occasions in the Fairbanks' building books.[110]

Unlike many later furnace buildings, the Cutlers' had a standard double pitch roof with gable ends, structurally independent of the furnace stacks.[111] Each furnace appears to have been constructed as a single unit, served by its own flue and capable of receiving one crucible. While the building shell was of stone, the furnaces and flues were built of firebrick to withstand the intense heat of melting. There is no mention of the iron reinforcement that became a standard feature in later furnaces, although this could have been subcontracted directly to an iron manufacturer and thus omitted from the Fairbanks' valuation of Blagdin's work.[112] The brickwork for the furnaces was valued by its vertical length in yards, with the portion 'below the Grates' and the 'Chimney Pipe' costing the same, while the portion 'above the Grates' was twice as expensive, as it was effectively furnace and chimney combined. [fig. 2.48]

Each crucible was capable of holding around twenty pounds of steel, larger than the thirteen-pound ingots ascribed to Huntsman at around the same time.[113] Although dimensions for the cellar arch and stone flooring are given, it is not possible to definitively locate the furnaces within the interior, although it is probable that they would have been located towards the rear of the shop, and centrally to the building width allowing working space to either side. [fig. 2.45]

A single storey, uncellared building containing clay house and pot house was built as a lean-to structure against the eastern perimeter fence wall, directly abutting the melting shop. Unlike the main building, its roof was a monopitch, the ridge of which ran just below the eaves level of the former, falling towards the yard.[114] It also differed in having walls of brickwork (one brick's length in thickness), possibly used to save money, as its construction seems to have been something of an afterthought.[115] The space was partitioned into two distinct areas connected by an internal door, and lit by three identical glazed and shuttered windows.

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[110] He undertook general building work and seems to have made his own bricks, SCA FBC FB49 p. 60 'Part of a close... for getting clay for Geo. Blagden' (1777). The family business appears to have been long-standing, as the 1797 Sheffield directory lists a 'John Blagden', Mason of 2 Eyre street.

[111] See appendix 2.1, FB26 pp. 6-7, 'The Corporation Steel Furnace in Scotland slating by G. Blagdin 26/11/1763'. The roof form may be deduced from a comparison of the total eaves length of the '2 G[able] Ends each 7.14 by 3.25' and the area of slating '17.60 by 10.25' for the main roof (17.60 yards being the length of the building). The difference (around 400mm) may be accounted for by the slight projection of the eaves over the front and rear façades.

[112] The same is probably true of other iron fittings to the furnace, including the grate bars, iron window bars, ironmongery for doors, shutters and gate, etc.

[113] It has been suggested that the heavier ingot weight was problematic, but this view is not supported by the evidence for the later occupancy of the furnaces by Peter Cadman; see below.

[114] See appendix 2.1, FB26 pp. 92-93, 'Clay House & Pot House in Scotland brickwork by G. Blagdin 13/3/1764'. The height of the outbuilding is calculable from that of its front wall (2.70 high by 9.27 long) and the averaged measurement of its end gable (3.90 by 3.90), a common surveyor's shorthand. The additional masonry 'On the Back Wall 9.27 by 1.16' confirms both that the roof was monopitched, and also which of the two (different height) boundary walls it adjoined. The absence of a second gable suggests that the outbuilding was connected to the main melting shop.

[115] The valuations relating to the clay house and pot house are dated 2 and 13 March 1764, over three months after that of the main furnace building, although including some items from the latter

Inside the melting shop, seven stone steps led to a fairly sizeable cellar which was excavated to a depth of 1.85 yards (1.7m) and measured almost 7 by 10 yards in plan (c.6.1m by 8.7m).[116]

Some additional items in the carpentry bills suggest that a crane of some kind may have been erected in the yard, for the handling of steel bars. The structure, with its large timber 'Spurns within Ground' and upright 'Middle piece' was most likely a hand operated 'derrick' crane, located close to the main gates.[117]

Secrecy, security and site

Contextually, the site chosen offered considerable advantages to anyone wanting to maintain their privacy, in addition to which stringent anti-intruder measures appear to have been employed, particularly in comparison with the open courtyards prevalent in the district.

About the perimeter of the site ran a continuous stone wall, averaging four yards in height (c.3.7m). The form and material of this walling reflected the different conditions to each side. Facing the street, the cost of the material was slightly higher, suggesting the use of ashlar stone. To one side of the front wall were the 'Great Gates', almost the full height of the wall and 2¾ yards wide, allowing access to practically any size of cart.

The pricing of the other walls matches that of contemporary quotes for dressed stone, also used in the construction of the furnace building. To the east, where the adjacent land had already been developed, and along Scotland Street, the fence wall was level and a consistent height. The measurements of that to the west, however, were more complicated, broken down into several areas and divided by two 'ramps'. Interpreted in the context of the site, the top of the wall can be shown to have risen incrementally with the gradient of the land, while the foundations followed the horizontal level of the yard. This indicates undeveloped land or a lane running between Scotland Street and Pea Croft behind, the latter appearing to be the case in 1771.

Where the steel furnace defined the site perimeter the building itself acted as both retaining wall and secure boundary, completing the enclosure and making the Cutlers' yard practically impregnable to intruders unassisted by ladders or ropes. At four yards high, even a man standing on another's shoulders would have been unable to scale the fence wall.

The purpose of such a defensive site is not known, but at a time when Huntsman was still cautious of 'visitors' to his works, it may be assumed that the Cutlers' Company also felt they were guarding a secret process, reflected in the design of the building and yard. Their sudden entry into steel melting may have been in response to competition from the London cutlers

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[116] This would make each riser c.240mm, high by today's standards, but commonplace in utilitarian buildings of this period. See appendix 2.1 for cellar dimensions.
[117] A 'spurn' is a slanting prop or stay fixed in the ground. The ironwork of the mechanism would have been contracted for elsewhere

such as Horne and Waller, who were certainly making razors of cast steel by 1755, and may have begun to challenge Sheffield's trade in fine cutlery. There is no evidence that Huntsman sanctioned the Cutlers' cast steel production, but it may have played in his favour if it encouraged the Sheffield cutlers to use his steel. If such an agreement was made, then 1764 may have been the effective date of the secret's 'leakage' through the Cutlers' Company, explaining the rapid uptake of the process in the following years.[118]

Inexplicably, as other firms rushed to establish cast steel furnaces, the Cutlers' interest began to wane: the furnace ledgers recorded fewer campaigns of steel melting and dwindling ingot sales until in 1769 the ingot moulds were sold, concluding their involvement in the trade. According to antiquarian Robert Leader, however, this was not the end of the furnaces, which by 1784 the Cutlers' Company had assigned 'for £200, to Mr Peter Cadman and Mr James Camm', both steelmakers.[119] Contemporary evidence shows that Peter Cadman was still operating the cast steel furnace on Scotland Street in 1800, while a rate book entry for December 1785 reads 'Steel Furnace to Peter Cadman', implying that the site had only recently come into his possession.[120]

The Cutlers' Company records give no explanation for the abrupt cessation of steel melting, although it had never been particularly profitable, especially during the later years. It has been suggested that the scale of operations, producing ingots that were fifty percent heavier than Huntsman's, created insurmountable technical difficulties.[121] In the light of Cadman's continued use of the furnaces over many years this seems unlikely, and may indicate that there were motives other than profit behind the Cutlers' venture. Intriguingly, the accounts include purchases of local iron from Richard Swallow of Attercliffe Forge (Swallow had taken over much of the Fell's steel trade): Swedish iron had long been considered the only iron suitable for cementation steelmaking and therefore also for cast steel, but it was expensive and subject to the uncertainties of international trade. The Holy Grail of British steelmakers was a native iron that could be made into perfectly sound steel, and even up to the end of the Napoleonic Wars it was noted in the *Transactions of the Royal Society* that 'attempts are at present making by some very spirited steel makers at Sheffield; and, from the products already obtained, good hopes are entertained of ultimate success,' in producing home-grown steel.[122]

Perhaps the Cutlers had been engaged in secret trials on different kinds of iron, with the intention of breaking the Swedish monopoly, and challenging Huntsman's dominance of the

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[118] Prior to 1764, the only rivals to Huntsman's monopoly were the Walkers' 1750 furnace (which may have been a failure, as discussed above) and the unconfirmed premises visited by Robsahm in 1761, possibly operated by Marshall or his progenitors.
[119] Leader (1905) pp 174-176. As Leader was unaware of the cast steel furnace's existence, he interpreted this as a reference to the cementation site.
[120] RB121 (1800) Item 6, pp. 83; RB31 (3 Dec 1785) p. 24. The former entry is sufficiently contextual to demonstrate the location to be the identically shaped housing court as seen on the 1850 OS plan.
[121] Barraclough (1973) p. 28.
[122] Thomson (1812) Book I, Chapter III, p. 223, 'Swedish iron', also indicated that 'The superiority of Swedish iron over that of other countries, for the making of steel, is well known. Hitherto the British steel makers have not been able to employ British iron in their processes; they have found it too brittle to bear cementation'. It was not until the process developed by Bessemer and Mushet that this goal was finally achieved.

field. Much of the experimental steel produced would naturally be wasted, and it would have been necessary to sell just enough conventional ingots made of Swedish bar to break even, and perhaps provide a cover for the furnaces' true purpose. A more prosaic explanation, in keeping with the Company's reputation for excess (embodied in the annual Cutlers' Feast) and earlier business failures, exists in a local saying that the Cutlers' Company had 'swallowed its steel furnaces and drunk up its grindstone quarries'.[123]

Importance of the Cutlers' furnace

The Cutlers' Company crucible furnace is the earliest known steelworks site of its kind within the town of Sheffield itself, predated outside Sheffield only by Huntsman's original works and the Walkers' unconfirmed furnace of 1750.[124] It is also the first example of what might be termed the 'self-contained' crucible cast steelworks, which became ubiquitous in the built up areas of Sheffield during the nineteenth century. Its marginal location in the town, and its early demolition in the early 1800s, meant that its existence went largely unrecorded. Nevertheless, its importance not only to Sheffield's industrial history, but to the subsequent development of the building type cannot be overestimated.

Its influence may be seen in the surviving furnaces at Abbeydale Works, built towards the end of the eighteenth century and possibly based on the template of the Cutlers' Company furnaces. [figs. 2.50, 2.51] The melting shop at Abbeydale is stone built, like most of the other works buildings, occupying a corner of the courtyard against the high embankment of the millpond.

Like the Cutlers' building, Abbeydale has a conventional double pitch roof structure with gable ends. The furnace stack located towards the rear of the plan is brick-built, with a characteristic striping of light clay-coloured firebrick courses exposed by the English garden wall bond construction. Other similarities may be found in the raised shop floor, reached by external steps from the yard, and the small arched cellar accessed by an internal stair. The disposition of clay house and pot house to one side of the melting shop and coke shed to the other is also the most likely arrangement of the Cutlers' furnaces.[125]

The site of the furnace today remains a marginal zone of light industry in consequence of its unfavourable geography. [fig. 2.52] Development has been relatively slow, and with the buildings upon its site presently unoccupied (as of 2003) possible archaeological remains at

[123] Leader (1905) p. 176. The company had also abandoned a profit-making scheme to supply grindstones within the Corporation from its own quarries

[124] This statement reflects the obscure origins of Marshall's steelworks, and the otherwise uncorroborated report by Robsahm (which, unfortunately, cannot be connected with the Cutlers' Company furnace as suggested by Barraclough).

[125] However, at Abbeydale the clay- and pot house may have been a later addition to the furnace building. See the advertising view of the works under the ownership of John Dyson, White (1833) p. 433. This standalone rectangular plan would have been much closer to the Cutlers' design than to Huntsman's.

Scotland Street deserve to be investigated further. As the area of the 'Crofts' began to accept greater numbers of immigrant workers, the site was redeveloped as a courtyard of low-grade tenement blocks, one room deep.[126] [fig. 2.53] The probable site of the furnace holes themselves (towards the back of the yard) was left clear of building other than a small single-storey block of privies.[127] It is therefore possible that the extant retaining wall, formed of a patchwork of stone and brick, may include elements of the Cutlers' furnace structure where it abutted the rear boundary.

[126] This redevelopment occurred prior to 1850 when the Ordnance Survey mapped the site, and probably in the first decade of the nineteenth century when the furnace disappears from the rate books.
[127] There is consequently a good chance that subsurface remains (including the cellar and furnace structure below the grates) may still be intact, as recently found at similar sites around Sheffield.

Part 3: The small urban steelworks

> *It is easier in Sheffield to start the manufacture of crucible steel than it is anywhere else in the world. You have everything at hand. You can hire a furnace. You do not want much capital. You find the workmen there. You find the material–all that you want–and you find a market.*
>
> Charles W Kayser (1904).[128]

Typology of the early crucible furnace

Following the example of the Cutlers' Company, the first independent melting shops were small buildings housing between three and six furnaces, each capable of melting about twenty pounds of steel (9kg) in a single crucible. In the decades after Huntsman's extensions (1767-1772), larger groups of up to twelve holes were adopted (the ten- and twelve-hole shops were to become standard units of the nineteenth century) and ingot weights steadily increased as crucible making was brought to perfection.

By 1831 John Holland. well acquainted with Sheffield's cast steel furnaces, observed that 'six or eight [melting holes] are generally constructed in a row'; the situation was much the same a decade later when Le Play wrote that 'the number of furnaces grouped together is never less than four and rarely more than ten'.[129] It is true that the three-hole furnace had practically fallen out of use, and that few manufacturers could justify twelve or more holes, although there were notable exceptions (see chapter 3). Within the range of four to ten, certain combinations appear to have been preferred. In construction a number of flues would be built to each stack, usually in groups of three or four, and a number of these stacks placed along the rear wall or on opposite sides of the melting shop.[130] Like Huntsman's original plan, shops based on multiples of three were the most common, while the four- and eight-hole variants were found less often; Abbeydale Works' furnace is an anomaly with just five holes. The popular ten-hole shop–just the right size to be operated by a standard team of seven–marked a departure from the earlier rule of multiples, usually consisting of one monolithic stack in which the flues converged slightly towards the top. This design meant that roof structure could not pass through the spaces between stacks, as was the custom, but bore directly on to the continuous chimney structure, usually supported on iron shoes or stone brackets.

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128 BLPES Tariff Commission Papers, evidence given to the Commission (4 May 1904) p 7.
129 Holland (1831) p. 236; Le Play (1843) p, 642.
130 Therefore prime numbers of furnaces are generally not found (7, 11, 13, 17, 19, 23).

Crucible making

It is widely held that the real secret of Huntsman's process was to produce a vessel capable of withstanding the heat of the furnace, the chemical attack of the charge, and the stresses of manhandling during casting. This is supported by the importance of this second industry to Sheffield's cast steel works. From the earliest days, the on-site manufacture of crucibles was an integral part of the process, almost every furnace building having its own clay stores and pot house, and shelving in the casting shop on which to dry the pots. The otherwise inconvenient cohabitation of steel-melting and pot-making plant was greatly outweighed by the imperative of having fresh crucibles on hand, their fragility prior to annealing ruling out bulk transportation by cart.

On his tour of Sheffield steelworks in 1842, Professor Le Play noted that 'having had occasion to visit more than twenty melting shops, I have not seen a single one which was not provided with a shop for making crucibles'.[131] There is little evidence that even the smallest establishments bought in crucibles from outside, although Le Play added that '...a number of steel melters buy their crucibles at a price of 1s 6d each [but] these purchases must be the exception'.[132] Nor do the trade directories suggest that crucible manufacture was anything but a marginal industry: in 1852 there is a solitary example, 'Gilroy Michael, crucible maker, 27 Little Pond street', while in earlier directories the category is absent. The exception to this rule was the manufacture of plumbago crucibles, harder than the usual fireclay pots and sturdy enough to be reused many times (as opposed to the maximum three-melt lifespan of the clay pot).[133] Although popular in the USA, Sheffield steelmakers felt that the high levels of carbon damaged the quality of the steel, and they never entered widespread use.[134]

On the 1889 Ordnance Survey plan, a group of buildings labelled 'Crucible Works' on Wicker Lane may have been one of Sheffield's rare workshops dedicated to crucible manufacture, its occupants including James Higgins 'crucible maker' (1888-93) and Louis Morgan 'crucible maker and German silver caster' (1895-1913).[135] [figs. 2.54, 2.55] Whether the product was sold to cast steel manufacturers is not known, as there were many non-ferrous metal industries that also used clay crucibles.

At most steelworks, the crucible-making spaces would be located to make best use of the waste heat evolved by the furnaces, with shelving for drying crucibles built against the melting shop partition wall (as well as the ubiquitous shelves above the furnace holes for final storage of the crucibles). Another space was usually set aside for the storage and thorough

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[131] Le Play (1843) p. 666; translation from Barraclough (1973) part 2, p. 39.
[132] Le Play (1843) p. 666
[133] 'Steel-melting crucibles' (1867) p. 438, noted the 'practice of some eminent Sheffield steel-makers who, from preconceived notions, and probably from some former experience in that district, consider fire-clay to be the only suitable material for steel-melting crucibles', whereas Krupp used plumbago pots; 'Plumbago steel' (1867) p. 408.
[134] One of the largest manufacturers of plumbago crucibles in Britain was the 'Patent Plumbago Crucible Company' based at Battersea, London, advertisements for which can be found in mid-nineteenth century trade directories.
[135] 1890 OS plan sheet 294.8.7; Goad fire insurance plan (1896) sheet 20. Occupancy information sourced from trade directories of the period. The buildings still stand, see Aitchison (2001) p. 169 (no. 72: Crucible Works), prepared in collaboration with the author.

desiccation of clay before use, this repository commonly known as the 'clay place' or 'clay room'.[136]

An area was usually dedicated to the process of treading the clay mixture with bare feet, placed in a semi-permanent timber or metal tray of a size proportionate to the number of pots produced daily. [fig. 2.56] Once clay was mixed with water, it could not be kept for long, so large batches of crucibles were made in day-long campaigns, dried and stored for later use. In all but the smallest shops the work of pot-making was sufficient to employ one man full-time (known as the 'pot maker') and therefore required dedicated spaces, unlike some of the earliest furnaces where crucibles were made in the cellar during the intervals between melts.[137]

Site and context

The Fairbank Sheffield rate valuations made from 1835 onwards constitute a rich source of information on the state of the steel industry at a time of great expansion, with many sites described by dimensioned sketches showing the distribution of functions.[138] These are augmented by Shepherd, Fowler & Robson's valuations for the township of Ecclesall Bierlow in 1842, which provide a similar level of detail over a different area.[139] Using these sources it is possible to assess the scale and situation of urban steelworks in their heyday, and to investigate the development of premises through later map evidence.

The degree to which small crucible steel furnaces were embedded in the established urban pattern of dwellings, shops and workshops is surprising even by the prevailing standards of the day. Melting shops needed a relatively small site area compared to cementation furnaces, many sites managing with much less than the 400m² yard recommended by Le Play. Typically a complex dedicated to steel melting might take the form of a tiny courtyard works with only a handful of melting holes such as that owned by Alfred Ward, saw manufacturer, and situated within the middle zone of a block of building, sandwiched between parallel rows of street-facing dwellings.[140] [fig. 2.57] Entrance was by a cross-lane typical of the area, derived from the paths along burgage plots, effectively an unofficial street onto which opened the longitudinal yard.[141] The buildings including the crucible furnace itself addressed the yard, presenting their gable ends to the minor thoroughfare in traditional manner.

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[136] After a day's shift of three melts, the furnace flues would remain hot for many hours due to the thermal mass of their heavy firebrick construction, giving fairly even drying conditions.

[137] Le Play (1843) p. 654, considered ten holes to be the minimum size of furnace to require a full-time pot maker.

[138] Most of the books are catalogued in the run SCA FBC MB391-402; This primary evidence was used by Belford in his study of pre-1850 steelworks. Note that Fairbank's 'Book A', belonging to the MB run, is catalogued in the notebook series as NB31, and other related fragments are scattered throughout the 1830s notebooks.

[139] SYCRO 141/B 2/1 (1842)

[140] White (1841) 'Ward, Alfred. Ironmonger... and Saw mfr. (late Edw. Taylor) 53 Carver Street'. Wm. Taylor was the owner of adjacent property on Shepherd, Fowler and Robinson's valuation plan of the site, SYCRO 141/B (1842) plan no. 7, Ward's property is given as survey numbers 12, 14, 17, 19, 21, 23-27.

[141] The attenuated morphology of these early block forms gave rise to many small lanes, most unnamed (on maps) and semi-public in character, providing access to parallel back lanes and buildings within the depth of the block. A rare example survives in Bethel Walk.

In the absence of any effective regulation, the furnace had been built directly against a terrace of single-cell tenements, rendering them effectively back-to-back and exposed to the radiant heat of the compound stack along the rear wall.[142] On the other side of the yard two-storey workshops offered some breathing space to the terrace along Carver Street, although this was probably of mutual benefit as the workshops would have been lit from both sides (unlike the crucible shop). On the large-scale 1889 Ordnance Survey plan, the works has evolved into a more conventional courtyard plan, the through-route blocked off and built over, with a single entrance from Carver Street. [fig. 2.58] The steel furnace was still in operation at this date, and the uncomfortably located tenements had been converted to cutlers' shops.[143]

Equally astonishing relationships of domestic and industrial structures could be found throughout the town, particularly in the low-grade areas of the Crofts and the Ponds, but by no means confined to these districts.[144] The location of these small-scale works–crammed into confined yards and cheek-by-jowl with houses, pubs and shops–often betrays their relatively late development. A report on the sanitary condition of the town painted a bleak picture of the Crofts, in which 'some parts of the locality are very hives of industry, where local trades are carried on up dark, dank yards and jennels, and human habitations are scarcely in better condition than the works'.[145]

Some examples, such as William Parkin's Pea Croft cementation and crucible steelworks did not even have a street presence, but were hidden away at the end of narrow lanes, invisible to unsuspecting passers-by. Three cementation cones and a crucible furnace were distributed around the three free sides of a small yard, with little room left for any other accommodation. Due to the inertia of its fragmented surroundings, the Pea Croft steelworks is still evident on the Ordnance Survey plan of 1889 despite the obsolescence of its cementation furnaces. [fig. 2.59] The resistance presented by highly built-up urban areas with diverse land ownership to large-scale development must have influenced the decision of many manufacturers in removing to the suburbs. Persistence of ownership boundaries and their associated physical fabric are one of the most characteristic qualities of Sheffield's eighteenth century industrial districts, many of which retained their original form until the slum clearance programmes of the early twentieth century.

By comparison, the development of crucible steelmaking sites outside of Sheffield remained more closely aligned with the typical semi-rural early industrial site. Examples of this kind may be found in the works of Krupp at Essen and Fischer at Schaffhausen, both of which evolved into enormous concerns from humble beginnings. In the case of Krupp, the melting shops were built alongside the family's cottage, both freestanding structures within the steelmaker's modest field plot. [figs. 2.60-2.62] Subsequent additions of steam hammer shop and forge

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[142] Clearly little attention was paid to health and comfort, and only the requirement of a clay storage space seems to have prevented the furnace flues being built contiguous with the dwellings.
[143] See the Goad fire insurance plan of the 1890s, which even details the position of melting holes, windows and skylights in the furnace, SCA 674/B1/20, sheet 19.
[144] See Belford (2001) pp. 113-115; Pollard (1959) pp. 91-93 on immigration to Sheffield; 'The Builder' (1897).
[145] From the *Sheffield and Rotherham Independent* (10 Feb 1872) 'The Sanitary State of Sheffield', no. XI.

reinforced the dispersal of the site layout. Certainly no area of the works could be considered to be a courtyard, nor were individual buildings assigned clearly demarcated service spaces. [fig. 2.63]

Similarly, Johann Conrad Fischer lived on his first works premises, which over the years resisted intensive industrial development to retain its rural character.[146] An early nineteenth century view of his steelworks in the Mühlental valley might be mistaken for the stereotypical Swiss chalet were it not for a man carrying iron bars and the signs of water-powered machinery on the Durach stream in the foreground. [fig. 2.64]

By the early nineteenth century, the small steelworks had become an established urban fixture in Sheffield, although not one without its attendant problems of pollution, heat and noise. Beyond the more obvious environmental hazards, concentrations of industry also brought social conflict; the Police Act of 1818, subtitled 'an act for cleansing, lighting, watching and otherwise improving the town of Sheffield', stipulated that 'Penalties of from 10s to 20s are also ordered to be levied by the magistrates...for wheeling or carrying any barrow upon the footpaths, or carrying thereon any iron rods or bars after sun-set...', a decree that can only have emerged as a result of frequent accidents involving steel workers.[147]

In other ways, the steelworks and its paraphernalia were assimilated into the everyday life and practices of Sheffield workers: the shallow wickerwork baskets used in charging the furnace holes with coke were customarily set upon heaps of coal or sand and used as impromptu seats, and might turn up in the household as baskets. Spent crucibles with the bottoms knocked off were used in allotment gardens to force rhubarb and vegetables, or set on their sides to build walls.[148] [fig. 2.65] Festivals and celebrations gave rise to some of the more creative and colourful examples, such as the coming-of-age (or 'Lozin') of an apprentice cutler, when:

> *Early in the morning of the day when a cutler is at age, the whole neighbourhood is made aware of the fact by a peal of bells, which happen to be ingots of steel, suspended and struck with a hammer, to the great annoyance of all around.*[149]

The employees of a melting shop were also known by distinctive nicknames that expressed their respective duties, including the 'melter', 'taker out', 'mould getter up', 'coaky', 'pot maker'

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[146] Henderson (1966) pp. 7-8, plate f.p. 8. Fischer and his sons chose to develop more heavily in Austria, probably never making more than twenty-five tons of steel per annum at Schaffhausen.
[147] White (1833) pp. 73-74.
[148] Olive (ed.) (1994) p. 143, a more formal use of waste industrial materials, including crucible pots, 'crozzle' from cementation chests and spent grindstones may be found in a concealed grotto at Broom Bank (now a public house). Sadly derelict, this structure is a rare example of the industrial vernacular that developed in the steelmaking districts of South Yorkshire. The author is grateful to Joan Sewell (formerly of the Department of Landscape, University of Sheffield) for bringing this structure to his attention in 1996; see also Sewell (1997) pp. 222-223.
[149] Bywater (1839) p. v.

and 'cellar lad' or 'boy'.[150] These characters became as much a part of the working life of the town as the grinders were in the valleys (see chapter 4).

Form of the melting shop

Following Huntsman's adoption of the symmetrical melting shop enclosed on both sides by short stacks of four holes, crucible shops conformed to two broad types. Of these, the older and more common was the longitudinal monolithic stack forming the rear wall of the melting shop, to which the roof structure was usually perpendicular and may even rely upon for structural support. Huntsman's more modern layout employed transverse stacks running in parallel with the roof structure and therefore independent of the external building shell. While the longitudinal type was more tightly integrated and offered the potential of linear extension, in practice shops of ten to twelve holes represented the workable size limit for one team. Along with the commonly constricted sites of urban steelworks, this meant that additional capacity tended to be built incrementally.

In contrast, the transverse arrangement simplified the construction and repair of stacks, as they remained structurally detached from the main building. Extensions within a shop were also generally ruled out, as the number of holes was usually in optimal proportion to the area of melting shop floor, but further shop units could be built alongside the first, conveniently forming a heated space for clay between stacks.[151] A major disadvantage was the limitation of windows to the front of the shop, so that holes towards the back received considerably less light, placing a practical limit on the depth of the space. However, for typical units of six to twelve holes this was not a serious problem, particularly when augmented with opening roof lights.

For similar reasons, the cellar stair could only be accommodated outside the shop, although this was standard practice in all but the earliest of cast steel furnaces. For a good supply of air to the furnaces, it was important that the cellar was open to the outside, preferably at the opposite end to the melting holes. In Huntsman's first Attercliffe shop air was admitted to the cellar through external chutes, but the presence of an internal stair would have allowed smoke and heat up into the melting shop and was most likely abandoned for this reason.

As the design of crucible furnaces became refined, there was a tendency towards the separation of the furnace proper and the surrounding building. Flockton's valuations of the 1840s even differentiated between furnaces and the enclosing 'shells' or buildings, giving

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[150] Le Play (1843) p. 654.

[151] A later modification of this pattern (c.1853) used the hot intra-stack surfaces to preheat combustion air, by drawing it down into a common cellar behind the melting holes, prefiguring Siemens' more efficient regenerative furnaces. See Carnegie (1913) pp. 55-56, fig. 3.

each a separate value.[152] Structural separation was, however, accompanied by a closer integration of functions, by encouraging the exploitation of ancillary spaces (such as pot- and clay-rooms) as pioneered at early works such as Abbeydale, above.

The form of the eighteenth century crucible furnace proved to be astonishingly durable, demonstrated by the construction of new buildings on the same pattern into the twentieth century. A small twelve-hole unit designed in 1899 for Spear and Jackson opposite their Etna Works site (see chapter 5) bears a strong resemblance to its distant ancestor the Cutlers' Company furnace.[153] [fig. 2.66] Aside from minor changes–the entrance to the yard was from the side, the roof monopitch and the steel house on the opposite side–the plan is essentially the same, fine-tuned over 140 years to the point of optimum efficiency. All the more surprising is that this scale of premises, dedicated to the production of special tool steels to order, outlived the larger works where hundreds of crucibles would be used to make huge steel castings (see Sheaf Works, chapter 3; Vickers, chapter 5).

Typology of the small urban steelworks

In the low-value district of the Crofts, Kenyon & Co.'s Hollis Croft steelworks were built to a plan very similar to Naylor & Sanderson's, although on a smaller scale (including a 20ft diameter cementation furnace and eight crucible holes). The business was established as early as 1720 by John Kenyon, reputed to be 'one of the pioneers who opened up direct trade with the Continent, making protracted journeys to Germany and Portugal'.[154] His success was such that by the 1780s Kenyon's site area amounted to 1742 square yards, the equivalent of four normal-size plots along Hollis Croft, making it one of the largest industrial complexes in the district.[155] A survey of 1834 shows a large open yard with furnaces, warehousing and file workshops forming a continuous range at the back.[156] [fig. 2.67] As at West Street, the street frontage consisted simply of a high wall, left clear other than for a lean-to coke shed and three-stall stable.

As the site developed more furnaces were added, seen on an early nineteenth century view of Kenyon's premises in which the various buildings are presented panoramically, expressing the yard's linearity.[157] [fig. 2.68] The single storey structure with a fully-glazed bow end was clearly the counting house, from which the entire works could be observed.

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[152] See SYCRO 141/B (1844) p. 120: 'Twenty Melting Furnaces complete £300... Building or Shell for Melting Furnaces £200'.
[153] SCA AP89 (6 Oct. 1899) 'Drawing of 12 Hole Melting Furnace in Greystock Street' (scale 8ft-1in) designed by local architects Holmes & Watson.
[154] Leader (1905) p. 275
[155] Belford (2001) p. 109
[156] SCA FBC NB31 (1834) 'Book A', p. 2, 'Kenyon & Co.'
[157] From the John Johnson collection of printed ephemera at the Bodleian Library

Just like its smaller counterparts in the Crofts, Kenyon's steelworks site continued as a spatial entity long after its original function had been abandoned. The premises is clearly visible on the 1889 OS plan, redeveloped as the 'Globe Forge and Rolling Mills' with few if any of the steelworks buildings remaining. [fig. 2.69]

Far from being a phenomenon of the eighteenth century, this type of site continued to be built throughout the first half of the nineteenth century. On the Devonshire estate to the west of Sheffield's centre, whole streets of steelworks were developed during the 1820s and 30s as an alternative to the overcrowded Crofts. Most steelmakers followed the Kenyon's example (if on a smaller scale) such as the Rockingham Street sites occupied by William Tyzack and Maw & Stayley, which rejected the street-front warehouse and passage in favour of a walled yard.[158] [fig. 2.70] Tyzack's works produced saws, scissors and scythes of cast steel and conformed to the classic arrangement with the melting shop along the back of the site and workshops built alongside leaving the street entirely free of building. In a reversal of the traditional pattern, his neighbours Earl & Co. had erected a two-storey warehouse along Rockingham Street with cast steel furnaces immediately behind.

This latter type was to quickly eclipse the earlier front yard model, offering benefits of increased security and privacy. It seems that no single factor prompted this shift, but it was probably the result of a number of considerations. Following the deregulation of the Cutlers' Company in 1814 (see chapter 3) many more manufacturers had established themselves as merchants, erecting warehousing at their works and moving their residences out into the suburbs. Although Sheffield's warehouses were small and unostentatious by comparison to those of the textile regions, they slowly came to prominence as an expression of status, put on display at the front of the works. Around this time, large areas of glazing were also becoming more affordable, encouraging the construction of well-lit and secure workshops and warehouses on the street frontage. Workshops of the eighteenth century and earlier sometimes had shuttered windows filled with translucent oiled paper or cloth, cheaper than glass (and avoiding the payment of window tax), but poor in terms of illumination, insulation and strength; furnace buildings were similarly unglazed with and often fitted with insecure roof hatches.[159] In such cases, the perimeter wall was an essential outer level of security to the street, augmented by the backs of inward-looking structures (such as crucible furnaces, storage sheds, stables and shallow workshops) built along the perimeter of the yard.[160]

While these steelworks were technically on the edge of town when first established, they must be considered as an urban type, built in the knowledge that they would soon be enveloped by

[158] See SYCRO 141/B 2/1 (1842) Shepherd, Fowler and Robinson's valuation plans nos. 19, 20; Pigot (1828) includes entries for both Tyzack and Stayley at Rockingham Street. Baines (1822) lists among the street names for 1821 'Staley's yard, Rockingham street'.

[159] Leader (1905) ch. 2, described the eighteenth century cutler's shop as a low building in which 'the sides were open, with shutters hanging ready to be put up when work ceased; or, if there were windows, these had no glass, but paper, which had once been white, well saturated with boiled oil'.

[160] Other evidence of the contemporary concern over infiltration can be found in the advertising views and surviving fabric of town centre works. The rear workshop ranges of both Leah's Yard (chapter 4) and nearby Eagle Place [figs 2.72, 2.73] were originally blind at ground level, save for a loading bay door, in contrast to the generous glazing to their upper floors and internal façades.

the intended estate plan. [fig. 2.71] Unlike their more generously planned predecessors, none of the sites on Rockingham Street described above included dwellinghouses, indicating a break from the old backyard model.

The true peripheral condition was exemplified by Samuel Newbould's Bridgefield Works, built on fields belonging to the Earl of Surrey close to the river Porter at the junction between the Moor and Ecclesall Road.[161] [fig. 2.74] It began life in the eighteenth century as an edge-tool works without on-site steel furnaces, and was subsequently enlarged over a number of campaigns, first with the addition of steelmaking facilities and later by the need for extra workshop capacity.[162]

A square house, almost equal in size to Francis Huntsman's, faced South Street from which it was separated by a partly culverted goit (elsewhere referred to as the 'horse dyke' or 'watering place') leading to the Bennett Wheel reservoir. A short lane alongside led to a courtyard behind, loosely divided into domestic and works areas, its perimeter lined with single-depth workshops and, to the southwest, a stable block. Behind the main yard, the workshops doubled back to form a smaller square court, open to one side.

By 1832, more land had been added at the back of the site, and both crucible and cementation steel furnaces erected.[163] The cast steel furnaces defined a small yard, behind the existing workshops, from which a short flight of steps led up to the casting shop. Further dedicated rooms (housing the usual pot room, clay and coke stores) adjoined the three remaining sides; in addition, the cementation furnace shed also abutted to the rear, served by a separate yard. The length of the cementation shed reinforced the existing boundary, increasing the length of the works portion of the site and defining a linear route along its northeast edge.

Additions made over the next decade increased the importance of this axis, particularly the long range of workshops built upon a narrow strip of land that had been acquired by eating into the adjacent plot.[164] [fig. 2.75] A dwelling house accessible only from the yard terminated this row, probably used by the works porter or furnace-men, to oversee the converting furnaces during their protracted night and day operation. This overall configuration remained essentially unaltered in the succeeding years, save for minor additions such as the installation of a weighing-machine in the yard.[165] [fig. 2.76] Although it was one of the town's older works, the buildings were by no means ramshackle with the 1840s file shops praised for their high

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161 SCA ACM 2034S.
162 The Master Cutler of 1751 was Thomas Newbould, edge tool maker of Sheffield Moor, a likely antecedent of the later firm. Leader (1905) vol. 2, p 57
163 Tayler (1832) town plan. Uses adapted from rate book information
164 SYCRO 141/B 2/1 (1842) Shepherd, Fowler and Robinson's valuation plan no 62.
165 1850 OS plan, 6":1 mile.

space standards.[166] It seems that the final removal to Attercliffe was due to land pressure, the business better able to expand out of town.[167]

[166] Haywood and Lee (1848) p. 126, mentioned the 'new shop at the works of Messrs. Saml. Newbould & Co.' where each filecutter occupied 540 cubic feet of space, the most generous in the town.
[167] Leader (1905) vol. 1, p. 276, 'Samuel Newbould & Sons, though removed to Attercliffe from the familiar house and works beside the old horse-dyke on Sheffield Moor, continue'.

An example of multi-site working: W & S Butcher

Among the most extensive and long-standing steel manufacturing premises based in Sheffield's Georgian estates was that belonging to the firm of W & S Butcher, whose development is an exemplar of the accretive and multi-centric working that was so widespread among the local metal industries. The Butcher brothers were primarily toolmakers, but invested in steel furnaces at an early stage of the business. Their experience may be taken as representative of the opportunistic and accretive acquisition of steel furnaces in the town common to many small to medium sized firms; Butchers first built a small crucible shop at their original works site before acquiring larger premises nearby with both cementation and crucible furnaces. Later still, the firm was to augment its production with steelworks further out of town, demonstrating the difficulty in obtaining suitable premises and the consequent value of established steelmaking sites to the industrial economy.

Eyre Lane (1819)

In 1819 William and Samuel Butcher began business in a small premises fronting Eyre Lane, one of the minor streets of the gridiron Norfolk estate. Their father, James Butcher, had been a cutler operating from small workshops nearby on the corner of Charles Street and Arundel Lane, but died in 1806 when William (the elder brother) was about fifteen years of age.[168] Although starting out with only a warehouse, workshops and a yard, their product range was diverse, typical of the smaller Sheffield manufacturers and reflecting the unpredictability of the market, and by 1822 William Butcher was listed in directories as a:

> *...[manufacturer] of edge tools, skates, saws, files, hoes, trowels, joiners' tools, West India & Brazil plantation tools, & steel converter & refiner, Eyre lane.*[169]

The inclusion of steel converting at this early date provides the first evidence of offsite cementation steel furnaces of unknown location, as none had been built at Eyre Lane.

A plan of the site in 1822 shows it to have been made up of three distinct parcels of land and including a 'fourteen feet' lane which, having been granted to the Butchers on lease, was soon assimilated into the works. [fig. 2.77] Nevertheless, this potential thoroughfare was preserved in the works layout, passing through the entrance archway and initially unimpeded by the buildings in the yard. This suggests that the Norfolk estate operated a flexible policy regarding contiguous building lots, allowing parts of the street grid to be 'privatised' while protecting their longer-term interests in the development.[170] Also notable is the persistence of

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[168] See William Fairbank's estate plan, SCA SheS 745L (1788-). The site of W & S Butcher's later Eyre Lane premises had not been leased at this date, being on the edge of the developed area. It is unknown whether William inherited his father's Charles Street business, or served his apprenticeship elsewhere, building up capital through his own work. Also Tweedale (1986b) p. 22; Tweedale (1996) p. 167.

[169] Baines (1822) p. 309. See also Gell (1825) p. 25, which lists much the same range, and also gives the home address of 'Butcher William, merchant, Broom hill'.

[170] Deeds or indentures have not been found for this site, but may have included covenants that the land belonging to the lane should not be built upon; evidence in later chapters (Bees' Wax grinding wheel, Park Wheel; the Don Valley

plot boundaries in the planning of the works buildings, perhaps the result of piecemeal expansion over the three years from 1819.

It is probable that the 1822 plan was made on the acquisition of land for a crucible furnace, built in the same year on the plot to the west. If so, it may be surmised that the centre plot formed the core of the works, with the two areas to either side added soon after. The entire block is conspicuously undeveloped on the Fairbank town plan of 1808, and in light of the depressed state of trade over the following decade it is quite possible that W & S Butcher were the first tenants of the site.[171]

During the first few years at Eyre Lane additions to the works were made in earnest, beginning in 1820 with a coke oven, a prerequisite of the melting furnaces installed two years later.[172] [fig. 2.78] The furnace building was built towards the rear of the yard, only later augmented by adjoining coke shed and privies.[173] The casting shop faced the main entrance to the yard from the north west, with the seven melting holes ranged along the back of the space; behind the stacks was the 'clay place' for storing the raw clay to be made into crucibles. Storing the clay directly alongside the hot stacks helped it to become completely dry (as seen in Huntsman's 1842 furnaces and elsewhere). It would then be sifted and mixed with fresh water before treading.

An early label for Butchers' cast steel scissors dating from between 1822 and 1836, (probably closer to the earlier date) displays the original extent of the Eyre Lane premises, most of which still survives. [fig. 2.79] The two-storey frontage shows little stylistic treatment, excepting the pair of openings to the yard with their three-centred arched lintels and bevelled stone quoins. Nor was the façade symmetrical, with irregular window positions fitting the internal arrangement.[174] This mattered little in context, as the buildings could only be viewed obliquely along Eyre Lane; [fig. 2.80] more importantly, the main entrance arch was approached directly the short Fisher Lane, which communicated with the major Eyre Street. The origin of this arrangement in the earlier truncation of the lane (discussed above) may have been contractual, but it was also desirable both functionally (carts could drive straight in, without having to turn in the tight back lane) and visually, allowing the works to be seen from the main road. [fig. 2.81] Through the arches in the print can be seen glimpses of buildings at the back of the yard, those on the right clearly representing the freestanding crucible furnace, conspicuously given pride of place.

By 1836 the frontage had been extended to the left by a three-storey house on the corner of Brown Lane to the northeast, and at the same time adding of a third storey to the entire length of the original warehouse buildings. [fig. 2.82] The works had also spread to the opposite side

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estate) supports this hypothesis. It is interesting to note that the street in question, Fisher Lane, was a supernumerary addition to the grid, perhaps resulting from the difficulty of leasing larger plots

[171] Fairbank (1808)

[172] Timmins 1977 p. 91.

[173] *FBC MB398 (9 Apr. 1836)* p. 11. The 'privies' and 'cole hole' (as the coke shed is labelled) were built on the land formerly part of the lane. Cf. 1822 plan, above.

[174] The idealised elevation records the correct number of windows, but shows them to be evenly spaced.

of Eyre Lane, with a pair of new three-storey workshops occupying part of a block with a central yard.[175] The now heavily built up neighbourhood of the original site was a serious impediment to expansion, the Butchers' premises locked-in on both sides by dwellinghouses, workshops and a steam grinding wheel to the southeast. In the meantime, trade in the 1830s was rapidly increasing, especially with America presenting a valuable opportunity to extend manufacturing capacity.

Dispersal: Furnival Street, Philadelphia and Globe Works

Consequently in 1835 when the nearby steelworks of Mitchell Brothers became vacant, it was immediately taken over by the Butchers.[176] Mitchell Brothers' works had occupied a large rectangular corner site fronting to Furnival Street and Eyre Street, arranged on a courtyard plan with the furnaces to the rear and warehousing and workshops to the front. Like Butchers' Eyre Lane premises, this had been formed from two distinct sites separated by one of the estate's minor streets, which had at some point been absorbed by the works although a side entrance remained as evidence of the lost route.[177] Although the yard was essentially one large space with its perimeter almost entirely built-up, the projecting crucible furnaces defined a smaller rear yard dedicated to the cementation furnaces (similar to the Bridgefield Works, above).

The new tenants immediately recommenced cast steel production in the range of twenty crucible furnaces, while modifications were made to other parts of the works to suit their particular manufacturing needs, rebuilding the cementation furnaces at the rear of the site.[178] Mitchell Brothers activities had been comparable to the Butchers', listed in the trade directories as merchants and manufacturers of edge tools, files, saws, steel, and emery.[179] At the time of takeover the Furnival street site was already slightly larger than that at Eyre Lane, and the addition the following year of a contiguous plot, not part of the original Mitchell site and with a separate entrance (the 'lower yard'), resulted in one of the largest establishments on the Alsop Fields Estate.[180] [fig. 2.84]

A key advantage of the new location was its relatively direct communication by road with Eyre Lane, carts having only to turn the corner onto Eyre Street before passing down Fisher Lane and straight into the works' yard–a distance of just 180 yards door-to-door (c.165m). [fig. 2.85]

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175 FBC MB398 (9 Apr. 1836) p. 11.
176 Timmins (1977) p. 91; SCA Sheffield rate book SU (1835-36) vol. 3a, p. 97, FBC MB400 (1836) p. 26.
177 See SCA FBC FB231, p. 56; also town plan Fairbank (1797).
178 Timmins (1977) p. 91.
179 Pigot (1834) lists Mitchell Bros. & Co. under various trade headings.
180 Reconstructed from the dimensions and areas given in SCA FBC MB400 (1836) p. 26, and correlating with the 1850 OS plan; also SYCRO 141/B, Flockton valuations (25 June 1844) p. 120, which valued the works at £3533, compared to £1917 for Eyre Lane. The adjacent site with stables was surveyed in 1836 FBC MB396 (22 Apr. 1836) p. 11, at which time it housed a joiner's shop and stables, but was soon adapted for use as workshops (its proposed redevelopment was most likely the motive behind the Fairbanks' survey).

The most important change to the business came with the acquisition of the Philadelphia Works, a long-established water-powered site, to the north of the town on Penistone Road.[181] [fig. 2.86] Initially taken on a seven-year lease from the merchant George Hounsfield at £350 per annum (sometime after 1828), by 1844 William and Samuel Butcher had bought the freehold outright.[182] The property encompassed a large island formed by the diversion of the Don's waters below a weir, and in 1839 included 'Tilts and Forges worked by Water and Steam Power, Steam Rolling Mill, Workshops, Office, Warehouses, Three Dwellinghouses, and other Buildings', to which W & S Butcher later added steelmaking facilities.[183] Its importance to the firm's development cannot be overestimated, enabling the brothers to tilt and roll their own steel (hiring out any spare capacity to the trade) and taking them into the same league as firms such as Sandersons, Greaves and Naylor Vickers (see chapters 3, 5).

Butchers, in common with most Sheffield steel firms of the nineteenth century, no doubt from time to time rented furnace capacity elsewhere. Evidence of short-term arrangements, sometimes undertaken on a piecework basis, is understandably difficult to trace. Fortunately, in the Butchers' case, their tenancy of the Globe Works on Penistone Road following Ibbotson's relinquishment of the property to the Sheffield & Hallamshire Bank (see chapter 3) is documented in William Flockton's valuation books.[184] The demand for large, centralised works producing a wide range of products had diminished, and in consequence the site had been subdivided, the Butchers taking the rear part containing the steel furnaces at a rent of £140 per annum, adapted to be usable as a self-contained premises with its own entrance.[185] [fig. 2.87]

Towards the end of 1852 when the brothers moved in, the 0.4-acre site (1640m²) included a house and warehouse, the cast steel furnace with twenty-two melting holes, four 'cupolas' (i.e. cementation furnaces) two of which were enclosed by large iron-house, and the usual sheds and stores (see appendix 2.5). The decision to locate some distance from their established Alsop Fields steelworks was clearly influenced by the Globe Works' proximity to their Philadelphia Works where all of the steel would be taken for tilting and rolling.

The convenience of centralising steel production at Philadelphia guided the Butchers' choice of location for new furnaces erected in 1854, immediately alongside the Philadelphia Works.

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[181] Originally known as Morton Wheels, a water-driven grinding wheel on the site appears in the first Norfolk rental list of 1581, see Crossley (1989) pp. 12-13. For the Butchers' interest in the works, see SCA Aurora Holdings 491:2 (1845) Map of Philadelphia Works by Wm. Flockton; 491:3 Deeds 1795-1836; 491:4 (2 Aug 1858) Valuation of land, buildings, machinery, fixtures, etc. by Geo Hawksley; 491:27 (1 May 1830) Dissolution of Partnership John Brown / Wm. & Sam. Butcher (his share £1750).

[182] SCA Aurora Holdings 492; 491:1 (2 Nov. 1843) Lease Geo Hounsfield merchant, etc. to Wm & Sam. Butcher, Philadelphia Works / Bacon Island (7 years) ann. rent £350; includes detailed valuation of premises; 491:8 Hounsfield sale to Butchers a moiety of the Philadelphia Works and Bacon Island £11,000. Also land for £3218 15s.

[183] SCA Nether Hallam rate book RB83, item 3, 1st rate (27 May 1839) pp. 42-43 'Hounsfield Butcher & co. Philadelphia Works'.

[184] SYCRO 141/B Flockton valuations (c.1852) p. 213: 'Valuation of Freehold Property forming part of Globe Works belonging to the Sheffield & Hallamshire Bank Co. and occupied as Steel Works by Messrs. Butcher'.

[185] This has been calculated from the areas given in William Flockton's valuation of c.1852, above; additionally, the 1883 sale 'plan' only describes the front portion of the works, demonstrating that the partition was a permanent one.

When complete, this site more than doubled the combined capability of Furnival Street and Globe Works (the crucible shop at Eyre Lane having been dismantled before 1850), comprising a sixty-eight-pot melting furnace and a linear array of six cementation furnaces.[186] [fig. 2.88] As a purpose-built premises, the buildings were laid out to a rational orthogonal plan, in which the banks of furnaces ran perpendicular to Penistone Road where the works' entrance was located. In total, the company now operated twelve cementation furnaces and 102 crucible holes, comparable in size to its largest competitors including Sanderson Brothers, Jessops, Naylor Vickers and Thomas Turton (all covered in chapters 3 and 5).

Consolidation at Eyre Lane and Arundel Street

The buildings that today constitute Butchers' Works are largely the product of the final phase of expansion and consolidation. Plans for the enlargement of the Eyre Lane premises seem to have already begun by 1844 when a valuation of the Butchers' properties lists six three-storey cottages and a stable on Arundel Street, directly to the rear of their Eyre Lane crucible furnaces.[187] [fig. 2.89] The decisive moment came in the early 1850s when the adjacent steam-powered grinding wheel of J B Raworth fell idle and was acquired by the Butcher brothers, completing the block (for the development of urban steam-wheels see chapter 4). Bounded by Arundel Street, Charles Lane and Eyre Lane, this was now a substantial urban plot, twice the size of their original works and facing the main road, so called for a new strategy. [fig. 2.90]

Examination of the surviving buildings suggests that Raworth's grinding wheel was assimilated much as it stood, the main alteration being the partial rebuilding of the façade to the newly enlarged courtyard, increasing the depth of the hulls. [fig. 2.91] The engine and boilers were, at this stage, housed internally at ground level, at the Arundel Street end of the building.[188] The façade to Charles Lane still retains much of the earlier wheel building, albeit extensively altered and with an additional floor. The first two floors presented a blind wall to the street, save for the cast-iron ventilation grilles (a number of which still exist), while the third was almost fully glazed, with minimal brick piers between regular casement windows. [figs. 2.92, 2.93] Most of the glazed area was confined to the courtyard elevation, broken only by the vertical bands of the hearth flues, features characteristic of the private urban steam wheel building type (see chapter 4).[189]

Perhaps of greatest significance was the acquisition of the Arundel Street frontage, allowing the works to be reoriented to face one of the estate's major routes. To achieve this, an entirely

[186] SCL Sale plan (19 Dec 1871) depicts the Philadelphia Works at the time of W & S Butchers' departure, and is accompanied by a comprehensive description of the plant See also Timmins (1977) p. 60; Sheffield rate book SL (1854-55) vols 1-2, p 108.
[187] SYCRO 141/B, Flockton valuations (25 June 1844) p. 120.
[188] See the RCHME report on 72 Arundel Street, Giles (1996).
[189] A range of similar buildings can be seen along the side of Sellers' Wheel, just opposite Butchers' premises on Arundel Street. Grinding accommodation is identifiable by the solid external wall, while workshops are lit from both sides; the placing of heavy grinding on the ground floor gave the associated benefit of improved security.

new front range was constructed, containing porter's lodge, offices, workshops and warehousing, as well as the steam engine and boilers, the engine house courtyard walls strengthened by inverted brick arches at ground level, spreading the load over strip foundations. [figs. 2.94, 2.95] The new frontage wrapped around the corner where it abutted the old, and the now superfluous entrance archways from Eyre lane were bricked-up on both sides to form usable workshop space. Another large range of grinders' hulls was built along the southwest boundary where the crucible furnaces had previously stood; as a consequence of the enlarged engine and boiler capacity (the latter now moved out into the yard), a new chimneystack was built in the centre of the redefined square courtyard, dominating the space and acting as a landmark for the works. [fig. 2.96]

These structural changes indicate that the role of the works had changed fundamentally, with steel production now taking place on a much larger scale elsewhere and valuable town centre premises rededicated to more profitable activities. Demand for central and secure tenement workshops and grinding space at this time was acute, and the Butchers found no shortage of cutlers willing to take surplus places at a weekly rent.

Butchers' Wheel, as it became known, came to occupy a special position among the town's grinding wheels, largely due to the rising incidence of 'rattening' (or trades' unions 'outrages', see chapter 4) in the 1850s and 60s. From evidence given to the Trades Union Commission inquiry it emerges that Butchers' was known locally as the 'safe wheel', being guarded day and night by porters and accessible only from the main gates on Arundel Street.[190] Unlike most purpose-built grinding wheels, the Butchers' premises were a tightly knit accretion of different buildings and sites, precisely the qualities that made it intrinsically defensible. There were no boundary walls to be breached, as the perimeter of the site was fully built up. Access to all areas of the works could be gained through the internal courtyard, with its single entrance overlooked by the porter. [fig. 2.97] In this respect, Butchers' Wheel was better adapted to tight security than the Tower Mills, which was supposedly purpose designed as a 'safe wheel'.[191]

The firm was also well regarded in terms of the quality of its accommodation, the Arundel Street grinding wheel attracting praise in Haywood and Lee's otherwise damning *Report on the sanatory* [sic] *condition of the Borough of Sheffield*:

> *Among the master manufacturers, we have met with many instances of anxiety for the health and comfort of their workmen. We mention with pleasure the works of Messrs. Johnson, Cammell, and Co., and those of Messrs. William and Samuel Butcher, in both of which proper structural arrangements and ventilation*

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[190] The Sheffield Outrages Inquiry resulted in the publication in 1867 of two volumes ('Report' and 'Minutes of evidence', by London: Eyre & Spottiswoode for HMSO) and reprinted as Pollard (1971), see evid. 9923 'There is more difficulty in getting into Butcher's wheel, is there not?–Yes, it is what they call the safe wheel'.
[191] See 'Tower Wheel' (1983) p. 34; Pollard (1971) 'Seventh Day' (13 June 1867) pp. 110ff. from evid. 6038; discussed further in chapter 4.

have been attended to. The latter are unquestionably the cleanest works in the town.[192]

This may seem surprising given the buildings' tumbledown appearance, [fig. 2.98] but it must be remembered that W & S Butcher had become one of the most prominent (if not dispersed) firms in the town, exporting large quantities of tools, knives and razors to America where they were marked 'Wade and Butcher', reflecting the role of Robert Wade in managing their New York office. William Butcher's attempt to establish steelworks in Philadelphia is beyond the scope of this study, but is further evidence of his willingness to adapt to changing circumstances, a quality common to many successful Sheffield manufacturers.[193] It was this progressive instinct that led to the installation in 1852 of the latest American file-cutting machinery at their Sheffield Works–a move that angered the file makers' unions who perceived it to be a threat to their time-honoured craft. Butcher may have been able to claim philanthropic motives, as the use of lead in file-cutting made it one of Sheffield's most lethal trades, but the experiment seems ultimately to have failed for reasons of cost and quality.[194] Nevertheless, William Butcher was the target of a 'rattening' incident, when an incendiary bomb was thrown through the window of his house (for rattening and trade union intimidation, see chapter 4).

Conclusions

Dual and multiple site operations of this kind were more common in Sheffield than is often assumed. This misrepresentation has been due in part to the reliance upon documentary evidence such as trade directories and rate books, which very often list only the main business address of each company.

Aside from the circumstantial trade directory evidence (above), survey drawings show that as early as 1823 William Butcher owned several properties in Sheffield.[195] By 1844, the brothers' holdings were quite extensive, and had diversified to include some non-industrial properties. On Norfolk Street in the centre of town, for example, they owned 'Workshops and Warehouses occupied by Messrs. Hutchinson', manufacturers of surgical instruments, along with a pair of dwelling-houses; architect and surveyor William Flockton described the properties as being 'in an excellent situation, in good repair, fitted up with every convenience, and…let at very moderate Rents'.[196] Further dwelling houses and shops were held in South

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[192] Haywood and Lee (1848) p. 128. There may have been an element of sycophancy to their positive reporting, as William Butcher had been Master Cutler in 1845 and was prominent in local government. Butchers were also mentioned for the relatively high standard of their file cutting accommodation: 'We cannot say that there are more than three really well constructed file-cutting shops in the town. The first is Messrs. Johnson, Cammell, and Co., where the bulk is upwards of 300 cubic feet per man; Messrs. Butchers' 367; and a new shop at the works of Messrs. Saml. Newbould & Co., where the bulk is 540 cubic feet each'. p. 126.
[193] For the development of Sheffield method steelmaking in America, see Tweedale (1987) *passim*.
[194] *The installation cost over £15,000. Tweedale (1986b)* p. 23; *Pawson & Brailsford (1862)* p. 150, *Pollard (1959)* p. 127. The best qualities of file, and 'specials', continued to be cut by hand into the twentieth century.
[195] SCA FBC FB167 (1823) p. 35, Steam Street and Plum Lane.
[196] White (1852) places the Hutchinson's company at 76 Norfolk Street. SYCRO 141/B Flockton valuations, p. 49.

Street and Porter Street close to their Alsop Fields works, and at Philadelphia where in all 53 houses and a lodge house belonged to the firm. In the absence of employment records, it is unclear whether this accommodation was provided for Butchers' workers, but its strategic location alongside the Philadelphia and Globe Works premises suggests this may have been the case.[197]

In addition, both brothers owned large houses in the western suburbs. As early as 1825 William Butcher was living at Broomhill where his home, 'Five Oaks' just off Glossop Road, was one of many new manufacturers' dwellings that came to populate the area.[198] The property was one of the larger examples of its kind, flanked by symmetrical glasshouses and set within grounds covering a larger area than the Eyre Lane and Furnival Street works combined. [fig. 2.99] Unusually for such a successful manufacturer, he continued to occupy the same house until his death in 1870.[199] Samuel Butcher owned a similarly sized dwelling in Endcliffe.[200]

After William Butcher's death at the age of seventy-nine, the lack of a suitable successor meant that the works were sold as separate concerns, the Arundel Street premises continuing until 1959 as W & S Butcher, but equally suited to their subsequent use as tenement workshops (still in use at the time of writing) with grinding wheels powered first by steam and later by electricity. The collage of buildings that can be seen today contains elements from every phase of the works' development, yet it is often cited as a 'complete' example of a courtyard works.[201] [fig. 2.100] As demonstrated by the half century of development from back-lane works built to full-block courtyard layout outlined above, to understand urban industrial buildings one must look to their often fragmentary history and sporadic growth. Subject to an ongoing process of redesign and compromise in which the constraints of fixed capital (existing buildings or parts of buildings), function and propriety must be balanced, complexes such as Butchers' Works may be regarded as an extension of the pre-industrial organic growth pattern of farms and villages, constantly evolving but held together by an underlying structure. The next chapter examines in greater detail the emergence and characteristics of Sheffield's village-like steelworks, many of which like Butchers' developed over several decades and in close integration with other sites around the town.

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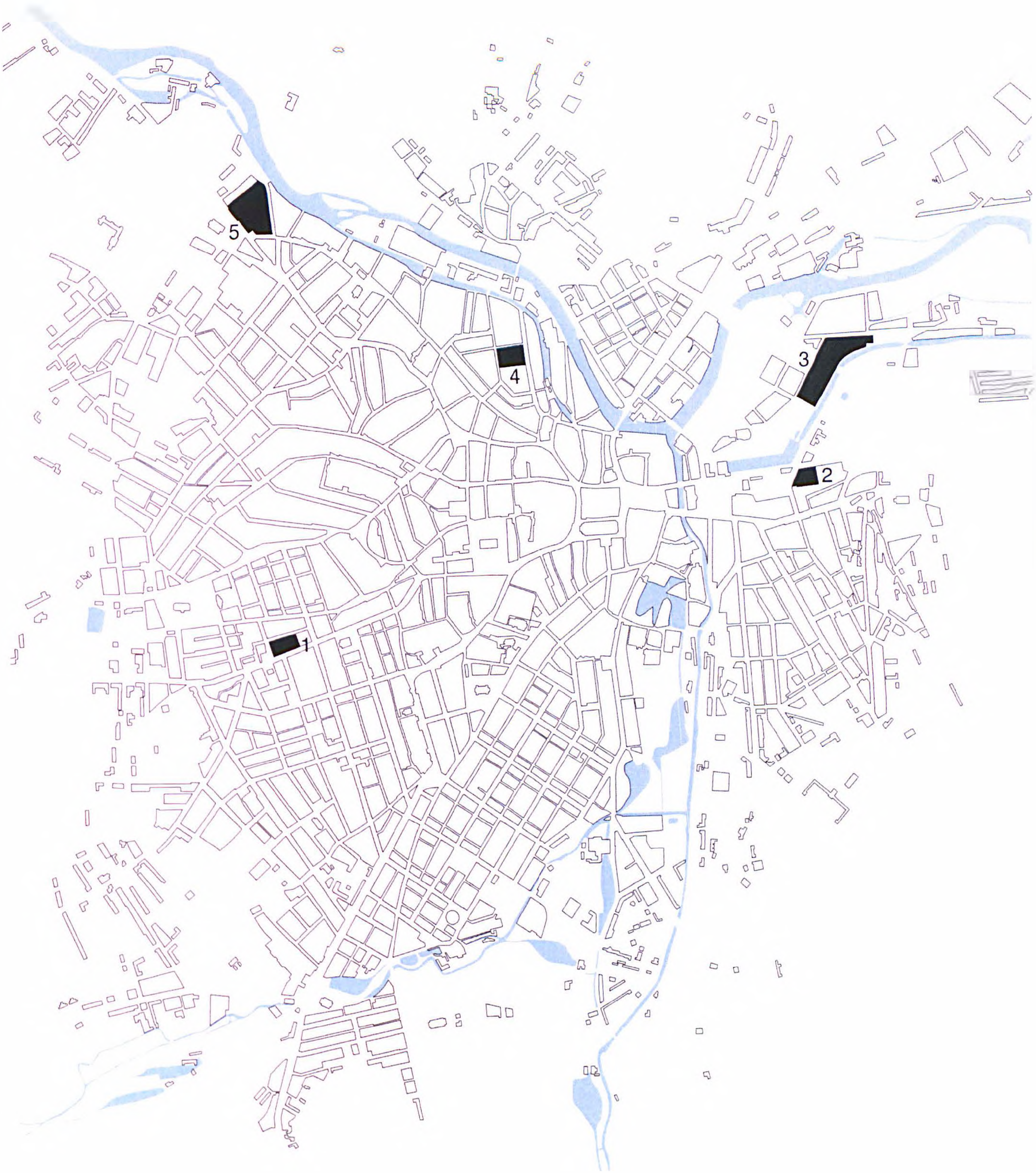
[197] SCA Nether Hallam rate book RB83, item 3, 1st rate (27 May 1839) pp. 42-43. Hounsfield Butcher & co. Philadelphia Works.

[198] Gell (1825). The house lay within the site of the present Hallamshire Hospital.

[199] The property was described as a 'mansion' in Flockton's 1844 valuation. It appears on the 1832 town plan already with its glasshouses but without the later rearward extension. A small building shown at the rear was probably the original stable/gig house. For details of William Butcher's life, see Stainton (1924)

[200] SYCRO 141/B. Flockton valuations (1844) p. 122. valued at £3000

[201] For example, Beauchamp (1996) p. 292: 'The floor plan of Butchers' Wheel shows that it was designed as an integrated works as the workshops are linked to one another'



Key to case studies in chapter 3. Scale 1:15,000.

Chapter 3: Location of case study sites

scale 1:15,000

key:

1 Naylor & Sanderson (later Sanderson Bros.), West Street

2 Jessop & Sons, Park Works, Blast Lane

3 Greaves, Sheaf Works, Maltravers Street

4 Ibbotson, Coulson Crofts steelworks, Bridge Street

5 Ibbotson, Globe Works, Penistone Road

Chapter 3: The first integrated steelworks

Abstract

During the Napoleonic wars, Sheffield's steel industry was relatively stagnant with little new development; following the peace of 1815, however, major new enterprises on an unprecedented scale quickly began to appear. The motivation for the rise of these early nineteenth century steelworks complexes, which signalled a new age and scale of steel manufacture within Sheffield, is considered. Examples of the large new works which sprung up on the fringes of the town centre (Naylor and Sanderson on West Street and Jessop on Blast Lane, for example) are viewed both within their urban context and as an emerging building type, and the possibilities and limitations posed by their rapid expansion and the consequent encroachment of the town are considered. Soon to follow were the first integrated cutlery and edge tool factories, in which all stages of the production process from the raw bar iron to the dispatch of the finished items were accommodated 'under one roof' (as at the Sheaf Works and Globe Works), assisted by the increasing availability of steam-power. It is demonstrated that in each case, the conflict between the need to extend fixed plant and the restrictions posed by the urban site defined the key characteristics of this type of development. Finally, the importance of change over time as a crucial factor in the study of industrial architecture and its environment is established.

The case studies in this chapter comprise two major (c.5000 words: Naylor and Sanderson; Greaves) and two minor (c.2000 words: Jessop; Ibbotson) for comparison, along with a number of additional examples discussed in a broader context at the end.

Part 1: The post-Napoleonic steelworks

> *...the extent to which it has grown, the number of furnaces constantly at work, and the quantity of steel cast into ingots, to be tilted or rolled for the various purposes to which it is applied, have rendered Sheffield the greatest laboratory in the world of this valuable material.*
>
> Samuel Smiles, *Industrial Biography* (1863) p. 111.[1]

During the drawn-out Napoleonic Wars, Sheffield's trades stagnated, with very limited investment in new buildings and plant even in the relatively prosperous years of 1806 and 1809.[2] How much this was due to the war itself is subject to debate. The 'Continental System' or blockade resulting from Napoleon's Berlin Decrees of 1806 had rendered European trade difficult, but not impossible: many firms soon found ways of circumventing its stranglehold, while others turned to the burgeoning market of the colonies.[3]

Despite Napoleon's defeat in 1815 and the lifting of the blockade, the immediate aftermath of the war saw little improvement, and it was not until the 1820s that the metal industries recovered their previous vitality (although the good year of 1818 triggered some developments, including Naylor & Sanderson's steelworks, below, and the Union Grinding Wheel, chapter 4; W & S Butcher followed in 1819 chapter 2).

Of the new enterprises emerging in the post-war economy, many seemed to depart from the traditional dispersed business structure, with its reliance on outwork, hire-services and small workshop units. In their place came large works complexes, often bearing progressive, heroic names (representing the new global markets or commemorating the victories of the recent war) and organised on the principles of pioneer industrialists such as Boulton or Wedgwood.[4] This scaling up and restructuring of what were still essentially craftsman-led trades also entailed the blurring of the old hierarchical distinctions of master, workman and apprentice, resulting in an increased polarity between employers and men (as discussed below).

Nor was this alternative model confined to new firms; many long established businesses that had grown modestly before and during the war (Greaves, Ibbotson) also saw the opportunities of new markets and technologies, and soon found demand outstripping their ability to acquire additional plant and labour. America in particular had no real steelmaking

[1] Paraphrased by Smiles from the earlier work of Holland (1831) p. 236.
[2] Crouzet (1972) pp. 208-11.
[3] Hunter (1869) pp. 173-174. The end of the war was even seen by some as detrimental to Sheffield's trade, 'as the old war arrangements were broken up, and a new plan of business had to be constructed'. Holland (1831) vol. 1, pp 13-14, recalled how the year 1814 had seen enormous quantities of plantation knives exported from Sheffield, known locally as 'tormentors' (as some cutlers believed them to be for the purpose of terrorising slaves).
[4] New works of the decade 1820-30 included Washington Place, Columbia Works, possibly Alma Works, etc. A similar zeal was followed in the naming of new streets (e.g. Wellington, Trafalgar, Portobello). See F. T. Wood's summary of war-derived place names in Sheffield: *Notes and Queries* (1944) vol. 187, 7 Oct. p. 172.

capability of its own at this time, and was dependent on Sheffield's products–whether wrought into knives and tools, or as steel rods, bars and sheet–imposing relatively low tariffs on their import.[5]

The question of how these large firms made the transition from an industry conducted largely in the small courts and back yard workshops of cutlers and tool-makers was addressed by John Holland in 1831:

> *Later years, however, witnessed the springing up of a large and influential class of monied or speculative individuals, who, under the denomination of* factors, *took advantage of the fluctuation of the markets to collect goods and merchandise at a cheap rate, never purchasing at the regular prices when they could avoid it. These enterprising dealers presently obtained large influence in the foreign markets, and, catching the full spirit of modern competition, they soon distanced the tradesmen of the old school. The latter, indeed, frequently became, through necessity, first satellites, and then victims to the new system.*[6]

Although such practices can be traced back to the previous century, the factors' ability to exploit the increasingly severe economic cycles was greatly assisted by the 1814 act of parliament that stripped the Cutlers' Company of much of their long-held power.[7] Most importantly to the new generation of factors, the act 'gave liberty to all persons, whether freemen or strangers, whether they had served an apprenticeship or no, and either with or without a mark being assigned them by the officers of the company,–of engaging in the incorporated trades of the Cutlers of Hallamshire'.[8] Strong opposition from the artisan cutlers, whose pay demands and walkouts were bringing the town's industries to a halt,[9] was no match for 'the principal merchants and manufacturers, who had formed themselves into an union for the purposes of resisting the demands of the workmen'.[10] The Cutlers' Company itself had been surprisingly indifferent to the proposed changes–including the deregulation of

[5] Tweedale (1995) p. 42 In 1842, George Calvert Holland included among the 'substantial houses' such 'highly respectable firms, engaged extensively in foreign trade' as Sandersons Brothers, Huntsman, Greaves & Sons, Butchers Brothers, and Dixon & Sons. Holland (1842) p.44.

[6] Holland (1831) vol 1, pp. 12-13.

[7] Leader (1905) vol 1, p. 165, presented evidence that the factors and stuffing system had been in vigorous operation since the early 18th century. The workmen's contempt for their masters boiled over in the riot of 1756, provoked by the high price of bread, when the crowd 'Publickly declared they wd destroy all ye mills, and afterwards pull down ye Houses of ye Factors, Mr Roebuck's was mentioned for one y' he has been obliged to keep a guard to prevent y'" They publickly told ye Factors they wd. not be used also in ye manner as before wth. half stuff, and a great deal more...' From Sitwell (1900-01) vol. 2, pp. 238.

[8] Holland (1824) p. 165.

[9] Indeed, at the time bill was brought, the grinders were out on strike, with many works effectively closed down. Ward (1909) p. 217, explained in a letter to Hunter of 12 May 1814: 'Our [Cutlers'] Corporation Act prevents our supplying the wants from persons who have not served a seven years' apprenticeship, or purchased their freedom, and the [masters'] Union have seriously turned their attention to a measure long talked of, the procuring a repeal of such clauses of the Act as hinder the employment of such persons. The Cutlers' Company were solicited to join in an application to Parliament for the purpose, but though generally friendly to the measure declined complying. However, an application is made; a solicitor and 3 deputies are in London about it, a Bill has been brought in, and the workmen (jealous of their privileges, and fearing an influx of hands) are, with a solicitor and deputies, opposing it They have asked the Cutlers' Company to support them, and they refuse'.

[10] White (1833) p 71

apprenticeships, marks and freedoms–as many of its most influential members were the very same merchants and manufacturers, eager to reap the benefits of free trade.[11]

As a result, it became much easier to obtain labour, although often at the expense of ability, while experienced cutlers were faced with little choice but to work for the factors at whatever price was offered, and in bad times even driven to accept payment in 'stuff'.[12] Even when moves were made later in the century to abolish the 'stuffing' system (or 'truck' as it was otherwise known) the Cutlers' Company gave no support to the bill, as 'many houses regarded of high standing, conducted by citizens claiming all the moral virtues, not a few of them prominent members of the Cutlers' Company...made large profits from it'.[13]

It was of this climate that the 'little master' (or colloquially, 'mester') was born: a new category of workman unable to make a living as an employee, so forced to find his own premises (either at home or at one of the tenement-factories or 'wheels' in the town–see chapter 4), and sell his wares directly to the factor. Although later romanticised, and to a certain extent confused with the traditional artisan cutler, the 'little master' was a product of this ruthless, deregulated free-market economy, and very few made the transition to factor, or genuine master.[14]

It would be misleading to consider all 'factors' unprincipled speculators, and some continued the old patterns of work, albeit on an increased scale. George Naylor (of Naylor and Sanderson) was described in the trade directories as a 'factor', yet operated a traditional steel business with an emphasis on quality and honesty; W & S Butcher had a high reputation for fairness to their employees, introducing improved working conditions in their grinding wheels and file-cutting shops.[15]

In parallel with the boom in trade, Sheffield experienced an unprecedented explosion in its population, calculated to have been 'greater in proportion from 1821 to 1831 than in any other decade of its history'.[16] How much this was a product of the deregulated cutlery trades, as opposed to the more general migration to industrial towns, is uncertain.

Backed by the necessary capital, and with the cementation furnaces and crucible holes of the first generation steelmakers as their building blocks, the 'factors' established works capable of supplying themselves with the necessary in cementation and cast steel, dependent only on the supplies of Swedish and Russian bar iron from Hull.[17] A few even financed the

[11] White (1997) pp 312-13, discusses the role of merchants and artisans in bringing the bill to parliament, and its consequences

[12] Holland (1831) vol 1, p 13, declared the stratagem to be 'The crowning evil of this new order of things'. Leader (1905) vol 1, pp 165-166 See also Rule (1981) p 138; Lloyd (1913) p 215; Hilton (1960).

[13] Leader (1905) vol 1, p 166

[14] See the more general discussion of Engels (1845) pp 104-110, concerning the effects of a superabundance of labour and speculative cycles of 'boom and bust' Some of Engels economic arguments appear to be derived from an earlier publication of Sheffield's G C Holland (1842) pp 32-35

[15] Robinson (1797), Haywood and Lee (1848) pp 126, 128

[16] Hunter (1869) p 175 Much of this increase was credited to the renewed American trade

[17] See also *W & S Butcher, in chapter 2.*

construction of their own steam-powered grinding wheels and forges, in a bid for independence from the long-inadequate capacity of Sheffield's water-driven sites (Greaves, Ibbotson).

These were the first 'integrated' works, where the various stages of manufacture could be monitored throughout, without recourse to 'hire-work' or outsourcing.[18] Evidence for the decline of outwork over the following years is found in the complaint of a Sheffield grand jury that a fifth of all cases concerned the theft of scrap metal. This was the result of a change of definition: the offence would only have been considered embezzlement under outwork conditions, but when taken from the employer's property constituted larceny.[19]

Although self-sufficiency was in most cases the immediate concern, many manufacturers were also able to sell surplus steel at a profit, particularly so on the European and American markets. A number of firms, including Sanderson Brothers, began life as manufacturers but moved increasingly to steel production, sometimes to the exclusion of their original trade. More often, steelmaking remained at the service of (more lucrative) manufacturing, first of traditional cutlery and edge-tools, later of more modern requirements such as coach springs, buffers and steel rails. Only William Jessop & Sons remained uniquely dedicated to the production of cast steel.[20]

Of the four case studies in this chapter, by the middle of the nineteenth century three of the firms ranked among the six largest in Sheffield (Jessop, Sanderson Brothers, and Greaves' successor in business, Thomas Turton), their dominance unquestionably a result of investment in the steel trade. The works' comparative capacities were published in a letter to the *Sheffield Independent* of 2 October 1852:[21]

[18] For the purposes of this study an integrated site is one that included, as a minimum, its own steam or water-powered grinding, forging or rolling facilities (but not necessarily all of these) as well as steelmaking plant and any associated workspaces.

[19] Emsley (1996) p. 131. The episode occurred in 1854.

[20] Pawson & Brailsford (1862) pp. 124, 134.

[21] 'Sheffield Manufactories' (letter), *Sheffield Independent*, 2 Oct. 1852; also see Pollard (1959) p. 80, Tweedale (1995) p. 51, table 1.4, based on Timmins (1982).

	Converting furnaces	Melting holes
William Jessop & Sons	10	120
Sanderson Brothers & Co.	10	110
Naylor, Vickers & Co.	8	90
Thomas Firth & Sons	unknown	80
Beet & Griffiths	unknown	70
Thomas Turton & Sons	11	48
Johnson, Cammell & Co.	6	40

Such manufactories did not constitute the typical Sheffield steelworks, most of which were still on the pattern of the smaller premises that had proliferated during the 18th century. As their number increased, however, with smaller firms emulating the principles of their larger counterparts, they came to represent a distinct type, which was to fundamentally alter the pattern of industrial and urban growth in the steelmaking regions.

Naylor and Sanderson / Sanderson Brothers: West Street

Naylor and Sanderson were among the many cutlery and hardware firms to diversify into steel production in the aftermath of the Napoleonic wars.[22] Buildings belonging to the partnership can be dated back to before 1800, when George Naylor (who had completed his apprenticeship with his namesake father), then based at a small domestic site on Coalpit Lane to the south of the town,[23] [fig. 3.1] was sharing workshops and a yard with cutler Thomas Sanderson, located behind tenements on the recently set-out Carver Street.[24] The premises were typical of the smaller cutlery manufacturer and merchant, situated at the back of a yard accessible only through a narrow passage or 'jennel'[25] between four symmetrically planned tenements. With a footprint of just over 60 square yards (51m²) and over three floors, it provided basic but readily adaptable space that could be turned to a variety of cutlery and edge-tool trades.[26] Warehousing was probably located in the same building, as by 1797 George Naylor, junior, was described as a 'cutler & factor'.[27]

The Sandersons had long been associated with the water-powered forge at Attercliffe, in more recent years sharing the lease with Richard Swallow.[28] In forming a partnership with Naylor, the complementary resources of each side–cutlery merchant and steelmaker–were combined in a single organisation of considerable size.

By 1814 the company Naylor & Sanderson is known to have moved to 'West Field', later to become West Street (around 1818), but at this time a largely undeveloped area on the western fringe of Sheffield.[29] The neighbourhood was close to the town, but still retained its pre-industrial character and field patterns, much as those depicted on Fairbank's 1795 map of the parish of Sheffield.[30] [fig 3.2] It was these qualities that had also led to its notoriety as a gathering place for radicals: on a number of occasions large night time meetings of Jacobins

[22] Naylor and Sanderson had manufactured razors and cutlery from the final decade of the 18th century. Henderson (1966) p. 65, mistakenly dated the establishment of the partnership to 1776, this being the date given by Walton (1948) p. 180 for the beginning of the Sanderson Brothers' (Thomas and James) firm. Also see Tweedale (1996) p. 267

[23] George Naylor took over the existing Coalpit Lane cutlers' shops of Sam Dickinson (entered as a cutler in the 1774 Directory), see SCA SheS 286S (1766-87), also FBC FB 26, pp. 48-49. By 1824, he still occupied workshops at the back of the site, while George Linley, shear-smith, had taken over the other buildings. Gell (1825). By 1842, the buildings were in the possession of Naylor's executors, SCL SYCRO 141/B, Flockton valuations, *Coalpit Lane*.

[24] RB120. Item 1 (1800) pp. 106-7, SCA FBC FB108, p. 62, survey of workshops occupied by Naylor and Sanderson and owned by Wm. Vickers (1807), also SheS 247S.

[25] See Mather (1862) p. 33, also OED, var. of 'gennel'.

[26] The building measured 14.2x4.28 yds. [13.0x3.9m]. A structure of the same footprint was reported to be 3 storeys high on a fire plan the 1890s, as many of these generic workshops remained in continuous use over many decades, there is every reason to believe this to be the same building (although floors may have been added later).

[27] Robinson (1797) under 'Carver Street'. The full entry runs: 'Carver Street: Naylor, George, jun. cutler & factor (9)'. By 1822, George Naylor was still operating his cutlery business from Division Street, see Gell (1822) p. 156, 'Naylor, G. & Co., Division St., Table knife cutler', and p. 153, 'Naylor & Sanderson, West St., Steel converters and refiners'.

[28] Hawley (1992) p. 95, notes that Sanderson's firm emerged from the Copley Ironmasters who held Attercliffe forge of the Earl of Shrewsbury from 1585-c.1660; Crossley (1989) pp. 20-21.

[29] Rate book RB150. Item 2 (17 Feb 1815) p. 30 'Carver St. 10 Naylor Sandersons–Counting Ho[use]., Shop -/5/6 Shed, yd. WH & yd. [warehouse and yard] -/15/-'; p. 34 'West Field Naylor Sanderson WH [warehouse] 14/10 Sellor [cellar] 1 5 Land 1-9 [total] 16/3'

[30] Fairbank (1795) *A Map of the Parish of Sheffield in the County of York*. In fact, the area had seen little change since Harrison's 1637 survey of Sheffield, see Scurfield (1986) pp. 147-171, fig. 2.

and secret societies were held in the fields, ring-fenced by lookout men and out of earshot of the townspeople.[31]

Nevertheless, the locality held the potential for much larger plots of land than were afforded by the cramped medieval streets of the old town. West Street itself followed the high contour line running from west to east into town, and as an ancient route may have even predated Broad Lane to the north. Ease of access and its proximity to the centre of the cutlery trades therefore made it an attractive option for a business reliant on expensive road haulage.[32]

The turning point came with the development of the land to either side of West Street–an area previously made up of farmland and allotments–bounded approximately by Broad Lane in the north and 'the Moor' in the south.[33] First to be developed was the land to the south owned by Earl Fitzwilliam, keen to capitalise on the commercial success enjoyed by the Duke of Norfolk's estates that had been laid out from scratch on former agricultural land. By the early 19th century, Thomas Holy was pursuing an almost identical strategy with his lands to the north. The building of the turnpike road over the Pennines (Snake Pass, constructed 1818-21), which ran into town along West Street, catalysed further development by the Church Burgesses, who owned much of the land either side of West Street to the west.[34] As with the Norfolk estates, the Fairbanks acted as surveyors to these developments with the responsibility of setting-out the building lots and keeping a record of the buildings erected. A comparison of the Fairbanks' town plan of 1808 and John Leather's of 1823 reveals the extent to which the grid of roads had been laid out (but not entirely built up) over just a few years. [figs. 3.3, 3.4]

It was one of Thomas Holy's newly defined plots that Naylor and Sanderson took to augment their existing premises just across the road. [fig. 3.5] To begin with, they seem to have built only warehouses with cellars, [fig. 3.6] but they were soon to construct their steelworks on the north side of the increasingly important West Street.[35]

The rate books indicate that the warehouse was built on a much smaller plot of land than later occupied by the steelworks, with a built frontage of just under 19 yards and a rectangular yard behind, a modest increase on their earlier buildings.[36] Entry to the yard may also have been gained from the back lane (Holland Street). In its layout, Naylor and Sanderson's plot followed the established pattern of estate development, the warehouse building following the common building line, with ancillary structures located at the rear of the site. It seems likely that the

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[31] Thompson (1968) p. 517, cites one such example where 'at 10 o'clock in the Evening–an orator in a Mask harangues the people–reads letters from distant societies by the light of a candle & immediately burns them'.
[32] Sheffield was not served directly by canal until 1819, so all carriage was road-based, drawn by horse.
[33] See SCA FBC FB87 p. 43, FB89 pp. 40-41, 'West Street Fields, measured for to divide into gardens...' 4 April 1801. The Moor was the name given to the road from Chesterfield, also known as South Street.
[34] Hey (1998) pp. 92-96, Jones (1997) pp. 72-77.
[35] Rate book RB166, Item 2 (27 June 1818) p. 39 [before West street] 'Naylor & Sanderson–WH & cellers -/16/3 Land -/6/9', also RB174, SU (1820) 10B, p. 56 'West Field–Naylor & Sanderson–WHo & cellar 1/12/6 Land -/13/6 Cast Steel Furnace 1/11/-' (NB the rates were occasionally doubled, so the warehouse and land can be safely assumed to be the same in each case.)
[36] For detailed method and calculations refer to appendix 3.2. See also SCA FBC FB151 (1820) p. 58; also FB150 (1819) p. 21

warehouse was initially intended to be part of a continuous terrace of building, as found throughout the earlier Norfolk estates.[37]

By April 1818, however, a larger plot of contiguous ground to the west had been acquired, increasing the site area almost fourfold to 3169 square yards (2650m²).[38] Concurrently, a major campaign of building was underway, with a large cast steel furnace the first structure to be completed. [fig. 3.7] To this were shortly added two cementation furnaces housed in a substantial shed.[39] [fig. 3.8]

In plan, the enlarged site formed a slightly attenuated rectangle, roughly 2:1 in proportion and bounded on three of its sides by newly formed roads. It occupied an entire block of the estate plan (already defined on an 1808 plan of the town), thus removing any future possibility of extending southwards the pattern of roads already established to the north (St. Thomas Street).[40] [see figs. 3.4, 3.5] In its dimensions, the plot was more than ample for the new buildings. It had certainly been planned with significant future expansion in mind–Naylor and Sanderson may have opted to take yet more land, but for the course of Orange Street to the west.[41]

The general arrangement of the earliest steelworks buildings can be traced to within a few years of their construction, recorded on an estate development plan of around 1821. Superimposed on the same drawing are lines representing the former field boundaries, which clearly expose the disjuncture between old and new geometries; as with Sheffield's other regularly planned estates, the local topography was largely disregarded in planning the estate grid.[42] [fig. 3.9]

The new furnaces took the form of a long range along the rear of the site, terminated by a two storey stable block, which may have belonged to the earlier phase. Together these structures presented an continuous, windowless barrier to the entire length of the back lane (230ft / c.70m long), with a minimum height in excess of four metres.[43] The two-storey warehouse and office building remained in the southeast corner of the site, facing West Street, with the new site entrance opening to its immediate left. Access to the warehouse, which must

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[37] The warehouse took up almost exactly one quarter of the frontage to West Street, defining a block between Orange Street and the discontinued Newcastle Street to the north. For the planning of the Norfolk Estates see chapters 4, 5. Also Cruickshank (1998) pp. 34-35; Olsen (1973) pp. 333-357; Simmons (1995) *passim*. and Simmons (1997) pp. 403-431, the planning criteria of the less ordered 'Crofts' area of Sheffield are discussed in Belford (2001) pp. 106-117

[38] See SCA SheS 1308L for areas. Note that the original land rate of 1s 9d became assimilated into the later charge of 16s 3d for the warehouse and cellars (see note above). The additional land was rated at 6s 9d (sometimes double at 13s 6d), or almost three times the value of the first plot.

[39] Timmins (1977) appendix III, p. 264, lists Naylor & Sanderson as having erected 2 cementation furnaces in 1821, and a further pair in the following year.

[40] Further west, the street grid came back into alignment on Charlotte Street.

[41] SCA FBC SheS 943S (1815) 'Building Lots meas^d. for Thos. Holy...' shows the extended portion of Naylor and Sanderson's plot undeveloped, with the intended route of Orange Street, not yet built.

[42] SCA FBC SheS 1308L (1812-1818) with prior field boundaries indicated, and note 'Naylor Sanderson 3169, 310, 247 Total content 3726'

[43] The minimum height of the cementation furnace shed is based on M F Le Play's drawings of a pair of Sheffield furnaces, almost identical in arrangement and plan dimensions to those at West Street. Neither furnace building would have required openings to the back lane; similarly, the rear wall of the ground floor stable was most likely solid.

previously have been from the street, was moved around to the side of the building, within the space of the yard.

The yard was unusually generous, even for a new works, and was surrounded by a high masonry wall. Built against its eastern boundary was a small structure, unlabelled on the early plan, which was probably a simple lean-to housing a row of privies serving the occupants of both the warehouse / office and the furnaces.[44]

In contrast to the clutter and confusion usually associated with Sheffield's industrial sites, the initial design of the West Street works is remarkable for its discipline and clarity. A stripped classical idiom–as found throughout English industrial towns of this period–was adopted for the warehouse and office, its symmetrical façade articulated only by the minimal projection of the centre pair of bays, topped with a simple brick pediment.[45] If not for its position hard against the street edge and lack of a formal front entrance, the building could easily be mistaken for an industrialist's house or minor institutional building.[46] That the frontage was composed of an even number of bays provided an additional clue that this was not the case, the lack of a central opening denying axial entry to the building.[47]

More unusual was the extension of this compositional language to the furnace buildings themselves. The cementation furnace shed, where the steelmaking process began, housed two large conical shells or chimneys, each containing a large double-chest furnace (see below). These cones would have spanned the entire internal width of the shed, partitioning the volume into three spaces: a large area shared by both furnaces and accessed by a central flat-arched opening, with two smaller spaces at either end of the building serving the opposite firing holes. The shed itself–usually referred to as the 'iron-house' or 'firing-shed'–acted as a store for bar iron prior to cementing, with space for coals with which to fire the furnaces at either end. It would sometimes even double as the sleeping quarters for the furnace tenders, who had to manage the fires both day and night for the duration of a 'heat'.[48]

The resultant building was plain but harmonious, its design reflecting its function and eschewing superfluous detail in a way that would have appealed to late 18th century European rationalists such as Ledoux or Gilly.[49]

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[44] Plans of this date often omitted to identify WCs, or otherwise to euphemistically label them 'necessary-houses' or just 'necessaries'. See OED.

[45] See SCA FBC FB150 (1819) p. 21. This format was retained after the later extension of the warehouse, rebuilding the projecting part of the façade in order to maintain its symmetry. See below.

[46] The same anonymity of Georgian and Regency classicism prompted Pugin (1841) pp. 53-54 to criticise 'modern collegiate buildings' that 'might be taken for a barrack hospital or asylum', and Dickens (1995) p. 29, to satirise the architecture of 'Coketown' where 'The jail might have been the infirmary, the infirmary might have been the jail, the town-hall might have been either, or both, or anything else, for anything that appeared to the contrary in the graces of their construction'. See fig. 3.10.

[47] The earlier arrangement of the site would have required a doorway and/or loading bay to the street, most likely occupying one or both of the building's end bays (see, for example, the rear warehouse at Eagle Place on Carver Street, Butcher's Eyre Lane works chapter 2). By the time of the only surviving drawing of the works (c.1830s), no doors to the street were shown.

[48] An 1861 valuation of the Agenoria Works (chapter 6) details the converting furnaces as incorporating 'Watch House & Bed' as well as a desk and the usual fixtures. SYCRO 141/B, Flockton valuations, p. 307.

[49] Gilly's pupil, Karl Friedrich Schinkel, did visit Sheffield and some of its works: his observations will be discussed in chapter 4.

Immediately adjoining the cementation furnace shed, but deeper in plan, was the crucible shop. At the time of its construction, this was probably the largest example of its kind, containing thirty melting holes.[50] The uncommon size of the shop is evident when compared to the more usual scale of operation of the time, ranging from four to ten holes (see chapter 2).[51] A sketch of the 1840s–the only known image of the works[52]–shows the furnaces to have been grouped into five stacks (each therefore containing a minimum of six flues) arranged along, and partially constituting, the rear wall of the shop.[53] The single-sided mansard roof is reminiscent of Broling's earlier drawing of his own furnace building in Sweden, which incorporated extra storage space in a garret directly above the melting shop.[54] [fig. 3.11] At West Street, however, it is more likely that the great volume of the casting shop remained open, with roof hatches to assist the dissipation of the fumes and heat generated by the twenty or more furnaces likely to have been fired on a daily basis.[55]

The building's overall symmetry was compromised only by the presence of the adjacent coke shed. Although sheltered under the same roof structure, internally it would have been partitioned off from the melting shop, with separate cart-sized doors opening to the yard.

Once again, the yard acted as a general circulation space on to which the various shops opened, as there was no direct communication between the different blocks, or even between the three distinct compartments of the cementation shed.[56] Both the significance of the yard in documentary evidence, and its treatment in the development of the works complex, suggest that it was perceived as a distinct functional element, rather than just leftover space. Its role was twofold, both in maintaining access between buildings and in providing discrete working and storage areas for each. These were sometimes clearly delineated by structures or partitions, but more often their presence was defined and reinforced only by the procedures and practices of the workers. Although 'invisible', such cognitive spatial distinctions could be just as powerful an organising device as their physical counterparts.[57]

Hierarchically, the works may be seen as a layered arrangement, with the most prestigious buildings facing West Street along the front of the site, while the furnaces bounded the lane to

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[50] In 1818 Huntsman's original furnace had reached the end of its life, and his second was no larger, so it was unlikely he had more than 10 holes. According to J C Fischer, Samuel Walker had 12 by 1814; Hague & Parkin are known to have operated a relatively large unit of 16 holes, Timmins (1977) p. 41. Most firms had 6 or fewer.

[51] Holland (1831) p. 236 gave the average as six or eight furnace holes. His comment is particularly insightful, as it was not made in ignorance of the Sanderson's furnaces, its author having toured the works. See also Le Play (1843) p. 642, who observed in 1842 that 'the number of furnaces grouped together is never less than four and rarely more than ten'.

[52] Hawley Collection, Firms' Histories, Sanderson Kayser (n.d.) *400 Years of Iron and Steel*, vol. 1, p. 13 West Street works 'early 19th century', p. 46, view of four works: West St., Attercliffe, Wadsley Bridge, Darnall; also Syracuse NY.

[53] It is unlikely that all the stacks would have been identical, as extra flues for the necessary annealing and lighting furnaces, etc. would doubtless have been incorporated in the same structures. Above the level at which the stacks narrowed, the gaps may have been closed with a lightweight infill of brick or possibly timber. See chapter 2.

[54] Broling (1812) pl. 3, fig. 2. The similarity suggests that the two buildings may have shared a common archetype, although none is known.

[55] No roof openings are shown on the sketch, but they were an almost indispensable feature of the cast steel furnace building, and ubiquitous in Sheffield examples.

[56] See the later development of the site, which leaves a narrow passage to the west end, and a small portion of the extreme east end unimpeded. Also the geometry as suggested by the reconstruction, below.

[57] For another example, see Jessop's Park Works, below.

the rear. Later additions to the works respected this front to back hierarchy as far as possible while preserving the integrity of the yard, as shown below.

The influence of the works

Naylor and Sanderson's new works made an immediate impact, both on the town of Sheffield and further afield. That they went unchallenged in terms of steelmaking capacity for over a decade, despite the opening of the much larger Sheaf Works (see below), stands as testament to their unprecedented scale.[58]

The novelty and reputation of the West Street works attracted visitors from outside the town, some leaving eyewitness accounts of their experiences. In allowing outsiders access to the steelworks, the Sanderson brothers seem to have been particularly generous. John Holland, in preparing the volumes on metallurgy for Lardner's *Cabinet Cyclopædia* (1831), was 'allowed the most prompt and free access, and this too under circumstances which might well have justified a refusal on the part of the proprietors, had they been influenced by a narrower or less independent spirit'.[59]

In 1828, Sir Richard Phillips was shown around the works at both West Street and Attercliffe Forge, also taking notes for an intended book.[60] In the main casting shop he observed:

> *...thirty [holes] in action, each containing two crucibles...and the melted steel poured out, like water, into moulds in the form of ingots, about two feet long and two inches square...*[61]

The Stourbridge clay crucibles held a steel charge of 28 lbs. in weight, a fairly high capacity for its day;[62] when the ingots were cool, they were taken to the hammering, tilting and rolling mills at Attercliffe 'to confer solidarity'.[63]

European industrialists seem to have been equally welcome to tour the site, and it is their evidence that best documents the Sheffield steelworks of this period. Johann Conrad Fischer (see Huntsman, chapter 1), who in 1825 had made the chance acquaintance of John Sanderson on the Birmingham mail coach, established a friendly relationship between the two cast steel firms that was to last over a quarter century. Fischer's diary of this date confirms

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[58] Although the Sheaf Works was greater in area, with more extensive plant, it had at the time of its commencement 2 cementation furnaces and 27 crucible holes; by the same date, the West Street works had already been extended to 4 cementation furnaces and 40 crucible holes. See RB194, SU (c.1825-1826) p186; Timmins (1977) p. 56.
[59] Holland (1831) p. 243.
[60] The notes on Sandersons' steelworks were intended for a final unpublished volume of Phillips (1828) *A Personal Tour through the United Kingdom*. Phillips wrote and published books on a wide range of popular subjects, including general science and technology. Early in his career he had been discovered selling Paine's (1791) *Rights of Man*, and was called 'a dirty little Jacobin' by Christopher North; it is therefore perhaps unsurprising to find him visiting Sheffield in his retirement. See Lee (1896) *Dict. Nat. Biog.*, vol. 45 pp. 210-211.
[61] Quoted in Callan (1976) p. 13. See also Barraclough (1984) vol. 2, p. 127.
[62] The Cutlers' Company had melted 20 lbs as early as 1764; Le Play saw crucibles holding 28 to 32 lbs in 1842 (see below), while the standard weight by the late 1860s was 60 lbs., Vickers occasionally employing 100 lbs charges (chapter 5).
[63] Callan (1976) p. 13.

that John Sanderson, with his two brothers, had become the largest manufacturers of cast steel in England, with a substantial American export trade.[64]

During his next visit to Sheffield, in 1827, Fischer–to his great astonishment–was taken on a full tour of Sanderson's West Street works, described enthusiastically in his diary.[65] He began in the coke shed, where he was shown the 'beautiful (light) cokes' used in the furnaces next door. Progressing into the melting shop, he found everything in readiness for casting, and watched the process for some time, before moving on to the cementation furnaces where he noted the exclusive use of high quality Swedish 'Hoop L' iron. He returned to the works on two other occasions–in 1845 and 1851 (see below)–making further observations on the firm's equipment and practices.

Frédéric Le Play, while carrying out research for his report *Mémoire sur la fabrication de l'acier en Yorkshire* (previously mentioned in connection with Huntsman–see chapter 1), also appears to have visited Sanderson's West Street works, and based his description and accompanying drawings of cementation and crucible furnaces on examples seen here.[66] [figs. 3.12, 3.13]

The cementation furnaces studied by Le Play in 1842 each had a capacity of 17,600 kg, (17.3 tons) compared to those seen by Fischer at West Street three years later of about 17.1 tons (160 *centner* per chest).[67] In format also, Le Play's drawings follow the general plan of the buildings at West Street; he considered them to represent 'the most usual arrangement in Yorkshire'.[68] Inside the open space of the shed, two furnaces sit to either side of a central doorway, lit by arched windows to the yard and with a blind wall to the rear.

Le Play, in idealising the plan for European audiences, eschewed the depiction of the minor entrances at each end of the shed, instead increasing the internal width to allow free circulation around the cones–a practice rarely, if ever, encountered in Sheffield. Otherwise, the dimensions and arrangement of the furnaces correspond extremely closely to those at West Street,[69] and can be safely assumed to represent the type of furnace in operation there since the early 1820s.

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[64] Surprisingly, Fischer made no mention of Naylor, who was still officially a partner in the firm. Schib (1951) p. 336, 'Den 4. Juli [1825]. Ich hatte die Bekanntschaft dieses auf alle Fälle sehr respectablen Mannes [John Sanders, i.e Sanderson] in der Mailcoach nach Birmingham gemacht, und er ist nebst seinen zwei Brüdern der größte Gußstahlmanufacturist in England, und seine Exportation ist nach den beiden Amerika'.

[65] Schib (1951) pp. 438-445. Fischer's diary gives the date of the visit as 5 October 1827. 'Statt aber nach der Thüre zu gehen, führte er mich zuerst in das Kohlenmagazin, und zeigte mir ihre schönen (leichten) Coks, und dann, zu meiner größten Verwunderung in das Schmelzgebäude, wo Alles in Thätigkeit war'

[66] Le Play (1843) p. 592, plates 12, 13. The Professor of Metallurgy visited England in 1836, and for a long period in 1842. Although he names Mr. [Jonathan] Marshall as his source for the historical passages, Le Play's illustrations of contemporary steelworks seem to be idealisations of actual examples seen in Sheffield, similar in nature to the *Useful Metals* drawings, based on Huntsman's furnaces, and examined in chapter 1.

[67] Henderson (1966) pp. 157-158, was incorrect in translating *centner* to hundredweight, as there is no reason to assume that Fischer was not referring to his native units. For the value of a *centner*, see appendix 3.1, note 2.

[68] Le Play (1843) p. 592.

[69] The external length of Le Play's cementation shed is 33.42m, just 0.2% smaller than the measurements taken from map evidence of Sandersons' (33.49m). Although his idealised depth of 11.32m is significantly greater than at West Street (8.04m), the figure given in his text for the diameter of the cementation cone is 8.08m, providing further evidence that Sandersons' cones met the external walls of the building (difference +0.5%).

Similarly, the crucible shop is an idealised form derived from actual sources, described in the text as 'one of the best steel melting shops in Yorkshire'.[70] Sandersons' first furnace to feature a monolithic stack was a ten-hole shop built along the west side of the yard between 1826 and 1832. Le Play seems to have taken detailed dimensions of the shop itself, but approximated those of the 'wings' to indicate the additional spaces required for the process, although the latter are arranged differently to Sandersons' plan.[71]

Three successive melts could be made each day, with decreasing crucible charges of 32, 30 and 28 lbs.[72] On this basis Le Play estimated that each ten-hole shop would be capable of producing 8750 lbs. (3970 kg) of steel ingots each week–around 200 tons per annum. With a maximum output for each cementation furnace of about 700 tons per annum (assuming all four to be of similar size),[73] the West Street works could theoretically, by the mid-1830s, have made up to 2800 tons of cementation steel every year, and to cast over half of this steel into ingots. In actuality, however, working to full capacity was rare. Le Play added that 'in 1842, the 97 cementation furnaces in Yorkshire distributed between 33 works have produced in all 16,250 tons', which would indicate a likely halving of the theoretical output.[74]

Both of Le Play's examples were embellished with simple classical details, such as the quoins of the cementation shed and plain pediments of the crucible furnace outbuildings, while retaining the essential characteristics of the buildings seen at Sheffield. Sandersons' own buildings, as noted above, also displayed a degree of classical formality in both detail and composition, although probably not to the extent of Le Play's drawings.

Expansion of the steelworks: 1823-1850

By the early 1820s additions had already begun to be made to the works, establishing the pattern of growth to be followed in the succeeding years. Major modifications were also underway at the tilts and rolling mills at Attercliffe Forge, making the firm one of the earliest to have such comprehensive facilities at their disposal.[75] Only the distinct segregation of their various departments excludes them from the category of integrated steelworks.

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[70] Le Play (1843) pp 713-714.
[71] Le Play gives the external depth of the crucible shop as 7.42m, compared to Sandersons' 7.30m (+1.6%). His basic length of the shop including external walls is 9.10m; this dimension is more difficult to discern from the later OS plan, but can be assumed to be 10m (-9%).
[72] Comparative weights in English pounds are taken from Barraclough (1973) part 2, p. 38. Note that the final charge of 28 lbs., which would have been made around midday, is similar to that seen by Phillips 14 years previously.
[73] Le Play (1843) pp 592, 712, plate 12 and key description.
[74] Le Play (1843) pp 620-621. The lack of equilibrium between cementation and crucible steel capacities at Sandersons' works is not unusual, as there was still a strong demand among cutlers for tilted blister steel and shear steel, which may also have been manufactured at Attercliffe Forge from the surplus output.
[75] SCA FBC FB171 (c. May 1825) pp. 20-24, 37, 'Naylor & Sanderson's weir' at Attercliffe. Note that the entry in Pigot's directory (1834) that reads 'Tilters: Sanderson Brothers & Co. 66 West St.' actually refers to the forge at Attercliffe. West Street was dedicated to steel manufacture only, and was used as their main business address. Leader (1875) recorded the local tradition '...that the Binneys had at one time the best country trade in the town as merchants, and the largest steel furnaces...[and] were the first steel manufacturers who had a tilt', although this is unconfirmed.

In 1829 the firm of Naylor & Sanderson was dissolved, George Naylor moving to Millsands to join his old landlord at Carver Street, William Vickers (and later William's brother, Edward Vickers), in a new steelmaking company Naylor Vickers[76]–the progenitor of the famous Vickers firm (see chapter 5).

The remaining partners meanwhile remained at West Street, reorganising the firm–now known simply as Sanderson Brothers–and issuing a printed circular to inform their customers, particularly those in America, of the changes.[77] The period that followed was a prosperous one, both for the Sandersons and more generally for the Sheffield metal trades.[78] During the mid-1830s, most existing steelworks underwent dramatic changes as they struggled to meet the demands of an insatiable market.[79] By the early 1830s, the Sanderson Brothers still retained their pre-eminence in the cast steel trade, as confirmed by the popular *Cabinet Cyclopædia*, which declared that:

> *The most extensive and celebrated works in the world for converting, casting, and preparing steel by tilting, rolling, &c., are those of the brothers Sanderson at Sheffield.*[80]

This dominant position was due to both systematic additions to the West Street site, and the acquisition in 1835 of further premises at Attercliffe, closer to the forge, where the brothers became neighbours of Huntsman's. In the latter case, the site of an old glassworks was taken on lease, for which Naylor and Sanderson had contrived an ingenious use.[81] Within the vacant cone–originally the space in which the glass blowers worked at the furnace–the steelmakers constructed a large cementation furnace, an unprecedented change of function.[82] In principle the glass cone differed little from the smaller cementation furnace, and the conversion must have been relatively straightforward.[83] [figs. 3.14, 3.15] The underground air passages were ideally suited to adaptation as the fire-room, and a number of attached outbuildings may have been used to store iron and coals. Two of the external arches–originally closed off by doors during glass-making–would also have been retained for the loading and firing of the new furnace inside (as was usual in purpose-built cementation furnaces) and the others perhaps filled in.

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[76] Leader (1905) vol 1, p. 281. Edward Vickers also married Naylor's daughter, following the Sheffield tradition of close business and family ties. See Tweedale (1995), and White (1990) *passim*

[77] SCL Local Studies MP 227L. 'Announcement to the importers and consumers of steel' (1832) reports the dissolution of the firm There exists evidence for a continued business relationship between the Naylors and Sandersons, albeit one that ended in humiliation, when in 1843 'Samuel Naylor and William Sanderson were convicted, under the Act of 1818, of marking "Shear Steel" or "Cast Steel" on cast-iron blades', being fined almost £2,000 between them. The illegal wares were publicly destroyed 'by three men with hammers on three anvils' before a crowd in Paradise Square, addressed by the Master Cutler. See Leader (1905) vol. 1, p. 120.

[78] Crouzet (1972) pp 208-11, demonstrates that after the economic crisis of 1825-6, and subsequent chronic instability, the iron and steel trades saw a recovery beginning in 1832 and culminating in the boom of 1836.

[79] See, for example, the developments summarised by Belford (1998) and Timmins (1982) *passim*.

[80] Holland (1831) p 243

[81] SCA FBC SheD276S (1835) 'Plan of the glasshouse & premises adjoining situate near Darnal proposed to be taken on lease by Messrs Sanderson Bros. of John Fisher & David Walker', Also see Timmins (1977) p 106.

[82] Rate book, 22 Dec. 1835, p. 13, records Sanderson Bros. as having taken '2 Houses' and a 'Glass House' rated at £14 10s., by 9 Sept 1836, p 15, this has been amended to '2 Houses & Steel Furnace', still at £14 10s.

[83] Ashurst (1993) pp 55-59, fig. 14.

As an unusual example of industrial reuse, this episode reflects the wider economic changes then taking place across the region. As demand for steel grew exponentially, the market for traditional local industries such as glass-making and the potteries was in steady decline. Likewise, older water powered sites such as silk, cotton and fulling-mills were turning increasingly to uses connected with the metal trades (see chapter 4).

Back at the West Street works, the potential to extend the original crucible shop was severely limited by its relationship to the neighbouring buildings.[84] Instead of expanding linearly, which would have required the demolition of the stable block (as in the case of Jessop, below), the Sandersons decided to leave the original structure untouched, choosing instead to build new, smaller shops towards the front of the site. The first of these was a ten-hole shop with two transverse gable stacks, situated on the eastern boundary between the offices and stables.[85] This location had the advantage of relatively direct communication with the coke shed and main shop, while the adoption of transverse stacks obviated the potential conflict with developments on the neighbouring land.[86] This was to be the first of a series of new crucible shops built around the perimeter of an increasingly crowded yard.

In contrast, when the need arose to increase the production of cementation steel, the strategy adopted was straightforward. An identical block of two further furnaces was built on to the front of the original, retaining through access to the rear pair and allowing any of the four furnaces to be operated by a single team of workmen if necessary.[87]

By the time of Fairbank's survey for the revised 'third division' rate (i.e. industrial class buildings) in 1836,[88] the works had almost reached full capacity. [fig. 3.16] No further cementation furnaces had been added to the site, but crucible capacity had grown incrementally, in units of ten holes each.[89] These subsequent shops were all built to a common pattern, with a monolithic stack of ten flues (with additional lighting furnace and/or annealing oven flues) forming the rear wall and emerging at the ridge of a steep monopitch roof. The view of the works shows detailing consistent with other industrial buildings of the period: round arched window and door openings in brick with inset stone springers and keystones, plain brickwork external walls and minimal eaves detail.

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[84] Had the original furnaces been designed to hold one crucible, it is possible that the holes were at some time before 1828 enlarged to two pots each, effectively doubling their capacity. Such an expansion is, however, conjectural and unsupported by rate book evidence.

[85] RB194, SU (c 1825-1826) p186, 'Naylor & Sanderson: WH Sta. Yd. & apps. £2 6s ; Cast Stl. Furne. £1 11s.; add. Furnaces 5s , 3 Convg furne. £1 13s. 6d.; 1 Do. Do. 11s.'
An additional note refers to building occupied elsewhere in the town, amounting to just over half the value of the West Street works '6,6,6 here; -,16,0 pa 183; 1,5,0 pa 184; -,16,0 pa 177; -,11,0 pa 185 [total] 9,14,6'.

[86] Adjacent buildings may have impaired the draught induced by the flues (requiring taller stacks), and impeded the maintenance of the stacks. The neighbouring site was measured for building in January 1820; see SCA FBC FB151, p. 58. However, it was still shown as vacant ground on John Leather's town plan of 1823.

[87] Compare SCA FBC SheS 1308L (2 furnaces) with the 1850 OS plan, 6" 1 mile, sheet 25 (4 furnaces). This was a common layout, as seen at Ponds Forge in 1864, Pollard (1954) pl. 14, also the Holmes Works, Allison (1936) fig. 7 (see chapter 2).

[88] SCA FBC MB 401, South Div. No. 3 (1836) p. 9. This new valuation probably resulted from the great boom in trade during the early 1830s, resulting in the construction of a large number of industrial buildings. Fairbank's valuation method based on walking the site sequentially, assisted in the reconstruction of the plan, see fig. 3.18.

[89] See Fairbank's valuation of the site, SCA FBC MB401 (1836) p. 9, indicating 3 furnace groups of 10, and one each of 20 and 30 holes. The group of 20 was itself an extension of an earlier 10-hole shop.

There were by this time 80 crucible holes in all, along with the four 17-ton cementation furnaces The warehouse had also been extended by a further four bays (to twelve), the later sketch of the works indicating that the pediment-topped central portion had been rebuilt to restore the overall symmetry.[90] Correspondingly, the adjacent main gates were moved further down the street, off the axis of the crucible shop. New stables and a gig house had also been added, reflecting both the increasing traffic of the works and the rise in social status of the owners.[91]

These final additions to the works still respected the front/back hierarchy, the gig house and stables built as an autonomous structure adjacent to the main gates, directly against the fence wall. Even in the final extensions to the crucible furnaces, the positioning of furnaces against the front wall was avoided, instead reserving the street frontage for simple lean-to sheds dedicated to the storage of iron, steel and coke, as well as low outdoor bins for coal. [fig. 3.17]

Once again. Fischer's diary observations of a tour of the works, this time in 1845, provide valuable evidence of the rapid growth seen over the past two decades (see appendix 3.1 for full translation). He claimed that the Sandersons operated 36 crucible holes and 6 cementation furnaces (although the former figure is certainly erroneous), and documented the processes of conversion and melting in some detail.[92]

It is notable that notwithstanding the evident pressure on space, each addition to the steelworks took the form of a self-contained unit, in most cases structurally independent of its neighbours. Even in the final arrangement each building is instantly recognisable, its function clearly articulated in relation to the other parts. This was a characteristic common to most of the 'Sheffield method' steelworks, as well as many other contemporary industrial sites, and constituted a language of forms, variations of which were to be found repeated throughout the town. Although governed foremost by principles of function, cost and expediency, the builders and designers of these structures had an intimate understanding of their formal potential, and would sometimes (effortlessly, and perhaps unconsciously) introduce an element of compositional play, to achieve the maximum visual impact.

Michael Faraday and the development of alloy steel

The firm of Sanderson contributed to a fascinating yet little-known episode of scientific history, culminating in the first commercial production of steel alloys. Michael Faraday, known today

[90] The Fairbank survey (MB401) distinguished between 'Old' and 'New warehouse and cellars', their measurements in agreement with the plan evidence before and after the extension. In contradiction to the sketch of the works, the OS plan of 1850 shows a lantern fixed to the façade on the earlier axis of symmetry.

[91] A private carriage was fast becoming *de rigueur* among Sheffield industrialists. Francis Huntsman had built new stables and a coach house in 1835 (rate book, 24 April 1835, p. 16), while Holland (1831) p. 237-238 had been astonished to find instances even of the head-melters of steelworks 'having become persons of property, not to say that they have set up their carriages!'

[92] Possibly the result of an error in transcription for publication in Schib (1951). The author has been unable to consult the original diaries to verify this

primarily for his work with electricity, was the son of a smith, and many of his earliest contributions to knowledge related to metals, particularly iron and steel.[93] Since his analysis of Indian wootz steel, published in 1819, Faraday had been conducting small-scale experiments on steel alloys using 'a most excellent blast-furnace, which has been in use for some years in the laboratory of the Royal Institution'.[94] Although Faraday could melt almost any metal, including rhodium and platinum, the scale of the operation limited the weight of his trials to well under a pound of metal. Another problem encountered during these early experiments was the frequent failure of crucibles at the temperatures required, recorded in Faraday's work diaries.[95]

By the beginning of the 1820s, Faraday's research had progressed sufficiently to warrant the undertaking of experiments on a larger scale than was possible in London.[96] For this he turned to Naylor & Sanderson, a young firm, but already one of the largest of its kind. Faraday's choice reflected not only on the scale of their operations compared to their competitors, but also their methods. Unlike other steelmakers, their openness in allowing outsiders to witness the process would have been indispensable to Faraday's trials, as only under strict supervision could their scientific validity be guaranteed. Naylor and Sanderson were also among the first steelmakers to operate their own tilt hammers, so were able to offer Faraday the equivalent of a 'turnkey' contract.

As Faraday was not personally able to supervise the large-scale tests, he dispatched 'an intelligent and confidential agent' to act on his behalf, along with sufficient steel and ready-weighed alloying metals, with clear instructions to:

> *...see the whole of the metals, and nothing else, packed into the crucible and placed in the furnace, to attend to it while there, and to suffer it to remain for some considerable time in a state of thin fusion, previous to its being poured out into the mould.*[97]

The resultant ingots were still relatively small by Sheffield standards–from 6 to 20 lb. in weight–due primarily to the scarcity and expense of the alloying ingredients.[98] Subsequently,

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[93] Hadfield (1931) p. 70, quoted Faraday as having said in later years: 'I love a smith's shop and anything relating to smithery'.

[94] Faraday (1827) pp. 96-98, published a detailed description of the furnace in his book *Chemical Manipulation*. It was a simple but effective bellows-blown furnace, made from two graphite crucibles placed one inside the other, with a cast-iron grate upon which stood a small crucible containing the metals. Most of his London trials involved quantities of 1600 grains or under (c 0.1 kg). See Hadfield (1931) pp. 119, 125.

[95] Hadfield (1931) p. 125. For example: 'February 10th, 1824. 565 grains of steel and 16 grains of nickel packed in a crucible together for fusion – February 11th. Fused but being interrupted only imperfectly; must fuse again. Ultimately failed in furnace'; also p. 119. Faraday (1827) p. 294, referred to these earlier trials, 'When very high temperatures are required, as in the fusion of platina or rhodium, the crucibles become so soft as to sink and fold like leather, and the results are often lost'. Faraday ultimately failed to produce an alloy with titanium, for this reason.

[96] Stodart and Faraday (1822), 'In making the alloys on a large scale, we were under the necessity of removing our operations from London to a steel furnace at Sheffield'.

[97] Stodart and Faraday (1822). Faraday was clearly wary of the fluxes and other additions used by practical steelmakers, and wished to avoid any chemical reactions that could affect the outcome. Faraday (1827) p. 298, warned that in the case of green bottle glass in particular, 'traces of silicium and aluminium have been observed in iron, previously pure, after being heated with it'.

[98] Hadfield (1931) p. 108, lists the substances used by Faraday in his steel alloying experiments. Faraday undertook large-scale trials with almost all of the inclusions attempted earlier on a smaller scale, consisting of thirteen metallic elements (chromium, palladium, copper, platinum, gold, rhodium, iridium, silver, iron, tin, nickel, titanium, osmium);

the cast ingots were tilted down into bars, taking care to heat them no more than necessary, before being sent back to London for chemical and physical analysis. In addition, the various types of steel were used to manufacture tools (probably by Faraday's research partner, Stodart, who was a cutler by trade), which were then put to everyday uses to test their hardness, toughness and other qualities.

Faraday's trials at Sandersons went well, and in 1822 he was in the position to announce to his fellow academicians that:

> *...alloys similar to those made in the Royal Institution have been made for the purpose of manufacture; and that they prove to be, in point of excellence, in every respect equal if not superior to the smaller productions of the laboratory.*[99]

Particularly successful was the alloy of 500 parts steel to 1 part silver, proving to be harder than both cast steel and wootz, but not as liable to crack under the hammer or during the hardening process. Faraday envisaged that 'its application will probably be extended not only to the manufacture of cutlery, but also to various descriptions of tools; the trifling addition of price cannot operate against its very general introduction'.[100]

Publication of Stodart and Faraday's paper aroused considerable interest, and it was not long before a Sheffield firm of ironmongers, Green, Pickslay & Co., wrote to Faraday with the intention of making commercial trials of his steel alloys. The company was considered to be the 'most extensive ironmongers in Yorkshire', occupying a large warehouse on Sheffield High Street and a steel foundry on 'The Isle', just adjacent to Marshall's Millsands works (see chapter 2).[101]

A number of the letters written by Charles Pickslay to Faraday survive (see appendix 3.3), documenting a collaboration that was to result in the manufacture of the first commercial products of alloy steel including silver-steel fenders and razors of a rhodium alloy.[102] Two and a half years after Faraday's trials had come to an end, Pickslay was still actively engaged in the development and production of special steels, particularly his 'Peruvian steel', which featured prominently in the firm's advertising of the time.

Word of the new steels spread fast; in 1827, J C Fischer was back in Sheffield with the express intention of discovering 'where or by whom are made the so-called *Imperial* or *Kaiser Steels*, and furthermore the *Peruvian Steel* (two entirely new phenomena in cast steel

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three non-metallic elements (carbon, sulphur, silicon); and four ferrous substances (meteoric iron, wootz or Indian steel, carburet of iron, alumine alloy; the latter was a term used by Faraday to describe an imitation wootz, or 'damascene steel') Stodart and Faraday (1822) p. 253, acknowledged the assistance of Dr. Wollaston (former President of the Royal Society and discoverer of palladium and rhodium), who 'furnished all the scarce and valuable metals with a liberality which enabled us to transfer our operations from the laboratory of the chemist to the furnace of the maker of cast steel'

[99] Stodart and Faraday (1822) pp 253-270.

[100] Stodart and Faraday (1822) pp 253-270.

[101] Leader (1875) Ward (1909) p 17, stated that it was at this foundry that their 'Peruvian steel' was made.

[102] Three communications are reproduced in appendix. Hadfield (1931) pp. 132-136, published a transcription of the letters and commentary on the undertaking.

manufacture)'.[103] He suspected the Sandersons (who he knew from his previous visit) to be involved, and met one of the partners, along with Francis Huntsman, at the Wicker Tilt. Huntsman informed Fischer that only Pickslay and Green made Peruvian steel, and that in his experience it would not bear the hammer. Coincidentally, Huntsman was also experimenting with a new variety of steel made with Indian ore (perhaps with a view to competing with Pickslay), but with little success, insisting that the best steel was made of good Swedish iron alone.[104]

Arriving at Pickslay and Green's showrooms, Fischer was given a tour during which he was shown–with great devotion as if it were a reliquary–a steel and glass box containing the additives used in the manufacture of Peruvian steel (including cupronickel, silver, gold, platinum, borax and alum). Interestingly, Pickslay and Green would not sell Fischer a sample of their steel, but only products fashioned from it–a stratagem clearly intended to protect their monopoly, reminiscent of the earlier prohibition of the export of wootz ingots (see chapter 1).[105]

There was considerable resistance locally to the introduction of these new materials, both from rival steel manufacturers and also from the workmen who had to use the steel. Some grudgingly acknowledged the superior qualities of the finished product; in a letter of 16 November 1826, Pickslay informed Faraday that 'the Grinders were very much prejudiced against it, but now admit it bears a finer colour, than any other that comes into their hands'.[106] Others maintained that the new steel was a sham, and in no way superior to the best cast steel produced from the highest grades of Swedish bar iron.

The hostility was, however, not entirely unjustified; other firms had begun to produce their own 'alloy' steels marked 'Silver Steel' often of dubious quality, and certainly not under the auspices of its discoverer. J C Fischer's attempts to promote his own independently developed 'Meteoric steel' in the town may have further fuelled the craze for new species of metal, and spawned yet more imitators.[107] In evidence Pickslay sent Faraday:

> ...*a Newspaper, in which you will observe, an attack upon our Peruvian Steel. We must however admit the writer has cause (from the conduct of some other manufacturers) to draw the inference he has done.*
> *I send you a rasor,* [sic] *marked 'Silver Steel,' it is made of the commonest Steel that can be produced, the Person who forged it informs me, he makes a great*

[103] Schib (1951) p. 441, '... und vorzüglich zu erforschen, wo oder von wem der sogenannte Imperial- oder Kaiser-, und dann wieder der Peruvian- oder peruvianische Stahl (zwei ganz neue Erscheinungen in der Gußstahlfabrication) gemacht werden'.

[104] Schib (1951) p. 441. Francis Huntsman told Fischer: 'My name is Huntsman, and I make the best cast steel here. If you came to Attercliffe where my works are, I would show you steel that cuts glass'. ['Ich heiße Huntsman und mache sonst den besten Gußstahl hier, und wenn Sie nur zu mir nach Attercliff kämen, wo ich meine Manufactur habe, so wollte ich Ihnen dergleichen zeigen, der Glas schneidet'.]

[105] Pickslay and Green's reluctance to sell their steel could be interpreted as an attempt to retain for themselves the whole alloy steel market, or otherwise a confirmation of Huntsman's opinion that Peruvian steel was not all it was claimed to be, and could only be used for certain products (such as items cast in a mould).

[106] See appendix 3.3

[107] Henderson (1966) pp. 5-6, 105-111; Schib (1951) pp. 313-335.

quantity, of the same quality all marked 'Silver Steel.' We therefore deem it prudent to keep the alloys we use secret, for should we publish them, the same Persons who mark 'Silver Steel' on such spurious articles as the blade sent, would not hesitate to assert that they used the same alloys as we did, and thus bring it into disrepute.

Ultimately, Pickslay's fears may have been justified, as alloy steels went out of fashion almost as rapidly as they had arrived. By 1831 John Holland, in a chapter of the *Cabinet Cyclopædia* devoted to 'Alloys of steel', had little time for such 'specious appellations', satirising their various mythical origins and restating Huntsman's opinion that the best items simply consist of steel of the purest quality.[108] For Pickslay and Green the speculative efforts and expenditure may have proved too great, for in 1828 Green left the business, which was reorganised as Pickslay, Appleby and Bertram.[109] By 1833 they had vacated the long-established showrooms on High Street, and after 1837 no further record of the business can be traced.[110]

Pickslay's failure–attributable in equal measure to both his detractors and imitators–may have set back the development of steel alloys by several decades, as purist steelmakers refused to admit the value of alloying elements. Faraday had also been on the verge of discovering stainless steel, almost a century before Brearley's success, but for the discontinuation of his experiments before completing the trials with chromium.[111] Resistance to corrosion was, ironically, one of Faraday's main objectives, for which he had undertaken tests on the other alloys; there is little doubt that Faraday would have recognised the technological and commercial value of such a material.

The end of steelmaking at West Street

Sanderson Brothers' reputation had been built on the high quality of their steel, achieved by the application of Huntsman's strategy to only use the best grades of Swedish iron in this case 'Hoop-L', as Fischer's observations confirm (see above).[112] Unlike Huntsman, they made no attempt to conceal the basis of their success, openly contributing to some of the most widely published works on steelmaking.[113] By the latter half of the century, the firm was still sufficiently well regarded for Samuel Smiles to cite it as an exemplar of British industry, noting that:

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[108] Holland (1831) pp 248-263. Chapter XIV 'Alloys of steel'. The four varieties subjected to his vitriolic sarcasm are *silver steel, Damascus steel, Peruvian steel* and *meteoric steel.*

[109] Blackwell (1828), also Leader (1875). Pickslay's partner is said to have given extended credit to his friends, 'and was not the man to ask for payment, so that the inevitable end resulted, and Mr. Green came to poverty'

[110] Ward (1909) p 17 added that the High Street premises were replaced by the 'Commercial Buildings', described as 'a disastrous scheme which ended in the occupation of the building first used by the Post Office (1835-1845), and then by Levy's tailoring establishment'.

[111] Hadfield (1931) p 119

[112] Sanderson (1855) p 451, noted that Hoop-L was the most expensive of all the Swedish Dannemora irons, at £36 per ton

[113] Examples included Holland (1831); Le Play (1842); Percy (1864) drawings provided by E. F. Sanderson; the latter reproduced in Jordan (1878). Also Charles Sanderson's own contribution to the Society of Arts (1855).

Some of the manufacturers still affect secrecy in their operations; but as one of the Sanderson firm–famous for the excellence of their steel–remarked to a visitor when showing him over their works, "the great secret is to have the courage to be honest–a spirit to purchase the best material, and the means and disposition to do justice to it in the manufacture".[114]

As their business increased, the steelworks had continued to expand beyond the confines of the West Street site, adequate in the 1830s, but unable to cope with the sustained growth in trade thereafter. Its location, once peripheral, had long since been overtaken by the rapidly expanding town centre, with its attendant problems of inefficient transportation and a shortage of affordable land. Moreover, the capacity of the works, while not insignificant, paled in comparison to that of the large works based in the Don Valley (see chapter 5), its ageing furnaces facing slow but certain obsolescence.

Instead of looking to piecemeal acquisitions in the town centre (as did Butchers or Marsh & Shepherd, for example–see chapter 2) the Sandersons' activities centred increasingly around Attercliffe, and by 1840 a new steelworks had been erected close to the converted glass cone, which was to form the nucleus of their extensive Darnall works.[115] [fig. 3.19]

The decision to consolidate their works out of town, with future expansion in mind, seems to have run in parallel to the original partners' withdrawal from the business. When Fischer visited West Street for the last time in 1851, his friend John Sanderson–who had on previous occasions been directly involved in the works' day-to-day management–was confined to his home about a mile away, suffering from gout and arthritis.[116] By 1869, Sanderson Brothers had been converted to a limited company, and it was under this new management that the West Street site finally succumbed to commercial realities.

United States tariffs on steel had been raised considerably, and Sandersons' response was to enter the American market directly, establishing a subsidiary company at Syracuse, New York around 1870.[117] In effect, this was a trade-off with the West Street site: by 1872, the latter had been sold and the steelworks demolished, replaced by William Hutton's large 4-5 storey silver and electro-plate works.[118] [figs. 3.20, 3.21]

The new buildings were very different to their predecessors, more like commercial premises than a manufacturing complex in appearance, and occupying the entire urban block with massive, heavily ornamented architecture. To West Street, the ground floor was designed as

[114] Smiles (1863) p. 113, reproduced almost verbatim a passage originally published in Holland (1831) p. 243, who had made a note of the remark during a tour of the works by one of the Sanderson brothers.
[115] SCA CA VA3 (1840) Attercliffe valuations, Bright & Unwin, p. 23: 'Sanderson Bros. Cast Steel Furnaces £50, Converting Furnaces & iron houses £70, Office & weighing machine seating £4...'; the glass cone was also still in operation 'Converting Furnace, Iron houses & firing shed £20, stable £1...' (owner John Fisher).
[116] Baines (1822-23) vol. 1. confirms the home of John Sanderson to have been 'West Grove', adjacent to the Hospital that still stands on Winter Hill near the University, and fitting Fischer's description of the location. The house no longer exists. Not long after this final meeting, both John Sanderson and Fischer died.
[117] Tweedale (1995) pp. 88, 93, Hawley (1992) p. 95.
[118] Barraclough (1976) p. 53. The report of the buildings still standing in 1935 is therefore incorrect. Tweedale (1996) pp. 210-211

shop frontages, indicative of the extent to which the area had become an appendage of the town centre. Only a large archway on the west side gave a clue to the courtyard beyond, the inward-looking works within including a rolling mill powered by two 25 hp steam engines at its centre.[119] [fig. 3.22] Crucible melting was still practiced on-site, although the ingots produced were now of silver. Hutton's buildings still exist, retaining much of their original external appearance, but now house shops and office space. [fig. 3.23, 3.24]

Sandersons meanwhile continued to expand their Darnall works site, increasingly specialising in high-grade tool steel. In 1900 the firm disposed of its Syracuse works, to concentrate on its Sheffield business, in the same year taking over the nearby Attercliffe Works of long-established edge-tool manufacturer Samuel Newbould (see chapter 2).[120]

Ultimately a merger with the crucible steelmaker Kayser Ellison & Co. in 1960 to become Sanderson Kayser, secured their position as one of Sheffield's largest steel firms. They continued at their Darnall site despite several changes of ownership and the resulting cutbacks, and were re-launched as Sanderson Sheffield Steels at the end of 2000. The surviving crucible shops now constitute Sheffield's best surviving examples of the type, and have been listed. In 2003, the site is still vacant, and its buildings partially demolished, earmarked for a later phase of the 'Attercliffe Urban Village' speculative housing development.

[119] Illustration from Pawson & Brailsford (1889), reproduced in Tweedale (1996) p. 211. See also SCL Local Studies, Local Pamphlets vol. 52, no. 7, *Institution of Mechanical Engineers* (1890) Proceedings, July. 'Sheffield meeting', p. 452. By 1920, Hutton's West Street business had been acquired by James Dixon & Sons of Cornish Place.
[120] Tweedale (1995) pp. 130, 147. Under the banner of Sanderson Bros. & Newbould, new product lines were introduced, including edge tools and hacksaw blades of the recently-developed high-speed steel.

Jessop: Park Works, Blast Lane

In Sheffield, the name of Thomas Jessop is best known in connection with the Jessop Hospital for women, established in 1878 by the philanthropic steel master.[121] His reputation and fortune had been made in the mid nineteenth century at the extensive Brightside Works, (see chapter 5) in its day one of the world's largest steelmaking sites. However, the business had its origins in the 1790s, being first based at Blast Lane (later Navigation Hill) to the east of Sheffield.[122] [fig. 3.25] Its Park Works, named after the locality of Sheffield that had historically served as the Duke of Norfolk's hunting grounds, belonged to a new category of steelworks that had originated in the boom years that followed the conclusion of the Napoleonic Wars.

The business began as a partnership between W. G. & T. Eadon and William Jessop, under which the new works were erected in 1826.[123] Jessop and Eadon appear to have built the Park Works from scratch, on a vacant plot of land close to both William Jessop's house and the recently opened Sheffield canal basin. This choice of site reflects three of the major considerations common to many new establishments at this time: availability of fuel and raw materials, access to cost-effective transportation and proximity to the dwelling-place. Of the latter, it was said that William Jessop's Blast Lane cottage was 'a very charming place with a lovely lake and gardens'.[124]

Some idea of the landscape within which the works were to be built can be derived from Leather's town plan of 1823,[125] which showed the area to consist largely of fields, undeveloped save for a row of buildings along Blast Lane to the north of the site–among them possibly William Jessop's house. [fig. 3.26] To the west, immediately opposite the works' site, was the Duke of Norfolk's coal yard–the primary source of fuel for Sheffield's works–supplied from his nearby mines by horse-drawn corves running on one of the world's earliest tramways. The newly constructed Canal Bridge provided a direct road connection to the town.

The rapidity with which the neighbourhood of the Park Works developed is evidenced by the next available town plan of 1832, on which the fields of the previous map have become densely occupied with building.[126] [fig. 3.27] A number of contemporary sources allow the various stages of the site's development to be traced and reconstructed in plan.[127]

In its arrangement the original site layout [figs. 3.28, 3.29] differed from most other steelworks of the time (Naylor and Sanderson's, for example), with the furnaces, warehousing and office

[121] Stainton (1924), 'His own munificence in supplying the town with Jessop's Hospital for women is well-known; it cost him £26,000, and stands as a monument to his benevolence'. The hospital buildings were vacated in 2001, and are currently empty.
[122] Stainton (1924), stated that the firm had been established in 1793.
[123] Timmins (1977) p. 57, n. 1, gives a brief summary of the firm's beginnings. See also Sheffield rate S.U. (1826-7) vol. 1b, p. 234. Stainton (1924), claimed to the contrary that 'Mr. Jessop, the father [was] a member of the firm of Mitchell, Raikes & Jessop' on Blast Lane, only to become William Jessop and Sons in 1832.
[124] Stainton (1924) Chapter 13, 'Thomas Jessop'.
[125] Leather (1823)
[126] Tayler (1832)
[127] These are principally the Fairbank rate survey and valuations of 1834-36, including later amendments; Sheffield rate books, the 1850 OS plan, 6" 1 mile

forming an unbroken frontage along the main route of Blast Lane, protecting a south facing 'good yard' at the back of the site.[128] Two freestanding double-chest cementation furnaces with large 24-foot chests occupied the yard, one firing hole of each opening into a rectangular iron-house, the other open to the yard.[129] Immediately to the east was a sixteen-hole crucible furnace, the furnaces themselves arranged in two transverse rows of eight on opposite sides of the shop floor. The main entrance from the yard was flanked by structures housing scrap room, coke shed and 'lightening' furnace.

To the west of the cementation block was a dwelling house with projecting kitchen, separated from the adjacent office and warehouse by the covered entrance to the yard. Together these formed one curved block, turning the street corner with the main gates on axis. In common with other contemporary works (Ibbotson, below; Butcher, chapter 2), the identity of the Porter's lodge and dwelling was suppressed, amalgamated into a larger building containing warehousing and other works functions, resulting in a more impressive range of buildings, organised behind a unified façade.[130] Over the main gates at eaves level, a rectangular field proclaimed the identity of the works (a device also found at Cornish Place). At the time of its construction the main façade would have been clearly visible from the adjacent canal basin, and even commanded an unobstructed vista from Lady's Bridge–the traditional point of entry to the town.

The symmetrical dwelling can, however, still be identified in later views, with its paired end-wall chimneys and central front door from the street. [fig. 3.30] Whether this house predated the steelworks (possibly as William Jessop's cottage) acting as a nucleus around which the later buildings were constructed, or else was designed to be semi-integrated into the premises, is not definitively known. However, it was in keeping with the modest scale and appearance of the works, in contrast to its direct contemporaries discussed in this chapter.[131]

At this early stage, the site was much smaller than that indicated by the 1850 OS plan, the rear (southern) boundary following the same building line as the sites further to the east, and the warehouse along the northwest edge of Blast Lane only 12 yards (11 m) long. By the standards of its day, however, Jessop's works was by no means small and could be even considered one of the more progressive concerns (alongside Greaves, below), in exploiting the potential of the reasonably inexpensive peripheral land in the vicinity of the new canal.[132]

For reasons unknown the founding partnership was disbanded only two years after its establishment, with Jessop taking the steel side of the business and the Eadons continuing as

[128] SCA FBC MB391 (1834) p. 50, 'W. Jessop, Park Works'.
[129] Presumably the chests of these furnaces were designed to hold two rows of iron bars, usually around 12 feet in length, see Raistrick (1967) pp. 72-73; Sanderson (1855) p. 454.
[130] For close parallels see, for example, Ibbotson's Globe Works, Butcher's Eyre Lane.
[131] The cottage element of the works was built to a plan not dissimilar to Huntsman's of 75 years earlier; such attached dwellings were a common feature of Sheffield's industrial sites prior to the 1820s and 30s when the mass exodus to the suburbs began. See Holland (1841?).
[132] Pawson & Brailsford (1862) p. 124, wrote that the Park Works '...were many years ago, from the quantity of steel manufactured there, entitled to the first rank of the trade'. Also see Barraclough (1984) vol. 2, p. 157

tool-makers.[133] From this date onwards, the Park Works were dedicated purely to steel manufacture.

Development: 1830-50

In 1830, as a result of the growing demand for cast steel, Jessop brought his four sons into the partnership, and within two years the firm had become William Jessop and Sons.[134] Around this time Thomas Jessop, who was to be the main influence on the later development of the firm into one of the East End giants, was acting as traveller to the United States, in an attempt to develop a customer base for their steel.[135] Cutlery and tools had long been established export commodities, but the demand for steel in its raw state was increasing rapidly. It was ultimately this lucrative American trade that provided the capital for the development of Jessop's works (in common with most of the post-Napoleonic concerns covered in this chapter).

By 1834, in response to the growth in business, the works had begun to expand further into the yard, with the construction of a third, freestanding cementation furnace across the yard from the first pair.[136] [figs. 3.32, 3.33] While Jessop was clearly attempting to capitalise on the upturn in trade, investment in fixed plant still constituted a financial risk. Jessop's acute awareness of cost is evident from a note made by Josiah Fairbank on a pencil survey of the alterations, noting that 'He says he can build a converting furnace for £150 complete'.[137]

Within two years, the stable and coke shed, which had occupied the eastern side (adjacent to the crucible furnaces), were demolished and a new twelve-hole crucible shop built in their place, well positioned to share facilities with the existing furnaces. At the same time, further buildings were erected along the southern boundary, including a small (crucible) annealing room and replacements for the coke shed and stable, the latter upgraded to include a gig house.[138] With these extensions, appear the first signs of the site being divided into notional but distinct zones for cementation steel and cast steel production, with an intermediate circulation area, a policy to be followed in later stages of the works' development. [fig. 3.31]

These additions, although significant, were soon outgrown; as a result, a plot of land immediately to the south of the site was taken, and a series of extensions planned that would effectively double the capacity of the works.

133 Sheffield rate S U (1828-9) vol 2b, p 236. Stainton (1924), claimed that 'Mr. Jessop, the father, lived next door to his works, being a member of the firm of Mitchell, Raikes & Jessop'.
134 Stainton (1924) Of William Jessop's sons, Montague and Sidney assisted their father with the steelmaking, while Thomas and Henry developed the commercial interests of the business. Tweedale (1986) p. 50.
135 Stainton (1924)
136 SCA FBC MB391 p 25 (27 Aug 1834) partial sketch, no orientation, located by scale and context. Timmins (1977) appendix III p 264
137
138 SCA CA VS(U)2 Sheffield Rate South Division, Fairbank Valuations (1836-) p. 116, Blast Lane 'Wm. Jessop & Son Warehouses Co House & Cellars, Iron Warehouse & Two Converting Furnaces, Lightening House, Melting Furnace & Scrap Room & ~~Coke House~~, ~~Stable & Gig House~~ taken down; addition: Melting Furnace, Annealing Room & Coke Shed Converting Furnace, Steel House, Gig House & Stable'.

Due to the constraints of the original site, the rear boundary had become cluttered with makeshift additions, to the point at which the yard was almost completely enclosed by building. In consequence, the expansion southwards necessitated the demolition of much of this earlier plant, including the lone cementation furnace; only the annealing room and coke shed were spared, now isolated in the centre of the enlarged yard. [fig. 3.34] Despite the difficulty and expense incurred as a result of the old closed perimeter plan, the same strategy was again adopted for the new structures built around the yard.

The various functions are easily identifiable on a (remarkably honest) wood engraving of the works, published in 1862, but representing buildings largely unaltered for over a decade.[139] [fig. 3.35] As with its close neighbour, the Sheaf Works (below), the site's connectedness is represented by road, canal and coal-tramway; extra cementation cones in the background, along with a couple of steam engine stacks, add to the impression of industry.

To the Blast Lane, the warehouse was extended the full length of the new site, continuing the pattern of the short original wing, and at the centre of which a second entrance to the yard was placed. Passing through this arched opening into the yard, two new cementation furnaces could be seen to the left, mirroring the earlier pair about the axis of the main corner entrance. Directly ahead, along the rear site boundary, were two new crucible shops, both built to the pattern of the first example, marking a return to transverse stacks. Each shop commanded a small area of yard, defined partly by the retained coke shed, while shared facilities common to both shops were located in between. [fig. 3.36]

It would be misleading to view the expansion of the Park Works as an isolated example of industrial development. From the earliest stages of Jessop's business, there exists tentative evidence for other steelmaking plant dispersed throughout the town, either owned or hired when needed.[140] During the periods of greatest growth, additional works had been acquired both on Furnival Street in the Alsop Fields estate, and also at Baker's Hill alongside the Ponds Works. The latter were dedicated rolling mills called the Soho Works (not to be confused with the Soho Wheel, chapter 4), illustrated in the company's advertisements, and used particularly in the manufacture of sheet metal for steel pen nibs.[141] [fig. 3.35]

By the early 1850s, largely as a result of its expansion into Brightside, Jessop's had become the largest manufacturer of steel in the country.[142] As noted above, it was relatively unusual to find a steel producer not engaged in the manufacture of other articles; as such, Jessop was one of the only major firms to concentrate exclusively on crucible steel.[143]

[139] Pawson & Brailsford (1862) p. 121. Cf. the layout of the site depicted on the 1850 OS plan, 6":1 mile.
[140] Leader (1875) Ch. 7, recorded that 'Near Sheffield Moor, William Jessop, father of Thomas Jessop, had a steel furnace'. Estimations of hired steel capacity in particular are very difficult to make.
[141] The steel pen is a good example of the profound but largely forgotten social and technological impact of crucible cast steel. Prior to the availability of the high-strength, flexible sheet from which the nibs were cut, the feather quill had been the predominant writing-instrument. Joseph Gillott of Birmingham–responsible for the mass-production of the steel pen–was himself a large customer of Jessop's steel. Pawson & Brailsford (1862) p. 124; Stainton (1924).
[142] Tweedale (1995) p. 51
[143] Pawson & Brailsford (1862) p. 134. 'With the exception of Messrs. W. Jessop and Sons, there are few large firms engaged *exclusively* in the manufacture of steel, but great numbers who combine that with other manufactures...'

Part 2: The integrated works

> *During the present century, and since the introduction of the steam-engine, many extensive manufactories have been erected in the town, in which every process is performed from the conversion of the iron into steel, to the finishing of the articles for the market, and in which the laborious treadle glazing and polishing frames of the hafters and finishers, have been superseded by the powerful agency of steam.*
>
> White, *History, and General Directory of the Borough of Sheffield* (1833) p. 44.

Greaves: Sheaf Works

The Sheaf Works has often been referred to as the world's first cutlery 'factory', in which all of the processes were centralised on one site.[144] Prior to this, different stages of the work were carried out at a number of locations, and outwork was the general rule. Recently, historians have cast into doubt the Sheaf Works' claim to self-sufficiency, intimating that despite its size, there must have been a degree of reliance on outwork from the beginning.[145] Its priority is also subject to some uncertainty. Belford, in his recent archaeological review of urban steelmaking sites, dates the establishment of the works to 1822;[146] the revised second edition of Hunter's *Hallamshire* (1869), however, recorded that John Bower Brown, a partner of William Greaves and Sons, laid the first stone of the new complex in 1823, and that a full three years later, 'in February, 1826, the wheel of the steam engine made its first revolution in the Sheaf Works'.[147] By this time, Ibbotsons and Roebuck's Globe Works, while not quite as large as Greaves', was already in operation, manufacturing a similar range of products (see below).[148]

The works were located immediately alongside the Sheffield to Rotherham canal, which finally connected Sheffield to the rest of the canal network (conceived in 1813, it finally opened to great fanfare in 1819).[149] [fig. 3.37] It is alleged that the construction of the Sheaf Works cost Greaves £30,000, an incredible sum when compared, for example, to the total expenditure on

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144 Hunter (1869) p. 174. This text constitutes the main source of evidence to date, including the claim that 'As to the size and adaptation of the new Works, one grand end was kept in view, namely, that of centralizing on the spot all the various processes through which the iron must pass after its first rude separation from the matrix, until fashioned into razor, penknife or other article of use'. Also Pollard (1959) p. 55; Lloyd (1913) p. 182.
145 Tweedale (1995) p. 51, comments that 'Whether this factory was quite so self-contained as [Gatty's description] implies, may perhaps be doubted'.
146 Belford (1998) p. 16, cites Hunter (1869) p. 244.
147 Hunter (1869) pp. 175-214. The Reverend Gatty was responsible for the additional text relating to industry. Pollard (1959) p. 55, assumed the Sheaf Works to have commenced in 1823.
148 The Sheaf Works originally occupied a site area of 8145m², compared to the probable 4710m² of the Globe Works. There is, however, evidence that Ibbotson relied on offsite supplies of cementation steel.
149 SCA WWM (Wentworth Woodhouse Muniments) F.68a; F68. 53-7. The incorporation of the Sheffield Canal Company was in 1815 by act of parliament 55 Geo. III, c 65. The canal was completed at a final cost of £107,000

the canal of £107,000.[150] It is uncertain how Greaves secured the financial backing for his ambitious enterprise. Their earlier premises were not unusual in scale and character, nor did they hold a particularly prominent position among the town's manufacturers.[151] Gatty suggested that the firm's previous 'prudential habits through many years of profitable business' had allowed them to accrue this enormous sum in cash;[152] this is a view supported by Crouzet, who considered self-finance to be a defining characteristic of many, if not most, firms in the Sheffield metal industries.[153] In any case, the investment was a sound one, as within a few years of its establishment, a further £20,000 had been ploughed back into the Sheaf Works' plant.[154]

To the workers of Sheffield, this was something on a scale never before seen; the local poet James Wills captured their sense of awe in his verse *The Contrast; or the Improvements of Sheffield*, published just two years after the works opened. Standing at the canal basin, Wills invites the reader to:

> *Turn your eyes to the left,–a vast building you see,*
> *In magnitude large as a village might be,*
> *Extends a great distance along the canal,*
> *With internal fires like suburbs of h-ll.*[155]

Wills was generally positive toward progress, but the comparison with the infernal regions betrays a suspicion of this new mode and scale of operation. His comparison of scale with a village was not altogether poetic licence: the site covered over 2½ acres (10,610m²) stretching some 200m along the canal-side–comparable in size to the nearby hamlets of Crookes or Handsworth.[156] A later visitor to the works noted that the numbering of the workshop doors ran to 73.[157]

It was not only its physical size, but also the scale of its ambition that set Sheaf Works apart from other comparable establishments. However, aside from Gatty's statement concerning the 'one grand end' of centralising all the necessary activities in one place, any objective

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150 Hunter (1869) p 174, Binfield (1997) p 59

151 Leader (1875), stated that 'In Hollis croft, on the premises now occupied by the Messrs. Elliot, were the Greaveses, before they removed into Division street (now I. P. Cutts, Sutton and Co.'s premises) prior to building Sheaf works' Baines (1822-23) vol 1, trade directory list the firm as 'Greaves Wm. & Sons, merchants and manufacturers of table knives and razors, 12, Division st.'; an unconfirmed earlier reference has been found in RB31 (3 Dec 1785) p 13, 'Norfolk Street, Messrs. Greaves, Ho. & Steel House 4d, Other Houses 7d, Warehouse 3d.' William Greaves began work at Burgess Street in 1775, and was later said to be a razorsmith of 27 Cheney Square Directory (1787), Hawley (1992) p 90

152 Hunter (1869) p 174, considered this to be a continuation of the business practices necessary for survival during the difficult years of the continental blockade.

153 Crouzet (1972) pp 188-191, also cited the examples of the Walkers of Rotherham, and Marsh Brothers in Sheffield, who were entirely self-financed.

154 Hunter (1869) p 174

155 Wills (1827) p 16 (SCL Local Pamphlets, vol 3, no. 15) The subject is not explicitly named as the Sheaf Works, but at this date no other building would fit Wills' context.

156 The use of the word 'building' in this context does not signify a single edifice, but the act of building–still in progress when Wills wrote

157 From the diary of J C Fischer, 1851, in Schib (1951) pp 723. A translation of the full entry is included as appendix 3.4

assessment of the Sheaf Works' organisation and planning has been prevented by a lack of contemporary evidence.

The first design

Fortunately, a recently discovered document held by Sheffield City Archives has contributed significantly to the history of the works. This anonymous and untitled plan of a canal-side manufactory, identified by the author as of the Sheaf Works, constitutes the earliest evidence of building on the site.[158] [figs. 3.38, 3.39] The drawing is of particular interest as it represents the complex as first designed and built; the proposed route of the Manchester, Sheffield and Lincolnshire (MS&L) railway viaduct was added to the same plan at a later date.[159]

In contrast to later pictorial evidence, the early plan conveys a sense of spaciousness and logical organisation. Each of the various buildings stands freely in the yard, with a clear function and belonging to a legible hierarchy. The underlying intention seems to have been based on the idea of progression from the rear to the front of the site, beginning with the raw materials and ending with the finished product. Gatty's description provides confirmation of this idea:

> *The Swedish iron was received at one end of the building from the canal, and when it left the other end, casked up as finished goods for the consumer, it had intermediately undergone on the premises, and under one supervision, converting, casting, forging, tilting, rolling, grinding, and completing.*[160]

This sequence can be read in the distribution of the various functions around the works, emerging as a clear route around the yard between and through the respective buildings. [fig. 3.40] The strip of land between the works and the canal served as the wharf, where steel could be unloaded from barges, bypassing the canal basin and avoiding the expense of road haulage.[161] Iron bars entered the works through a gate cut into the wall at the rear of the site, where they would have been loaded into the adjacent cementation furnaces or stored in the yard until needed. The furnaces were generously planned, perhaps based on those of Naylor and Sanderson (above), and conformed to the geometry of the site, rather than the orthogonal precedent of the buildings towards the front. From here, the bars of blister steel made the short journey to the crucible shop next-door, a relatively large building for its time, with its forward projecting 'steel and pot house, and clay room'. The crucible holes were arranged in two opposing banks, to either side of a large casting floor, as discernible on an

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158 SCA ACM Misc Maps 52 The plan forms a part of the Arundel Castle Manuscript collection held by Sheffield City Archives, and may have been drawn by the Fairbank firm of surveyors. Slight differences to later plans of the works, combined with its regular dimensions and simple geometric construction lines, indicate that this was a design drawing for the new works, and not a survey based on field measurements

159 The additions are clearly in a different hand, made with brown/red ink to indicate amendments to the original information. They would have been added before 1849, contemporaneous to the railway planning (see below).

160 Hunter (1869) p 175

161 The canal towpath was on the opposite bank. Initially the wharf was shown to be open, and would have been used only for loading, the iron bars being stored within the walls of the works. Later, as the works yard became more congested the wharf area was privatised by the construction of walls and gates, providing additional storage space.

early engraved packaging label of the works.[162] [fig. 3.41] With 27 holes, Greaves presented serious competition to Naylor and Sanderson's dominant position, and could have been capable of producing up to 14½ hundredweight (735 kg) of cast steel daily.[163]

It was more important to keep the ingots of cast steel free from corrosion, than in the case of iron, so these were stored indoors before progressing to the tilt, the next building in sequence. Usually this stage would have represented the most time-consuming (and potentially expensive) of the process, the ingots being taken to distant water-powered forges for drawing out into bars and rods.[164] Greaves confined it–along with the subsequent stages of hand forging and file cutting–to the rear courtyard. Some items would require a number of trips between the forger, file cutter and grinder before continuing on their way.[165] In this sense, the cutlery 'factory' did not operate to the same rigid discipline as, for example, the gravity-fed corn mill or a modern production line. Contrasted with the slow pace and inefficiency of the traditional cutlery and tool trades, however, such a degree of self-containment was unprecedented.[166]

Grinding and finishing took place in the large, three storey structure that shared steam-power with the tilt. [fig. 3.42] Low-walled bins for 'wheelswarf', the sludgy by-product of wet grinding recycled in the cementation process, lined the northwest perimeter wall;[167] coals for the engine were stored on the opposite side of the site, near to the boiler house. The final stages in the manufacture of most goods were hafting (the fitting of a handle or scale) and packing, both activities housed in a small building subservient to the main warehouse. Wrapped in strong, oiled paper and tied into bundles, most products were loaded into casks or barrels for transportation, in the meantime stored in the large warehouse at the front of the site. [fig. 3.43]

To the visitor or outsider, this warehouse was the dominant architectural gesture of the works, an impressive four storey sandstone building resembling an oversized Palladian townhouse, or suburban villa, with delicate rococo ornamentation about the windows and doors. [fig. 3.44] Unlike a villa, however, the building was entered at its side, directly on axis with the main gates. Facing the town, the pedimented formal front was intended mainly for display, representing the dignity and affluence of its owners, and always pictured larger-than-life in

[162] SCA William Fawcett's scrapbook, p. 102, 'W. Greaves and Sons, Sheaf Works, Sheffield'. Also, see below the later replacement for this furnace, which probably replicated many of its features.
[163] Timmins (1977) p. 56. The author's calculation of daily production is based on M. F. Le Play's evidence (above) of an average crucible charge of 30 lbs., with double holes as at Sandersons' in 1828. This figure reflects the maximum capacity and would have been affected by repairs, etc.
[164] Francis Huntsman, for example, used both the Wicker Tilt in Sheffield and even more distant sites such as Broadhead Wheel–4 miles as the crow flies from his works at Attercliffe, and much further by road.
[165] See, for example, the numerous stages involved in the manufacture of a folding knife, described in Bywater (1839). Also Tweedale (1995) pp. 37-50, Grayson and Hawley (1995) pp. 5-15.
[166] Matthew Boulton's Soho Works offers a closer parallel, with its diversity of manufacturing processes centred upon one site. See Dickinson (1937), Markus (1993) pp. 256-257.
[167] The term is defined in Bywater (1839) p. vii, '*Wheelswarf*, the yellow *sludge* formed during grinding on a wet stone'. Its role in cementation is dealt with in chapter 2. These bins are only reproduced on later plans, but were a near-ubiquitous feature of the wheel yards of Sheffield; see chapter 4.

engravings of the works.[168] [figs. 3.45, 3.46] In effect, the building itself was an advertisement for the Greaves brand, and its success as such spawned a number of look-alike imitations across the town. The firm's application to the Cutlers' Company in 1835 for the use of the mark 'SHEAF WORKS' reinforces the emblematic importance of the buildings and their location to the firm.[169]

The actual front entrance to the works was tucked around the southernmost corner of the site, at the end of Maltravers Street (running along the front elevation and leading to the canal-side wharf), overseen by a standalone porter's lodge, itself modelled on the gatehouses usually found at stately homes. [fig. 3.43] Access to the warehouse was on two levels: a steep gradient difference across the site was cleverly negotiated by a rusticated stone plinth, containing a series of arches opening from basement level to the main yard below. One storey up, at entrance level, the plinth was entirely absorbed by the ground; a straight earthwork ramp connected the two plateaux, descending from the main gates down to the yard. The axial porch of the warehouse was mirrored on the other end by a double staircase leading to the lower level.[170]

Technology and planning

At the heart of the works was the steam-powered grinding wheel, tilt hammer and forge. Greaves' most important and valuable asset–the engine itself–occupied the geometrical centre of the site, housed in a tall, vaguely Italianate engine-house and marked the usual obelisk-like stack. Two sides of the engine-house were contiguous to the grinding wheel and forge respectively, their relationships determined by the requirements of transmission. The wheel building ran perpendicular to the direction of the motive power, driven by a line-shaft, while the forge lay to one side, allowing power to be diverted relatively easily with a minimum of gearing.

Besides functional expediency, this 'T' shaped arrangement also contributed to the definition of a formal rectangular yard on axis with the warehouse, the other two sides of which were formed by the rear façade of the warehouse and retaining wall of the ramp. [fig. 3.47] The space served as outdoor storage in connection with the warehouse and also as the 'wheel yard' used by the cohort of grinders working in the 'hulls' (see chapter 4), and stood in contrast to the distinct yard at the rear of the site. The latter was more irregular in form, reflecting its association with the lower grades of building, including the steel furnaces, hand forges and, at the very furthest extreme, the noxious and potentially dangerous gas house.

[168] SCA William Fawcett's scrapbook, pp 95, 102, SCA photo G1 10 main; Barraclough (1976) *Sheffield Steel*, pp 21, 63

[169] Leader (1905) vol 1, p 117, added that the request was refused, the Cutlers' Company giving the reason that 'it might interfere with the interests of other houses established upon the banks of the Sheaf previously' Cutlers' marks were ordinarily made up of abstract symbols or mottos, rather than names or places. See, for example, Unwin (1999) pp 93-103

[170] Neither ramp nor stair is indicated on the first plan, but it is reasonable to assume that they were both present from the start due to the nature of the site this is confirmed the surviving pictorial and archaeological evidence.

This organisation of the site into front and rear groups of building is not entirely the result of functional planning. A sharp division along the line of the crucible furnaces and tilt literally separates the works into two self-contained parts. An explanation for this can be found in the pattern of fields that predated the works: a comparison of plans indicates that the dividing line is coincident with a field boundary that crossed the site, the works falling within two areas of land. [fig. 3.48] Although the deeds have not been traced, it is a possibility that the two halves were subject to distinct leases, or even under different ownership. Consequently, the more costly structures, including the warehouse, steam-powered grinding wheel and tilt, occupied the front portion of the site, while the (relatively) cheaper steelworks buildings and shops for file and blade forgers were consigned to the rear.[171] It was also immediately northeast of this boundary that the railway viaduct was soon to run, turning the virtual divide into a physical one.

The progressiveness of Greaves' planning of the Sheaf Works was matched by his technical innovations. Given Sheffield's abundance of water-powered tilts, the application of steam power to tilting was almost unprecedented.[172] Although more expensive than its traditional counterpart, steam in this case meant freedom from the geographical constraints of running water: Sheffield's rivers were already exploited to capacity, and the benefits of a large, well-connected site on the edge of town were substantial. Besides the clear locational benefit, steam also gave independence from the control of the Cutlers' Company, whose members' tilts were closed to outsiders in times of water shortage. In 1803, a Sheffield steelmaker explained to his client, the Lancashire file-maker Peter Stubs, that:

> *It hath been an impossibility to get any steel tilted for several months on acct. of the extraordinary scarcity of water. The principal parts of the Tilts are in the hands of the File Makers and Cutlers in Compys. so that what little hath been done was merely for their own use.*[173]

Other manufacturers soon followed Greaves' example, steam powered trip hammers being used for the forging of table-knife blades in Hunter's urban Talbot Works from 1839–a move widely resisted by the hand-forgers (see chapter 3).[174] [fig. 3.49]

In addition to steam-power, Greaves employed coal-gas to light the works, evidenced by the 'Gas House' indicated on the earliest plan of the premises. It was perhaps to this that Wills referred when he wrote of 'internal fires', employed by the grinders to prolong the working day (see chapter 4). Gas lighting had been introduced relatively late to the streets of Sheffield, in

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[171] It has not been possible to locate the deeds of the works, but it is possible that certain conditions attached to each plot restricted the types of use admitted, e.g. steam power. Such clauses were typical of other estate developments in Sheffield.

[172] John Darwin had operated a steam powered helve hammer at the Ponds Works by 1828, and possibly as early as 1812, although on a much smaller scale than Greaves. Pollard (1954) p. 15, pl. 8.

[173] Ashton (1961) p. 46, quoted a letter from Joshua Shaw to Peter Stubs.

[174] Berg (ed.) (1979) p. 144, reproduced from Callis (1903).

1819.[175] It had been installed by its inventor, William Murdoch, at Boulton and Watt's Soho Foundry before 1802, and applied to the whole of the Soho Works in 1803, so Greaves' adoption of the technology could hardly be considered cutting-edge.[176] Nevertheless, the Sheaf Works' use of gas light–especially in the grinding hulls–became a prototype for a number of the large Sheffield establishments that followed.

Development: 1827-48

As is often the case, it is difficult to determine precise phases of development of the Sheaf Works. Almost immediately upon completion of the initial plan, work was underway to enlarge the production capabilities of the plant, and over the next few years Greaves expended a further £20,000 on the site.[177] A further pair of cementation furnaces was added in 1827; unlike the extension to the West Street works, these were built without their own shed, but attached to the front of the existing enclosure.[178] By rotating the furnaces through 45 degrees, and constructing two small extensions between their conical shells and the main building, one of each of their firing holes was brought into the space of the existing iron-house, saving the expense of an entirely new structure. This was the first known example of an arrangement that was to become a common feature of steelworks, examples including the Globe Works (below). Although simple, it sufficed for the loading and emptying of the chests, as well as most of the firing, and was much more convenient than the entirely freestanding furnace that came to populate many of the larger works (and was later resorted to by Greaves–see below).

By 1832 the number of extensions made to the original design had almost doubled the built coverage of the site. [fig. 3.51] In planning these additions, the overarching principle of progress from one end of the works to the other continued to be followed.[179] A group of new structures ancillary to the crucible shop, for instance, made a tangent between the corner of this building and the line of the ramp from the main entrance, reflecting the flow of traffic across the site. Where this line came too close to the footprint of the boiler-house,[180] it adopted a concave profile in plan, the indentation maintaining a minimum clearance about the pinch-point. Although this kind of improvised solution was largely the consequence of the unforeseen and pragmatic growth of the site, there is a sense of happy compromise and opportunism about the results; an opening driven through the centre of the arc negotiates the

[175] Holland (1824) p. 190-191, admitted that 'Sheffield waited to have its [gas light's] utility fairly tried' at London and other large towns. Its first introduction was 'on the night of the 6th of October, 1819', when the proprietors of the Gas Works 'displayed to the town. the advantages of their establishment, by enlivening the streets with a light but little inferior to meridian splendor'. Murdoch (1892) p. 47, gave the date 1813 of its first introduction to London.
[176] Murdoch (1892) pp. 34-37. The first factory to be lit by gas other than those of Boulton and Watt (of which firm William Murdoch was an member) was the Manchester cotton mill of Phillips & Lee, completed in 1807.
[177] Hunter (1869) p. 174
[178] Timmins (1977) appendix III, p. 264, presented rate book evidence for the first two furnaces completed in 1825, with two more added in 1827
[179] The state of the works in 1832 is known from the unusually detailed delineation to be found on Tayler's town plan of that year, augmented by the schedule of buildings recorded by the Fairbanks for the third division rate survey during 1836
[180] A third boiler had been added to the original pair, to serve the new rolling mill powered by its own engine

change of direction between old (orthogonal) and new (flow of traffic), while creating a formal entrance to the enclosed yard behind. [fig. 3.50]

The same consideration of natural movement is evident in the form of a new range of hand-forges built in the space of the rear yard: the long, linear block was cranked in the middle, one half parallel to the old forges and lining through with the gas house, the other half running diagonally to meet the face of the tilt building, again in sympathy with the path of least resistance through the works.

Besides these additions to the existing site, a significant parcel of land at the east end of the site was also acquired, with the result that the route through the works was considerably lengthened. As in the case of the earlier field boundary, there is a clear distinction in plan between the structures to either side, the new portion home to the most humble buildings including joiners' shop and cask shed, stables and gig house (the former provided in-house facilities for making the barrels in which exported goods were shipped).

Despite this extra territory, over the following few years (up to 1836) the first signs of pressure for space began to appear in plan. [fig. 3.52] The end of the site, until this time left clear for the arrival of iron bars, was closed off by the construction of a new crucible shop, coke furnace and shed. This move, with the demolition of some marginal sheds, now defined a more conventional yard, but also meant the loss of the route through the site that had been key to the works' development up to this point.[181] Meanwhile, what had remained of the old back yard was finally obliterated by a clumsily planned block of file-shops, wedged tightly between the former cranked range and the projecting cementation cones, and further obstructing the old path.

The formal front yard, too, had already been eaten into by the large new rolling mills, while an extension comprising shops and offices–in plan an extrusion of the grinding wheel–had completed the northwest side, giving rise to a (probably unintentional) square plan.

Impact of the railway: 1848-50

Further disruption ensued in 1848, when the mainline of the MS&L railway cut across the site of the Sheaf Works. [fig. 3.53] Communication between Sheffield and Manchester had first opened in December 1845, on the completion of the Woodhead tunnel.[182] It was not until 1849, however, that the line was extended through to Lincolnshire, and the Victoria passenger station at Sheffield was only completed in 1851. The proposed route was mapped out in detail on a copy of the original drawings for the works.[183] In determining its path, the railway engineers were guided not only by topography and directness, but also by the need to

[181] The rear gates to the site are just visible on the Tayler (1832) plan of Sheffield, situated in the end wall, on the axis of the main traffic route through the site; this entire boundary was later blocked by the new crucible steel furnaces
[182] See *The Gentleman's Magazine*, vol 25 (March 1845) p. 303, gives the date as 15 Dec. 1845. Bayliss (1995) p 66, suggests a week later, on 22 Dec
[183] SCA ACM Misc Maps 52

minimise the financial costs involved in the purchase of land and also in compensation for the intervening property that was to be swept away.[184] Fortunately for both Greaves and the railway company, the hilly terrain meant that the railway had to pass over the Sheaf Works on an elevated viaduct, minimising its impact on the site.[185] In planning the location of the piers, most of the major structures were accommodated, the arches spanning the tilt and forge, and leaving clear the access ways through the site. [fig. 3.38] The only significant casualty was the original steel melting shop, and for this loss the firm was compensated by the construction of an equivalent building on some free land at the very end of the site, back-to-back with their later furnaces. In their layout, the new building was a surprisingly literal reconstruction of the old (perhaps due to a rigid 'like-for-like' attitude on the part of the railway company), with two opposing banks of melting holes each with its own monopitch roof, in a 'butterfly' form.[186] The principal disadvantage of the substitute shop was that its main access was no longer from the main works site, but via the canal-side wharf. Consequently, a small walled yard was created in front of the shop, effectively completing the privatisation of the entire embankment of the canal alongside the works.

Photographs taken of the crucible furnaces prior to demolition show them to have been of dressed stone construction, with similar window details to those of the engine-house (see archaeological evidence, below). The replacement furnace building–built as a seamless extension of the earlier longitudinal shop–presented a plain but characteristic elevation to the street, its saw-tooth gables punctuated at the ridges by the tall fins of the furnace stacks. [fig. 3.54]

It was with the coming of the railway that the generative idea of the Sheaf Works was finally abandoned; the canal–once its *raison d'être*–was being rapidly eclipsed by its speed and scale, reflected in the falling dividends to the canal shareholders.[187] From this point onwards, with no real guiding principle, extensions to the works became haphazard, planned only with respect to their immediate context. A row of four converting furnaces was crammed into a narrow strip of the wharf, between the viaduct and the extraneous crucible shop. More freestanding cones were peppered about the old works, wedged awkwardly into any available corner. Other essential additions to the steam-powered side of the works grew by accretion about the rolling mill, or else were crowded around the external walls and ramp.

By 1850, at its height under Greaves' ownership, the Sheaf Works occupied a total area of three acres (12,500m^2), with buildings covering over 50 per cent of the site. A view created at

[184] William Flockton's notebooks contain valuations for the proposed route of the Sheffield to Chesterfield railway extension, made from 1845. SYCRO 141/B, pp. 141 ff.
[185] The Wicker viaduct was completed on 12 December 1848, its 40 arches spanning 660 yards in total. At the time of its construction it was considered one of the largest masonry structures (by volume) in the world; it is now a grade II* listed structure. Aitchison (2001) pp. 38, 52-53.
[186] The 'butterfly roof', with its central valley, is a form more familiar in twentieth century buildings, but evolved here as a twinned version of the conventional crucible shop. Its limited adoption was presumably due to the difficulty in maintaining the valley gutter, and the obstruction of the intermediate roof supports (columns or loadbearing masonry).
[187] There were no dividends paid between 1842 and 1845, and the Cutlers' Company sold its shares in 1850 for £1,120–a loss of £880. Leader (1905) p. 173

about the same time, although not wholly accurate in its proportions,[188] evokes the tremendous development that the works had undergone. [fig. 3.55] A proliferation of smoke trails suggests industry, while the favourable location of the site is represented by four distinct and busy routes: canal, road, railway and finally the horse-drawn tramway serving the Duke of Norfolk's coal mines on the opposite bank of the canal.[189]

Turton and Sons: 1850

Over a quarter of a century the works of William Greaves and Sons had grown to such an extent that, on the retirement of the major partners, it proved impossible to continue business under sole ownership. Thomas Asline Ward, Sheffield magistrate, industrialist and Master Cutler of 1816, recorded the details surrounding the firm's demise in a letter of 1850:

> *The old firm of William Greaves and Sons, of Sheaf Works, is dissolved, the Messrs. J[ohn] B[ower] Brown and Thos. Blake, who married daughters of old William, retiring. Mr. Eyre (son of Eyre, grocer) one of the partners, continues, and has invited my sons to join him, with two of the travellers, Hale and Brownell. They are to have part of the Sheaf Works (the cutlery department) under Turton and Sons, who succeed to the steel trade, the file and heavy tool manufactory. If industry will insure success, they need not fear, as they are the reverse of idle.*[190]

Thomas Turton and Sons was a well-established firm of steel and file-makers, operating from much smaller premises at Bower Spring, near Furnace Hill. They had made substantial profits from the American trade in particular,[191] but it was primarily the booming trade in carriage springs that the firm hoped to capitalise on. The decision to expand was an ambitious one; the entire capacity of the Sheaf Works clearly exceeded their needs, but the chance of acquiring such substantial steelmaking premises was not to be missed. Therefore Turton chose to sub-let those parts of the works not immediately connected with the steel side of the plant to Eyre, Ward and Company, cutlery merchants and manufacturers (including Asline Ward's sons, as above).[192]

By the time of Turton's takeover, Greaves was said to have spent £60,000 enlarging the works, still a substantial sum in comparison to many other works of the period.[193] Its arrangement and extents in 1850, the year of the transfer, were essentially as discussed

[188] The foreground structures, including the warehouse and porter's lodge, are exaggeratedly large; the site has been straightened by a trick of perspective, and the draughtsman was more concerned with the number, rather than the location, of the cementation furnaces. Otherwise, the layout of the buildings corresponds to that of the contemporary OS plan

[189] This final route led directly into the town of Sheffield, and as such was of little direct advantage to Greaves, but nevertheless adds to the busyness of the scene. As the first of its kind, the tramway and its originator, John Curr, are both well-documented elsewhere. See Mott (1969-70) pp. 1-23; and Raistrick (1967) pp. 69-72.

[190] Ward (1909) p. 313, letter of 1850 to Joseph Hunter (the antiquarian and author of *Hallamshire*).

[191] Their advertisements listed the firm's numerous American offices, at New York, Boston, Philadelphia, Montreal and Toronto. See Hawley (1992) p. 90, fig.

[192] Hawley (1992) p. 90

[193] Stainton (1924). It is unclear whether his figures are derived from Hunter's, or an independent source; in either case, the sum is a plausible total based on the evidence for the works' growth.

above, as shown on the Ordnance Survey plan of the same date (see gazetteer).[194] By 1852 the steelmaking plant was said to have comprised 11 cementation furnaces and 48 crucible steel melting holes.[195]

The underlying order of the premises meant that its subdivision was achieved with a minimum of interventions. The cutlery department included the long strip of buildings to the northwest of the rolling mill and tilt, of which the most important was the grinding wheel, while to the other side of the viaduct a number of short walls partitioned off the hand-forges and file-shops from the steelworks. [fig. 3.56]

Besides the furnaces, Turton retained the rolling mill and forge, in addition to which two of the 30-foot high arches beneath the viaduct were adapted as makeshift buildings, becoming spring-maker's shops.[196] He doubtless also kept control of the impressive warehouse and main entrance. In any case, the dual occupation of the site must have been on amicable terms, with the firms sharing access to the works as well as steam power.

Greaves' reputation had been enviable, and Turton made the most of having acquired their prestigious works, their advertisements bearing the motto 'successors to Wm. Greaves & Sons'. Not long after taking over the works, Turton & Sons took the opportunity to flex their newly-found industrial muscle, producing the widely-publicised 'monster ingot', weighing 24 cwt. (1,200 kg) and exhibited at the 1851 Great Exhibition Crystal Palace as the largest mass of steel ever made in England.[197] This would have required not only the full capacity of the Sheaf Works' rebuilt crucible furnaces, but an incredible degree of organisation to coordinate the teams of melters: any break in the stream of molten steel could have ruined the whole mass. Assuming a charge no greater than 35 lbs. with two crucibles per hole, it would have been necessary to simultaneously fire almost all of the 48 holes, leaving little room for error.

Having proven its capacity to take on the largest of jobs, the firm's business grew rapidly. Alongside the firm's established business in files, saws and edge-tools, the anticipated boom in railway construction brought sufficient business that the decision was made to extend the works onto a nearby site, just across the canal.[198] Completed by 1854 and given pride of place on the company's new advertisements, the aptly named Spring Works were arranged about a single courtyard on an approximately triangular plan. An engine house and stack signal extra grinding shops, while square chimneys with dampers suggest that the steel puddling process had been adopted.[199] [fig. 3.57]

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[194] 1850 OS plan, 6" 1 mile The date 1850 is that of the survey itself.
[195] Statistics from a letter to the *Sheffield Independent* of 2 Oct. 1852, quoted by Pollard (1959) p. 80
[196] Pawson & Brailsford (1862) p. 150
[197] Pollard (1959) p. 160 It would have been the largest in the world, had Krupp (of Essen) not emerged from obscurity to steal the show with his 2¼ ton ingot (2,286 kg); see Percy (1864) p. 837. Ellis (ed.) (1851) vol. 2, p. 614.
[198] Stainton (1924)
[199] Turton's 1850s advertisement is the first to downplay the importance of the warehouse–pushed into the left-hand corner and seen from the rear–while bringing the Spring Works to the foreground, its main entrance clearly visible by Cadman Bridge on the right. The engraver attempted to regularise the works' plan (almost totally obliterating the intervening canal) to give the impression of a large, rectangular site, symmetrical about the viaduct. See engraving in Pawson & Brailsford (1862) p. 151, original advertisements, SCL Photo G1 10 Main, 'Sheaf Works'; Hawley CAT 1030, CAT 2419

Turton also introduced Sheffield's first Nasmyth steam hammer at the Sheaf Works in 1855, relatively late compared to the iron districts (it first appeared in 1839), most likely due to the wide availability of tilt and helve hammers and their operators.[200] Its success meant that within a decade such hammers were to be found in most of the major steelworks.[201] [fig. 3.58]

Thomas Burdett Turton, son of the founder and the driving force behind the business, retired around 1858-9, his place taken by the 38 year old Sir Frederick Thorpe Mappin (previously head of the well known firm Mappin Brothers) and son-in-law Thomas Bright Matthews.[202] B. J. Eyre & Co. eventually gave up their share of the site, leaving the Turton firm in full possession of the Sheaf Works.[203]

There is unfortunately scant information regarding the later modifications to the works under Mappin (retired 1885), but the general character of redevelopment that took place over the succeeding decades is made evident by the 1:500 scale OS town plan of 1889.[204] In common with other steelworks, many of the Sheaf Works' cementation furnaces had disappeared, replaced by much larger sheds on the pattern of the contemporary East End works (see chapter 5), giving little indication to their use or contents. This reflected changes in their product line, becoming increasingly involved in spring manufacture, boosted by the purchase of an important railway spring patent in 1882.[205]

Family connections with the long-established company of type-founders, Stevenson Blake, led to the works being shared once again, becoming the head office of the latter firm (1929), which was to ultimately purchase Thomas Turton Ltd.[206]

By the mid-20th century, the arrangement of the Sheaf Works, as seen in an aerial photograph taken during the 1940s, appeared little different to the earlier plan. [fig. 3.59] All of the earlier cementation cones had been pulled down, leaving only a block of four more recent furnaces at the easternmost extent of the site. These formed part of an almost independent steelworks area of the site, augmented by a number of parallel crucible furnace stacks, all opening onto a canal-side yard. The main site had become dedicated to the manipulation of steel, indicated by a proliferation of new steam engine stacks about the yard. Major buildings at the front of the site (such as the grinding wheel and warehouse) are still identifiable, but to the other side of the widened viaduct, the ridge-ventilated roofs of large sheds are in evidence.

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200 Pollard (1959) p. 80. Scoffern (1857) p. 856, '...Nasmyth's steam-hammer is also coming into use, the first of them having been for some time at work at Sheaf Works'.

201 Smith (1865) pp. 50-51, stated that there were 'Not fewer than seventy of this [Nasmyth] and other descriptions of large hammers' in Sheffield at the time of its publication.

202 Stainton (1924) T B Turton, of West Lodge, was a prominent figure in Sheffield society, having been mayor of Sheffield, and Master Cutler of 1846. He had inherited his father's business along with his brothers Joseph Turton and William Turton, and son-in-law Mr Matthews; the partners were later joined by Sir Frederick Thorpe Mappin. By 1858, when Turton retired, both of his brothers had died, leaving Mappin and Matthews in charge of the Sheaf Works. T B Turton died in 1869, aged 63

203 Eyre & Co had moved to Rockingham Street sometime between 1863 and 1876. Tweedale (1996) pp. 193-194.

204 OS Plan First Edition 1890 (surveyed 1889) 1:500, sheets 294.8.8; 294.8.13.

205 Tweedale (1995) p. 86. The patent was for web-section railway springs, invented by I A Timmis of London, which Turton made of high quality steel. It is also noted that their steelmaking was moved to Neepsend in 1879.

206 Millington (2002) pp. 144, 201, fig. 44. Bayliss (1995) p. 44.

Organisationally, the process-led progressive logic of the site and its various departments had been long since forgotten: the relative ease of powered goods handling and transportation had diminished the role of the yard as a storage and circulation space, the works now organised as a number of irregular, unconnected cul-de-sac yards. In this sense, any resemblance to its previous form was almost entirely superficial–a result of the legacy of built form.

The legacy of the Sheaf Works

Greaves' cutlery works was the first major example of its type to abandon the enclosed courtyard model ubiquitous in the town, opting instead for strategically located freestanding structures set within an all-embracing perimeter wall. His approach may have been influenced by the large public steam-powered grinding wheels that had begun to populate Sheffield's fringes almost three decades earlier (chapter 4); indeed, his own works included a smaller example of the type.

It was this formal redefinition of the works' buildings, rather than the early attempt to organise manufacture on a production-line principle, that was to prove most influential to future industrial planning. Ironically, the inability to acquire more land (due to the encroaching urban spread) meant that Greaves ultimately resorted to the old courtyard model, filling the peripheral space of the yard with additional buildings as necessary.

By the closure of the works, even the base of the warehouse had been engulfed by miscellaneous sheds and lean-to structures. [fig. 3.60] Years of layered additions and modifications had rendered the plan unintelligible, and consequently most of the buildings, including those of its original phase, were pulled down.

In 2003, only the main warehouse and porter's lodge–the most elegant of all the works' buildings–survive in a recognisable form. [fig. 3.44] Since the closure of the works in the 1980s, the buildings stood vacant until the conversion of the warehouse to a public house around 1997, retaining little of its surrounding context.[207] On the northwest façade, where stairs once descended to the lower yard, a new stair tower was added, in sympathetically chosen materials, but otherwise out of character. The main entrance was retained, but relegated to a back door, rendering the plan of the building unintelligible. [fig. 3.61] The area previously occupied by the front yard has recently become part of the city's inner ring-road extension, leaving the warehouse isolated at a lower level. [fig. 3.62]

With the catastrophic decline of Sheffield's metal industries, most of the other buildings were incapable of reuse for related purposes, and deemed too heavily modified to be of general historical interest. Nevertheless, part of the first engine-house still stands, in a dilapidated

[207] The 'Sheaf Quay' pub closed soon after, in 2001, the building refitted and let as office space. The rootless, unaccommodating character of the conversion perhaps contributed to its failure.

state, in the middle of the site. [fig. 3.63] This exhibits the methods of construction common to the first phase of development: solid loadbearing brick walls (of extra thickness in the engine-house, to support the structure of the beam engine), bevelled dressed stone quoins and details about the window and door openings, mildly Venetian in style. The massive wall that supported the beam of the stationary engine is constructed of solid blocks of stone, with a central arch. The chimney stack nearby is unconnected, but was added later by Turton, plain and square in plan, with articulated corner 'piers' closely spaced iron reinforcements. [fig. 3.64]

Behind this, along the northwest boundary are what may be remains belonging to the grinding-wheel, deserving further investigation. Beyond the viaduct, nothing of the steelworks portion has survived, although across the canal Turton's later Spring Works still exist as the grade II listed 'Sipelia Works'.[208]

[208] West (1998) p. 106

Ibbotson: Globe Works, Penistone Road

Just as Greaves had quietly amassed the capital necessary for Sheffield's largest integrated works, so the Ibbotson Brothers, William and George, had built up over many years a successful business in cast steel, edge-tools, saws and other assorted products.[209]

William Ibbotson has been described as 'the veteran Free-trader', and was arguably the archetypal 'factor', as defined by Holland (above). His single-minded pursuit of profit and strongly held belief in the free market are evident in political pamphlets published by the manufacturer during the 1830s (dealing with issues such as the House of Lords' rejection of the Sheffield and Rotherham Railway Bill and workers' combinations in the file trade).[210] In view of his purely commercial priorities, it is surprising that the surviving warehouse of the Globe Works is one of Sheffield's most impressive and elaborate industrial buildings, and one which in its day put to shame many of the town's public edifices. [fig. 3.65]

The Globe Works was born of the same boom in trade as Greaves' Sheaf Works and was built to augment the Ibbotson Brothers' existing steelworks and manufactory in Bridge Street. William Ibbotson had been one of the first tenants of the Duke of Norfolk's semi-regular Coulson Crofts Estate, having taken a plot of 2006 square yards in the last years of the eighteenth century.[211] [fig. 3.66] By the 1820s the works had been extended backwards, absorbing a further block of the estate. It was arranged around a double courtyard, enclosed by furnaces and workshops, and with a pair of axial gateways leading from the street.[212] Immediately to the north lay the large Coulson Crofts Grinding Wheel (better known as the Soho–see chapter 4), while across the road was Marshall's Millsands steelworks. Ibbotson's trade soon outgrew even the enlarged site, by which time Coulson Crofts had become largely built up with steam powered factories and steelworks, so in 1823 the decision was made to erect new premises.[213]

The area chosen for the new works was known as Philadelphia, situated to the northwest of Sheffield just beyond the built-up area, and bounded by the turnpike road to Penistone (later Penistone Road) and Cleakham Wheel Road (later Cornish Street).[214] Historically a marginal,

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[209] Wardle & Bentham (1814-15) listed the firm in the category of Fender Makers 'Ibbotson, William & George & Co. Bridge Street'; Baines (1822-23) vol. 1, included: 'Ibbotson William and George & Co merchants, mfrs. of edge tools, fenders, saws, scythes, and steel refiners, Bridge st.'

[210] Leader (1879); Ibbotson (1835); Ibbotson (1836). The earlier publication, p. 17, contains an interesting metaphorical argument equating the House of Lords to the architectural ornamentation of an edifice, and suggesting that 'should the ornamental parts become too burdensome to maintain, that these splendid decorations may be chiselled off, and the building reduced to a simple Doric' This idea of a sharp distinction between ornament and structure is reflected in the 'embellishment' of the various buildings at Globe Works

[211] See the Fairbanks' master estate plan, SCA ACM SheS 1479L (1790) 'A plan of Colson Crofts describing the proposed streets and lanes', with additions made before 1802. The site to Bridge Street is labelled 'W^{m} ~~John~~ Ibbotson & Co., including half the two Back Lanes, 2006 sq. yds.'

[212] Aitchison (2001) p. 136. By the 1820s the works included a crucible steel furnace with 20 holes (SCA rate book 1821-22; FBC MB394 p. 20), and were ultimately taken over by W. I. Horn & Co. (SCA, rate books 1829-30, 1837-38).

[213] Compare the Fairbank (1808) and Leather (1823) town plans, indicating the level of development in Coulson Crofts. As the surveyor to the development, Fairbank seems to have exaggerated the completeness of the plan, some pockets of which were still undeveloped in 1823.

[214] The area was probably named after the nearby 'Philadelphia Place', seen on the Fairbank (1808) plan; by 1814 the adjacent water-powered Morton Wheel was known as the Philadelphia Works. Crossley (1989) pp. 12-13.

neglected part of town, the neighbourhood had recently begun to see substantial investment and improvements, stimulated by the construction of St. Philip's church, a product of the Church Building Act of 1818.[215] Ibbotson's plot was highly visible, facing the new churchyard across Shalesmoor, the ancient route into Sheffield that led into the turnpike road. [fig. 3.67]

The transformation of the area did not escape the attention of local poet James Wills, who commemorated the recent developments in his characteristic naïve verse:

Turn round to North West, where manure once was laid,
Stored with vermin, which often made children afraid,
Is now a magnificent entrance made,
Where ladies and gentlemen often parade.
Near which the Infirmary, and St. Philip's Tower,
The Roscoe and Moscow-works, and many more.[216]

A survey of the site, made just prior to the design and construction of the works, shows the extents of the large, roughly triangular 'building lot in Cleakham Wheel Road taken of Thomas Shepherd by Henry Ibbotson'.[217] [fig. 3.68] Not all of the land was required for the new complex, but had been acquired presumably with future expansion in mind. A formal, near-rectangular plot was set out with a 46 yard (42m) frontage to Penistone Road, intended for the imposing warehouse.

The first buildings

Construction was well underway in 1824,[218] and by the following year the works were in operation, and the firm entered in a contemporary trade directory (1825) as 'Ibbotsons and Roebuck, merchants and manufacturers of edge tools, joiners tools, fenders, saws, scythes, stove grates, &c. Globe Works'.[219]

In their basic layout, the buildings bore similarities to those at Bridge Street, divided into front and back courtyards connected by archways. [fig. 3.69] The front portion of the Globe Works was in effect a scaled-up version of the urban courtyard works, but with much higher

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[215] Holland (1824) pp 144-145, recorded that the foundation stone was laid on 26 Sept 1822, and the projected cost was £11,960 The 1818 Church Building Act contributed £1m to new parish churches, followed by further sums, and was partly responsible for the success of the gothic revival as the dominant ecclesiastical style (being cheaper to build than classical churches, which required a portico).
[216] Wills (1827) p 15. Of the 'Roscoe and Moscow-works', the former refers to Roscoe Place (see gazetteer) while the latter is an (unconfirmed) allusion to the Globe Works, after a visit made by Russian royalty
[217] SCA FBC SheS 843 L (1823) 'A Plan of the building lot in Cleakham Wheel Road taken of Thomas Shepherd by Henry Ibbotson', 1in. to 10yds. Also see the relevant field surveys FB 167, p 39; FB170, p 43; FB174, pp 10-12 Cleakham Wheel Road was later renamed Cornish Street, after James Dixon's famous 'Cornish Place' white metal and plate manufactory. See chapter 4 for the fate of the Cleakham Wheel.
[218] Sheffield rate RB193, SL 4B, Item 2 (1824-1825) p. 196. Includes the note 'Philadelphia. Messrs Ibbotsons & Roebuck–Ho W.H. & appts., Shops Castg. sh.s Hardning shops yd & appurtenance—find old rate. their premises not yet ready' By the following year, the same buildings are rated at £8 10s 0d RB194, SL 1B, Item 4 (1825-1826) p 196
[219] Gell (1825) p. 52 Also note that on p 51, 'Ibbotson William, merchant, Globe Works' is listed separately At this date, the firm W & G Ibbetson was still based at Bridge Street and Wisewood Works. Also see Crossley (1989) p. 40; Belford (1998) p 16.

aspirations.[220] Obvious parallels could also be drawn with Matthew Boulton's Soho Works near Birmingham. [fig. 3.70] In both cases, the warehouse building affected the characteristics of a stately home, although at the Globe Works the same block did actually include living quarters designed for Ibbotson and his family.[221] [fig. 3.71]

In common with the Sheaf Works (above), the symmetry and logic of the country house model was contradicted by the lack of a formal front entrance. Access to Ibbotson's office and warehouse was gained by a flight of steps to the side elevation, the main door announced by a semicircular portico at the top in an attempt to compensate for its unlikely position. Any residual sense of grandeur would have been quickly dispelled by the adjacent 'Pig stie, Cowhouse and Privies', built just inside the boundary wall to Green Lane.[222]

Additionally, where it was customary for the wings of a country house to project forwards, enclosing the forecourt and symbolically welcoming visitors, those at the Globe Works were reversed, as if to protect the private realm of the courtyards behind. As a gesture, it suggested introversion and secrecy, appropriate symbolism perhaps for an establishment purpose designed to be self-sufficient. On the other hand, Ibbotson may have other reasons to be protective. His aggressive capitalism was later to bring him to the attention of Friedrich Engels, who explained that:

> *Mr. Ibbetson* [sic] *had aroused hatred by active participation in bourgeois movements, by mean pay, the exclusive employment of knobsticks,*[223] *and the exploitation of the Poor Law to his own advantage (as during the crisis of 1842 he had identified to the Commissioners of the Poor any workers who refused to accept reduced pay as those who could get work but would not take it, and therefore not deserving of any relief, so forcing them to take a reduction.*[224]

In consequence, an anonymous attempt had been made to blow up the Globe Works on Friday 30 September 1843, one of a series of 'rattening' incidents around that time (see chapter 4). Engels added that 'the explosion did considerable damage, and all the workers who came to see it regretted only "that the whole business had not been blown up"'.[225] The deterrence of such incidents–known to have occurred since before the 1820s–was

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[220] The 1823 Fairbank survey includes two lines coincident with the northwest and northeast boundaries of the first courtyard, which had presumably been pegged-out on site ready for construction. It is possible that at this early stage, the works was intended to be on a simple square courtyard plan–as at Bridge Street–and only later broke out of its original envelope.

[221] Tweedale (1995) p. 53.

[222] SCA FBC MB395 (1835-36) 'Book F', p. 15. A clearer version of the same survey previously made in MB393 (1835) pp. 66-70, but with some measurements retaken and additional outbuildings indicated.

[223] 'Knobstick' was a term used to denote one who did not belong to a union, or a union member who worked during a strike; used interchangeably with 'blackleg' or 'scab'.

[224] Engels (1845) p. 266, translated by the author. 'Herr Ibbetson hatte sich durch thätige Theilnahme an Bourgeoiste-Bewegungen, durch niedrigen Lohn, ausschließliche Beschäftigung von Knobsticks, und Ausbeutung der Armengesetze zu seinem Vortheil (indem er während der Krisis 1842 die Arbeiter dadurch zur Annahme niedrigen Lohns zwang, daß er die Weigernden der Armenverwaltung als solche, die Arbeit bekommen könnten, aber nicht wollten, und also keine Unterstützung verdienten, namhaft machte) verhaßt gemacht'.

[225] Engels (1845) p. 266. 'Ziemlicher Schaden wurde durch die Explosion angerichtet, und alle Arbeiter, die ihn zu besehen kamen, bedauerten nur, "daß nicht die ganze Geschichte in die Luft gesprengt sei."'

increasingly a consideration in the planning of industrial sites, to which the courtyard form was better adapted than the earlier, dispersed plans of standalone buildings and fence walls.

Behind the warehouse, less well-built structures completed the courtyard, largely comprising two to three storey file, fender and saw shops. Instead of ashlar stone, rough dressed sandstone was used for the walls, with wide, functional window openings in stark contrast to the well-proportioned fenestration of the warehouse. Floor-to-ceiling heights were also minimal: the three storey shops built against the wings of the warehouse were actually lower than the two floors of the front building. Admittance to the first courtyard was gained by a single covered cart-way, set below and to one side of the warehouse portico, and overseen by a porter's lodge. Within the yard, external stairs gave direct access to upper storeys, and a centrally placed archway in the rear range (two storeys) led to the larger steelworks yard behind. Here the buildings were cheaper still, with only one side of the 'yard' initially completed, and the steel-melting furnaces built at the very back following the line of Cornish Street, breaking the otherwise rigid geometry of the site. [fig. 3.72, 3.73]

This rear yard was to become the 'dirty' side of the works, containing not only the steel plant, but also the 20 horsepower steam engine and grinding wheels that were soon to be built on its northwest side, in continuation of the original courtyard geometry. Other single-storey shops were erected within the space of the yard, either as lean-to structures or as freestanding sheds. These later buildings were of plain red brick, cheaper still than the dressed stone of the earlier courtyard. Seen from the side, the architectural quality of the works diminished on a gradient from front to back in accordance with the perceived importance of its various functions.

The diversity of buildings at Globe Works mirrored the surprising breadth of its product range, much of which was destined for the Americas.[226] In a trade directory of 1833, the firm was described as 'merchants, steel converters & mfrs. of edge tools, scythes, saws, files, fenders, & hay, straw & table knives, Globe Works, Penistone Road; & tilters & rollers, Middlewood'.[227]

It was not unusual for firms specialising in cast steel manufacture to also offer fenders and stove grates, articles elsewhere more likely to be associated with iron foundries. From the 1820s a fashion had developed for iron fenders with polished cast steel inlays, and especially those 'most superb and expensive articles, composed of ground, glazed, or polished steel' alone.[228] Such products were cast in moulds and finished first by filing (in the fender shops), and then by grinding and buffing in the grinding wheel.

Another of Ibbotson's less common product lines was the so-called 'patent scythe'. Scythes were traditionally heavy items manufactured in the countryside, by first welding a cutting edge

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[226] Leader (1879). Ibbotson Brothers were said to be 'one of the first firms in Sheffield which established an extensive trade in saws and cutlery with America'.
[227] White (1833) p. 215. Robson (1839) adds steel refining and the manufacture of 'Felter's rollers' (for flattening felt, also presumably made of cast steel).
[228] Holland (1853) pp. 190-191. Such stoves were said to 'constitute the principal feature of attraction in the London and Sheffield showrooms'.

of shear steel (or for cheaper goods, simply blister steel) onto a back of iron, before grinding on the specially large stones particular to this branch of manufacture. Ibbotson's 'patent' scythes, on the other hand, were:

> *...composed of a web of cast steel, cut from the sheet with shears, to the proper shape, and then riveted to an iron rib or back. This web is carefully hardened, tempered, and ground before it is attached to the back.*[229]

The product had some advantages, largely derived from the use of a superior quality of steel, but its intrinsic flimsiness made it unsuited to cutting thicker stalks. Ibbotson, however, was unrestrained in the bold and unusual claims made for its capabilities: the cutting edge was said to be:

> ...equal to the best made razor *from the most approved and eminent manufacturer...These scythes are warranted so hard as to cut the iron part of* an anvil, *properly directed, with little injury to the edge; yet of such elasticity that, when separated from the back, they may be rolled up a hundred times, and put into a man's hat, and still return to their original shape.*[230]

It is easy to see how such marketing talk won the company considerable trade in America, while new techniques were adopted primarily to bypass the traditional, union-bound labour back at home. Unlike the old style scythe, Ibbotson's cast steel web could be ground on a smaller stone in his own grinding-wheel, while assembly was as simple as riveting the metal strip to its iron frame, something that could be undertaken by low paid, semi-skilled operatives.

Development: 1825-1852

A first pair of cementation furnaces and iron house was added to the works plant in 1832, followed by another pair–dovetailed into the same shed as at Sheaf Works–about three years later.[231] [fig. 3.74] Their location at the back of the site was significant, as it was the first sign of the works breaking out of its orthogonal confines, spilling over into an adjacent field.[232] Extra steelmaking capacity was needed not only to service the firm's own manufacturing requirements, but also the growing North American market for steel as a commodity in its own right. While great profits could be made from the sale of high quality tool steel, for Sheffield's toolmakers this trend presented new problems. William Ibbotson admitted to the *Sheffield*

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229 Holland (1853) pp. 54-55. Note that the use of the term 'patent' did not signify that the article had been patented by Ibbotson or produced under licence, but was used promiscuously as an indicator of quality along with such words as 'best', 'warranted', etc. Holland was especially irritated by this disreputable use of the word, evidenced by his diatribe on the subject.

230 Holland (1853) pp. 54-55. At the Great Exhibition of 1851, Ibbotson Bros. & Co. had displayed a 'Cast-steel scythe rolled up, to show its elasticity'. Ellis (ed.) (1851) vol. 2, p. 614.

231 Timmins (1977) appendix III, p. 264; SCA FBC MB393, pp. 66-70. A note in pencil reads '2 new converting furnaces', indicating their approximate location. This is confirmed by the 1850 OS plan, 6":1 mile.

232 On a Fairbank survey made after this extension, the original site boundary is still indicated by a dashed line, clearly breached by the new buildings. SCA FBC MB393, pp. 66-70.

Mercury of 20 November 1841 that as a manufacturer of cast steel he was 'sending steel to cut himself out of the market [for edge tools], but he could not avoid doing so. He was obliged to sell what the Americans were willing to purchase'.[233]

From the 1830s, additional buildings began to be constructed around the perimeter of this new plot, with file and scissor shops fronting Penistone Road, a screw shop along the northwest boundary, and a blade-maker's shop to the back lane, alongside the cementation cones. [fig. 3.75] Also in the new yard, a three-storey extension to the grinding wheel had been built back-to-back with the existing structure, powered from the same engine-house.[234] [fig. 3.76] The engine itself had to be upgraded to cope with the additional load; by 1851, a unit manufactured by Davy Bros. of Sheffield was said to be 'working up to 80 Horse power', or four times the original rating.[235]

Initially, this second plot resembled an open field, lacking the definition of the other yards. As more functions were added, it too became subdivided into two distinct zones partitioned-off by a long range of single-storey hand-forges. To one side was a long, narrow wheel-yard that related to the additional grinding hulls, and onto which the forge shops also opened; to the other was a large open space (probably used for general storage) bounded on two of its sides by the backs of the hearths and various other shops. [fig. 3.77] Access between these yards was maintained by an archway cut centrally into the row of forges and defined by an intersecting gabled portion of roof.

While some of the Globe Works' fixtures were dedicated to specific uses–the steel furnaces and grinding wheel, for instance–many buildings contained more generic spaces, suitable for a wide range of manufactures. This enabled Ibbotson to offer an extensive product range, shifting production to meet the often volatile needs of the market. On the other hand, such spaces could be inadequate working environments.

In construction also, many of the buildings had a distinctly ad hoc quality that owed more to economy than to functional expediency. Some structures seem to have been completed with whatever materials were closest to hand; the stone walling to Penistone road was topped by large rounded copingstones made of halved 'grindle-cokes', or worn-out grindstones.[236]

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[233] Tweedale (1995) p. 41.
[234] The new hulls were more spacious than the first, and intended for heavier grinding troughs: a note on the survey reads '*on ground floor scythe and grinders shops above*'.
[235] SCA MD717 (1851) Soho Wheel Minutes, June 5. The proprietors of the Soho Wheel were given a quote for a steam engine 'the same as Mr. Walker's [of Walker Eaton & Co., stove grate makers] at Globe Works for £780'. For Walker and Eadon see Morley (1997) pp. 126-127.
[236] These can still be seen from the street; recycled grindstones were a less usual wall-topping than 'crozzle', a sharp, vitreous by-product of the cementation furnaces. See also Aitchison (2001) p. 161, in collaboration with the author

Later uses of the site

Ibbotson Bros. had been badly affected by successive financial crises, beginning in 1837.[237] Although the firm remained solvent, by 1845 the Globe Works had passed into the hands of the Sheffield and Hallamshire Banking Company. William Flockton, local surveyor and architect, valued the property in July of that year, and came to the conclusion that no single firm would realistically require the works buildings as they stood, especially with the short term of lease remaining. Instead, he proposed that the works be subdivided into four smaller lots for sale with their freehold, each tailored to a different branch of manufacture (see appendix 3.5).[238] [fig. 3.78] One lot contained the original courtyard development with warehouse and grinding wheel, and was recommended for a mercantile manufacturer; another consisted of the steelmaking plant at the back of the site, Flockton adding that 'as premises of this description are in request just now, a customer would soon be forthcoming'.

By the following year, Flockton had received instructions to value the works as one lot;[239] ultimately, however, Flockton's intuition was to prove correct, as the works were never again to be occupied by a single tenant, and later sub-lettings apportioned the site largely to his plan. [fig. 3.79]

On Ibbotson's death in 1852, further reorganisation took place, the works' steelmaking plant reoccupied by W & S Butcher, as part of their diverse steelworks empire (discussed further in chapter 2). The Ibbotson firm also remained at the site until 1863, when they consolidated their premises to the nearby Globe Steel Works, on the site of the old Workhouse.[240] Their immediate successors were John Walters & Co., a well-established firm of cutlers, who had occupied part of the works from 1852, and on Ibbotson's departure took over most of the site. By 1865, however, Walters' firm had vanished, replaced by Unwin & Rodgers employing about 150 on-site (not the entire premises) with several smaller manufacturers in the workshops to the rear.[241]

This pattern of multi-occupancy characterised the remainder of the works' history: by 1978, when a serious fire led to its final closure, over seventy different firms could be counted as tenants of the Globe Works.

A major restoration programme, costing £1.5 million, resulted in the reopening of the warehouse as a public house (aptly named the 'Ratteners' Rest') and attached museum. The conversion was short-lived, beset by similar problems to the Sheaf Works, and likewise reoccupied as offices and workshops.

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[237] Tweedale (1995) p. 35, notes that Charles Cammell, a traveller for Ibbotson Bros., had left in 1837 to become a partner in the steel, file, and merchanting business later to bear his name. Also Stainton (1924)

[238] See Flockton's valuations, SCA SYCRO 141/B, pp. 138-9, 156, 177-185, 213 (dates from 1845-52).

[239] SCA SYCRO 141/B, p. 156. The entry is dated 30 July 1845 as the earlier valuation, but was copied into Flockton's valuation book around March 1846.

[240] Caulton (1997) pp. 177-179; Aitchison (2001) pp. 60-61.

[241] Unwin & Rodgers stayed until 1911. Another longer-term tenant was the sheep shear manufacturer Ball Bros., present between 1882-95. Tweedale (1996) p. 287; Hawley (1992) p. 86.

Chapter 4: Sheffield's industrial revolution–the arrival of steam

Abstract

A generally underestimated influence on Sheffield's urban and industrial growth came with the introduction of steam-power in the late eighteenth-century. This chapter shows that, far from being latecomers in the adoption of steam as a prime mover, Sheffield firms were at the forefront of developments, utilising some of the earliest rotative steam engines pioneered by Boulton and Watt as an alternative to water-power. The resulting 'steam wheels' were the giants of Sheffield's industrial buildings, yet they have remained largely unknown due to the unusual circumstances of their construction and operation.

This chapter attempts to fulfil the need for a detailed study of the adoption of steam-power in Sheffield, identified by Crossley in his landmark study *Water power on the Sheffield Rivers*.[1] The development of the earliest 'public' wheels is traced, as well as the social and environmental impact of this emergent building type. A reappraisal of their location and design, and in particular the importance of the town's rivers and ancient network of watercourses, concludes the study.

Other uses of steam-power, including rolling mills and tilt or steam-hammers, and the role of the small engine in the town's tenement factories, are also addressed.

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[1] Crossley (1989) p. xiii.

Part 1: Early grinding wheels

The mighty arm of mist, that shakes the shore
Along the throng'd canal, in ceaseless roar
Urging the heavy forge, the clanking mill,
The rapid tilt, and screaming, sparkling stone.

Ebenezer Elliott, Steam at Sheffield.[2]

Cutlers' wheels harnessing the abundant water-power of Sheffield's rivers are known to have existed since at least the sixteenth century. As early as 1604, there were at least 28 'Cutlers' Wheeles' held on rent of the Earl of Shrewsbury, and a similar number was listed by Harrison in his 1637 survey of the township, said to be tenanted by 'four or five hundred master workmen'.[3] Generally their location out of the town reflected the availability of sites with sufficient water-power, and to a lesser extent the supply of grindstones from the Derbyshire quarries. Even the sites most closely connected with the town and recorded on the earliest maps–Kelham Wheel, the Wicker Tilt, Castle Orchards Wheel and the Ponds Forge–belonged to an essentially rural type, built at the outer limits of the settlement.[4] [fig. 4.1]

This predominantly rural setting was paralleled in the pre-industrial work patterns of the wheels' occupants. Before the eighteenth century most cutlers and edge-tool makers did much of their own grinding, hiring places at the country wheels as and when needed.[5] The emergence of a specialised class of grinders was a gradual process, although it predated the introduction of steam-power and the factory system by several decades. As early as 1714, the terms of one apprenticeship dictated instruction 'only in grinding and glazing knife blades'; in 1748 a 'Grinders' Sick Club' was established, but only following the statute of 1791 was a positive distinction made between 'makers' and 'grinders' of metal wares in the terminology of the Cutler's Company.[6]

Over the same period, the number of wheels continued to grow, until by 1770 there were 133 distinct sites providing places for almost 900 cutlers and grinders.[7]

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[2] Elliott (1876) vol. 1, pp. 352ff. The poem was written during the 1830s, the 'heyday' of Sheffield's steam revolution, see Warburg (1958) p. 17.

[3] Leader (1905) vol. 1, p. 11; Crossley (1989) p. vii, Miller (1936).

[4] Kelham Wheel occupied fields to the north of the town, close to the flood-plain of the Don, Castle Orchards similarly so, but to the northeast. The Wicker Tilt was located on the opposite side of Lady's Bridge, while Ponds Forge was built on stagnant marshland just to the west of the river Sheaf. None could be considered to lie within the town at the time of construction.

[5] Knight (1822) pp. 5-6, in tracing the history of the 'Grinder's Asthma', stated that: 'Until the beginning of the last [i.e. eighteenth] century, grinding was not a distinct branch of business, but was performed by men who were also engaged in various other departments of the cutlery trade...[but from the mid-century] an important change took place in the division of labour, and grinding became the sole employment of the grinder'.

[6] Leader (1905) vol. 1, p. 38. He noted that scythe grinding, one of the heaviest trades, had been an occupation in its own right since the mid-seventeenth century. Hall (1865) p.11, on the other hand, linked the segregation of the trades to the appearance of the first steam-powered grinding wheels.

[7] Lloyd (1913) pp. 179, 443; a total of 896 troughs. See appendix 4.1.

The water-powered grinding wheel may have been an original invention of the town;[8] outside of Sheffield, only the German town of Solingen achieved a similar degree of specialisation, and then not until the nineteenth century.[9] Elsewhere, mechanically powered Grinding wheels were less common, cutlers relying instead on the traditional treadle-driven grindstones that had existed since the medieval period.[10] So close was the relationship between industry and the rivers, that one local writer described the Sheaf and the Don as 'the "Abana and Pharpar" of the modern Damascus'.[11]

The prevalence of water-powered grinding wheels in Hallamshire may have been a result of one of the earliest ordinances of the Cutler's Company, which specified that items with a cutting edge were to be made of steel only, which compared to iron would have required faster stones. With the advent of crucible steel, the advantage of powered wheels became more important still, particularly for articles such as razors where a significant proportion of the rough forging had to be ground off.

Commonly, the power output of a water wheel on the Sheffield Rivers was relatively low, equivalent to between two and fifteen horsepower and averaging no more than ten (or enough to turn fifteen heavy grindstones).[12] This was not a technological limitation of water-power–Vickers supply of water to the Town Mill was calculated to be sufficient for 100 stones–but a reflection of the artisan-led industry, still based in the backyards of the town, in which larger scale operations were not economically viable.[13]

From an early date the grinding wheels of Hallamshire constituted an identifiable building type, with many features particular to the district. The anatomy of a grinding wheel–whether powered by water or steam–consisted of the same basic elements, each of which had undergone centuries of refinement and was known by local names specific to the trade. John Holland's *Treatise* defined the primary units:

> *Internally the building is divided into* hulls, *and these into* troughs; *the former consisting of one room, the latter comprising a single range of grinding accommodations.*[14]

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[8] Defoe (1724-27) was of the opinion that 'here the only mill of the sort, which was in use in England for some time was set up, (viz.) for turning their grindstones, though now 'tis grown more common'.
[9] Schellhammer (1993) *passim.*; Jessop (1791) p. 21, refers to a 'Grinding Wheel' on the river Thames at Abingdon. St Etienne en Forez in France also developed a specialisation for grinding metal wares. Fougeroux de Bondaroy (1772) *passim.*, Le Play (1855) p. 152.
[10] Lardner (1831) p. 301, for example, noted that manual methods of grinding files without wheels were adopted 'in Lancashire and other places where grinding wheels are not common'; Pollard (1959) p. 51, noted that manually-powered stones had disappeared from Sheffield by 1850
[11] Holland (1831) p. 289, from ch. 18 'Grinding'.
[12] SCA FBC CP25-32; NB34 (1831)
[13] SCA FBC NB3 (c 1790?) p. 17, 'John Vickers' Town Mill Grinding Wheel has 33 Troughs and it is supposed that the corn mill has power equal to 67 Troughs...in other words the Stream is sufficient for 100 Troughs at £5 each'.
[14] Holland (1831) p. 289. In earlier water-powered wheels, the building housing the hull was also known as an 'end'. Hall (1865) p. 11, noted that the literal meaning of the term 'hull' was a 'stye', adding that 'a visit to many of these places would convince you, Sir...that a more happy or appropriate appellation could not possibly be selected'.

A trough (or 'trow'), therefore, referred not only to the cast-iron container set partly into the floor in which the grindstone spun (sometimes in water), but also to a group of stones and wheels set one behind the other and powered by leather belts (wheel-bands) from a drum at the back of the hull, attached to the main drive shaft.[15] [fig. 4.2] The largest stone was invariably at the front, closest to the windows that were the only source of light, and was partly enclosed by a timber structure known as the 'horsing' astride which the grinder stood as he worked. [fig. 4.3]

The grindstones were supplied to the grinder rough-cut from the nearby quarries, and required some finishing by mallet and chisel (usually performed in the wheel-yard) before they were ready for 'hanging' and 'racing' (see below). Worn or uneven stones would also be reshaped in this way, with cuts made across the face to improve the 'bite'; thus a grinder's work demanded some of the skills of the stonemason.[16] [fig. 4.4]

For table knife grinding, the new stone measured about four feet in diameter with a face of around nine inches; this might last ten weeks before it had to be replaced, by which time its diameter would have been reduced to just twenty inches. The used stone was never wasted, but could be split into halves along its width, becoming instantly suitable for scissor grinding; stones were thus passed down the hierarchy of trades by scale, ending with the 'mere *grindle coke*, as it is called,–the *ne plus ultra* of razor grinding, being the use of a "four-inch stone."'[17]

Beyond the variation in stone size, most branches of grinding were fundamentally similar; modifications to the basic arrangement occurred in saw grinding, which used the largest stones (five to seven feet in diameter) and sometimes required cords to suspend the ends of large items from the ceiling, and scythe grinding in which a similarly large stone revolved towards, instead of away from, the grinder.[18] [fig. 4.5] The dry stones used for razors and scissors were also often to be found arranged in rows on the upper floors of grinding wheels, rather than as part of a traditional trough. [figs. 4.6, 4.7]

The occupation was not without its dangers, the most catastrophic of which was the liability of the grindstone to shatter at high speed and without warning–often due to internal flaws in the

[15] Hall (1865) p. 12, provided a good summary of the various wheels: 'Each trough has several divisions - one for the stone, one for the glazer, the lap, and the polisher. The Glazer is a wooden wheel, which varies in size from four inches to four feet in diameter: it is covered with leather. This is "dressed" over with glue and emery, and when this application has set the surface is rubbed with emery-cake, which is a composition of emery and bees'-wax. The Lap is a wooden tool faced with lead, on which the sides of penknives, the sides of razors, and the flat sides of the better finished scissors are rubbed to give them a flat surface... The Polisher is placed at the back part of the hull. It is smaller in size than the wooden wheel already described. It is covered with leather, and made to revolve much more slowly than either the grinding stone or the glazer. If it revolved rapidly the blades either of the knives or the razors that were undergoing the process of polishing, would become heated, and the fine temper of the steel destroyed' White (1858) p. 366: 'At their work the men sit astride on a low seat in rows of four, one behind the other...'

[16] Holland (1831) vol. 1, p. 290: 'When, either from use or inequality of texture, the stone becomes more worn on one part than another, the prominency is reduced, and the whole surface of the stone chopped with cross lines to make it cut faster, by means of a hack hammer'.

[17] Holland (1831) vol. 1, pp. 290-291.

[18] Holland (1831) p. 337. Saw grinding also demanded an unusual working position: 'It is not easy to conceive the idea of muscular exertion, imminent danger, and peculiarity of attitude [of] a saw-grinder when at work, standing on tiptoes over a great grindstone revolving with a fearful rapidity, his arms outstretched towards the extremities of the board under which lies the saw, and pressing against it with his knees to keep it in the closest contact with the surface of the stone'. In France at the grinding-mills of St. Etienne and Thiers the *meulieres* (grinders) lay on their fronts facing a stone powered by a central waterwheel. Fougeroux de Bondaroy (1772) pl. 3; Lloyd (1913)

stone or incorrect 'hanging'–often injuring or killing the unfortunate workman. Little could be done to prevent such accidents, although the practice of chaining down the horsing to the floor in an attempt to lessen the risk of serious injury was widespread by the second half of the eighteenth century.[19]

Less spectacular, but much more lethal, was the condition termed the 'grinder's asthma', or what would today most likely be considered a form of silicosis, aggravated by tuberculosis.[20] Its onset was rapid and relentless: in certain branches of the trade–fork grinding, for example–the average age of death was under thirty years.[21] Dry grinders were more at risk than those who worked at the wet stone, although the latter were exposed to stone dust during the preparatory process of hanging and racing a new stone, which took around half an hour and entailed the smoothing of its surface using an iron tool.[22] Moreover, dry and wet grinders could often be found working side-by-side in the same hull, exposing all to the same risk. From the 1820s, mechanical fans were introduced into some hulls, comprising a hood over the stone into which the dust was drawn, connected to ductwork by which it was conveyed out of the hull.[23] [fig. 4.8] Despite its simplicity and effectiveness, there was considerable resistance to its use, not coming into general use until the late nineteenth century.

Consequently, the grinders were among the highest paid of all British artisans, Arthur Young noting in 1770 that earnings of '18s 19s and 20s a week, are common among them; but this height of wages is owing in a great measure to the danger of the employment'.[24] Some branches, such as the razor grinders and polishers, could earn around 10s 6d each day, considered by Young to be 'Surprizing wages for any manual performances!'[25]

Understandably, few grinders needed to put in a six-day week, and some chose to work only three, an extension of the widespread pre-industrial tradition of 'St. Monday', and 'St. Tuesday'.[26] Facing the prospect of chronic illness and an early death, many grinders chose to live for the day, freely spending their pay at the town's innumerable public houses. In fact, it was widely believed that alcohol staved off the worst effects of the disease, a misunderstanding that was not entirely groundless, as explained by a local doctor in 1822:

> *The grinders are in general aware that their life must be short, and many of them think it ought least be merry; hence they abandon themselves to habits of*

[19] Young (1770) p. 133. '. . accidents used to be more common than they are at present; of late years they have invented a method of chaining down an iron over the stone in such a manner, that . the pieces of stone can only fly forwards, and not upwards; and yet men by the force of the breaking have been thrown back in a surprizing manner, and their hands struck off by shivers of the stone'; see also Holland (1842) p. 175; Hall (1865) p. 14
[20] Knight (1822), Hall (1857) p. 26; Hall (1865); Pollard (1959) pp. 62-64.
[21] Hall (1857) p. 22. 'The average age of the fork grinders at these wheels was only 28. At the Soho wheel, a fine young man, a fork grinder, aged 26, remarked, "that he reckoned, in about two more years, at his trade, he might begin to think of dropping off the perch;" adding, "A fork grinder is an old cock at 30"'
[22] Hall (1865) pp. 14-16.
[23] Elliott (1822) *passim*.; Knight (1822) pp. 5-8; Hall (1857) pp. 15. 22ff.; Woodbury (1972) pp. 27ff
[24] Young (1770) pp. 132-133.
[25] Young (1770) pp. 133-134
[26] Aspinall (1949) doc. 6, p. 4, cites a report of 1792. The practice was also prevalent in the Midland nail industry Court (1938) p. 206 and among Leicester framework weavers, Patterson (1954) p. 48

intemperance and dissipation; and it is a melancholy fact, that the dissipated sometimes live the longest,–not that dissipation is beneficial to their health, but because it is less injurious than the dust of the grinding-wheel, to which such characters do not unnecessarily expose themselves.[27]

Recent excavations at the site of Vickers' Town Mill support the documentary evidence. Grinders appear to have been an affluent class, purchasing high quality goods usually affordable only to the gentry and emerging middle classes.[28]

To the outsider, however, the grinders were often no more than characters in the curious diorama of the cutlers' wheel, set in the picturesque Peak scenery. The short novel *Tom and Charles* set an early example, Samuel Roberts describing the grinders as:

...a rough half-civilized class...seen near every wheel, which, taken with the surrounding scenery, form such subjects as are well fitted for the pencil of a Salvator. Athletic figures, with brown paper turbans, the sleeves of their shirts rolled high up, exposing their brawny arms bare almost to their shoulders, their short jackets unbuttoned, and their shirt collars open, displaying their broad, dark, hairy chests; their short leathern aprons, their breeches' knees unbuttoned, and their stockings slipped down about their ankles, the whole tinged with ochre-coloured dust, so as to leave the different colours and materials faintly discoverable, form a figure, even when taken singly, sufficiently picturesque; when grouped, as they generally are, they become strikingly so.[29]

It is easy to see the appeal of the pre-industrial grinding works, with its human scale waterwheel and minimal mechanism; power was transmitted by simple leather belts looped around wooden drums, spaced at intervals along the sturdy timber driveshaft on iron bearings. Each drum usually served a pair of parallel troughs, separated from the next pair by a narrow walkway without the benefit of safety guardrails or boxing; individual grindstones could be stopped by disengaging the leather band at the front pulley.

To attempt an architectural survey of the water-powered grinding wheel, already covered in considerable depth by Crossley (1998), is beyond of the scope of this study, but a brief summary of their typical features makes a useful comparison to the later steam-powered type.

A plan prepared by the Fairbanks for a pair of hulls at Wadsley Forge may be taken as a typical example of its kind, with a central (overshot) wheel-pit powering a single run of

[27] Knight (1822) p 7

[28] Artefacts recovered from the goit included a variety of elaborate pipes, etc. Andy Lines of ARCUS likened the grinders to the 'Loadsamoneys' of their day, fast living and extravagant. Lecture delivered to the Five Weirs' Walk Trust, winter 2001

[29] Roberts (1868)

shafting to either side.[30] [fig. 4.9] A system of gearing made up of spur wheels and mortise wheels multiplied the revolutions of the waterwheel (c.6rpm at Shepherd's Wheel, below) by about a factor of twenty.[31] Within the hull, stones of different sizes could be accommodated by fitting a pulley of the appropriate diameter. The two hulls proposed for Wadsley were basically symmetrical, each containing five troughs accessed from the front. Windows, doors and hearths are not indicated, but a wide access way in front of the stones was the main circulation space, probably entered at either end. The double-thickness back wall of the building may have been built into the embankment of the millpond, acting as a retaining wall.

Of the few surviving examples, Shepherd's Wheel on the Porter (properly the Porter Wheel) best captures the qualities of the early industry. Here, the main hull was augmented by a second 'end' built to face the opposite direction, in response to the tightly constrained site between river and dam embankment. [fig. 4.11] Internally, both spaces are simple rooms with whitewashed sandstone walls, open to the thick stone slates of the roof. The hearth is the focus of the space, built alongside the single doorway into the hull and facing the walkway in front of the stones.

Although the waterwheel is housed externally, an opening in the back wall for the gearing makes its presence strongly felt in the main hull. Outside the wheel, various structures have been improvised from the materials close to hand, notably a stairway composed of used grindstones laid flat. Stones were also used as impromptu seating and tables in good weather, and as elevated platforms around the hearth for drying-out ground blades as at Shepherd's Wheel.[32]

There is a manageability about these old sites: repairs could be made with readily available building materials, and being as a rule single storey structures (often sunk into the ground) every part of the building was accessible to its occupants. [fig. 4.10] The machinery, likewise, once installed was straightforward enough to admit of ready maintenance and repairs. Only major works, such as the formation of reservoirs and embankments, stone-setting for goits and structural modifications to the roof and walls regularly appear in the building books of the Fairbanks, contracted out to local masons and joiners.

The transition to steam

In cotton mills, steam engines had first been applied in conjunction with water wheels, to raise water from the tailrace back up to the reservoir (also known as a 'throw-back' engine),

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30 SCA WC1806M (1812). The building was atypical in having an internal waterwheel and avoiding the use of a crown wheel (i.e. one with teeth set into the face, to transfer the rotary motion through 90 degrees). This was perhaps a concept borrowed back from the steam-powered wheels. The wheel must have been overshot to turn the stones the correct way, away from the grinder.

31 Steam engines tended to turn more rapidly than waterwheels–typically 17 rpm as at the Park Wheel (below)–so the gearing would multiply this by a factor of 8 to 14.

32 The hearth was both a social focus and a necessary source of heat; drying blades after wet grinding could prevent the onset of oxidation before they were returned to the cutler. Domestically, worn-out stones or 'grindle-cokes' were also used beside the fire for cooking upon. [fig. 4.12]

allowing for more constant use of the limited resource.[33] No instances are known of this technique being adopted in the Sheffield area, probably due to its unjustifiable expense in relation to the smaller size of water-powered unit common to grinding wheels and tilts.

Even with its extensive network of rivers, many of the town's cutlers had difficulty in finding suitable space at the local grinding wheels; by the end of the eighteenth century on some stretches of river, consecutive water-powered works lay no more than 200 yards distant from the last.[34] Combined with the reluctance of workers to travel excessive distances to work (few actually lived in the valleys close to the wheels), this meant that closer to the town the rivers were effectively full.[35] Furthermore, in the summer months drought could limit the length of the working day or even stop the wheels entirely, while conversely the height of the rivers during wet periods often made it dangerous to run the waterwheel.[36]

Some efforts had been made to find solutions to these natural limitations, one of the most ambitious being a scheme of 1785–the year before the opening of the first steam wheel–which proposed the creation of a huge dam at Deadman's-ford, several miles above Penistone.[37] Intended to cover thirty acres of ground to an average depth of three yards, it was suggested that the water collected during the winter would be sufficient to meet the needs of the grinding wheels in the summer. Due to technical difficulties, but also perhaps as a consequence of the arrival of steam, the scheme never left the drawing board.

From its arrival in 1786, steam-power made slow but substantial progress alongside the water-powered sites, at first augmenting the traditional wheels, but later increasingly supplanting them. The first three wheels alone powered 320 troughs by 1794, and by 1805 these numbers had more than doubled, beginning a period of exponential growth (see appendix 4.1). Despite the ill effects of the Napoleonic Wars, the German Factory Commissioner J G May, visiting Sheffield in 1814, found that:

> *On the banks of the Sheaf and the Don are many works for forging, slitting, rolling and grinding iron and steel. Steam engines have been installed in many of these ironworks...Some grinding mills and rolling mills are run by individuals while others are operated by groups of partners. There are workshops which are*

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[33] Fitton and Wadsworth (1958) p. 80, 107. Connell (1990) p. 192.
[34] Crossley (1989) pp. viii, x; in 1794 the average density over all five rivers was around four mills per mile.
[35] Beauchamp (1996) pp. 56-57, analysed the distance travelled to work as given in the flood claims of 1864; less than one percent of the sample group of 841 men lived over two miles from work.
[36] See, for example, Joseph Mather's song 'The Grinders' Hardships', Mather (1862) p.112:

> *It happened in the year eighteen hundred and five*
> *From May-day to Christmas the season was quite dry,*
> *That all our oldest grinders such a time never knew,*
> *For there's few who brave the hardships that we poor grinders do.*
> *In summer time we can't work till water does appear*
> *And if this does not happen the season is severe:*
> *Then our fingers are numb'd by keen winter frosts or snow,*
> *And few can brave the hardships that we poor grinders do*

[37] Holland (1837) vol. 1, pp. 44-45.

leased for a particular period so that customers can hire facilities for doing their own grinding and rolling.[38]

The latter were the public grinding wheels and mills, largely responsible for the uptake of steam-power in Sheffield during the first decades of the nineteenth century. When the architect Karl Friedrich Schinkel visited the town in 1826, he took away the impression of 'smoke from hundreds of tall obelisks. Grey, smoke-filled town built on hills and in valleys, the fires of many furnaces visible in the distance'.[39]

Certainly by the 1830s, it could confidently be stated that 'the agency of water has since been in great measure superseded in our large manufactories by the use of that more certain and efficient power–steam', although for a time the smaller water-powered grinding wheels continued to outnumber the steam wheels by site if not by capacity.[40] Many of these had also installed steam engines to augment, or occasionally to replace, their waterwheels; one of the first was Kelham Wheel, converted back to a grinding wheel in 1815 after a short-lived spell as a cotton mill.[41] [fig. 4.13, 4.14]

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[38] Henderson (1968) ch 4. pp. 152-3.
[39] Bindman (1993) p. 140. recorded by Schinkel in a diary entry of 29 June 1826.
[40] White (1833) p. 54, added that 'the grinding wheels of Sheffield alone, now possess the aggregate strength of 700 horses. There are now upwards of twenty steam wheels in the vicinity [and] upwards of forty water grinding wheels, but they are much smaller than the steam wheels'. Holland's later statement: 'The wheels in which they work are mostly propelled by water', has been misinterpreted as meaning that the *majority* of grinders still worked at water-powered sites. Holland (1843) p. 174. See appendix 4.1.
[41] SCL sale plan 13. AP1815; Crossley (1989) pp. 14-15.

Public wheels

The grinding wheels are amongst the most curious and characteristic of the manufacturing sights of Sheffield. The stranger looks in through the open door or window, and, after he has grown accustomed to the confused hubbub caused by the whirling and rattling of the machinery, the hiss of the steam-engine, and the noise of the grinding, he examines with lively interest the "wheel" and its occupants. The whole place is tinged with a peculiar brownish yellow hue, caused by the particles thrown off from the stones on which the blades are ground. These stones are revolving rapidly, and at each of them sits a workman, his hand grasping the steel, which, held dextrously to the surface of the stone, sends forth a continuous shower of sparks.[42]

Before the emergence of the heavy steel industries of the Don Valley, the 'public' steam-powered grinding wheels were the giants of Sheffield's industrial landscape, concentrated largely around the town centre.[43] Despite their size and number, towards the end of the nineteenth century they had largely disappeared from sight, and have subsequently been neglected by most historical surveys.[44] This obscurity can be ascribed to a number of factors. The majority of public wheels were constructed during the three decades spanning 1790 to 1820. Due to the cost of the steam engines required to power them, and also to the size and expense of the buildings themselves, the largest wheels represented considerable investments (often running to several thousand pounds)–greater than could be financed by most individual firms.[45] Consequently, they were usually established by groups of speculators each able to invest smaller sums in shares of the building.

The designation 'public' also meant that no single manufacturer tenanted the grinding space, but that individual troughs or hulls were hired out at a fixed rate to journeyman grinders or companies employing grinders.[46] Even so, public wheels were not usually advertised in the local press or trade publications; demand for places often exceeded the available capacity, and was restricted to the grinding trade, within which information was exchanged by word of

[42] Pawson & Brailsford (1862) p.136.
[43] See gazetteer
[44] No national surveys of industrial buildings or mills make reference to steam-powered grinding wheels, in spite of their close affinity with the eighteenth century textile mill and warehouse family of structures. Of the few local studies to include steam grinding wheels, Johnson (1959) pp. 17-20 briefly summarised the history and characteristics of the Union Grinding Wheel subsequent to its demolition in the same year, while Pollard (1959) was the first to seriously consider their importance to the economic and social development of Sheffield. Later scholarship has not significantly expanded upon these accounts, and even the recently published RCHME report affords only marginal coverage
[45] For the prices of Boulton & Watt's rotative steam engines in 1795, as commonly used in Sheffield's grinding and rolling mills, see the table given as appendix 19 in Roll (1930) p. 312. A typical 20 horsepower engine was listed at £940, while a 50 horsepower model (the largest listed) cost as much as £2109.
[46] For the terminology particular to Sheffield's grinding wheels, see Bywater (1839) pp. vii, 149-150, Pollard (ed.) (1971) p. xviii; definitions relating to the buildings and fittings may be found in the glossary

mouth.[47] For the historian, this means an almost complete absence of visual and printed sources of the kind that private firms were accustomed to produce (advertisements, entries in trade directories, brochures, photographs).

At the commencement of the Coulson Crofts or Soho Wheel in 1805, the new public wheels accounted for around a third of the total number of troughs in Hallamshire: by 1820, urban steam-powered sites had overtaken the capacity of the waterwheels on all of Sheffield's rivers.[48] Unlike the smaller watermills, these numbers were dominated by a handful of giant wheels, so that in 1857 it was estimated that up to eighty percent of Sheffield's grinders worked in just ten of the principal establishments.[49]

During the second half of the nineteenth century, however, as steam-power became less expensive and a number of larger cutlery and tool-making houses began to emerge, the demand for public grinding wheels diminished. As the old mainstays of the industry became unprofitable for their shareholders, they were sold off to the best advantage, usually as going concerns to expanding private companies in need of extra capacity. Thus, many sites were to be absorbed by larger works; additional buildings were constructed in the open space of the wheel-yards, often obscuring the original structure of the grinding wheel.[50] Later still, the ageing, inefficient steam engines were replaced by gas engines and electric motors, or the buildings were converted to alternative uses or simply demolished.[51]

Only a couple of the largest examples continued in use as public wheels before finally closing in the twentieth century (the Soho Wheel due to the pressure of increasing land values and impatience of the shareholders; the Union Wheel when it was declared structurally unsound, although there is evidence for financial and political motives similar to the Soho).

To document these elusive buildings has therefore demanded the close study of a wide range of unlikely sources, accompanied by field investigations. Fragments of a number of public wheels have survived unnoticed, embedded within other structures or modified beyond recognition, providing important evidence of a building type as central to Sheffield's industrial development as the cotton mills were to Manchester's.

[47] A limited number of advertisements for semi-public wheels are known, but the overwhelming evidence points to peripatetic grinders going wheel to wheel in search of work: Pollard (ed.) (1971) evid. 1063 'When we are out of work perhaps there are a dozen wheels we go to. We might have a job of hanging a stone, or something of that sort'.
[48] See appendix 4.1; this contradicts the figures given by Beauchamp (1996) p.336, who tabulated rate book references to cutlery firms with steam engines, concluding that Sheffield was a late adopter of steam technology. A similar underestimate was made by Taylor (1993) p. 197.
[49] Hall (1857) p. 22. There were said to be 96 wheels, of which 80 were steam-powered, p. 13.
[50] Examples include the Bees' Wax Wheel (later Imperial Works); Tower Wheel (taken over by Samuel Osborn); Ponds Forge Mills (taken by Marsh & Shepherd); Wells' Wheel (later Kangaroo Works). See below, 'decline of the public wheels'.
[51] The four-stroke gasoline engine developed in 1876 by Nikolaus August Otto, also known as the 'Silent Otto' engine, was quickly adopted by workshops of all sizes. As early as 1879, R Drury of Sheffield was advertising such engines in the town which could be installed anywhere, irrespective of water supply. Pawson & Brailsford (1879) ads. p. 87

The first steam wheels

Park Wheel: 1786

It is notable that the first application of steam-power to the grinding trades of Sheffield, was undertaken not by cutlers but a local firm of opticians. Charles Proctor and Joseph Beilby (the latter a Birmingham man whose name was sometimes given as Bailey), partners specialising in the manufacture of scientific instruments and telescopes, had for some time been eager to speculate on the increasing demand for grinding troughs in the incorporated trades of Hallamshire.[52] Their idea was ahead of its time, predating the development of the required technology: as early as 1776, they had enquired of Boulton and Watt–who at that stage were only building reciprocating engines for pumping–whether a rotary steam engine would soon be available, several years before Watt's patent for the double-acting rotary engine.[53] Watt responded:

> *We have also made two different rotative or wheel-engines that are turned by the force of the steam exerted within them...but although these engines have performed in such a manner as to satisfy us of the efficacy of the contrivance, yet there are some little deficiencys in the execution which we wish to cure before we offer them to the public.*[54]

It was suggested that in place of rotary motion, a reciprocating engine be used to raise water for a conventional waterwheel, as Boulton had himself installed at the Soho Works. Ultimately, Watt's designs for his 'steam-wheel' (a hybrid of a water-wheel and steam engine) failed to bear fruit, and in 1781 he patented a number of mechanisms for producing rotary motion from a conventional reciprocating engine.[55] However, due to the lack of power on the return stroke, and despite the introduction of heavy flywheels, it was not until the implementation of the double-acting engine patented in 1782 that the steam engine became fully capable of turning millwork.

Proctor and Beilby evidently did not act on Boulton's recommendation, but instead waited for the promised rotary engines; perhaps as a result of having already registered their interest, they were one of the first to receive the new engine. At this time, the Soho Works was producing engines in relatively small numbers–between ten and sixteen a year–and as the

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52 Local Register (1830) pp. 60, 118; Ward (1909) pp. 29, 149; Leader (1875) pp. 94-96. The firm was named Proctor & Beilby after its partners. Reference is made (ACM misc. plans 24) to third party, Robert Turner, of whom little else is known.

53 Lord (1923) pp. 106, 153, appendix. This was only the second written enquiry the firm had received for a rotary engine. Earlier attempts to turn machinery by steam included the proposals of John Stewart (1767) to apply fire-engines to the grinding sugar cane using a rack and pinion. Proctor and Beilby may have been alluding to a design for a rotative engine (or 'steam-wheel') included in Watt's patent of 1769, based on a hollow wheel within which the steam acted. Watt continued to investigate the potential of this kind of engine–without piston, crank or flywheel–taking out further patents in 1782 and 1784, but without success. Galloway (1831) pp. 72-82.

54 Lord (1923) p. 106 note 2. Watt to Proctor and Beilby, Sheffield, 8 November 1776. Tangye MSS.

55 These included the sun and planet gear, designed to overcome the patent on the use of the common crank. Lord (1923) p. 161. Farey (1827) pp. 348-349; Galloway (1831) pp. 72-73, 79, 82.

design was under patent protection, other options were limited.[56] Beilby's Birmingham roots may have accounted for the very early contact with Boulton and Watt.[57]

The engine was not only one of the earliest examples of its kind, but at forty horsepower one of the largest then available.[58] In comparison, the Albion Mill in London–designed by Samuel Wyatt and used by Boulton and Watt as a shop-window for their new rotary engines–only began work in May 1786, three months after the Park Wheel, initially with one fifty horsepower engine.[59] [fig. 4.15]

Of the limited available evidence the best comes from the Fairbank papers, which include a contemporary plan of the site and dimensions of the engine itself. Using these sources comparisons may be made with the application of steam power in other industries at this time.[60] The London breweries were among the first to install engines, commonly of around ten horsepower, the lower end of the range then available. Early adopters were generally only those who needed, and could afford, works on a scale to justify the enormous expense of the engine and buildings. Water-power, by comparison, could be exploited for even relatively small works, irrespective of the overall cost per horsepower.

The wheel's construction was not funded by Proctor and Beilby alone, but by a group of 'proprietors' (or shareholders) who shared the burden and the profits of the enterprise.[61] This business model was adopted by most of the subsequent 'public' steam grinding wheels, and notices survive of fund-raising meetings at which investors were persuaded to pledge large sums towards the cost of the steam engine.[62] To Sheffield's artisan-led metal trades, such a distinction between capitalist and industrialist was a new concept, most manufacturers relying on profits and family capital to fund development.

On the other hand, it seems likely that the firm of opticians may have intended to use part of the wheel for grinding lenses and turning brass by steam-power (probably on the upper floor,

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56 Roll (1930) appendix 2, p. 280.
57 Leader (1875)
58 SCA CP-25-(32) (watermark 1828). The Park engine was nominally called 35 horsepower, but its dimensions were equivalent to what was later termed a 40-horse engine (see appendix 4.2). Farey (1827) p. 659, estimated that '... Mr Watt had brought his rotative engines to a standard form, about 1786...', the year in which the Park Wheel engine began work, adding that 'their performance proved so much superior to that of the atmospheric engines, that [they] have since been generally adopted for all considerable manufactories, notwithstanding the great price of their first erection'. As Watt installed the first double acting engine at the Albion Mills, it may be adduced that the Park Wheel engine was at first single acting, later converted (as was customary) to double; pp. 471, 473.
59 Lord (1923) pp. 163-166; Farey (1827) p. 438, noted that a second engine of the same size was added to the Albion Mills in 1789, but the building was burnt down in 1791 before a third could be added. The first commercially employed rotative engine was installed at Coates and Jarrett's oil mill in Hull during 1784, with an eighteen inch diameter cylinder (therefore 10 horsepower); Mosse (1967-68) pp. 48, 50.
60 Although a complete search has not been made, there is no immediate evidence for the Park Wheel engine in the Boulton and Watt archive, so it cannot be confirmed with certainty that the Fairbank figures relate to the original engine. However, as many of the beam engines of the 1780s continued in use for many years, with modifications, and the Park Wheel still had an old haystack boiler in the 1850s (as used by Boulton & Watt until the 1790s), it is highly probable that these figures correspond to the engine as first installed.
61 See Sheffield rate book RB34 (1789-90) Nether Division, p. 166 'Proprietors of the Steam Ingen [sic]'. The building was rated at £3, comparable to the two forges and mill of Frith & Co. at Ponds Forge also at £3, Vickers' water-powered Town Mill, and the cotton mill, both at £3 15s. At this time, no other rotative steam engines were in operation in Sheffield, and the site corresponds to earlier entries concerning the Crook's Croft steam wheel.
62 SCA MD1738 (2-51)

or in the garret if present), while the engine was financed by letting out heavier grinding hulls built on the solid ground floor to the metal trades.[63]

Built on a square plot alongside the river Sheaf, close to its confluence with the Don, the new building was quite different to the water-powered wheels that preceded it. [fig. 4.16] Arranged over two main floors on a long rectangular plan with external dimensions of about 152 by 41½ feet (c.46.5m x 12.7m), the building was on a scale more usually associated with cotton or silk mills.[64]

The engine drove in all 100 troughs, equivalent to around seventeen traditional hulls,[65] which were arranged back-to-back in long rows, subservient to the line shafts that transmitted the power from the centrally located engine. The use of first floor accommodation had been practically unknown in the smaller water-powered variant, but on such a large scale the increase in friction of the line shafts limited the practicable length of the building. To overcome this, belts driven by the drums on the ground floor were sent up through holes in the ceiling to power lighter machinery on the first floor. At the Park Wheel it may reasonably be assumed that the usual practice of the later wheels was followed, with heavy wet troughs (for table knife grinders, etc.) on the ground floor, and lighter dry ones or even general-purpose cutlers' workspaces on the upper floors.[66]

Early plans show the central bay of the building to be articulated by a projection of its brickwork, its proportion indicating that the elevation was subdivided into five equal bays.[67] The façade projection is also likely to have marked the location of a simple pediment in elevation, lending the structure a more dignified appearance in keeping with the substantial investment it represented. Such simple motifs were to be found in innumerable designs for both grinding wheels and other industrial buildings well into the 1830s.[68]

This five-bay model suggests a layout of one hull per bay, giving twenty hulls in total, a plausible hypothesis when compared to later designs for public wheels.[69] [fig. 4.17] Even within such large-scale grinding wheels, the basic unit of the hull was commonly found to closely resemble that of the earlier water-wheel era, both dimensionally and

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[63] Charles Proctor and his brother Luke may also have had more immediate connections to grinding, as they are described as having been originally lancet-makers. Leader (1875). Proctor and Beilby also had interests in water-powered wheels, including the Rivelin Bridge Wheel (from 1794); Crossley (1989) p. 65.

[64] The internal arrangement of Proctor & Beilby's building is unrecorded, but may be estimated by comparison with later wheels and on the basis of the ratio of engine power to floor area. See appendix 4.2.

[65] SCA NB3 (c. 1786-1793) p. 15, a deleted note in pencil gives the number as 104. See gazetteer.

[66] Hall (1865) p. 11, observed that 'as a general rule wet grinding, and the heavier branches of the trade are carried on down stairs and the lighter branches in the rooms on the upper stories. There are however many exceptions to this rule.'

[67] ACM SheS1897 (1792), 'A Plan of the Steam Engine Grinding Wheel with its Appurtenances held by Charles Proctor & others. Drawn by Wm. Fairbank, 1792'; cf. 1850 OS plan, that corresponds well dimensionally to the earlier plan. A slight asymmetry to the projecting bay suggests the appropriation of an extra window in order to give the classical temple-front design a central opening, at the expense of exactly symmetrical wings.

[68] A precedent may have been Wyatt's Albion Mill at Blackfriars Bridge, destroyed by fire in 1791. See Fairbank's design for a wheel, below. Also other building types such the warehouses of Sheaf Works and Sanderson's West Street Works (chapter 3).

[69] This would give five grinding troughs per hull, if no other uses are accounted for. If, however, some of the upper hulls were dedicated to optical grinding, this number might increase to six or more. (Six seems to have been a common unit, see below.)

organisationally.[70] It appears that the grinder, able to choose his place of work, had more influence over his immediate environment than did the textile-worker, subservient to the machines that populated the vast floors of cotton mills. In any case, many aspects of the grinder's pre-industrial activities were carried over to the new urbanised. steam-powered context.

In the centre of the rear elevation was the engine house, augmented by an external circular 'haystack' boiler in the yard alongside.[71] The projecting portion only represented part of the total area of the engine house, as the space containing the steam engine with its flywheel and gearing would have extended to meet the shafting runs at the centre of the wheel. The central location was determined by the need to keep the line shafts as short as possible, while the great height of the fixed beam engine meant that the engine house would have been at least as tall as the main building to which it was attached (at over 38 feet or 11m). [fig. 4.18] In the Park Wheel's case, the external wall of the main building doubled as the structural pivot for the main beam, instead of a timber A-frame common to smaller engines, the large flywheel taking up the entire internal depth of a hull.[72] This kind of engine was known as 'house-built', as it could not be removed without dismantling the engine house, unlike the smaller 'portable' engines with their own structural frame.[73] [fig. 4.19]

The arrival of steam-power was seen, even at the time, as an important event in Sheffield's history. The *Local Register* for February 1786 recorded the establishment of a 'steam engine grinding wheel, first erected by Messrs. Proctor, on the east side of the Sheaf, about 200 yards south of the bridge'.[74] The cautious reception given to this new initiative is indicated by the appended verse by Anna Seward:

Blush venal genius of those outraged groves,
And thy apostate head with thy soil'd wings
Veil!–who hast thus thy beauteous charge resign'd
To habitants ill suited; hast allow'd
Their rattling forges, and their hammer's din,
And hoarse, rude throats, to fright the gentle train,

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71 See the comparative plans in the gazetteer of steam wheels. Knight (1822) p. 6, however, indicated that while the traditional hull 'did not contain more than six or eight stones', those in steam wheels sometimes housed ten or twelve In some steam-wheels this was the case, but not generally the rule.

72 The engine house was actually built just left of centre, to occupy the space of half a hull and avoid disruption of the structural grid In Boulton and Watt engines of this date (up to 40 horsepower) the boiler was housed within the engine house. but was always external in the largest examples. Note that the plan of 1792 does not indicate any external boilers, although the area later occupied by a circular 'haystack' boiler is reflected in the layout of walls in the yard. suggesting that it was an original feature (omitted from the plan as sometimes found in cartographic convention) See also Farey (1827) p. 474, who stated that 'the building for large house built engines is never wider than is requisite for the engine, the boiler being always placed outside...' The haystack type of boiler was favoured by Boulton and Watt for their engines until the 1790s, after which date it was largely superseded by the 'wagon' and 'Cornish' boiler variants Law (1976-77) pp. 25-26; Watkins (1967) p. 100; Farey (1827) p. 437.

73 The form of the 40 horsepower engine has been reconstructed by the author from Farey's textual description, intended to be read in conjunction with his plates of a 10 horsepower example, similar to the 'Lap Engine' held at the Science Museum London. and described in a plan of 29 July 1785. Farey (1827) pp. 502-505, plates XI and XII.

74 Woolrich (2001) pp 64, 76. Until the 1830s, these two varieties of beam engine remained the predominant types found in most large establishments Farey (1827) p. 474, noted that all engines of 36 horsepower and over were house-built

Local Register (1830) p 60, also Robinson (1797) p. 39.

Dryads, and fair hair'd Naiades;–the song,
Once loud as sweet, of the wild woodland choir
To silence;–disenchant the poet's spell,
And to a gloomy Erebus transform
The destined rival of Tempean vales.[75]

The origin of the wheel can first be traced to the local rate books of the same year. An entry dated 15 May 1786 includes the perfunctory note 'Steem Wheel Built', on fields belonging to a 'Widow Crook' (hence the alternative name 'Crook's Croft Wheel' sometimes given by eighteenth century sources).[76] Ultimately the land was owned, along with the rest of the Park, by the Duke of Norfolk, and a later survey of his territories confirms that he had made an 'Ind[entu]re of lease dated 12th Oct. 1792 to Joseph Bailey, Charles Proctor and Robert Turner in Trust'. This corresponds to the rectangular plot of land upon which the wheel was built containing 2490 square yards (2082m²), or just over half an acre of land, including half of an adjacent 14-foot lane–indicating that the development was made under the auspices of a wider estate plan.[77] Indeed, to the rear of the site the engine house enclosure and outbuildings were planned to allow the continuation of an existing back lane, although its route was ultimately diverted to accommodate the full wheel-yard.

Public reaction to the new power was said to be of awe and bewilderment, mixed with fear of the unknown, reflected by the local tradition (probably apocryphal), related by Robert Leader, that:

> ...*the wiseacres predicted ruin to the innovators and all sorts of disasters to their workmen*...*and for a considerable time no grinders could be found to occupy the vacant troughs. At length one, greatly daring, set at nought the protests and warnings of his relatives and friends, and began to work; and when it was found that prognostications of his speedy destruction were not realised, others followed his example. But even then, the prejudices against what was called "Old Steamy" remained, and they were encouraged by the frequency with which*...*first one thing then another went out of gear, and the wheel "fell lame."*[78]

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[75] Local Register (1830) p. 60. The source was Seward's 'Colebrook Dale' of 1785, see Warburg (1958) pp. 3-6, (the first line was slightly modified by the editor of the *Local Register* to suit the format). Earlier in the poem, reference is made to 'SHEFFIELD, smoke-involv'd; dim where she stands / Circled by lofty mountains, which condense / Her dark and spiral wreaths to drizzling rains, / Frequent and sullied; as the neighbouring hills / Ope their deep veins, and feed her cavern'd flames'. Seward was born at Eyam, near Sheffield, and made a number of visits to the town, see Seward (1796) p. 37

[76] Widow Crook's houses are rated at 5d, while the land in her possession is rated at 1s 6d. The information was presented in an uncharacteristic tabulated form with eight divisions. From the fifth division onwards, the rate for the land is replaced with the running note 'Steem Wheel Built', indicating that for the previous four rates the wheel had been under construction. The land was earlier a croft and orchard held under the Duke by George Crook; SCA FBC FB38 (1769) pp. 4-5

[77] SCA ACM SheS1897 (1792), showing the proposed streets of the estate as well as lightly dashed previous boundaries. See also FBC FB63 p. 1, 'Ground set out for a steam engine in the Park'; FB67 pp. 72-75, 78-82, 'Widow Crook's croft with the steam engine grinding wheel & sundry tenements lately erected'; FB177 p. 77; SheS817L, FB99 (1804) pp. 87-90

[78] Leader (1905). The story continues with a whimsical anecdote concerning the mother of the first grinder, whose kettle 'fell lame': she decided to apply the principles of a steam boiler–the safety of which her son had reassured her–by heating a corked bottle of water in the oven, resulting in the inevitable explosion.

These 'prejudices', however, did not prevent the proprietors charging a premium for grinding space, at six pounds (per annum) compared to the more common figure of five pounds for water-powered troughs;[79] commensurate perhaps with the longer working day, particularly in the summer months, made possible by steam-power.

Other less welcome innovations accompanied the new technology, most notably problems related to the design and operation of the new buildings. The earlier water-powered wheels were notoriously ramshackle structures, but nevertheless 'well ventilated in consequence of dilapidated windows and roofs',[80] and their working patterns prone to disruption by adverse weather. In contrast, the well-built fabric of the steam wheel and the reliability of its prime mover, while good for the proprietor, came to be seen as disastrous for the grinder. The principal differences were summarised by Dr. Knight, speaking in 1819 on the subject of the grinder's asthma: In the traditional water-driven wheel, grinders:

> *...worked in large lofty rooms, which did not contain more than six or eight stones, were open to the roof, without windows, and generally with the cog wheel in the inside; thus, such a complete circulation of air was effected, that the small quantity of dust raised from these few stones, was soon carried away. Moreover, for several months during each summer, they could not work more than four or five hours a-day, owing to a scarcity of water. About thirty years ago, the steam-engine was first adapted to the purposes of grinding; and then a very important era arrived in the annals of the grinder. He now worked in a small low room, where there were ten or twelve stones; the doors and windows were kept almost constantly shut; a great quantity of dust was necessarily evolved from so many stones, and there was scarcely any circulation of air to carry it away. Unfortunately, the steam-engine, unlike the stream which formerly supplied his wheel, allowed him no season of relaxation for the recovery of his health. He worked ten or eleven hours a-day on an average.*[81]

Most subsequent reports also laid the blame squarely on the architecture of the steam wheels, with their hermetically sealed interiors full of dust. To a certain extent this view was coloured by the anti-technological sentiment prevalent among middle-class commentators, contrasted with the romanticised imagery of the rural water-powered grinding wheel.[82] Contemporary evidence shows that the grinders found their own improvised solutions to some of these problems: the windows of public wheels were usually broken (their squares 'put out' by the grinders for ventilation), and the doors to the ground floor hulls stood permanently ajar, while the draught of the ubiquitous hearth around which idle time was spent provided

[79] SCA FBC NB3 (c.1786-1793) p. 15 and *passim.* provides contemporary evidence for the relative operating costs of steam and water-powered grinding wheels. Of the maximum £600 collected in rent, it was estimated that £200 went towards the purchase of coals for the engine.
[80] Holland (1843) p. 174.
[81] Knight (1822) p. 6.
[82] See, for example, Holland (1820) note p. 44; Holland (1837) pp. 179-184; Roberts (1868); Reade (1896) pp. 47ff.

additional ventilation.[83] There is little doubt that it was principally the longer working day made possible by steam-power that was responsible for the sharp increase in mortality among grinders. Nevertheless, the 1857 report into the grinders' disease by Dr. J. C. Hall suggested a more causal relationship with the built environment, attempting to classify some of the major public wheels by the average mortality of their tenants:[84]

Name of wheel.	*Return of deaths since the year.*	*Average age at death.*
Messrs. J. Rodgers and Sons	1836	42
Union Wheel	1850	40
Soho Wheel	1845	40
Old Park Wheel	1844	41
Suffolk Works	1845	38½

The Park Wheel was tenanted both by individual grinders working by the piece and manufacturing firms without their own grinding wheels. An example of the latter was the famous Joseph Rodgers & Sons, who had based their grinding operations there before the construction of their 'Top Wheel' in Norfolk Street enabled the closer integration of their cutlery making (see chapter 5).[85] The generic hull was able to accommodate troughs for a wide variety of different articles, from razors through table knives and even the larger saws.[86]

Few modifications were made to the basic form of the wheel, identical on the 1850 Ordnance Survey plan to the Fairbank survey of sixty years earlier, except for the extension of the first floor accommodation over the 14-foot lane to the north, abutting a terraced row of dwellings.[87] A walled rectangular enclosure was also constructed in front of the articulated central bay, probably in response to the lack of secure storage in the original design (see 'outrages' below). By the time of its demolitionin the 1870s to make way for street improvements, [fig. 4.20] the 'Old Park Wheel' as it was later known had been in operation for almost ninety

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[83] See for instance Pollard (ed.) (1971) evid. 7161, regarding the Tower Wheel: '(Chairman) How was the window? – Generally, in grinding wheels, the windows are all out. They generally break them. They get pretty well of air'; also *ibid.* evid. 4515. MD712 Soho Wheel rent book (1806-) includes numerous charges for 'windows', broken by the occupants of the hulls.
[84] Hall (1857) p. 22, Table IV 'Average age at death of grinders at the following wheels'. Dr. Hall did, however, conclude that the use of the fan had the greatest impact on life expectancy, noting that the worst record was held by 'the Suffolk Works wheel, which is a well constructed one'. He later morbidly suggested that the motto: 'ALL HOPE ABANDON YE WHO ENTER HERE', should be inscribed over hull doors. Hall (1865) p. 20; see appendix 4.8.
[85] Stainton (1924) provided biographical details of John Wilson, who was born around 1820 in Granville Street next to the Park Wheel and at 13 years old began his apprenticeship there under one of Rodgers' cutlers, until the 'workmen and their apprentices moved in a body to the new quarters'.
[86] Smith (1865) p. 88, recommended to visitors that saw-grinding 'may be witnessed every day at the old grinding wheel on the eastern bank of the Sheaf in the Park' (i.e. the Park Wheel).
[87] 1850 OS Plan, cf. ACM SheS1897 (1792).

years.[88] Charles Proctor had benefited considerably from his investment, and on his death in 1808 is said to have left property totalling £30,000 in value.[89]

Over its relatively long lifespan, this one time technological marvel was gradually assimilated in its increasingly mechanised urban setting, becoming the backdrop to, rather than the focus of, events. Irrespective of its unprecedented scale and influence, as a building it was consistently ignored by contemporaries: no detailed descriptions or images of the wheel are known, aside from possibly a faint silhouette in the background of a painting of the river Sheaf, probably late eighteenth century, and one among many tall stacks in topographical views of the town.[90] [figs. 4.21, 4.22]

First generation public wheels: Cleakham Wheel and Rolling Mill (1789); Ponds Forge Mills (1793)

The Park Wheel, itself based on the recently established steam mills, effectively defined the parameters of a new building type that was to be repeated with minor variations in a number of different locations. Its immediate successors, the Cleakham Wheel (built along with a steam-powered Rolling Mill in 1789 on Shalesmoor) and the Ponds Forge Mills (established 1793 in the Ponds district), closely followed the archetype while introducing some variations that would recur in later examples. Both wheels were around the same size as the Park–the Ponds Wheel one bay longer–and both were situated alongside Sheffield's rivers, the Don and Sheaf respectively. [figs. 4.23, 4.24]

Plans for the Cleakham Wheel must have commenced soon after the opening of the Park Wheel, suggesting that the first venture had been an immediate success, contrary to local tradition. The new project was correspondingly more ambitious, consisting of both grinding and tilting facilities housed in two separate buildings, on the site of what had formerly been a 'very large and neat Bowling Green' originally called Clayton Dam Field.[91] This location supports the view that it was still seen as a peripheral building type, as bowling greens (in common with other sporting facilities) were commonly made on disused land at the edge of town centres.[92] An early plan [fig. 4.25] shows the footprint of the wheel to have been almost identical to that of the Park Wheel, one gable end forming a party wall with the 'Cleakham Inn'

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88 SCA ACM misc. maps 24 (n.d.) showing the 'proposed road' running parallel with Sheaf Street, and land 'surrendered by the Duke of Norfolk's trustees'. Also Leader (1875) in which note was made of its recent demolition, replaced by a wooden circus, indicating that its location had remained peripheral to the town.
89 Leader (1875); Local Register (1830) p. 118; Ward (1909) p. 149. Proctor donated £200 to the Sheffield Infirmary of which he had been a governor.
90 Paintings held at Kelham Island Industrial Museum: Anon. (n.d.) 'River Sheaf and Shrewsbury Hospital'; William Ibbitt (1826) 'East View of Sheffield'; Ibbitt (1854) 'South East View of Sheffield'. See Baggaley (1929); Bostwick (1989).
91 It is not known for certain if each building had its own engine, or whether a common engine was shared. A nineteenth century plan of the site does not indicate the characteristic external engine house usually found in early grinding wheels, although the two functions occupied semi-independent yards, the tilt taking 1000 of the total 3918 sq. yds. SCA FBC SheS283S; FB167, p. 55-6. Woolhouse (1926?) p. 11.
92 In Sheffield, another bowling green had been set up within the ruins of the castle. Parallels may be found in the location of early sporting venues and theatres, usually confined to wasteland on the edge of towns.

public house from which the wheel took its name.[93] Despite the scarcity of firm evidence (the wheel did not even survive long enough to be recorded on the first OS plans) it may be affirmed that the building contained the same number of troughs as the Park Wheel, its location at the opposite end of town guaranteeing a ready demand (see appendix 4.1).

Once again the wheel was funded by shareholders, although operated by 'Joseph Ward & Co.', a firm about which little is known other than from a deed of March 1795 which declared Joseph Ward, John Ellis and Samuel Ellis to be 'tilters and co-partners' in the recently erected 'steam engines, cutlers' grinding wheels, tilt and tilts and other actions'.[94] One such investor was local cutler Thomas Nowill (also a major shareholder in the Soho Wheel, below), whose share in the wheel of £162 was subsequently lost when the business was liquidated in 1814.

Following its failure, the site and buildings were purchased in 1819 by James Dixon and Thomas Smith and soon adapted to the silver plate trade, for which Dixon must have primarily wanted the rolling mill as this was retained complete with its engine, boilers and stack.[95] Smith left the partnership in 1821, and about 1824 the grinding wheel was demolished, and upon the ruins Dixon constructed the well-known 'Cornish Place' silverware factory, soon to become one of the largest in the world. [fig. 4.26] The main range of warehouses, workshops and offices was built along the street frontage, exactly half the width of the wheel, suggesting that the foundations to the street and along the line of the old central spine wall had been reused.[96]

The Ponds Forge Mills, on the other hand, was developed within an existing works site operated by the Ponds Forge Company under Messrs. Kenyon and Frith–a large and long established business named after the low-lying marshy district in which its water-powered forge hammers and mills had been established. [figs. 4.27, 4.28] Perhaps the first example funded entirely by the substantial capital of one firm, the building appears to have been conspicuously designed to outdo its rivals–especially the original Park Wheel, which it addressed confrontationally from its site on the opposite bank of the river Sheaf. [figs. 4.29, 4.30]

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[93] SCA FBC SheS283S (1824) 'Plan of the Cleakham Grinding Wheel & Rolling Mill belonging to James Dixon'; also measurements for this plan, FB167 pp. 55-56. In the rate book for 1794, Ward & Co. paid £2 16s 6d and £2 4s 6d for a steam wheel and tilt respectively, both on Green Lane. By comparison, Messrs. Frith & Co.'s 'New Steam Wheel and Mill' was rated at £4 15s 5¾d, Messrs. Hague & Co.'s rolling mill at Gibraltar at £5 14s 8½d, and Wells, Heathfield & Co.'s main cotton mill building at £4 1s 4½d (as opposed to the 'little cotton mill', previously Kelham wheel, at £2 8s 0d with an engine at 1s)

[94] Wakefield Registry of Deeds, DQ192 No. 213 (indenture of 1 Nov. 1794, registered 10 March 1795). The land had been conveyed to them on 6 Oct. 1789 for 800 years beginning on 24 June 1789. Also see EP109 No. 155 (ind. 18 May 1803, regd. 18 Aug. 1803), FW236 No. 218 (ind. 12 Aug. 1812; regd. 27 Oct. 1812); HA611 No. 616 (ind. 30 Apr. 1819, regd. 10 Sept. 1819)

[95] The rolling mill is visible in Dixon's advertisement view of the late 1820s, Blackwell (1828) f.p. 27. Some modifications were made, including new boilers and shops, see FBC SheS 283S. Also RCHME Historic Building Report 'Cornish Place, Sheffield', June 1996, NBR no. 94375, pp. 1-5.

[96] The new buildings were sketched in pencil over the old plan of the wheel, as above. Woolhouse's comment that Dixon's white-metal manufactory was 'built upon the ruins' of the wheel, could also be taken to suggest the reuse of its structure. Woolhouse (1926?) p. 11.

At six bays long the building was the largest to date, powered by an 80 horsepower Boulton and Watt engine–an enormous example that remained unchallenged in Sheffield for over 40 years.[97] Despite the increase in scale, it is tempting to read its situation–an almost exact mirror image of the Park Wheel–as an analogy of the relationship to its model. Apart from the addition of a rolling mill to one side of the central engine house at the rear, the basic characteristics of the building were identical, with back-to-back hulls arranged over two storeys. Those on the ground floor opened directly to the yard, while an external stair at one end led to a central first floor corridor with rooms to either side housing lighter troughs and other powered tools, as at the later Union wheel.[98] The wheel was also built on land owned by the Duke of Norfolk, which although predating the earliest planned estates, may indicate a conscious decision on the part of the Lord of the Manor to capitalise on the demand for steam power.[99]

This is the earliest steam wheel of which an image survives [fig. 4.31] which, being almost the same size as the Park and Cleakham wheels before it, can be taken as representative of the emerging type.[100] A plain rectangular volume with a simple gabled roof, the tall volume of the engine house and its adjunct stack are clearly visible behind. The front elevation ran parallel with the Sheaf, separated from the water by a narrow yard in which new and used grindstones can be seen propped against the exterior of the building, while wheelswarf would have been dumped nearby. Grinders gained entry to the building from its northern end, either from the town via Forge Lane / Wheel Hill or from the Park by crossing the purpose-built footbridge over the Sheaf.[101]

Most characteristic was the row of regularly spaced chimneys that punctuated the eaves and established the rhythm of the windows beneath, forming a tartan-grid pattern in elevation. As it will be seen, these were an external manifestation of the internal hearths, one of which could be found in every hull. The number and location of external doors on the ground floor also echoed the pattern of hulls behind, so that it is possible to derive the internal layout of the wheel from its façade features with some certainty. To a greater extent than at the Park Wheel, the engine dominated the organisation of the site, with a rolling mill to one side (later enlarged), the gear room projecting into the centre of the grinding wheel to reduce the length of the line shafts, while even the space above the gearing was employed as workshops for glass-cutters.[102]

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[97] Holland (1837) p. 243. For specifications of B&W engines see Farey (1827) p. 574.
[98] SCA CP-25-(32) (n.d.; watermarked 1828), lists: 'Pond Forge Steam Engine, Boulton & Watt's, called 80 hp, 44 in. cylinder, 8 ft. stroke, 15 dbl./min., 10 lbs./sq. ft. (say 83hp)'. SCA FBC MB399, p. 34, describes the engine as 80 horsepower, with a stack 30 yards in height.
[99] SCA CP-25/36; FBC NB3; Crossley (1989) pp. 113-4, added that Kenyon and Frith bought the freehold from the Duke in 1805.
[100] The view actually dates from the time of its occupation by Marsh & Shepherd, who eventually converted it to a warehouse, leaving its external appearance unaltered.
[101] This bridge replaced an earlier footbridge built to serve the Park Wheel and indicated on the earliest plan, which fell within the area of the Ponds Mill wheel-yard. Its replacement may represent an early example of 'planning gain'.
[102] SCA FBC MB399 (1836) p. 34. FBC SheS129L, Owned by Pond Forge Co., occupied by Fox and others.

Unusually, in this case the engine-yard could be interpreted as the 'front of house', with access from the main gates on Forge Lane supervised by a row of cottages and a counting house alongside, and the tall engine-house and stack towering over the long, low wheel building to dominate the site.

Built closer to the riverbank than the Park Wheel, the infrastructure of the building can be more clearly seen to have modified the natural topography. The cumulative alterations made to the river Sheaf by such developments (particularly the man-made channel between the two opposing steam wheels) prompted an observer of the 1830s to complain that it had become:

> *Straight-jacketed with stone walls, and invaded by the foundations of steam-engine grinding-wheels and other large buildings, the soiled and disturbed water, after passing under two adjacent bridges, mingles with the stream of the Don.*[103]

Close proximity to the river was greatly advantageous, if not essential, for the thirsty steam engine. The site of the wheel, and the Ponds area in general, had been host to earlier water-powered mills, and the water rights held by the Ponds Forge Company may have been the decisive factor in the establishment of a steam engine here.[104]

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[103] Holland (1837) vol. 1, p. 313.
[104] SCA FBC NB34 (1833?) pp. 18-19, records the relative cost and power of waterwheel and steam engine: the former was equivalent to 18½ horsepower, costing 60s per horsepower [per annum] and the latter 83 horsepower at 15s. In total, the works consumed some 1353 cubic feet (38,300 litres) of water every minute–mostly for the water wheel–compared to the Park Wheel which required 67.23 cu. ft./min. (1900 l/min.) and the later Bees' Wax Wheel (below) at 23.49 cu. ft./min. (665 l/min.) Water for the engine and boilers may have been taken from the Sheaf itself or from the tailrace that ran directly below the wheel, and as the supply was constant, no reservoir was needed.

Soho Wheel (also Coulson Crofts Steam Wheel)

Built in the heyday of the steam mill, perhaps no other single building could claim a greater influence on Sheffield's urban development than the Soho Wheel: it was one of the clearest examples of the emerging *laissez-faire* attitudes to industrial, social and urban development that characterised the town and its region until the second half of the nineteenth century.

Its historical significance is enhanced by the relatively comprehensive documentation that has survived it. Unlike most public wheels (excepting perhaps the Union Grinding Wheel), the Soho Wheel is well represented by a wide range of minute books, ledgers and wage books, as well as maps and images.[105] From these sources it has been possible to establish not only the circumstances of its construction and subsequent development, but also a detailed picture of the economic and social context in which it operated.

The site

Until the late eighteenth century, the Coulson Crofts had consisted of 'swampy meadows and damp osier grounds' on the flood plain of the Don, and consequently unsuited to building uses.[106] It was, however, an important point of entry to the town from the north, crossing the Don at Bridgehouses and leading via Bridge Street to the marketplace. [fig. 4.32] In Oughtibridge's prospect of Sheffield (1737) the fields are shown as sparsely populated with a mixture of grazing animals and hayricks, typical fringe activities of the pre-industrial town. Leader uncovered evidence for its earlier use as a 'game preserve', an extension of the Duke of Norfolk's Park on the other side of the Sheaf.[107]

Around 1790, following the successful establishment of estates at Alsop Fields and the Park, the Fairbank firm of surveyors was commissioned to draw up a masterplan for the Coulson Crofts. [fig 4.33] The first design was a departure from their earlier tartan grid based systems, based instead on a pair of convergent main roads intended to meet at the existing bridge crossing over the Don. Secondary cross streets ran between the two, like rungs of a ladder, the overall scheme having a monumental character reminiscent of Sistine Rome or Hausmann's Paris. Implementation of this plan appears to have begun, preserved in Water Street, Love Street and Lane, and the east end of Bower Street (which follows the intended path of the second main road), but it was never completed. Upon the same masterplan drawing the Fairbanks made an alternative layout of gridiron streets that meshed with the existing parts of the earlier plan, abandoning the focus on the river crossing. [fig. 4.34]

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[105] Held at Sheffield Archives, with the following catalogue numbers: MD709 (Minutes 1820-37), MD710 (Dividend book 1813-31), MD711 (Ledger 1802-13), MD712-714 (Rent books, 1806-24), MD 715 (Treasurer's book 1822-35), MD716 (Receipt book 1852?), MD717 (Minutes 1837-52), MD718 (Minutes 1853-70), MD719 (Dividend book 1832-35)

[106] Holland (1837) p. 212, referring to the pre-industrial character of Coulson Crofts. 'Osier grounds' were for the cultivation of a species of willow, the pliable branches of which were used in basket weaving.

[107] Leader (191?) in *Trans. Hunter Arch. Soc.*, vol. 1, pp.365-369, under the subheading 'Coulston Crofts as a Game Preserve' noted that deeds to the Crofts around 1700-1720 still reserve game and sporting rights to the Duke

In contrast to the Fairbanks' other estate plans, the revised plan was loosely based on the existing field boundaries–already roughly orthogonal in outline–subdivided by major and minor streets.[108] The largest single plot, significantly taking up an entire 'croft' in the northeast of the estate, had already been reserved for the intended Soho Wheel, designated on the masterplan as held 'in Trust for the Prop^{rs}. of a Steam Wheel' followed by the names of the principal investors.[109] [fig. 4.35] It was perhaps the lucrative development opportunities presented by larger plots more suitable for industrial uses, coupled with a growing demand for steam-powered sites, that led to the abandonment of the earlier classical scheme for the utilitarian plan as ultimately built.[110]

It is certain that the Coulson Crofts estate was never intended to be a genteel residential district as had been envisaged for the Alsop Fields scheme, and from the beginning it was dominated by industrial uses; by the 1820s the Soho Wheel had been joined by the Pilot Works of Marsden, the Reform Wheel of Ashforth and the Bridge Street Works of Whitham and Hattersley–all with steam engines–as well as a number of steelworks and foundries. Rapid industrialisation had also characterised the surrounding areas, the third incarnation of the Cotton Mill (after 1810) being entirely steam-powered and the Union Grinding Wheel built on freehold land to the other side of the Town Mill headrace from 1818-20.[111]

A number of factors contributed to the suitability of Coulson Crofts for steam-powered works. The area was one of Sheffield's most waterlogged, in close proximity to the river Don, and so would not have been in great demand for residential or commercial building purposes.[112] In addition, several water channels (now lost) traversed the area; the principal of these is shown on an early Fairbank survey of the Soho Wheel, demonstrated by reconstruction to be coincident with the line of the later 'Water Street' (evidently named after its location).[113] This water source may well have determined the location chosen for the Soho Wheel, the importance of which is discussed below.

The Proprietors

As one of the largest speculative ventures of its day at a regional level, it is important to consider the background conditions that led to its development. While the first rash of steam grinding wheels brought several hundred new troughs to market in less than a decade, they were soon outstripped by the burgeoning demand for urban workspace. In 1802 Thomas

108 For the pre-development layout of the fields, see Fairbank (1771); Oughtibridge (1737); Gosling (1736) [area obliterated by the heraldic arms of the Duke of Norfolk].

109 SCA ACM SheS1479L (1790) 'A plan of Colson Crofts describing the proposed streets and lanes'.

110 A similar concession to the realities of Sheffield's property market led to the abandonment of the classical plans intended for the Alsop Fields estate twenty years earlier. See Cruickshank (1998) pp. 34-35. Interestingly, the Fairbank's first plan was effectively returned to with the construction of Corporation Street along much the same route (see below).

111 The cotton mill was closed and the building sold in 1815, after which it was converted to become the Poor Law workhouse. Caulton (1997) pp. 167-169; Crossley (1989) p. 14.

112 Holland (1843) p. 47

113 SCA FBC FB105 (1805) pp. 44-45

Dunn, later the proprietor of Kelham Wheel, wrote that 'grinding room is so scarce that there are about 200 grinders who cannot get a trough in the corporation'.[114] With the building of the Soho Wheel, the investors evidently intended to provide at least this many new places.

The venture was backed by eight principal 'trustees' (as listed on the estate plan above), some of whom were directly involved in cutlery and edge manufacture or merchanting, while others seem to have had no immediate trade connection, but were local gentry investing primarily for the promised dividend returns.[115] Surviving documentation gives a reasonably clear indication of the amounts invested by various 'proprietors', and held as shares, being generally defined as an investment in the wheel of £50.[116]

At a meeting to raise funds for the wheel, it was announced that the engine was 'to be a 40in Boulton Double powered one', an impressively ambitious choice that yielded the desired result that '...£5000 was subscribed for it [presumably the entire wheel] in an hour'.[117] As it happened, the wheel was eventually built with a pair of more modest engines, although this did nothing to detract from its novel size, still considered noteworthy enough to be included by John Farey in his chronology of early steam mills:

> *A very large mill was built at Sheffield, in Yorkshire, in 1797, for grinding cutlery, with two 40 horse engines of Messrs. Boulton and Watt's plan, placed in the same building; they were executed by Mr. Francis Thompson, under license from the patentees, who supplied some of the parts from their manufactory.*[118]

Farey's observation confirms that the project had been in gestation since the last years of the eighteenth century (probably the date at which the engines were ordered), although his rating of the engines does not concur entirely with a later Fairbank survey of the wheel, which stated: 'There are two Steam Engines ~~of 70 horse power~~ of 30 HP ea[ch] and they reckon 16 hulls to one Engine...'[119] As these figures were given for the purpose of assessing the rateable value of the wheel, it is possible that the owners had understated the power of the engines. This is borne out by an entry in the minute book concerning the replacement of a piston with 'one of the Best Metalic [sic] Pistons 31½ inches in diameter warranted to work well together with a new piston rod 9½ feet long & 3 inches diameter weighing 225 lb', dimensions consistent with a 40 horsepower Boulton and Watt pattern engine.[120]

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114 SCA MD1738 (2 151) cited by Flavell (1996) p 155

115 SCA ACM SheS1479L (1790) 'Jno. Yeomans, Geo. Skidmore, James Barlow, Jno. Wainwright, Saml. Stanley, George Cooper Thos Nowill & Wm Keeton'; confirmed by MD711 (1802-13) undated note at rear, adding that Wainwright had died and Skidmore 'sold out'. William Keeton, for example, was described in Baines (1822) trade directory as 'Gent[leman]' while Thomas Nowill (of the firm Hague & Nowill, Meadow Street, and from 1836 John Nowill & Sons) was a prominent manufacturer of cutlery.

116 For example SCA YWD1068, transfers of a share in the Soho Grinding Wheel (1824-1835).

117 SCA MD1738 (2 51), cited by Flavell (1996) p 155. This would have been equivalent to a 70 horsepower model, see Farey (1827) p 574

118 Farey (1827) p 508 Also mentioned on p. 444, note 'a'.

119 SCA FBC NB25 p 106 (c 1829-30) 'Colson Crofts Grinding Wheels'.

120 SCA MD709 (17 April 1835). cf Farey (1827) table p. 574. Fairbank went to great pains to ascertain the true power of engines for the rate (see appendix 4 2), but may have been occasionally misled by the statements of owners and enginemen It is possible that such evasion of taxes was in part responsible for the underestimates of steam power employed in Sheffield's works

Aside from the engines, accounts detailing the construction of the wheel buildings survive and record the breakdown of costs in some detail (brickwork, joinery, plastering, glazing, etc.), including the individual contributions of each proprietor.[121] Thus by October 1803, Robert Unwin had invested £1560 14s 7d, broken down into individual 'Jobing', 'Measure', 'Brick', 'Lime' and 'Clamp' bills; others invested in troughs, wood, spouts and cisterns.[122] The engines were a significant outlay, one of which was supplied by Smith & Co. of Chesterfield for £1389 7s 7d, exclusive of the cast-iron boilers from Booth & Co. of Sheffield's Park Iron Works at £748 11s 9d. By comparison, the carpenter and joiner work was said to have amounted to £1265 15s 3d.[123]

All of the general contractors–including bricklayers, carpenters, plumbers, glaziers and millwrights–were based in Sheffield.[124] For more specialised components the proprietors looked further afield, although even in these cases most of the firms were reasonably local: the engine makers Ebenezer Smith and Francis Thompson were both based in the Chesterfield area, while iron troughs were sourced of Gregory, Longden & Chambers of Thorncliffe Iron Works near High Green (about 12km north of Sheffield).[125] The logistics and cost of transportation would have been a major consideration in the procurement of such massive items, at a time when road haulage was the only option. James Montgomery (1771-1854), a Sheffield journalist and poet, recalled that in 1803 a boiler for the Soho Wheel had been pulled by a team of 18 wagon horses through the streets of Sheffield to its final destination, a spectacle that was evidently greeted with enthusiasm by the townspeople.[126]

The rules for the wheel were published in 1809 as a pamphlet, entitled *Articles for the Government of the Proprietors of the Soho Engines*, setting out the conditions by which investors were bound.[127] Each year, the shareholders elected a committee of nine members,[128] in addition to which from 1809 a treasurer was to be appointed annually, although in practice it was common for the position to be held for a number of years.[129]

Besides the expected pecuniary benefits, becoming a proprietor also conferred other privileges. The original trust deed stated: 'That the holders of shares in the said concern shall

121 See account book SCA MD711 (1802-13).
122 Other heavy investors were John Wainwright at £1311 and William Keeton at £742; more usual sums were £107 and £204, equating to monthly payments averaging £2 12s 6d and £5 5s 0d respectively.
123 SCA MD711 (1802-13) pp. 52, 69, 1802 to 15 Sept. 1803, Oct. 1803; FBC MB391 (1834) p. 37.
124 The millwright Thackray (used by the proprietors for later mechanical modifications) and mason Beavers were both based at 'Newfields' in Sheffield. Senior & Drury (spouts and plumbing) were well-established family firms in the town, while Joseph Machon (troughs, timber and day bills) was a wheelwright and joiner. See Gales & Martin (1889), Baines (1822), Gell (1825), Blackwell (1828).
125 Jones and Jones (eds.) (1993) pp. 6-8, 18. Until 1802, such castings had been made at the Phoenix Foundry on Furnace Hill.
126 Fravell (1996) p. 384. Everett and Holland (eds.) (1854-56).
127 Proprietors of the Soho Engines (1809) *passim*; transcribed as appendix 4.3.
128 Originally all nine committee seats were subject to annual review, but by 1809 it was decided that only six be re-elected each year, while three continued to sit. Proprietors of the Soho Engines (1809) p. 9.
129 SCA MD709, 6 May 1822. Nowill had been treasurer since at least 1809 and was one of the names in the trust deed. Bibbs was also involved from 1809. Apart from Nowill and Wainwright none of those mentioned by the trust deed had an active role in the committee by 1822.

have at all times a preference of recommending tenants of troughs, or working places, in the said wheel or wheels either from amongst their own workmen or otherwise'.[130] This would have been a great incentive for manufacturers to invest, particularly in boom times when space was at a premium. Tenancy records confirm that many proprietors took advantage of this right: the committee member Paul Bibbs, for example, occupied a whole hull with six troughs from 1806.[131] As demand increased, however, the opportunity to rent entire hulls diminished, and by the 1820s the tenancy of hulls had become more differentiated, evident from a comparison of the number of troughs rented by individual grinders, as abstracted from the rent books of 1806 and 1824.[132]

Troughs	*Number of grinders renting*	
	1806	1824
½	----	1
1	14	35
1½	----	4
2	14	13
2½	----	7
3	12	6
4	3	1
6	7	1

As active members of the trade, the proprietors of the Soho Wheel also took an unusually active role in its management of the wheel, in contrast to many of the speculative investors and sleeping partners in other industries. Meetings were held on a regular basis, first at the homes of prominent committee members and subsequently at the wheel itself; at these gatherings, the proprietors were able to vote on resolutions relating to all matters—even relatively trivial ones (see below).

A more sinister role of the proprietors is also alluded to in the minute books from 1830, acting in combination with owners of other public wheels under the appellation of the 'General Union of Proprietors of Steam Engines'.[133] This body appears to have been in effect a cartel dedicated to fixing the prices of troughs and rent of rooms across the industry, opposed by

130 Proprietors of the Soho Engines (1809) p. 4.
131 SCA MD713, p. 2, Michelmas *1806*.
132 Based on Pollard (1959) p. 56, with additional figures from SCA MD713. These relate only to one of the two wings, as the rent books were organised by engine ('number one engine' and 'number two engine').
133 SCA MD709, 30 Sept. 1833; 7 July 1837.

the equally strong branches of the Grinding Unions and Tenants' Associations. Inevitably, the resulting conflict of interests often resulted in deadlock; thus the romantic notion that public wheels were an expression of the individual 'little masters' freedom is entirely unfounded.[134]

The building

The form of the building was unusual not only among large public wheels, but for steam powered mills in general. It comprised of two parallel wings powered by a central engine house spanning between them (with one steam engine to each wing) arranged as an 'H' in plan. Each wing was divided into sixteen rectangular hulls arranged back-to-back in eight bays, all single storey except for the middle two bays, above which was an additional 'chamber' floor of timber construction (see below) occupied by lighter grinding and other rooms with power, all accessed by an external stair.[135] These two storey portions also formed an interface with the double-height engine house. [fig. 4.37] As usual, each hull had a central hearth built against its outer wall and terminating in a chimney above eaves level; at the higher level the stacks contained flues from both floors and were correspondingly wider.

The wheel-yard was large, and although open to the streets in the earliest years, was soon to be encircled by brick walls up to four yards high, presenting a hostile and undistinguished front to its surroundings.[136] It had a variety of uses (for example, cutting and storage of stones, deposition of wheelswarf), few of which found expression in built form; over time, however, a number of low bins for wheelswarf were erected against the walls of the wheel (between adjacent hull doors) and to either side of the long boiler in the north engine-yard. Paving was also at first deemed unnecessary, both in the wheel-yard and the two smaller engine-yards, and only introduced in selected areas in later years.[137]

The 'H'-shaped plan, although unique among large steam-powered mills, had a precedent in the earlier water-powered wheels in the vicinity. Many of these comprised two buildings on either side of a shared wheel-race (sometimes housing two separate water-wheels each with its own pentrough), designed to make optimum use of the expensive system of reservoir, sluice and goits.[138]

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[134] See *Sheffield Independent*, 21 Jan. / 4 Feb. / 11 March 1854; SCA MD709, 7 Dec. 1854.
[135] These stairs, reconfigured on a number of occasions, were always located on the northern gable ends and must have led through the roofspace of the single storey hulls to the chambers. Some of this space was later converted to workrooms: SCA MD717, 4 May 1838, 'the Entrance to the chambers over that part of the Wheel fronting to Bridge Street & originally only one story high be from the steps at that end next the river'. See also the painting 'Bridge and White Rails at Bridgehouses', now held at Kelham Island Museum. [fig. 4.36] Baggaley (1929) p. 22.
[136] SCA MD717, 5 Dec. 1844; also based on the author's observations of surviving fragments, some of which date from the early nineteenth century.
[137] SCA MD717 26 Dec. 1839: 'a dwarf brick wall with strong stone coping to be erected on each side [of the new long boiler], so as to form a depository for Wheelswarf & rubbish'; at the same meeting it was decided to 'pave that part of the Yard, lying between the Walls and the Wheel, similar to what has lately been done in the other yard on each side of the boilers'.
[138] Where this was not possible, a configuration such as at Shepherd's Wheel could be substituted.

One such antecedent of striking similarity to the Soho Wheel, in spite of its much smaller size, was the Rivelin Valley Wheel (or Spooner Wheel) owned by the Norfolk Estate.[139] [fig. 4.38] Here cutlery grinders were accommodated in two equal wings or 'ends', each with twin-gabled roofs punctuated by six evenly spaced hearth chimneys. In the middle was a wheel-race with paired waterwheels fed by a reservoir behind, driving a total of sixteen troughs. The two wheel-yards (one belonging to each wing) were connected by a bridge over the tailrace at the front of the building; that to the north was defined by a retaining wall with built-in steps leading to the higher-level dam. [fig. 4.39] From scale plans of the building it seems unlikely that the hulls could have been arranged back-to-back, as suggested by the engraved view.[140] Larger examples on the same pattern included the Limbrick Wheel, itself later augmented by a steam engine.[141] [fig. 4.40]

At the Soho Wheel, a single engine house gave the advantage of central supervision, and simplified the arrangements for the storage of coals and supply of water. Like its water-powered equivalent, it also allowed the sharing of costly infrastructure–in this case the boilers with their seating, and the deep stone foundations for the engines. Consequently there were three boilers between the two engines, which in the event of one breaking down or having to undergo maintenance would have allowed both wings to continue normal operation; the rest of the time, each boiler could be run at a lower pressure, saving fuel.[142] A survey drawing of 1834 shows two boilers in the secure 'weigh house' yard to the south and one in the north yard, separated by the engine house with its central 41-yard stack.[143] Repairs to the boilers were frequent and by 1839 the original boilers had been replaced (not for the last time) by three large wagon boilers.[144]

In a similar way to the Park Wheel, both existing and unexecuted elements of the estate plan influenced the design of the Soho Wheel and its position on the site. The strongly symmetrical elevations were aligned with the streets leading towards the site, designed to close the vista at the end of Bower Street in the west and the unfinished extension of Cross Love Street in the south. A reconstruction of the intended street grid [fig. 4.41] demonstrates that beyond these visual gestures, the buildings were also planned to respect as far as possible the potential routes across the site: the engine house set slightly off-centre in order to lie just north of the line of Bower Street, and the north end of the wheel defined by an extension of the same grid pattern. Traces of this plan are also evident in neighbouring plots, and in some

[139] Crossley (1989) pp. 63-64. Also see entry for John Hartley & Son and accompanying illustration of 'Rivelin Cutlery Forge' in *Industries of Sheffield* (1890?) pp. 60-61.
[140] See plans SCA ACM Bra170S; 1890 OS plan.
[141] SCA Bush S526 (1890); S226 (1916).
[142] Originally, only two boilers may have been installed, as the earliest plans indicate only those in the south yard.
[143] SCA FBC MB391 (1834) p. 37. This stack appears to have been built to replace the original early in 1823 (MD709, 8 Nov. 1822) and was relatively unusual in having four separate flues within its square section, less efficient than a single large section and possibly an aggravating factor in the Soho Wheel's lamentable pollution record. See Simmons (1995) p. 202.
[144] By 1826 at least one wagon boiler was in use. An 'Old Round Boiler' was still in need of repairs in 1839. See appendix 4.4.

cases–Steam Street along the western boundary of the wheel, for example–existing streets were absorbed by adjoining properties (see also Ibbotson's Bridge Street Works, chapter 3; Whitham's Works, gazetteer).

In 1833, the Soho and Union Wheels were singled out as the two largest in the town, each employing up to 250 grinders and as many more apprentices, with a 'gross yearly income of upwards of £2000', of which about half was spent by the proprietors on building repairs.[145] They were also considered to be among the best constructed and managed, emerging from Dr. Hall's report with slightly better than average mortality statistics.[146]

The workers

Like most steam wheels, working hours at the Soho were from 8 am to 5pm, extended to 7pm on Fridays when grinders tended to make up for the slower pace following 'Saint Monday'. Saturdays were also worked from 7am to 4:30pm giving a potential working week of around 56½ hours, although even at busy periods most grinders would take time off during the earlier part of the week.[147]

It was usual practice for almost everything required by the grinder to be included in the rent charged by the wheel, with the exception of wheel-bands, tools and the grindstones themselves (although grinders working for a master would have the latter provided). A grinder working at the Soho Wheel around 1830 related that 'they pay as a rent 8 Gus. per Troughs for Penknife grinding & 17 Gus. per Trough for Tableknife grinding, & they have everything found them except the stones & straps, even Coals to warm the rooms'.[148] As trough rents were closely regulated they remained remarkably constant, the figures quoted above unchanged for at least the period 1820 to 1833.[149]

Collecting rent was not always straightforward, and disputes arose over the cost of troughs and credit extended to the tenants; in 1835 such difficulties led to the suggestion that 'an agreement book be drawn up and printed for each new tenant to sign previous to his being allowed to continue work'.[150] Late payment and other misdemeanours could result in the imposition of 'forfeits', the proceeds of which were spent each summer by the proprietors on a

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[145] White (1833) p. 54. See also Hall (1857) p.22: 'The Soho wheel has fifty Hulls, and, on average, five hundred men and boys work at it. The Union wheel contains forty-six hulls, and from three hundred to four hundred men and boys are employed'. The rank of the Union and Soho wheels is confirmed by the primary sources; see gazetteer and graphs.

[146] Hall (1857) p.22, commented: 'The Union and Soho wheels are both first class wheels, and the mortality at them may be considered below rather than above the usual mortality'.

[147] SCA MD709, 26 Dec. 1832; 25 March 1833; 5 Jan. 1854. Meetings of the proprietors were held at the wheel during the week from 6pm–one hour after the engine stopped, at which time the gates were locked. See also Pollard (1959) p. 61.

[148] NB25 (c.1829-30) p. 106 'Colson Crofts Grinding Wheels'. The abbreviation 'Gus.' stands for 'guineas'.

[149] SCA MD709, 3 July 1820. White (1833) p. 54.

[150] SCA MD709, 1 Jan., 5 Feb. 1835. Also 6 Oct. 1836, 'That Elliss Bradwell be forthwith written to for Payment of the amount due to the Company in consequences of his insolent behaviour this evening towards the Committee'.

dinner or even a short holiday![151] The small masters that made up a great proportion of the wheel's tenants were obliged to find enough work to pay their rent, or risk losing their place at the wheel upon which their livelihood depended. That tenants often saw the public wheel as a long-term investment is indicated by the number of entries in the minute books concerning the adaptation of hulls to particular needs, with internal partitions being erected or demolished and different troughs and machinery installed (see 'development', below).

The congregation of wheels in certain districts gave rise to an informal 'marketplace' for the workers, particularly unemployed or jobbing grinders who would go from wheel to wheel in search of odd jobs such as hanging and racing stones. In this sense, the urban wheels created localised steam communities, much as the confinement in the valleys had. Unlike some of the urban wheels (most notably the Union Grinding Wheel) the Soho had no dedicated workers' housing, tenants such as the cutler studied by Le Play travelling from their homes about the town to the wheel each day.[152]

The only workers employed directly by the proprietors were the engine tenters, whose responsibility for the safe operation of the engines and boilers commanded a relatively high income. As a specialised occupation, tenters were in high demand: in 1811, an advertisement was placed in the *Sheffield Iris* for a 'steady man to work and manage a Watt patent engine in Coulson Croft'–almost certainly a reference to the Soho Wheel.[153] On those occasions when accidents did occur, however, it was often the tenters who took the blame. In 1833, damage to one of the engines was initially ascribed to 'the connecting rods not being sufficiently strong', but the following week the committee resolved: 'Tenters to pay more attention to cleanliness of the Engines & Wheel in general'.[154]

From the beginning, provision was made for them to live on the premises in a pair of three storey dwellings at the corner of Bridge Street and Plum Street, set within the wheel-yard with little in the way of private external space.[155] The interlocking plan areas would have allowed only one room to each floor, a familiar layout common to much of Sheffield's back-to-back housing.[156] Residence at the wheel was both a benefit and a condition of the job: when in 1830 a new tenter was taken on, his terms of engagement included 'wages 1 guinea per

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[151] SCA MD709, 28 Sept. 1835: 'Forfeits used to pay for a Dinner at the Barrack Tavern for the Committee'; 12 Aug. 1836, spent £3 14s 8d on purchases for a dinner (mostly alcoholic drinks); 6 July 1837, the forfeits were to be spent on an excursion to Derbyshire, the 12-13 July.
[152] Le Play (1855) pp. 194-199; the subject lived by the river Sheaf, 150m from the edge of town, but had to rent a two-room workshop in a wheel in the town one kilometre away–probably the Soho Wheel, described as 'un groupe considérable de bâtiments, où 200 meules environ...sont mises en mouvement par une machine à vapeur dont le force se transment au loin au moyen d'arbres de couche et de courroies', p. 195.
[153] Advertisement from the *Sheffield Iris* of 12 March 1811; quoted by Flavell (1996) p. 155. It has already been noted that the Soho Wheel was powered by two Thompson engines built under Boulton's patent.
[154] SCA MD709, 1833 April 29, 1833 May 6.
[155] SCA MD709, 8 July 1834, mentions '...the engine tenters house in Coulston Street [i.e. Bridge Street]', alongside which offices were later built. The two houses and their occupants appear in earlier rate surveys, carrying identical charges, SCA RB150 (1815) Item 1, North Div., 6 Jan, p. 164: '18 Richd. Johnson, Ho[use] 2s 9d; 19 Saml. Cocker, Ho[use] 2s 9d; Paul Bibbs & others Proprietors of the Soho Grind Wheels, Eng[ine] Ho[use] Sheds & Weigh Machine £9 3s 0d', [the whole entry contained within curly braces 'The Proprietors of the Soho Wheel']. Also see the nineteenth century Goad fire insurance plans.
[156] Pollard (1959) pp. 17-18.

week, House rent & coals no extra charge...for packing Piston, Cleaning boiler, etc.'[157] Although the tenters' round the clock presence on site was not strictly necessary (the engines were shut down in the evening), it meant that in effect they doubled as night porters, able to oversee the main gates from their chambers. Less skilled labour was hired for the day-to-day stoking of the boilers and related tasks; the tenters probably supervised the supply of coal, operating the weighing machine that had been installed by the main gates in the engine yard.

Development: 1805-1920

Unlike steelworks, where capacity tended to expand incrementally by the addition of furnaces and workshops, the growth of steam-powered sites was limited by the capability of the engine–a substantial fixed investment–the upgrading or replacement of which was difficult and expensive. The need for good natural light prevented the adoption of deeper plans and the construction of lean-to structures in the yard, so the basic form of most public wheels remained remarkably static over their lifetime.

On the other hand, the prime mover could be adapted to provide room and power for any number of trades, and changing demand led to the conversion of some hulls to other uses. The diversification of trades at the wheel is first indicated in 1829 when the committee approved 'George Smith to commence Sep 25 paying at rate of £5 5s 0d per Ann. for yard quarterly & give or take a quarters notice', although the arrangement was short lived.[158] Previously, the wheel-yard had been treated as a communal space for the grinders, used in the preparation and storage of grindstones, deposition of wheelswarf, and also for impromptu social gatherings. The letting-out of certain areas to tenants with particular requirements, such as lumber storage and sawing facilities for wood-turners, signalled the beginning of a gradual privatisation of the 'public' wheel.

From the 1830s onwards, an assortment of new buildings sprung up in the wheel-yard, some built by the proprietors at the request of tenants, and others–generally sheds and warehouses–constructed by the user.[159] These speculative ventures were not without their attendant problems: one dispute arose when a tenant 'unceremoniously proceeded to pull down the warehouse & premises [he] erected on the Comp[any's] land some years ago', and had to be threatened with legal action to stop.[160]

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[157] SCA MD709, 2 December 1830.

[158] George Smith gave notice to vacate the yard by 25 March 1830, the end of his second quarter. SCA MD709, 4 May 1829; 7 Jan 1830.

[159] SCA MD709, 9 Aug. 1833: 'Mr. William Unwin the Architect be requested to prepare plans & specifications of a number of shops to be erected to the front of Coulston St.'; MD717, 4 May 1838: 'That two shops be built at the end of the Wheel next the river for the use of Mr. Holdsworth and other tenants occupying chamber room to lay their wood in'; 26 Dec. 1839: '...two small shops to be erected for the use of the Wood Turners on land adjoining the Shops occupied by Mr. Holdsworth & Mr. Shepherd'; 28 Sept. 1846: 'That the Sub-Committee be authorized to build a shop or shed about 14 ft by 14 yards at the north end of the west wing of the wheel to be let to John Jepson if they can agree with as to terms'.

[160] SCA MD717, 5 Aug. 1844. The tenant was 'Geo. Timmon' or 'Truman' who had constructed a 'wood warehouse' on the Company's land (extended by a further storey in 1837); the dispute seems to have arisen over a condition that

About the same time hulls also began to be modified for specific purposes, in response to changes in market demand. During the summer of 1831, for example, the first conversions for saw grinding were made; meanwhile the proprietors 'declined making any more heavy room at present, there be a probability of the Places being occupied to better advantage'.[161] Further subdivision of hulls was made in the following years, particularly to the chamber (first) floors, which were put to lighter, more general-purpose uses.[162] By 1834, the rigid pattern of six troughs per hull (making 264 in all) had given way to a more varied distribution of uses, with some rooms adapted to purposes other than grinding.[163]

A comparison of the internal partition arrangements from 1805, 1850 and c.1890 [fig. 4.42a-c] clearly shows the progressive breakdown from the original rigid order of identical hulls, as alternative uses of space led to a greater variety of subdivisions and extensions, in addition to the more obvious structures built against the exterior.

Whereas it was usual to find office accommodation at the works of most manufacturers, for a public wheel this was generally considered an unnecessary expense. The Soho Wheel was no exception, and in the early years of its operation meetings of the committee and proprietors were held at members' houses.[164] By December 1832, committee meetings were being held at the wheel itself in what must have been very basic surroundings.[165] It was not long before the committee decided to build a new office at the wheel, 'for the transaction of all business connected with the establishment'.[166] A budget of £130 was proposed, and the wheel's regular architects, William and Charles Unwin, instructed to draw up plans and specifications. The buildings were to be situated along Bridge Street 'adjoining the engine tenter's house in Coulston Street', at the southeast corner of the site closest to the town.[167]

By August, the tender of £138 from local builder Henry Clarke had been accepted, and construction must have begun immediately as the new offices were complete in time for the

'if the Co. should...require him to give up possession of the land...he shall be allowed to take away all the old materials'; 3 Aug. 1837.

161 SCA MD709, 2 June 1831; 10 July 1831; 25 March 1833: 'That the committee look at the Rooms which Jos. Moore wishes to have altered'; MD717, 4 May 1838: 'The alteration now making in the Hull next the Engine house on the left hand going into the lower yard for Mr. Woodhouse of Rockingham St. Table Knife Manuf. was also looked at and app[r]oved of. Thos. Nowill'.

162 SCA MD709, Good Friday 1833: 'Meet at wheel relative to the division of rooms...'; 7 July 1835: '...to consider the propriety of dividing the two large chambers in No. 2 Engine into five rooms [as] in No. 1 Engine.

163 Compare SCA FBC NB25 (c.1829-30) p. 106 and NB31 (c.1834) p.10.

164 For example: 'At a General Meeting of the Proprietors held at the House of Mr. Bibbs, May 1, 1809', Proprietors of the Soho Engines (1809) p. 9; meetings were still being held at Mr. Bibbs' house in 1822, SCA MD709, 6 May 1822.

165 SCA MD709, 26 Dec. 1832. Committee meetings were to be held at the wheel from '6pm instead of 3 as before until 8, & the wheel run until 5'.

166 SCA MD709, 5 June 1834.

167 SCA MD709, 8 July 1834. The name Coulston Street appears to have been used colloquially to denote the stretch of Bridge Street running along the eastern site boundary, not the short street to the south (of which it could be seen as a continuation) as marked on contemporary maps. An entry of 1830 specifies that 'The upper gates be removed to the Corner of Bridge Street,' which in plan refers to the angle at the north east corner of the site. In this context, Bridge Street was the narrow lane running alongside the water and leading to the Bridgehouses crossing.

customary Boxing Day meeting of the Committee.[168] The new building was not large, but evidently quite comfortable, as the minutes record purchases including green cloth for furnishings, a (kitchen) range and twelve 'Winston' chairs; soon after, it was resolved that 'the office be papered & painted & a new clock fixed therein'.[169]

With the increasingly heated union disputes of the 1840s, the large public wheels became the unintended targets of attacks on the property of individual workmen or companies renting troughs there. A number of fires at the wheel are recorded in the minutes, and while no cause is attributed, it is certain that some of these were the consequence of incendiary attacks. The parts of the Soho Wheel most at risk from fire were the raised chamber floors, originally constructed of timber joists and boards. Following the burning down of one wing on Sunday 28 October 1827 (a day the wheel would have been empty), it was proposed that in addition to the £39 insurance valuation of the board floor, the proprietors should contribute a further £56 to reinstate it in fireproof construction, a technique adopted by the later public grinding wheels.[170] In 1842 a similar fire destroyed part of the chambers in the west wing, leaving the proprietors underinsured and unable to pay dividends for that quarter.[171]

More serious still was the fire of 1844, reported by Engels to have been the result of an arson attack.[172] This time, plans were drawn up by Unwin for 'the restoration and improvement of the North West Wing of the Wheel–The Chamber floors to be Fire Proof Brick Arches and the Roof Laths & Spars Wrought iron & cast metal–the cost of the whole exclusive of machinery being estimated at £1100', of which £1000 was to be borrowed 'on security of the company's Title Deeds'.[173] However, the proprietors seem to have got cold feet, rejecting the proposals in favour of renovating the destroyed wing to its original state at around a third of the cost; existing tenants had obviously begun to desert the building for alternative premises, as it was decided to subdivide three of the new hulls into six smaller rooms and offer them 'for competition' between the investors.[174]

Aside from changes to the fabric of the building, other less visible developments were of equal importance to the operation of the wheel. In 1837 a meeting was arranged with Vickers who possessed the rights to the Town Mill system of goits, 'to purchase a sufficient supply of water for the steam engines–in the mean time to make all necessary inquiry relative to other supplys'. Vickers at first insisted on 40 years' purchase on the annual water rent of £21

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[168] SCA MD709, 7 Aug. 1834, Clarke was based on Meadow Street to the northwest of the town centre, Pigot (1834) [Yorkshire section] under 'Stonemasons & bricklayers'; MD709, 26 Dec. 1834, the minutes begin 'At a meeting of the Committee held for the first time in the New Office on the Soho Wheel premises...'

[169] SCA MD709, 6 Nov. 1834; 3 Nov. 1836. The building is marked as single storey on the late nineteenth century Goad fire insurance plans, and was just one room deep.

[170] SCA MD709, 1 Nov. 1827. The most notable example at the time was the Union Grinding Wheel; see 'form and construction', below.

[171] SCA MD717, 28 March 1842; 2 June 1842.

[172] Engels (1845) p. 266: 'Donnerstag den 1. Februar 1844 wurden die Soho Wheel Works in Sheffield in Brand gesteckt und ein Raub der Flammen'. The date given by Engels does not agree exactly with that in the Soho Wheel minutes, but is certain to refer to the same incident.

[173] SCA MD717, 15 Feb. 1844; 29 Feb. 1844.

[174] SCA MD717, 25 March 1844; 9 May 1844; 16 May 1844; 20 May 1844.

(therefore £840), while the proprietors were only willing to offer 35 years (£735); after some months of negotiations, the price seems to have been settled at £800.[175] The significant cost of such a transaction was clearly worthwhile when offset against the short term cost of rent and the difficulty of securing alternative sources.

The only major change to the site area came around 1854, with the building of a major new route–Corporation Street–connecting West Bar to a new bridge over the Don that led to Bridgehouses and Nursery Street. [fig. 4.43] Compared to other premises in the Coulson Crofts area, the Soho Wheel escaped relatively unscathed, the route missing the main wheel building and requiring only some reconfiguration of the boundary walls and demolition of accumulated workshops in the yard. To what extent this was the result of negotiations between the relatively powerful committee and the Sheffield Corporation is not known.[176] The Union Grinding Wheel was similarly undamaged, as the new street was cut across the site precisely between the wheel itself and the Union Buildings.[177]

In plan, the wheel as recorded by the 1889 Ordnance Survey retained its essential form, although the effects of cumulative modifications and rebuilding are visible.[178] The Soho Wheel continued in use as a grinding wheel under steam-power until 1920 when it was closed down and partly demolished.[179] Its closure was primarily a financial decision, the Board of Management having been persuaded that the land upon which the wheel stood was more valuable than the proceeds arising from the business, and that as such it should be sold.[180]

The remains of the wheel

Following the demolition of the east wing and engine house, the west wing remained in use as workshops, the old pattern of hulls still identifiable on fire insurance plans of the 1930s.[181] [see fig. 4.42d] With the erection of new buildings about its perimeter, the surviving wing became internalised, and was ultimately demolished from the inside to form an open yard. Due to structural connections with the new buildings, the external walls of the hulls survived, embedded in the perimeter of the yard; these remained unnoticed until identified by the author in 2000, in the course of a limited building survey.[182]

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[175] SCA MD709, 2 Feb., 2 March, 6 April 1837. A cheque was withdrawn from the Sheffield and Rotherham bank on 1 June 1837.
[176] SCA MD717, 3 Feb. 1853, records the committee's intention to undertake negotiations with the 'Corporation to take the land & premises for the approaches to the New Bridge'.
[177] SCA Sale Plan JC1828 (1854) land left over by the intended creation of Corporation Street and Alma Street, auctioned Tuesday 12 Dec. 1854.
[178] 1889 OS plan, sheet CCXCIV.8.8.
[179] Details from a loose note in MD709, written post-1920 and summarising major events in the wheel's history. Also SCL 942.74(S) NCRS vol. 18, pp. 123-4.
[180] SCL UGW27, loose letter of 1 July 1954 from Edward Bramley (solicitor, Town Collector and ex Soho Wheel Board member) to R. E. Pickford of the Union Grinding Wheel.
[181] SCL Goad Fire Insurance Plans, sheet 14, includes the note on buildings adjacent 'under const^{n}. July 1937'.
[182] The author's initial fieldwork was followed by a limited archaeological survey and desktop study by Kenneth Aitchison of ARCUS at the University of Sheffield and the author, included in the unpublished report: Aitchison (2001) pp. 28, 57-58.

What was once the interior of the hulls is now a car park. Much of the west façade survives from the central two storey bay southwards, including the cut ends of roof joists and rough-hewn stone tiles, timber lintels and hand forged nails, along with some of the east engine-yard façade. [figs. 4.44-4.46] The latter includes a salvaged cast-iron column, which may originally have belonged to a ground floor hull, used to the support the vaulted brick first floor above.[183] [fig. 4.47] There are no above ground remains to indicate the survival of structures belonging to the engine or boilers, but on the evidence of nearby sites of a similar type it is possible that the massive stone beds of the seating remain beneath the later concreted floor.

Elsewhere on the site, remains of perimeter walls can be found, generally postdating the construction of Corporation Street but incorporating elements of earlier gateposts, including large blocks of ashlar stone.

Despite modifications in use, the surviving fabric belongs to a part of the wheel largely unaffected by fire and rebuilding, and therefore representative of the early nineteenth century building. The remains present the opportunity of further research into a significant local building type thought to have become extinct with the demolition of the Union Wheel in the 1950s,[184] one of the earliest and largest of its kind.

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[183] A brick arched first floor is indicated on the 1930s fire plan referenced above, probably installed following one of the fires of the mid 19th century.
[184] Johnson (1959) pp. 17-20.

Part 2: The urban context

Water sources: rivers

Almost all of the earliest grinding wheels to adopt steam-power were located at the very edges of Sheffield's built-up area, a pattern of development that can be attributed to several factors. The sheer size of the structures (dictated by the economic viability of steam-power) and the large site area needed for the surrounding wheel-yards was more easily accommodated on greenfield sites than in the patchwork of small-scale town centre plots. Restrictive covenants prohibiting the erection of steam engines were also a common feature of leasehold agreements for sites in the town--particularly the managed estates--forcing such unsavoury land uses to the low-grade hinterland of its rivers.

On the other hand, the steam engine is held by tradition to have freed industry from its dependence on water, instead allowing the location of factories to be determined by the supply of raw materials or proximity to the market.[185] It can be demonstrated, however, that this view is an oversimplification and that the availability of a good water supply continued to be an important, if not decisive, factor in the planning and location of early steam-powered works.[186]

The volume of water required by early steam engines was considerable, especially in comparison to the smaller, more efficient engines of the later nineteenth century.[187] As seen above, the first public wheels were built directly against the rivers Sheaf and Don; the Soho Wheel also depended on the Vickers' Town Mill supply from the Don, as did the later Union Wheel (1818-20). Only one large wheel, the Bees' Wax (c.1816; see below), was built upon the smaller Porter, more a stream than a river. By 1822, the Nursery Steam Wheel (below) was the furthest removed from a source of flowing water, but even then by little over 100m. A plan of that year indicates the path of an underground sough from the river Don, constructed to supply the boilers (situated closest to the river) and augmented by a reservoir.

Even when it became more feasible to erect engines away from the riverbanks, steam wheels tended to cluster in particular districts of town, particularly the Coulson Crofts estate, the Nursery and the Wicker. A report in *The Builder* of 1897 observed that:

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[185] Tredgold (1827) p. 45; Evans (1805) article 1. There was some contemporary scepticism towards this view, expressed in a quote from *The Scots* [i.e. Glasgow?] *Mechanics' Magazine* (1825) vol. 1: 'Such, indeed, has been the éclat of the steam engine, that whenever a work became scarce of water, either from its being enlarged or from a dry season, nothing was to be heard but the general cry "Put up steam engines and be independent of water."'; SCA FBC NB23 p. 32.

[186] Connell (1990) pp. 191-194, supports this hypothesis with a parallel study of the location of steam-powered textile mills in Leeds before 1834.

[187] NB34 (1833?) pp. 18-19. Woodcock's (Park Wheel) engine required 67.23 cu. ft. of water per minute. Farey (1827) pp. 593-594, 'Quantity of cold water required to supply Mr. Watt's double engine'.

From the eastern hill, behind the Midland Railway station, bird's eye views of practically the whole town may be obtained, and one notes how the tall chimneys congregate in the valleys, particularly in the north-east.[188]

Without denying the importance of land ownership and leasehold terms, one factor that made these areas more conducive to the establishment of steam-power was their relationship to the underlying water table. While Sheffield's hilly terrain made it one of the best naturally drained towns in the country, the land in the immediate vicinity of the rivers could be flat and marshy, with pools of standing water.[189] The river Don in particular had historically run in a much wider channel than during the modern era, frequently flooding the low-lying ground to each side;[190] [fig. 4.53] many of the street names in these areas pay testimony to their former character– Watery Street, Water Lane, Spring Street, Mill Sands, Pond Street, even a lane called 'Under the Water'.

In medieval times, much of this ground may have been permanently flooded. John Holland recalled that during building work at the old Silk Mill (a relatively early steam-powered site), the ground exhibited 'traces of fluvial action alternating with sedimentary beds', while at Spring Street in the Coulson Crofts, excavations for a gas holder uncovered a large tree,

...evidently lying as it had been cut, marks of the axe being visible at the kerf: the wood of this tree was interiorly a bluish black, looking as if recently dyed with ink: a considerable number of hazel nuts, thoroughly coloured in like manner, were found in a sludgy blue clay, lying above what appeared to have been the ancient river bed.[191]

Other locations with a similar history included the canal basin and its surroundings (Sheaf Works), and even as high up as Philadelphia (Globe Works).

These archaeological findings are supported by former topographical features of the area: the Fairbanks' 1771 town plan shows an unusual water feature just south of the Silk Mill, known as 'the Serpentine' and said to have been anciently used as fish ponds.[192] Nearby was the abundant Bower Spring, collected in troughs and reputed to be the best source of potable water in the town.[193] This supply descended from the higher ground of Furnace Hill in the south, and was said to have suddenly dried up when Hudson & Clarke built their steam

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[188] *The Builder* (1897) vol. 78, no. 2853, October 9, p. 280.
[189] Holland (1843) p. 47, 'There are probably few towns better situated for natural drainage than Sheffield; in one part only does water falling from the clouds remain, viz.: Shalesmoor, Spring Street, Norris-field, &c., in the North district'. Norris Fields constituted part of the Coulson Crofts estate, named after 'Mr. Norris in West Barr, a very opulent Razor Manufacturer', and former Master Cutler; Woolhouse (1832) p. 22.
[190] Smith (1865) p. 95, related that 'In 1768 a portion of the Shrewsbury hospital [in the Park] was washed down by a sudden rising of the Sheaf; and the waters of the Don have often overflowed the locality named "The Nursery."'
[191] Holland (1837) vol. 1, pp. 212-213. He concluded that the constriction of the Don's channel was due either to 'silting up the bed...or the deposition of rubbish from the town'; however, the most profound effect may have resulted from the early adaptation of the natural topography to water-powered uses.
[192] Fairbank (1771); Aitchison (2001) p. 60.
[193] Leader (1875) p. 129.

engine on that street (c.1834-5), suggesting that it had been diverted to feed the reservoir at Union Foundry.[194]

Prior to the industrialisation of these districts, water was also conveyed through the fields by numerous watercourses and drainage channels, both artificial and man-made, which were subsequently culverted or filled in.[195] One such channel, possibly related to the Bower Spring source, passed behind (and may have fed) Hague & Parkin's steam-powered rolling mill of 1793, the first in the area.[196] Another ran from the chain of reservoirs at Crookesmoor, following the route of Watery Lane and Street and along Green Lane to meet the Don.[197]

More elusive is the watercourse shown on the survey of Soho Wheel, from which the course of Water Street appears to have been determined. Its proximity to the Soho Wheel, Reform Wheel, Bridge Street Works and Pilot Works suggests that it may have been instrumental in the industrial development of Coulson Crofts. Surviving fabric of the Pilot Works includes a broad brick arch built into the lower part of the works' western wall, in line with the site of the engine and boilers. In the absence of any evidence of a basement, this arch probably served to relieve load above the works' water source, predating the installation of mains water in the area. Also unaccounted for is the Soho Wheel supply prior to the negotiations with Vickers (see above), which may have come from the same channel. Certainly, a pattern emerges from the distribution of early steam-powered sites in the area of Kelham Island and Coulson Crofts.[198] [fig. 4.54]

As demonstrated by the drawn out negotiations between the Soho Proprietors and Vickers, the water rights themselves were a valuable asset, and sale plans of steam-powered premises often made reference to this. On the 1889 auction particulars of the Exchange Works, much is made of 'a Capital Supply of Water from a Stream running through this and adjoining land'.[199] At Forge Lane, in the Ponds district, 'The owner of this mill has for the purpose of supplying it and the Steam Engine therein with water, the right of taking water through a pipe 4 inches in diameter from the adjoining Ponds Dam; or in the event of such dam being discontinued...from the River Sheaf'; the Globe Works (chapter 3) similarly came with 'The Right of taking Water from the River Dun for a term of 50 years from September 1872 subject to the payment of a yearly sum of £10, and conveying such water to the works, subject to the payment of the yearly sums of £4, 10s and 5s...'[200] Thus, even towards the end of the steam age, water supply to the boilers and for condensing remained an important consideration in the location and planning of large powered works.

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[194] MB393 (1835) pp. 34-35, includes a plan of the foundry dated May 4.
[195] For references to some of these lost channels and wells, see Leader (1897) pp. 217, 239, 314-9, and *passim*.
[196] SCA FBC SheS478L shows the site to be defined to the north and west by a channel, which emerges on the northern side of Gibraltar Street, parallel with Trinity Street, before curving eastwards, running straight along the rear of the site and then slightly northwards, possibly connecting to the 'Serpentine'.
[197] Woolhouse (1826?) p. 11.
[198] One hypothesis would link the cotton mill engines (final phase) and the location of the engine added to the Kelham Wheel, continuing in a practically direct line through the Pilot Works, Soho Wheel, Bridge Street Works, before returning to the Town Mill goit at Vickers' grinding wheel.
[199] SCL Sale Plan: Exchange Works (1889). The stream supplying Exchange Works is likely to have been the same one Josiah Fairbank intended to use for the Thomas Street grinding wheel, below.
[200] SCL Sale Plans: Forge Lane (1885); Globe Works (1883).

Water sources: reservoirs

For the smaller sizes of engine, the sinking of reservoirs enabled the construction of wheels in districts away from the rivers. To limit the cost and land area, these were generally planned to hold only enough water for a working day, which would be replenished overnight by the running supply. To further improve the reservoir's efficiency, the water could be compartmentalised, keeping fresh, cold water apart from recycled warm water that had been used in the engine for condensing, and could be reused as preheated boiler water.[201] Therefore, for an average engine of ten to twenty horsepower, the areas required were not great, and often needed to be no more than a yard in depth; even so, many of these urban reservoirs can be identified on or near to the sites of steam wheels on the 1850 OS plan (see gazetteer).[202] Where not visible in plan, reservoirs were often hidden beneath the yards and buildings of works, while the increasing demand for space led to many open reservoirs being built over (but continuing in use).[203]

Davenport's sixteen horsepower engine, for example, was fed by a reservoir considered by Fairbank to be a 'small' one, occupying an area of 192 square metres.[204] Elsewhere, the reservoir was placed centrally in the works yard as at the canalside Fitzalan Works of Marriott & Atkinson, which occupied 'a quadrangular space...having a large tank or reservoir near the centre, and around it are the various workshops for conducting the manufacturing processes'.[205] When Hudson & Clarke of the Union Foundry doubled the power of their steam engine for a new grinding wheel (from eight to sixteen horsepower), the reservoir had to be correspondingly enlarged from 5x7 yards to 10x11, although its location in the yard did not change.[206]

Where engines were added to existing works, and in other cases where space was limited, reservoirs could be built on nearby land connected by underground pipework to an on-site

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[201] This improved efficiency as well as economising on limited water supply; Fairbank claimed of his design for a public wheel on Thomas Street (1832) that 'by proper management [the reservoir] may be so contrived as to keep the cold water separate from the warm & to work it over again & again if necessary'. One of his notebooks contains the rule 'Christy says that every Horse Power of a Steam Engine requires 5 Galls of water per minute for condensing with, the Boiler requires very little for waste and can take the condensing water when done with–', SCA NB29 (c.1832) inside back cover. Compartmentalised reservoirs can be seen on the 1850 OS plans of Rodgers' Sycamore Street (partly under the building), Arundel Forge, Roscoe Place, Portland Works, Phoenix Foundry, and possibly Washington Place.

[202] Beauchamp (1996) p. 356, surprisingly states that a study of the 1850 OS plan 'revealed no reservoirs that were obviously connected with...steam power'.

[203] See for example SCA MB399 (1836) p. 25, Rodgers' Sycamore Street 'grinding wheel & reservoir under' and 'reservoir under pt. of yard'.

[204] SCA FBC NB29 p. 123 (16 July 1835) 'Devenport's [sic] Engine in Rockingham Street, 16 Horse Power'. Fairbank recorded that Davenport 'says the expence or loss of water for this engine working 11 hours per day & 6 days per week is 60,000 Gallons per week' calculated as 9.46 gallons per minute per hp. He considered this to be 'a much larger quantity than is sometimes calculated...Christy says 5 and others 7 Galls. p. minute p. HP, but Davonport [sic] says he has made very accurate calculations, he draws all his water from a Well & has but a small Reservoir'. SCA FBC MB401 (1836) p. 13, reservoirs 600x745, 520x3550 [hundredths of a yard], in all 229 sq. yds.

[205] 'A Day at the Fitzalan Steel and File-Works, Sheffield', *The Penny Magazine Supplement*, vol. XIII (March 1844) pp. 121-128.

[206] SCA MB393 (1835) pp. 34-35 includes a plan dated May 4, listing 'Engine House 8hp' with further notes added in pencil 'Now 16hp', 'Is now where old stable was 3 stories grinding wheel', 'New reservoir'. A sketch shows the reservoir to have been enlarged from 500 by 700 to 1100 by 1005.

tank near the boilers. Due to the legal difficulties involved in crossing other premises, offsite reservoirs were usually to be found directly adjacent to the works, or just across the road as in the cases of Roscoe Place, Arundel Forge, Portland Works and Doncaster Street. The largest proposed reservoir was planned by the Fairbanks for the unbuilt public wheel on Thomas Street (below), intended to be fed by a stream (for which numerous calculations to ascertain the rate of flow and potential consumption exist). It is tempting to speculate that it was the lack of a substantial and reliable water supply–all the other public wheels were built on Sheffield's rivers–that led to the abandonment of the scheme.

Being of such importance, it is unsurprising that water rights were frequently the subject of disagreement, an example of which is contained in the Fairbank archives. The surveyors had been commissioned to calculate the amount payable for water taken from the Don by proprietors of steam engines to the Wicker Wheel Company. Josiah Gallimore, an engineer who had recently erected new steam-powered workshops, disputed that his water was taken from the goit, claiming instead to draw the necessary supply for his twenty horsepower engine from a well beneath his small works, and return it warm to the river. Recent excavations at the site of his works suggest that Gallimore's claims were unfounded, and that a more substantial source for the engine and boiler would have been needed. The same property also gave rise to a rights of light case and a boundary dispute.[207] [fig. 4.55]

After the establishment of the Sheffield Waterworks Company by Act of Parliament in 1830, wheels began to be built in otherwise inaccessible areas. For some years the piped mains supply was only available for three days each week, so did not remove the need for a reservoir, but had the advantage of being relatively unaffected in periods of drought.[208] A report of 1843 was claimed that 'besides houses, the [water] company supply many steam engines, breweries and manufactories of various kinds', a situation that did not meet with universal approval.[209] In 1845, the Millowners of the Rivelin, Loxley and Don published a protest against the plans of the Water Company to build a new 37-acre reservoir on the Rivelin, which they claimed would deplete the stream and damage their business. While the Water Company claimed the reservoir was for domestic supply only, the Millowners questioned whether the real intent was:

> *...to supply the 100 steam engines of the town, from which the annual income must be enormous, and which the company could not supply if it did not first unjustly deprive the Mill-occupiers of a right which they and their forefathers had, long before a Water Company was contemplated in Sheffield?...If this Water Company is to become the great monopolist feeder of the steam engines and the*

[207] SCA FBC NB30 (1830) pp. 26, 66, 68; copy of note from J Marshall on behalf of J Gallimore to J Fairbank and Son, 11 March 1830. For the rights of light case, see SCA FBC EBu117S, FB191 p. 37, SheS713-715S.
[208] Holland (1843) p. 14. The supply was still intermittent as late as 1869. Linton (ed.) (1956) p. 183.
[209] Holland (1843) p. 16.

factories, it must also become the monopolist of every streamlet that wanders through the hill or dale of the vicinity. But is this the legitimate province *of a Water Company?*[210]

In spite of their representations, by 1854 the Redmires reservoirs had been completed, and the growing demand for water meant that further and larger schemes were to follow.

It was only at this point that the much vaunted ability of the steam engine to liberate works from natural sources of water became a reality within the town, allowing location to be determined by economic considerations such as supply of materials and workforce, much later than is often assumed. In the case of the grinding wheels, proximity to the town-dwelling grinders and the related cutlery and tool trades was the primary consideration, clearly demonstrated by the distribution of wheels about the town in 1850. Mostly situated within the built-up area, the sites formed a ring around the town centre and inside the Police District boundary (defined as three-quarters of a mile from the cathedral) close to the districts in which grinders and workmen generally lived. [fig. 4.57]

During the second half of the nineteenth century, the availability of smaller, more efficient engines and a more regular water supply allowed many works to dispense with their reservoirs, replacing them altogether with elevated iron tanks fed by mains water. While map evidence for these header tanks is limited, they are often visible in topographical views of works. On the explosion of a boiler at Joseph Smith's Sidney Street wheel in 1875, a Sheffield newspaper stated that 'over the boilerhouse and supported on iron pillars was an iron cistern (pillars visible), which weighed, when full of water, 110 tons'.[211] Similar cisterns could also be found at the Union Grinding Wheel and Soho Wheel.[212] The cylindrical header tank for the horizontal engine at Leah's Yard still remains fixed to the first floor façade of a workshop block, directly above the ground level engine and boiler set under the yard. [fig. 4.56]

Other uses were quickly found for the valuable land liberated by the removal of reservoirs; in some cases the excavated volume seems to have been reemployed as cellaring in new buildings, while in others the land was sold off for development.[213]

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[210] Millowners (1845) p.10; also p. 5: 'The Millowners are not unreasonable. For proof, we refer to their inaction during the past 15 years, in which their waters have been continually drained into the reservoirs of the Company, who have sold the water to the inhabitants of Sheffield, *not merely for domestic, but for manufacturing purposes*; while the Millowners themselves have been obliged occasionally to stop their works, or to resort to steam at a great expense, to supply the loss of power of which the Water Company deprived them'.

[211] Hawley Collection, not catalogued. Three photographs of 'Explosion of boiler, 1875', with extract from 'a Sheffield newspaper'.

[212] Pollard (ed.) (1971) evid. 121-124, describes a case in which a grinder's wheelbands were hidden 'in the store room under the cistern', the latter being 'a great height up in the Union Wheel yard. We could not get in without a ladder'. See also Goad Fire Plans from 1890.

[213] Examples of buildings constructed upon the site of old reservoirs include Kangaroo Works (at Wells' Wheel) and Joseph Smith's front range of buildings at Sidney Street (where the grinding wheel was also extended over the river Porter).

Smoke and pollution

With the increasing centrality of steam-powered works came new environmental difficulties. Although Sheffield had long been considered a black, polluted town, the exhaust of steam engine chimneys significantly worsened the smoke problem; it is difficult to say at which point atmospheric pollution from the engines surpassed that of the metalworking trades and other (including domestic) uses.[214] Certainly by the time William Cobbett published his influential verdict in *Rural Rides* (1830)–'They call it Black Sheffield, and black enough it is',–the stacks of steam engines rivalled the steel furnaces as the town's most visible pollutant.[215]

To the nineteenth century mind, smoke and bad air were seen as the principal causes of illness and disease, against which improved ventilation and high ceilings could be employed in the design of buildings, perhaps most clearly expressed in the design of the great railway sheds of the second half of the century. Sheffield in particular, which had been badly affected by the cholera epidemic of 1832 (in which significantly the Master Cutler died of the disease), was widely perceived as an unwholesome place, and was quick to act with a programme of public cleansing when the disease returned in 1849.[216] Even so, the recurrent and fatal outbreaks of cholera were not definitively linked to the supply of water until some years after Snow's identification of the Broad Street Pump outbreak in London confirmed his 'germ theory' of 1855. Proponents of the competing 'miasma theory' still believed the disease to be airborne, remedied only by cleansing and fresh air.[217]

It was from this position that Sheffield architect William Flockton published a booklet entitled *Health of Towns*,[218] in which he criticised the intent of the recent Health of Towns' Act, protesting 'how little Sewerage, unaccompanied by some plan as we herein advocate, will do towards attaining the ultimate objects of the promoters of that great measure'. Such was Flockton's conviction that smoke was the greater evil, he proposed a new 'Act for consuming smoke, and Ventilating Buildings'. This was based around the idea that the exhaust of every chimney could be redirected to a system of underground flues feeding huge chimney stacks on the outskirts of the town.

The remarkable images accompanying Flockton's text leave no doubt that in addition to environmental improvement, the scheme also appealed to the architect's aesthetic sensibilities. One engraving depicts an enormous masonry stack embellished with Venetian

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[214] Eighteenth-century visitors' accounts abound with references to Sheffield's smoky atmosphere: Defoe (1724-27) described the town as 'very populous and large, the streets narrow, and the houses dark and black, occasioned by the continued smoke of the forges, which are always at work'; see also Skirne (1795) p. vi; Mavor (1800) vol. 5, p. 234 [tour of 1797]; Garlick and MacIntyre (eds.) (1978) vol. 5, p. 1595 [tour of 1801].
[215] Cobbett (1830) 31 January 1830; White (1858) p. 363: '...a stratum of "blacks" had come in at the window during the night...We commonly think the London atmosphere bad; but it is purity compared with Sheffield'.
[216] General Board of Health (1850) p. 107.
[217] Snow (1855) *passim*. A report on Sheffield from *The Builder* of 21 Sept. and 5 Oct. 1861 considered there to be 'no hope of health for people compelled to breathe so large an amount of putrefying refuse'.
[218] Flockton (1849) *passim*. The publication carried the verbosely optimistic subtitle: 'A Plan for removing, by simple means, all smoke noxious gases, vapours, &c. which are now discharged into, and mixed with, the atmosphere of towns; and at the same time effecting a complete self-acting system of ventilation, which may be easily and economically applied to all kinds of dwelling-houses, public buildings workshops, and sewers; and thereby, with the aid of a system of drainage, rendering large towns & manufacturing villages as healthy as the surrounding open country'.

detail, placed at the focus of a system of radial streets and circuses of neat, classical buildings. Most striking, however, is the absence of chimneys from the roofline, lending the scene something of the geometrical serenity found in renaissance paintings of the 'ideal city'.

Ironically, given his voluble writings on the ill effects of smoke, Flockton had been responsible for the design of one of Sheffield's last and largest steam-powered public wheels–the Castle Mills on Blonk Street–in which the chimney is raised to the status of architectural motif. For this fantasy on a medieval fortress, Flockton adapted the regular rhythm of the hearth flues to form a crenellated parapet, while the stacks for the steam engine were reinterpreted as corner turrets, balanced by redundant dummy turrets. [fig. 4.58] In the context of Flockton's anti-smoke diatribe, this apparent glorification of the attributes of steam-power might instead be seen as an attempt to disguise those structures that the architect dreamt of eradicating.

This obsession with smoke stood in marked contrast to the earlier ambivalence to, or even qualified appreciation of, the town's smoky atmosphere. A Sheffield newspaper of 1794 boasted that 'infectious distempers are not apt to spread in this place...the smoke, produced by the manufactories, is thought by many persons to be serviceable in this view'.[219] While later opinion was perhaps less enthusiastic about the heath benefits conferred by atmospheric pollution, many still refused to acknowledge it to be a problem:

> *It must indeed be allowed that the atmosphere of Sheffield is exceedingly charged with smoke, but its effects are not found to be in the least injurious to the health of the inhabitants, the higher and middle classes in life being as healthful and robust as those of any other town in the kingdom.*[220]

This attitude prevailed in some quarters well into the nineteenth century; a *Report into the Sanitary Conditions of the Working Classes in Sheffield* of 1841 was surprised to find 'a number of persons who think the smoke healthy', and even as late as 1865 a guide to the town defensively restated the received wisdom: 'Smoke there is *over* the town–but how seldom fever *in* it!'[221]

Nevertheless, from the first decade of the eighteenth century attempts had been made to curb the pollution caused by steam engines. In 1812, for example, it was reported that 'true bills for nuisances [were] found by the grand jury at the sessions, against the owners of two steam engines in Arundel-street and Pond-street, for not consuming the smoke'.[222] The penalty is not stated, but in any case cannot have been much of a deterrent, as by the Police Act of 1818 the problem was just as acute. In theory, this new act extended the powers available to the local commissioners to prevent smoke pollution, although fifteen years later it was still the

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[219] Extract from the *Sheffield Iris*, 4 Dec. 1794.
[220] Holland (1824) p. 69, an opinion he repeated on more than one occasion, Holland (1837) vol. 2, p. 281; and which found its way (almost verbatim) into other publications such as White (1833) p. 8.
[221] Symonds (1841) p. 222; see also Belford (2001) p. 110. Smith (1865) p. 23.
[222] Local Register (1830) p. 130, 16 Oct. (for the years 1811-12). The offending parties would appear to have been John Dewsnap and John Darwin respectively.

case that 'one clause in the act, which requires the owners and occupiers of steam engines to consume their own smoke, under a penalty of £50, has never been enforced'.[223]

The basic idea behind the 'consumption' of smoke, outlined in James Watt's patent of 1785, entailed passing the sooty exhaust fumes of the boilers (the result of incomplete combustion) back over the heated fuel bed, burning up most of the unwanted smoke and increasing the efficiency of the boilers.[224] The modifications required were relatively simple, although the reluctance of the Sheffield proprietors to implement them was not only because of the expense involved, but also the desire to run their steam engine boilers at maximum capacity, by over-stoking with coal. From 1844, the town council made further investigations into reducing smoke emissions, but by the time the new byelaws came into effect a decade later the difficulty in implementing them rendered them little more effective than the 1818 Act.[225]

Even if they had been enforceable, regulations targeting the reduction of emissions from individual engine boilers would have been thwarted by the exponential increase in their number; a report by the progressive Medical Officer of Health, Harvey Littlejohn, 'On the causes and prevention of smoke in Sheffield' (1897) enumerated 'over 600 tall chimneys to which about 850 steam boiler furnaces are attached, while there are 138 chimneys into which the smoke from 266 steam boiler furnaces, together with 383 metallurgical furnaces is discharged, and, lastly, there are 965 chimneys discharging smoke from metallurgical furnaces alone'.[226] Littlejohn's observations were made as steam-power in the town had reached its zenith, soon to be supplanted in newer works first by gas engines and later electricity.[227] Ultimately it was the convenience and economy of these alternative prime movers that achieved the reductions in steam engine smoke where legislation had failed.

'Outrages' and security

Excepting the earlier years of Huntsman's crucible steel process, industrial buildings seem to have been less prone to interference or sabotage during the eighteenth century.[228] Traditional patterns of building in the town had long exploited the openness and visibility of street-facing yards, unobstructed by building, to achieve a high level of security by communal

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223 White (1833) p. 74. Despite the repeated efforts of the Improvement Commissioners' to prosecute offenders between 1827 and 1831, most steam engine proprietors continued to ignore the requirements of the Act. Simmons (1995) pp. 201-202.
224 Partington (1822) pp. 180-181. It was noted that 'the dense smoke which is usually discharged at the top of the chimney, is in fact, so much good fuel, which requires but a sufficient supply of oxygen to render it fit for combustion'.
225 Simmons (1995) p. 203; Pollard (1959) p. 13.
226 Littlejohn (1897); Harris (1897) *passim.*; Hebblethwaite (1987) pp. 144-145; Hey (1998) p. 193.
227 Before the supply of mains electricity to the town, gas engines were used to power dynamos for electric lights, etc. Steam hammers and presses were also modified to use compressed air. Giles (1998) n.p. [17]. See also Pollard (1959) pp. 203-204.
228 It was noted, for example, that upon the conversion of the cotton mill in 1829 for use as the town's workhouse, 'several additions have been made to the buildings, and the whole enclosed by a strong wall, with a neat lodge for the principal entrance', indicating that it had previously stood on open or weakly-defended ground. Localised security may have been provided by the defensive courtyard layout of the buildings themselves. White (1833) p. 112.

surveillance.[229] Nor had intrusion by outsiders been a great problem for the more remote water-powered sites, located in sparsely populated valleys well beyond the urban area.

The earliest evidence for urban grinding wheels also indicates that most were designed without perimeter walls, their wheel-yards open to the street; only the engine yard was generally built as a secure enclosure.[230] As each hull was a self-contained unit with its own door, security was the responsibility of the tenant, although in practice they were often simply left unlocked for convenience.[231]

Only later in the nineteenth century did Sheffield gain notoriety as a hotbed of militant unionism, often involving destructive and sometimes violent punishment measures, known locally as 'rattening'. These 'outrages', came to national prominence in the 1860s after a number of lethal attacks, some involving the use of explosives, were a vicious extension of the self-regulation that had characterised the Sheffield trades for centuries, described by E. P. Thompson as a 'twilight world of semi-independence', regulated by strong unions and rigid adherence to price lists.[232]

Most rattening did not involve violence, but took the form of 'warnings' given to errant members of the trade, the most common manifestation of which was the theft of wheel bands (almost always the property of the grinder) by which power was transmitted to the grindstone, their return being secured only by compliance with the demands of the trade.

While such instances of maverick trade regulation can be traced to the eighteenth century, the incidence of rattening seems to have escalated in the wake of the effective deregulation of the Cutlers' Company in 1814 (see chapter 3).[233] The following year, six men were jailed 'for breaking into Mr. Thomas Ellin's grinding wheel, and threatening and assaulting him, in consequence of his having men in his employ who were working below the "statement prices," to keep up which, bodies of grinders often went to the different wheels in the night to "ratten," or destroy the bands, stones, &c., of those who refused to join their Trade Union'.[234] By 1818, the problem had reached such proportions that a contemporary felt:

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[229] Belford (2001) pp. 110-111, makes the same case for early site layouts in the Crofts area of Sheffield, where buildings were commonly constructed to either side of a long yard open to the street, only occasionally closed off by a low wall or fence. See also Oscar Newman (1972) *Defensible Space*.

[230] This was true of the Park Wheel (which had walling only about the engine house at the rear), the Pond Forge Mills and almost certainly the Cleakham Wheel; also see the early survey evidence for the Nursery Steam Wheel (1822, see below) and the Soho Wheel (1805, see above).

[231] Pollard (ed.) (1971) evid. 62-63: 'Then how could any person have got into the premises to destroy the apparatus? – It is the usual practice with grinders at most of the wheels where there are more than one working in a place that there is a certain place where the key is to be left, and the door was shut but not locked / Was that known to most other men about besides your own men? – Most of the wheelers would know. It was a regular practice amongst grinders to do so'.

[232] Thompson (1980) p. 286.

[233] Leader (1905) vol. 1, p. 98, recorded that 'the first mention in the [Cutlers'] Company's annals of that ominous word "Rattening" occurs in 1821 when, more remarkable than the fact that bands were removed from a grinding wheel, was the phenomenon of the apprehension of the perpetrators of the outrage'; Ward (1909) p. 250ff. cited evidence of threatening letters from workmen as early as 1780 and 1781. A workers' magazine of 1839 published a story entitled 'The Ratteners, a narrative of the last century'; SCL Local Pamphlets, vol. 331, no. 4, *The Sheffield Cutler*, no. 3 Saturday April 13, 1839, p.21. Sheffield: Alfred Denial.

[234] White (1833) p. 71.

It is not improbable that some measure may be introduced into Parliament for amending the law respecting the destruction of machinery in Sheffield, which the judge says is only a trespass (according to the present interpretation), which is an offence followed by too slight a punishment for its enormity. It is proposed to constitute it a felony.[235]

Throughout the 1840s, incidents of rattening became more serious in nature: in addition to the explosive attack upon the Globe Works already mentioned (chapter 3), Engels catalogued an attempt to blow up Padgin's saw works in Howard Street, an unexploded bomb found in Kitchen's Earl Street premises, and a devastating arson attack on the Soho Wheel (see above) all within the space of six months.[236] In this climate of fear and intimidation, where action taken against the tenants of grinding wheels also threatened the interests of their owners, security became a prime concern, reflected in the design of urban grinding sites, both public and private.

Existing wheels were faced with the problem of securing large sites that had been planned for accessibility, not defence; the close similarity of the early public wheels in particular (especially the Park and Ponds) also extended to the inherent weaknesses in their design. During the trade disputes of the 1860s, their open access and exposed position in the space of the yard left them 'too much exposed to ratteners', compared to some of the smaller wheels of more recent design.[237] This vulnerability may partly account for the decreasing popularity of public wheels in general from the mid-century onwards. The last of the great public wheels to be built–the Castle Mills (popularly known as the 'Tower' Wheel) by Blonk Bridge–had been specifically designed to be more secure in response to the rise in rattening incidents, its fortress-like character reflected in both its name and appearance.[238] [fig. 4.59] Despite being guarded by three resident watchmen, this wheel was host to one of the most notorious incidents investigated by the House of Lords in 1867 in which a pound of gunpowder was emptied into the saw-grinding trough of Joseph Helliwell, exploding when he began work the next day. The intruders had broken into his hull via the cog wheel race–the Achilles' heel of the design–and once inside were able to move between hulls, one keeping watch while the other perpetrated the sabotage.

One of the most comprehensively defensive premises was the Union Grinding Wheel, apparently designed with a number of deterrent features. [figs. 4.60, 4.61] Located on an island between the river Don and the Kelham Wheel tailrace, the complex was entered by its own private bridge, walled-in and closed to through traffic. [fig. 4.62] Day round surveillance

[235] Ward (1909) p. 250. Letter from Thomas Asline Ward to Hunter, 29 March 1818.
[236] Engels (1845) p. 266.
[237] Pollard (ed.) (1971) p. 94. evid. 4281 by John Hague of Hague, Clegg & Barton.
[238] Pollard (ed.) (1971) p. 110, evid. 6038-6116; *Quality of Sheffield* (1983) vol. 36, Nov./Dec., p.34, 'Tower Wheel'.

was achieved simply and effectively by the construction of a dedicated workers' housing complex alongside, the 'Union Buildings', complete with corner public house.[239] The dwellings were arranged about a courtyard with one side left open, addressing the wheel with a protective gesture, and having the character of a sentry-house on the principal northern crossing to the town. Some of the windows overlooked the main river crossing to the site, while from others the doors to the ground floor hulls and the steps to the upper chambers at the near end of the building were visible.

Within the space of the wheel-yard, access to the boilers (usually left exposed in the yard and protected only by a wall) was also restricted, being housed in an enclosed boiler house attached to the main building.[240] [figs. 4.63, 4.64]

Even with its defensive 'moat', rattening incidents could not be entirely prevented, especially as those who administered the punishments were often on the inside. One unfortunate grinder at the Union Wheel was purportedly lassoed as he worked at his wheel, dragged out of the hull into the river by men on the opposite bank–a violent reinterpretation of the 'dunking' in the wheel-dam that had been part of the traditional repertoire of horseplay at water-powered wheels.[241] Workers in the country wheels were no less vulnerable to rattening, as no differentiation was made by the grinders' unions between workers in the town and country, clearly symbolised in the logo of the Central United Grinding Branches, which depicts grinders coming to the aid of one of their fellows who is moving a heavy stone, from a single storey waterwheel to the left and a two storey steam wheel on the right. [fig. 4.65] Examples which made it into the Sheffield papers included an attack at the Limbrick Wheel on the river Loxley (1845), in which the timber horsings were set alight and the grindstones broken, and an incident at the Nether Spurgear Wheel (1850) when grinders found their tools destroyed.[242]

Security consequently carried a substantial price premium: at the height of Sheffield's outrages in 1867, a trough at W & S Butcher's 'safe wheel' (see chapter 2) cost between £84 and £85 per annum for power, while the equivalent in Davenport's more vulnerable Rockingham Engine could be had for around £50. [fig. 4.66] In the 'country' (i.e. water-powered wheels) a trough might be let for as little as £35, with carriage costs accounting for a further £10.[243] Despite the wide differential in rents, such was the menace of rattening that places at Butcher's wheel were usually oversubscribed.

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[239] This was a stratagem previously used at more remote sites such as Huntsman's steelworks (chapter 1) and Abbeydale Works.
[240] SCA FBC MB391 (1834) p. 37 noted 'Boilers under roof, well secured'; also FB227 p. 11, perspective sketch of the 'Union Wheel Boilers', 3 wagon boilers side by side with some measurements. Boilers were a favourite target of the ratteners, causing maximum disruption to work.
[241] SCL MP847M [typescript] Coun. F. Lloyd (n.d.) *The Union Grinding Wheel and the Town Trustees*; SCA UGW27 (1930) [typescript pp. 7; *South Yorkshire Industrial Progress*] no. 3, June, 'Rattening. Reminiscences of Sir William Clegg'. The incident with the noose was said to have been the culmination of a number of increasingly serious actions, taking place in the ground floor hull known as 'No. 10 down'–see plan of 1920, UGW27. Also see Pollard (ed.) (1971) p. xiii, who speculated on the origin of 'rattening' in the 'handicraft and guild days' of the trade. Roberts (1868) short novel *Tom and Charles* includes a prank played on apprentices resulting in their being dragged across the millpond on a rope (first published 1823).
[242] Crossley (1989) pp. 45, 77, cites extracts from the *Sheffield and Rotherham Independent* of 11 Jan. 1845 and 23 Feb. 1850.
[243] Pollard (ed.) (1971) pp. 174ff, evid. 9506-9526, 9923.

The decline of the public wheel

From the 1850s, perhaps due to decreasing levels of outwork, the larger public wheels began to close or be taken over by cutlery and tool firms.[244] One early sign of this reduction in demand was the introduction of non-grinding activities at public wheels, sometimes even taking power from a line shaft or belt to independent structures in the yard (see Soho Wheel, above). Trade directories of the 1830s and 40s make frequent reference to these room and power customers (or sometimes power only–almost an inversion of the common private strategy of renting out grinding troughs to subsidise an engine, as at Joseph Smith's sawmills), for example James Taylor, a 'wood handle & brush veneer &c. cutter' based at Chadburn's Shilo (Nursery) Wheel and Alfred Smith, a horn button maker at Rhodes' Sheaf Island Wheel.[245] A survey of Sheffield's sawmills at this time also reveals many to have been based at public grinding wheels.[246]

Examples of 'privatisation' were rare but not unknown during the first half of the century: the Nursery Steam Wheel had been acquired by Chadburn Brothers in the 1820s, although the firm of optical instrument makers continued to rent hulls and powered tenements to the metal trades. More dramatic had been the failure of the Cleakham Wheel and Tilt, abandoned as a going concern and purchased by James Dixon for the site of his famous Cornish Place silverware factory (above). Nevertheless, the period saw a steady increase in the number of places available at the town's public wheels, in parallel with the rapidly developing export market and its heavy dependency on outworkers.[247]

The turning point came towards the mid-century with the emergence of larger cutlery firms and availability of smaller, less expensive steam engines. This was compounded by the depression beginning in 1847, which weakened the unionised grinding trades, allowing the larger firms to erode the terms of employment.[248]

One of the first to succumb to the new order was Washington Place (or Wheel), a tenement factory owned by Joseph Oakes, purchased complete by George Wostenholm in 1848 to become the well-known Washington Works, and scarcely altered over the succeeding

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[244] Circumstantial evidence from Emsley (1996) p. 131 '...In 1854 a Sheffield grand jury complained that one-fifth of the indictments brought before them were for the theft of scrap metal. The decline of outwork did not mean that industrial workers no longer expropriated raw materials or finished goods...But the definition of the offence did change. An employer's ownership and possession of goods coincided in a factory and workshop, and consequently any expropriation by an employee who had not been given the goods to work on in his or her own home, came under the legal definition of larceny. Embezzlement increasingly was used to refer simply to fraudulent conversion of money'; also Philips (1977) p. 182; Jones (1982) p. 157.

[245] White (1849); White (1833).

[246] Those listed in trade directories of the 1830s and 40s included Ashforth's Reform Wheel, the Castle Mills, Smith at Sidney Street, Timmon at Soho Wheel, Taylor at Nursery Wheel, Kelham Works (stone and marble) Revill at Sheaf Island and Smith at Washington Wheel (ivory). White (1833); Pigot (1834); Pigot (1837); Robson (1839); Rodgers (1841); White (1849).

[247] These early instances of public wheel closure may have been a consequence of competition from the recently opened Union Grinding Wheel (1820); equally, those of the 1840s could have been in part due to the Tower Wheel (c.1836).

[248] The 1840s and 50s saw the growth of established firms such as Joseph Rodgers and Mappin Bros. See also Pollard (1959) pp. 74-76, cf. Pawson and Brailsford (1862).

decades.[249] [figs. 4.48-4.50] Oakes' original venture was reputed to have failed 'in consequence of the place being so large as to be greatly in advance of the requirements of the trade'.[250]

In the case of the large Ponds Forge Mills (see above), by 1852 it had ceased work and was leased to Marsh & Shepherd along with the rest of its site.[251] It was at first used only as a warehouse, but just over a decade later had been converted to a mill for crinoline wire manufacture, for which purpose its length was an advantage. Towards the end of the century it changed hands again to become the town's first electricity generating station and telephone exchange. [fig. 4.51] 1852 also saw the conversion of the Sheaf Island Grinding Wheel, originally owned by John Rhodes, into a fully-fledged cutlery factory tenanted by W F Jackson and renamed Sheaf Island Works.[252] [fig. 4.52] Bees' Wax Wheel and Wells' Wheel, both examined in greater detail below, were among the larger public wheels to be assimilated in the later nineteenth century.

It was Samuel Osborn's partial demolition of the Castle Mills or 'Tower Wheel' in 1907, to make way for a machine shop extension, that came to be seen as the death-knell of the public wheel.[253] This coincided with the appearance of larger factories in the town belonging to the principal firms, many accommodating more workers than the public wheels had in their heyday. Of the remaining public wheels of any size, only the Park, Soho and Union were not taken over by large manufacturers. Most remarkable of all, the latter was still working under steam-power in 1945 and remained a public grinding wheel until its closure and subsequent demolition in 1959.[254]

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249 Tweedale (1986b) p. 77, names the original firm as Oakes, Tompkin & Co.; a valuation by the architect and surveyor William Flockton describes the property as almost identical to Wostenholm's works in the 1860s, contradicting the later statement that Wostenholm enlarged the works to 'nearly four times their original size', Pawson & Brailsford (1862) p. 142; SYCRO 141/B (1836-37) pp. 12-13.
250 Pawson & Brailsford (1862) p. 142.
251 Pollard (1954) pp. 30-31. The lease was from the owners John Gibbs and Frederick Frith for 25 years beginning 1 Dec. 1852 at £1000 rent.
252 Tweedale (1996) p. 34; the firm specialised in Bowie knives and other goods for the American market.
253 Pollard (1959) p. 206; *Sheffield Independent*, 6 April 1907; Stainton (1924) p. 11; *Quality of Sheffield* (1983) vol. 36, Nov./Dec., p.34.
254 SCA UGW3: on 3 October 1944 it was finally advised to install electric power, and the steam engine ceased to run on 17 March 1945. Johnson (1959) p. 18.

Part 3: The development of a building type

Steam and estate development

Throughout the first half of the nineteenth century the grinding wheels could still be seen as a peripheral building type. By 1840, almost half of the steam wheels in Sheffield had been built on greenfield sites, including most of the public wheels (see appendix 4.6).

The exponential rise in the number of individual steam-powered wheels [fig. 4.67] can be ascribed in part to their generally decreasing size, as steam engines became more affordable and the larger public wheels less sustainable. This phenomenon may be demonstrated by a comparison of the average size of engines (based on their horsepower) at different dates.

By contrast, the decline of water-powered sites was almost linear, the economy of natural energy allowing existing mills to continue profitably until such time as demand fell, or else rising land values prompted the redevelopment of their reservoirs and water systems. The increasing exploitation of the rivers for other purposes, particularly the construction of reservoirs for the supply of piped water to the town, may also have diminished the power available to water wheels.

Orientation was an important factor in deciding on a site layout. The larger public wheels in particular were more likely to be constrained by the geometry of the site, their long, axial plans predetermined by the requirements of lineshaft transmission. Despite this, all but one of the early double-depth public wheels conform to a pattern, their central axes (defined by the direction of the main shafting runs) all falling within ±30° of (magnetic) north, most likely in response to the sunpath. [fig. 4.68] Grinding was an activity that required a steady, even light, evidenced by the larger than usual windows of most wheels, and direct south light appears to have been avoided where possible. Likewise, light was never admitted from the rear of the hulls, one reason why the back-to-back arrangement was so convenient.[255] In such cases, where hulls would inevitably point opposite ways, a compromise could be reached by aligning the long axis north-south so the grinders would face east and west respectively, only receiving direct sunlight for a part of the morning or afternoon.[256] A notable exception was the Union Grinding Wheel, the largest of them all, compelled by the restrictions of its long island site to adopt an east-west axis. For the same reasons, William Fairbairn's later invention of

[255] According to Hall (1857) pp. 17, 21, grinders often worked 'in a room every bit of glass from the windows of which has been removed, that the light might not be obstructed by the splashing of the dirty water from the grinding stones'. He also found that adequate ventilation was a problem, as 'hulls cannot be constructed with windows before and behind the grinder as has been suggested. The light at his back would interfere with his work. Ventilation, however, could be provided by gratings at the back of the hull'.

[256] Of those wheels prior to 1850 whose orientation is known, only three faced south, with five others having back-to-back hulls on both north and south sides. Seven other back-to-back wheels were built approximately east-west facing, seven east only, four west only and five to the north. On aggregate, south is the least common orientation.

the unequal north light roof (or sawtooth roof, c.1830) was adopted by a number of post-1850 grinding wheels, or retrofitted to the front façades of some existing premises.[257] [fig. 4.69]

Two cases of grinding wheels influencing, and being influenced by, their urban estate context may be seen in the Nursery Steam Wheel and the Bees' Wax Wheel, constructed on the Duke of Norfolk's land at opposite ends of the town.

Nursery Steam Wheel (also Shilo Wheel): c.1801

Prior to the development of the Duke of Norfolk's Nursery Estate to the northeast of Sheffield, a steam-powered grinding wheel had been built in the 'Spital Fields' along the old line of Spital Hill, a lane leading from the Wicker to the river Don near Bridgehouses in the north.[258]

Little information exists until 1822, when the surveyor John Leather (responsible for the town plan of the following year) made a plan of the 'Cutlers' Steam Grinding Wheel' and its immediate context.[259] [fig. 4.70] This fairly detailed drawing depicts a long, cranked range of single-depth grinding hulls facing an irregular yard open to the street, behind which a smaller walled yard was home to the steam engine and boilers. The wheel and its yard took up an entire block at the northern end of the Nursery estate. Each hull contained six troughs, with the exception of the irregular rooms at the north end and elbow of the wheel that provided less satisfactory accommodation; a similar triangular room on the corner of Johnson Street and Andrew Lane housed a circular saw, also steam-powered.

Access to the 'Engine Yard' for coal deliveries was by a large double gate to Johnson Street, with a smaller pedestrian entrance overseen by a 'tenement' projecting into the street–presumably home to the engine tenter. Other structures in the yards included a smith's shop attached to the wheel, two 'necessaries' and a 'proposed mill', the latter indicating that the drawing was made for the purpose of design.

More detail is provided by an engraving of the wheel published in 1828, soon after its sale to the optical and scientific instrument-maker William Chadburn.[260] [fig. 4.71] Taken from the corner of Stanley Street and Johnson Street, the view actually shows the rear of the wheel,

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[257] Fairbairn (1861, 1863) vol. 2, p. 172. An example of this was Butler's Trinity Works, proposal drawings for which are held at Sheffield Archives. Also SCL M2.2/27 Main (acc. no. 0305-8) 'Grinding cutlery c.1910. From slides lent by Medical Officer of Health; originals by J. E. Atkinson'.

[258] The earliest tentative evidence of a steam engine at this location date to the beginning of the nineteenth century, the rate books including a fairly substantial premises on Spital Hill, rated at £1 9s 6d and owned by a 'Jno. Andrews' (although there is nothing to connect Andrews with the wheel, and he may be the later [market] gardener who lived on Spital Lane) a remarkably high rateable value for which no alternative building can be found; SCA RB62 (from 1801 onwards). Subsequently RB64 'Mich. Hesting[?] Saml. Petty 4s 6d; Do. Engine', the first reference to a source of steam-power. Andrews possibly gave his name to the estate's Andrews Lane (and Street), bounding the site to the east, Tayler (1832); truncated to Andrew Lane on the 1850 OS plan and later.

[259] SCA SheS630L (Feb. 1822) 'A Plan of the Cutlers Steam Grinding Wheel with the small Tenement and Vacant Ground adjoining the same situate in the Nursery, Sheffield'. The title implies that the building was in use as a public wheel. John Leather appears to have taken ownership of the wheel around this time, see RB66 (5 Dec. 1820) p. 9, Nursery Street: 'John Leather 4/6; do. Engine 18/4 [total:] 1/2/10'.

[260] Blackwell (1828) gatefold facing p.18, 'Nursery Steam Wheel, Johnson Street, Sheffield. Wm. Chadburn'.

the large three-storey house in the foreground having been built in the space of the engine yard, while the earlier tenement to the right appears to have lost its corner encroaching on Johnson Street. Behind these structures may be seen the engine house with its double-height arched window and stack above, and at the very back appear the extremities of the grinding wheel–single storey to the north, but with an additional floor reached by an external stair at the other end. Closer examination reveals the main wheel-yard to be surrounded by a low, lightweight fence with an open gate leading to the hulls.

Comparison with the location of other public wheels of the early nineteenth century reveals that the Nursery Steam Wheel was the most distant from any of the rivers (see gazetteer). Leather's plan indicates that this was made possible by bringing water directly from the Don via an underground sough, terminating in the yard by the boilers. Three small reservoirs in the larger open yard were used to build up a sufficient reserve and perhaps to collect warm water returned from the condenser.[261]

As the wheel predated the development of the Nursery Estate, clues to the original form of the building may be found in the unusual geometry of the 1820s plan. The inefficient 45-degree interface between the main drive shaft and the shorter wing to the north is a feature not found elsewhere, and was clearly a compromise resulting from the constraints of the site: the same overall length of building could have been equally well accommodated in a single straight range along the east boundary to Andrew Lane. It may be concluded that the long wing and engine house of 1822 date back to an earlier phase of the wheel, later altered to suit the imposed estate plan.

As usual, the gearing that drove the main shaft would have been located as centrally as possible to the original building. Given no change in the power output of the engine, it may be concluded that the two hulls in the north wing were a like-for-like replacement of two earlier hulls at either end of the main range, the truncated remains of which persisted in the circular saw room and 45-degree elbow.

This suggests that in its original form the wheel consisted of a single run of seven equal hulls on two floors (therefore c.84 troughs), built in open fields along the pre-industrial line of Spital Hill (still evident to the west of the site). [fig. 4.72] On setting out the estate grid after 1808, those parts of the wheel coincident with the proposed streets were demolished and replaced with equivalent accommodation within the new site geometry.[262] The same is also likely to have been true of land areas, explaining the non-rectilinear northern boundary and unusually proportioned wheel-yard.

The new site configuration, in many ways compromised, was much better suited to private business use: the Nursery Steam Wheel was consequently the first public wheel to pass into

[261] SCA CA VB4 Sanderson's Survey (1832) Brightside Bierlow valuation, no. 116, Chadburn's Assignees [owner] John Sorby & others [occupier], see item g 'Reservoir' 7 square perches in area. Also FBC FB167 (1823) p. 66, 'Land in the Nursery...' delineating 'Line of the Sough' diagonally across Stanley Street.
[262] See the Fairbank (1808) town plan, which indicates the future plan of the estate (devised by the Fairbanks) while omitting to show any existing buildings, including the interfering cutlers' wheel, fig. 4.73.

private hands, although still offering room and power for hire (hence the motive behind Chadburn's advertisement). As a manufacturer of telescopes and other optical instruments, Chadburn would have used rotary steam-power for lens grinding and the lathe turning of brass items–lighter trades better suited to the upper floors, while heavier grinding continued in the hulls at ground level.

Later additions to both yards appear on the 1850 and 1889 OS plans. [fig. 4.74; also see gazetteer] The space in front of the hulls was kept clear, resulting in triangular shaped structures that negotiate the conflicting geometries. A number of rectangular bins for wheelswarf populate the wheel-yard, and the last vestige of a reservoir is still apparent. To the rear, the engine yard is practically full, with external staircases occupying the remaining spaces between buildings. Later modifications to the site layout consolidated its role as a private works by building up the perimeter of the yard to form a closed courtyard. Ultimately, the wheel fell victim to the twentieth century reorganisation of industry, demolished and replaced by general-purpose metal clad sheds extending over the adjacent Talbot Works site.[263]

Bees' Wax Wheel: c.1816

The first public wheel to be built after the peace of 1815 was located on the southwest edge of the Alsop Fields estate, on a semi-regular plot between Brown Street / Paternoster Row and the channel of the Porter Brook. [fig. 4.75] Peter Frith (already mentioned in connection with the Ponds Forge Mills, above) was behind the development, which was to operate on a similar basis.[264]

A survey of the 'Browne Street steam engine grinding wheel' (better known as the Bees' Wax Wheel) made in May 1816 describes a rectangular structure set towards the rear of the site, with an attached engine house and boilers occupying the attenuated corner closest to the river.[265] [figs. 4.76, 4.77] Within the yard, on the southwest gable of the building, a flight of steps led to the upper floors, while the opposite gable followed the building line of a steep, narrow lane that led to Boardman's Bridge over the Porter, soon to acquire the contextual name 'Grinder's Hill'.[266]

That the site had remained undeveloped until this time–long after the rest of the original estate plan had been let–indicates its unsuitability for general building purposes. The ground dropped sharply towards the riverbank, and required substantial terracing to accommodate

[263] SCL Local Studies Photo: Johnson St. Main (c.1937) Acc. No. 0635-192, shows approximately the same view as Blackwell (1828), with the changes made over the intervening century.
[264] See, for example, SCA RB174, SU10A, 26 Feb. 1820, pp. 4, 55, 59, in which Frith's share of the rates for both properties are added in a marginal pencil note.
[265] SCA FBC FB137 (1816) p. 43. Also a draft copy to scale with area calculations, SCA FBC SheS202.
[266] A later flight of stairs, shown projecting into the footway of Grinder's Hill on the 1889 OS plan, sheet CCXCIV.12.2, does not appear on these earlier plans, so it may be assumed that the end gable originally formed a continuation of the perimeter walls, and was built without openings.

the main wheel building.[267] On the other hand, the gradient meant that excavation for the boiler and engine seating was kept to a minimum, and a supply of fresh water could be drawn from the river with ease–important as the engine consumed 23½ cubic feet of water in a minute (665 litres).[268] Despite its irregular, peripheral condition, the land was not exempted from the wider estate plan, but was allocated with a view to extending the existing street pattern at a later date.[269] In practice, however, the development rejected the urban paradigm, the wheel-yard covering the area of two minor blocks and the grinding wheel itself straddling the intended path of Charles Street. Lacking a built-up street frontage, it was necessary to enclose three sides of the yard with a high wall, while the Porter provided security to the rear; this would have been all the more important as no provision was made to accommodate engine tenters or a night porter on the site.[270]

From the few known images of the Bees' Wax Wheel (its popular name was a reference to the substance used by grinders in the polishing of steel cutlery[271]) it can be surmised that the template of earlier public wheels was followed closely. [figs. 4.78, 4.79] A two storey brick structure with garret accommodation within its gabled slate roof, the wheel was shorter than its predecessors, containing only eight hulls on each main floor in the usual back-to-back relationship.[272] The long elevations reflected this subdivision with regularly spaced windows (with integral doors to the ground floor hulls) and a rhythm of stacks derived from the hearths located behind the narrow solid portions in between. Inside the small projecting engine house was originally a 24 horsepower beam engine manufactured by Francis Thompson of Ashover.[273] On the OS plan of 1850, three rectangular (wagon) boilers are shown, with adjacent bunkers for coal; a second gate at the bottom of Grinder's Hill allowed deliveries of coal into the small triangular yard defined by the relationship of the boiler-house to the Porter.

Further details emerge from the 1875 plan and particulars of sale, by which time the engine had been enlarged to a 40 horsepower condensing model, and the accommodation included

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[267] It appears to be for this reason that the main entrance to the site was located at the north corner of the site, rather than centrally to Charles Street as urban planning would dictate, thus enabling a ramp to run the length of the site.
[268] SCA FBC NB34 (1833?) pp. 18-19. This equates to almost 40,000 litres per hour, or 439,000 over an 11-hour working day; to supply this quantity of water from a reservoir of 1m depth, would have required a ground area of 440m²–about a quarter of the entire site area. By contemporary standards, the Bees' Wax engine was quite efficient.
[269] Fairbank's initial calculation of the plot's extents included not only half of the main streets, but also the areas of the back lanes extended to the Porter. See SCA FBC SheS202.
[270] The earliest Fairbank plans only represent walling implicitly, so it is uncertain at what stage the site was secured. It is, however, possible that an adjacent tenement with views over the site–such as that facing the main gates of the wheel at the top of Grinder's Hill, or the 'house low down' on Tatton's sketch–may have been occupied as a lodge. On the 1850 OS plan, sheet, the perimeter wall is shown with internal buttresses as at the Union Grinding Wheel (see below) and by 1889 (OS plan, sheets CCXCIV.12.1 and 12.2) the Porter had been partly culverted to form Shoreham Street, resulting in the total enclosure of the plot.
[271] See Holland (1840).
[272] SCA FBC MB399 (1836) p. 18, describes the main structure as a 2½ storey grinding wheel (i.e. with garret space). Rooflights are visible on Tatton's sketch of Grinders' Hill, SCL Tatton vol. 1, p. 94 [95]; vol. 3, p. 696 [276].
[273] The value of 24 horsepower was a nominal figure given by the manufacturer, as recorded in Fairbank's survey of water and steam-powered sites CP-25-(32) (watermark 1828) Fairbank recalculated this from first principles to give the alternative rating of 29 horsepower. In the rate survey of SCA FBC MB399 (1836) p. 18, the engine was rated at 30 horsepower, although it is not known whether this represents an upgrade or a rounding up of the earlier 29 horsepower. Francis Thompson had developed a double-acting atmospheric engine for mills in 1793, and also manufactured engines under Boulton & Watt's patent, including those for the Soho Wheel (see below). Farey (1827) pp. 508, 658.

'31 Heavy Troughs, 33 Light Troughs, and many spacious Rooms suitable for Light Trades, all estimated to produce a gross Rental of over £1000 per annum'.[274]

In its urban context, the structure was evidently designed to impress: in contrast to most earlier public wheels, the Bees' Wax Wheel was aligned not with adjacent river, but with the grid of the estate. Set back from the street, the main building closed the long vista at the end of Charles Street, one of the main roads of the estate running in a straight line from the junction of Norfolk Street and Pinstone Lane in the town centre. From this vantage point the symmetrical façade and central engine house with stack behind would have been a prominent landmark, its visibility enhanced by the fall of the land towards the river. That the building addressed the town, set within the girdle of its rivers, but retaining something of its semi-rural character, demonstrates the duality of the public wheel–at once an urban phenomenon and a satellite of the steel and cutlery trades.

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[274] SCL Local Studies, Sale Plan, 27 April 1875: 'Plan and particulars of important freehold land at the bottom of Charles Street, Sheffield. To be sold by auction...' (includes site plan).

Form and construction

The Fairbank family of surveyors had a keen interest in the early applications of steam-power, not only through their association with the local rate surveys, but also as the architects (and, it seems, in one case as speculators also) of a number of industrial buildings. As evidence of the latter, the papers and drawings left by the firm include proposals for the conversion of a water-driven grinding wheel to steam, various options for the design of a water-powered hull at Moscar Wheel, an urban steam wheel for John Dewsnap and the complete specifications for a large public wheel. [figs. 4.80, 4.81]

Josiah Fairbank, the last generation to run the firm, provided the impetus behind the increased design workload of the 1830s; his enthusiasm for the developing technology is apparent from the copious notes he made on steam engines and related subjects, including transcriptions of borrowed books, notes taken verbatim from proprietors and enginemen, field observations and ideas for various schemes.[275]

Dewsnap's site in the Alsop Fields estate, later known as the Arundel Works, was an enlargement of his existing steam-mill on Eyre Lane (mentioned above in connection with the smoke nuisance charge) onto hitherto undeveloped land fronting the more prominent Arundel Street (see gazetteer).[276] Dewsnap himself is described as a 'gentleman' and proprietor of 'steam mills' in trade directories of the 1830s and 40s, so the emphasis of the business seems to have been the provision of room and power to other trades.[277]

The Fairbanks' plans for the site can be dated to around 1827, when survey measurements of the works were taken, resulting in the construction of perspective drawing of the proposals.[278] [fig. 4.82] A bird's-eye view taken from Arundel Street shows a courtyard layout, relatively open to the front as was still common in the early nineteenth century works complex. At the centre of the street elevation a small two-storey tenement overlooked the main gates alongside, probably intended for the works' porter. Behind this, running across the middle of the site and dividing the area into front and rear yards, was the main grinding wheel consisting of a single depth range of hulls over three floors. Approximately symmetrical in design (the drawing marks the axis of symmetry with a dashed line) the wheel was

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[275] Much of this material is contained within the notebook series at SCA FBC NB; see especially NB23-34. He studied in particular the works of Farey (1827), Tredgold (1827), Brunton (1824), Robison (1822), Smeaton (1760), Conrad Malthe Bruun (1834) vol. I, Siborne (1827), in addition to extracts from numerous journals. His ideas did not end with steam-mills: one fieldbook contains a sketch plan and elevation of a steam-powered catamaran boat, FB227 inside back cover.

[276] Dewsnap's earlier mill was small, with an engine of only 4 horsepower and 12-yard stack; SCA FBC MB398 p. 3. The site still contained a tenement and boundary walls from the pre-estate crofts plan, see FB114 (1812) p. 77, 'Measures taken of J^no^. Dewsnap's Steam Engine Works in Arundel Street also of Several of the Premises near on acc^t^. of an Action for a Nuisance meas. 3^mo^. 5 1812'.

[277] White (1833), Robson (1839), White (1841)

[278] SCA FBC FB183 (1827) pp. 37-38, 'Premises in Arundel Street being formerly Amos Green's part now belonging to Thos. Dewsnap & part John Middleton's'. The undated drawing of the works was identified by the author, and seems to be the original construction, retained by the firm, from which copies were taken (indicated by pin holes at the junctions of the linework); SCA EBu218S, 'watercolour of unidentified works'. Some of the buildings survived until the 1980s, see the buildings on the right of SCL Photo G1 376 (2513-3) taken 11 Feb. 1986.

characteristic of its type with large areas of glazing, hearth stack at eaves level, ground floor doors to the hulls and an external stair to the upper floors. To the southwest end of the wheel was situated an integrated engine house–recognisable by its large arched window and adjacent stack–capable of powering three independent workshop buildings in a 'T' shaped arrangement. A rectangular reservoir took up much of the space of the front yard, reflecting the increased capacity of the new eighteen horsepower engine.[279] The rear yard was further subdivided, with Dewsnap's original mill leased to Shaw & Fisher for the manufacture of silverware.[280] Even following its conversion to a cutlery works, surplus troughs at the wheel continued to be made available to outside grinders, a common way of managing the fluctuations of trade.[281]

Excepting the grinding wheel, which was built with a brick arched first floor to support the cast-iron troughs (see below), the buildings were domestic in character, with timber floors and roof structure and standard loadbearing brickwork walls.[282] While the Fairbanks' design incorporated some existing elements of the works, the drawings provide convincing evidence for the holistic design of an industrial site within a clear brief, in contrast to the unplanned accumulative growth of premises seen elsewhere. In the years before the emergence of the architect as a professional, surveyors such as the Fairbanks and William Flockton undertook much of the work later considered to be the territory of the architect. Unfortunately, much of the evidence relating to the Fairbanks' design activities has been lost (possibly as it was less valuable as reference material than their archive of old survey drawings, often reused as the basis of later measurements).

When the opportunity arose to design a speculative public wheel in 1832, Josiah Fairbank envisaged a different approach to previous examples of the type. His projected building may be seen as an attempt to create the ideal public wheel, with every aspect of its planning and construction carefully considered and recorded in a detailed collection of schedules and bills. In addition, a statement of intent including the projected construction and running costs (presumably targeted at potential investors) elucidates the contemporary thinking behind such enterprises (see appendix 4.9).[283] Unfortunately, the accompanying drawings have since

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[279] SCA FBC MB397 (1836) p. 20. John Dewsnap & Son's Arundel Street works. See also SheS42S (1820) 'Ground belonging to Green & Dewsnap...referring to a boundary dispute between J Dewsnap and J Middleton'; AB12 p. 48; SheS43S, 44S (1820).

[280] SCA FBC MB398 (1836) p. 3. Warehouse, whitesmiths' shops, steam-powered buffing rooms and rolling mill belonging to John Dewsnap and occupied by Shaw and Fisher. CP-39-(12-30) papers from the case of Dewsnap v. Shaw & Fisher about a lease of silver works in Arundel Street and Eyre Lane, 1842.

[281] See, for example, the advertisement in the *Sheffield Independent*, 7 April 1855: 'steam power to let Arundel Works, heavy and light troughs'; cited in Beauchamp (1996) p. 338. Also Goad Fire Plan 674/B1/11, Arundel Works, C Smith & Sons, Tin Plate; with note 'grinding shops let off'.

[282] Goad Fire Plan 674/B1/11, two areas of the wheel are described as 'brick 1st'. SCA FBC FB183 p. 38, dimensions of the northeast warehouse in elevation and section.

[283] SCA FBC CP-2-(132) contains specifications for the 'New Grinding Wheels', undated, but accompanied by a two page 'Report on the Proposed New Grinding Wheels...' reproduced as appendix 4.9. Also see NB29 pp. 108-109 for calculations relating to the engine and reservoir.

been lost, but the bills of quantities allow a fairly detailed reconstruction of its location, form and structure.

The site was chosen on the basis of demand, as Fairbank explained that 'there are no other Grinding Wheels worked by Steam on that side of the Town'; [fig. 4.83] there were good geographical reasons for this absence, the area near 'Little Sheffield' being some distance from the rivers (the closest being the small stream of the Porter Brook). Fairbank, however, had acquired a wealth of information and experience relating to steam power through his work as a surveyor, and felt confident that an unexploited source close to the proposed site would be sufficient to fill a reservoir for two 30 horsepower engines–equivalent to the large Soho Wheel.

In its basic form and scale, the building was similar to its predecessors, containing twenty hulls arranged back-to-back on two floors, the first being of iron and masonry jack-arched construction. Each hull conformed to the standard size found in almost all of the major public wheels, with space for six troughs side by side driven from the rear. Likewise, the ground floor was dedicated to heavy grinding, with lighter troughs confined to the upper hulls entered from the usual central corridor and external end stairs.

With two engines and three boilers, Fairbank was planning for optimal redundancy so that if 'one [engine] might be out of order...a great part of the Machinery may be worked by one', making the wheel one of the best specified at that time. In technical terms, the design can be considered fairly representative of its kind, and fills in much of the missing detail that would have been common to other wheels. Where the project departed from precedent was in its architectural ambitions: the majority of public wheels were repetitive, utilitarian structures, lacking any detail or embellishment unnecessary for its efficient functioning. In contrast, Fairbank proposed a bold, palatial design of classical proportions, in which functional and decorative elements were, to a degree, integrated. [fig. 4.84] The key design decision was the incorporation of the twinned engine houses, boilers and stack in the composition of the building, rather than treating them as necessary evils subordinate to the main structure and hidden at the back. These were manifested in a boldly projecting portico, topped by a large pediment supported (visually, at least) by a pair of freestanding stone columns, complete with ornate capitals and bases. The classical vocabulary extended to the stack, also formed as a giant column on a square base, terminated by a stone capital. Fairbank had researched widely, and no doubt knew of Fairbairn's 'improved' mill (1827) and possibly the contemporaneous Orrell's Mill at Stockport (1832). [figs. 4.85, 4.86] In later schemes, such as Salt's Mill at Saltaire, the factory chimney as classical column was to become an essential landmark of industrial success.[284]

[284] A note by Fairbank in NB34 p. 90 reads 'Mem: At Newcastle upon Tyne there is a Steam Engine chimney 263ft high to underside of stone coping. The base is 27 feet sq. It weighs 2000 tons and contains 500,000 bricks'. Fairbairn (1861, 1863) vol. 2, pp. 113-115, figs. 248, 249; Ure (1835).

Care was taken to align the various parts of the wheel axially on the site, a large almost square plot on Thomas Street, just off Bramall Lane, later to be used as the Corporation depot.[285] This impressive frontage would have dominated the southern entrance to the town, whether approaching along Bramall Lane (at that time a relatively small track) or from the turnpike leading to London Road. The reservoir, one of the largest to be proposed for a steam-powered site, occupied the entire width of the yard's north end, surrounded by a paved walk; the remaining space of the yard was given over to the freestanding wheel and stack. Some of the features detailed in the cost appraisal are recognisable in three faint pencil sketches from the Fairbank archive, showing the design of the front portico, the relationship between chimney and wheel, and the location of the three wagon boilers.[286] [fig. 4.87]

For reasons unknown, Fairbank's wheel remained on the drawing board. Perhaps it was too costly and ambitious a venture even for the boom years of the early 1830s, although the construction soon afterwards of Flockton's even larger Castle Mills demonstrated that there was still scope for new public wheels of this magnitude.

Fireproof floor construction

The adoption of heavy fireproof construction in iron and brickwork for the upper floors was primarily to provide the necessary structural support for heavier troughs, rather than to reduce the risk of fire. Even if timber boarding was capable of bearing their static weight, with the stone spinning at a surface velocity of between 2500 and 4000 linear feet per minute the vibrations would have been unacceptable. In this sense, the motive was different to William Strutt's early fireproof mills and warehouses at Derby and Milford, where the weight and vibration of machinery (if present) was of secondary consideration, similar mills having been previously constructed with timber floors.

Unfortunately it is not known whether the first public wheel of 1786, containing 100 troughs on two floors, adopted a system of brick arches (and possibly predating Strutt's six storey high Derby mill). It seems likely that the examples from the 1790s did, especially as the Soho Wheel of 1802-5 economised on construction costs by placing the troughs on the solid ground floor with light workshops in the smaller boarded chamber floors. Certainly, by the design of the Union Grinding Wheel in around 1818 the jack-arched floor was well established; in addition, the roof structure of the Union Wheel was of lightweight iron construction, marking a break with the traditional building methods that tended to dominate the small-scale buildings of the Sheffield trades.

Additionally, but perhaps unintentionally, the vaulted ceiling offered the occupants of upper floor rooms some protection against the danger of broken stones from beneath. Such

[285] The site was located by the author, based on the specifications given in SCA FBC CP-2-(132). The slight irregularity of its outline only allows one position of the reservoir (and therefore the wheel) on the site.
[286] SCA FBC CP-2-(132) [loose sheet] undated (c.1832) with related notes, untitled.

accidents in the single storey water-powered wheels were known to result in 'the splitting stone not only tearing up the grinder's seat, strongly as it is chained down, but the fragments, in some instances, actually passing through the roof!'[287] However, the vaulted ceiling hardly constituted a deliberate safety feature, as the consequences of rebounding stones could be equally dire. In Charles Reade's fictional description of the inhumane 'modern' grinding wheel the indestructibility of its fabric is contrasted with the vulnerable bodies of the grinders:

> *"Every one of those marks," said he, "is a history, and was written by a flying grindstone. Where you see the dents the stone struck the ceiling," he added, very gravely, "and, when it came down again, ask yourself, did it* always *fall right? These histories are written only on the ceilings and the walls. The floor could tell its tales too; but a crushed workman is soon swept off it, and the wheels go on again."*[288]

The lack of known drawings for these hybrid iron-framed structures may indicate that they were considered straightforward enough to be undertaken by local millwrights and builders working to established patterns. Those documents that have survived support this idea, displaying a close conformity between different buildings: a costed schedule of ironwork and castings for the Union Grinding Wheel (1818-20) corresponds closely to the Fairbanks' proposals of over a decade later (1832), which includes a thumbnail sketch of one of the supporting beams.[289] [fig. 4.88] William Flockton's valuations also furnish detailed information of this construction technique, especially valuable in conjunction with scale plans.

One of the most comprehensive of Flockton's studies was of Wells' Wheel (also known as the Trafalgar Steam Wheel), a back-to-back semi-public site roughly contemporaneous with the unbuilt Thomas Street wheel, and the earliest example of which archaeological remains exist. Built on the newly available land of the Rockingham estate by a family firm of cutlery manufacturers headed by Sarah Wells, the grinding wheel was immediately opposite the main works site (including several houses occupied by the family) allowing easy access to their own grinders and cutlers while maintaining the autonomy and openness of the public wheel site.[290] [figs. 4.89-4.91] Its form and construction borrowed features from both public and private types, with the first and second floor of iron and brick arched construction supported on iron columns, and the third (top) floor timber boarding. This format admitted four floors (c.24 standard sized hulls) of heavy and light troughs as well as powered cutlers' shops in the

[287] Holland (1837) vol. 1, pp. 181-182.
[288] Reade (1896) p.105.
[289] SCA UGW27 [loose typescript, pp. 6] 'Castings supplied to the Union Grinding Wheel (1819)', with letter by H E Elliott of Newton Chambers (ironfounders) at Thorncliffe (c.1959); cf. CP-2-(132). This and other similarities between the two designs suggest that the Fairbanks may have been responsible for the Union Wheel, as suggested (although lacking supporting evidence) by Johnson (1959).
[290] SYCRO 141/B, Flockton valuations (1842) pp. 68-70; SYCRO 141/B, Shepherd, Fowler & Robinson valuation of the township of Ecclesall Bierlow (1842) plan no. 24, Sarah Wells & sons (not the site of the wheel); SCA CB1026 (1833); CB1024 (1832). See gazetteer for further examples of brick arched floor construction.

garret, in keeping with the firm's own requirements as well as those of the profitable grinding trades.[291]

A combination of half-beams and full beams was employed to span the depth of each hull, with a pair of cast-iron columns set between pairs of troughs towards the back of the space, as at the Union Grinding Wheel. [fig. 4.92] Above the vaulted brickwork, erected as usual with a timber formwork, the poché of the floor was filled with rubble and sand, not unlike a solid ground floor, and finished with stone or brick tiling.[292] The depth of the floor was also necessary for sinking the troughs to the correct level.

To counteract the lateral thrust of the vaults, stout iron tie-rods (c.¾ inch square) were introduced at regular intervals in the space (every five brick stretchers), penetrating the brickwork to be attached to the web of the inverted iron 'T' beams by vertical cleats.[293] Even with such precautions, the structure was still liable to movement, exacerbated by the vibrations of the grindstones, shafting and engine; at the Union Wheel, this problem had become so acute by the 1950s that it was necessary to close certain hulls for safety reasons, shortly followed by its total demolition. A structural survey reported that the arches were exerting a horizontal thrust of about 40 tons in the end walls, and that should the end arch fail it could trigger a domino effect, 'causing the arches to collapse successively from end to end'.[294] The engineer's verdict that 'even if we ignore the effect of the vibration on these old brick arches, the brickwork must be very near the collapse load', supports the idea that these structures were originally designed according to precedent, fine-tuned to achieve the optimum balance between cost and structural performance, and that development was a gradual, iterative process.

Wells' wheel was ultimately to pass into single occupancy under edge-tool manufacturers Robert Sorby & Sons (c.1898), and as the Kangaroo Works sizable extensions were made directly adjoining the formerly freestanding structure (including the front range of workshops built over the old reservoir)[295]. [figs. 4.93, 4.94] As a result, the end wall of the structure survives at the rear of the later works, the site of the wheel having remained vacant since its demolition. Iron inverted 'T' sections embedded in the brickwork display the truncated stumps of square section tie-rods, emerging from the springing of the masonry vaults. The same is repeated at first floor level, where a door to the adjacent workshops once opened to the

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291 Flockton's detailed schedule indicates that the ground floor was occupied by 21 heavy troughs, the first, second and third with 20 light troughs each, in addition to three circular saws and a buffing room.
292 See the estimate for a fireproof floor in the Soho Wheel Minutes SCA MD709, 1 Nov. 1827 '...Perkins' estimate of the brick work for arches & wood arches [etc.] to build upon – £30'. Compare this construction with that introduced by William Strutt in the Derby Mill of 1792-93, in Johnson and Skempton (1955-56) pp. 179-205; Fitton and Wadsworth (1958) pp.196-210; Pevsner (1976) p. 276; Markus (1993) pp. 270-272.
293 Observations and measurements taken by the author (2001). Brick dimension c.232x123x72mm; stretcher c.250mm including mortar.
294 SCL UGW27 [unnumbered typescript] letter from John H Haiste & Partners (31 May 1954) including report on the structural condition of the wheel; also 'Report of the Directors to the Proprietors...' (22 Feb 1954) relating the decision to close the wheel.
295 See trade directory for 1898; Hawley (1992) p. 96. Kangaroo Works was named after the noted trademark used by Sorby for edge tools.

walkway along the front of the troughs.[296] [figs. 4.95-4.97] A short return of the front façade includes the jambs of the tall windows, with shallow arched brick lintels and stone sills. The inside wall also shows traces of the joist-holes, set above structural floor level, that may have supported a raised timber deck to the back of the hulls. Nothing survives of the hearths that were present in each hull, indicating that they were centrally located in the outer wall as common elsewhere.[297]

Smaller private steam wheels

The change from the construction of large, centralised tenement factories to the ubiquitous smaller integrated wheels was rapid, and by the end of the 1830s was practically complete. An impression of the breadth of uses that had supported the public wheels is evident in the diversity of firms that were to install their own steam-powered troughs over the decade. While the cutlery trade remained the single dominant investor in dedicated wheels with around sixteen examples, the other local industries together accounted for a slightly higher proportion, including such uses as edge tools (4), saws (3), iron founding (6), engineering, optical instruments, silverware, spindle-making and sawmills (each 1).[298] Over the following decades, this multiplication in number and variety was to continue, while investors lost their appetite for centralised public facilities. While this spreading of risk reflected the boom and bust climate of the 1830s and 40s, it may also be considered a function of changing technology: especially in the wake of Boulton & Watt's patent expiry in 1800, the steam engine was progressively miniaturised, becoming cheaper and more efficient and increasingly within the reach of the small to medium sized firm.[299]

Although the increased availability of smaller, more efficient engines meant that some characteristics of the earlier building type became unnecessary, the primary features of the hull remained remarkably stable. In the case of Wilson and Southern's courtyard works at the corner of Wheeldon Street and Solly Street–preserved in an early set of architect's drawings for the buildings[300]–a very small hull of just two troughs was proposed for the southeast side of the site towards the rear of the yard. [figs. 4.98, 4.99] The engine itself was small enough to be located at the back of the hull, directly connected to the main drum, with a small boiler in the yard just adjacent. In its essential layout, however, the hull was very similar to its larger

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[296] As at the Soho Wheel, the end (south) wall of the main grinding wheel building survives within the more modern block to Wellington Street. Late nineteenth century Goad Fire Plans confirm the positions of some door and window openings.
[297] Pollard (ed.) (1971) p. 24: a grinder giving evidence to the House of Lords stated that the hearth at Wells' Wheel was about '3-4 yards off' the grindstones, and was where the grinders went for work breaks: 'No, they were not working, they were on the hull hearth, what we call the fire place'. A similar location of the hearth was found at the Union, Soho and Ponds Mill public wheels, and can be regarded as standard practice.
[298] These figures include only new wheels, omitting conversions from public wheels such as Wostenholm's Washington Place (cutlery) and Chadburn's Nursery Steam Wheel (optical instruments). See gazetteer.
[299] The reduction in size and improved performance of the steam engine may be likened to the progress of computer technology in the twentieth century, which moved from the large, centralised mainframes available only to governments and wealthy corporations to the ubiquitous embedded circuitry performing a wide range of dedicated tasks.
[300] SCA 2088M (n.d.) incorrectly catalogued as being located on High Street. The architect was J Frith, a relatively early example of a nominated designer.

counterparts, with two large northwest-facing windows immediately in front of the stones, and a hearth with minimal circulation space set against the same wall as the door into the hull. The depth of plan required to accommodate the various wheels and shafting set the building apart from the otherwise consistent dimensions of the hearths and cutlers' shops to either side, causing the hull to project into the space of the yard with its own lean-to roof.

Far less common was the accommodation of both grinding troughs and other steam-powered equipment within the same space; an engraving of James Howarth & Sons' works from 1879 shows just this layout, with steam hammers, forges and grindstones under the same glazed sawtooth roof.[301] [fig. 4.100] Even this arrangement would, however, have been preferable to the many grinding wheels allegedly installed in 'old houses' about the town, of which Dr Hall felt it 'hardly necessary to state that in sanitary and other requisite requirements many of such places are totally unfitted for grinding'.[302] An image of scythe grinders at work appears to be set in one of these makeshift hulls, with an earth floor, oppressively low ceiling, and poor lighting and ventilation.[303] [fig. 4.101]

Gaunt's Wheel on Cambridge Street (formerly Coalpit Lane) is unique in being recorded by a complete set of planning drawings.[304] [figs. 4.102-4.105] It was built for a medium-sized manufacturer of cutlery alongside the firm's existing works within the early 'burgage' strip pattern of long garden plots dating to before the 1730s.[305] [figs. 4.106-4.108] The front and back of the plot had been built up first with a pair of houses and cutlers' shops respectively (as at Leah's Yard–see below), and over time additional shops came to fill the middle yard. It was here that Gaunt built his new grinding wheel, accessible from his main works by a passage behind the front tenements, with little alteration to the buildings facing both streets. [fig. 4.109] Through access was maintained, the circulation space doubling as a narrow wheel yard, just sufficiently large for its purpose. In practice, the houses could function as an autonomous unit, separated from the wheel yard by a gate, while the main access to the works was from Backfields.

The three storey high building was just one room deep and lay along the length of the site. A 90-foot stack of square section was integrated with the front facade, although the engine for the new wheel is not included in the submitted plans; instead power came from an upgraded

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301 Taylor (1879) pp. 270-271. It is unclear from the available plans whether this was an accurate representation or the artist's attempt to show the variety and integration of trades 'under one roof'; certainly the dust from the stones would have greatly inconvenienced the other workers in the room.

302 Hall (1865) p. 11. This was in addition to the '164 Wheels in and near Sheffield' identified by the report.

303 Hawley (1992) p. 73, from the *Illustrated London News* 1866.

304 SCA CA206/2284. Unfortunately, the drawings survive only as poor quality microfiche copies, so have been used as the basis of the author's redrawings.

305 The first works occupied the site, and some of the buildings, of William Fairbank's eighteenth century school & house, see Hall (1932) f.p. 7, 'A Plan of the Tenement...belonging to W Fairbank...1770'. Garden plots are clearly defined on the town plan by Gosling (1736).

steam engine that had been installed some time before on the adjacent parent site.[306] Grinding hulls and workshops were cleverly integrated in the same structure. In section, the main building was based on the depth of a cutlers' shop, with the rooms dedicated to grinding breaking out of this envelope under lean-to roofs to meet the rear boundary. [fig. 4.110] As only front light was wanted for the hulls, their back wall adjoined the party wall of Gaunt's works to the north, an efficient use of space, but one that made effective cross-ventilation impossible. Above the projecting portions, external stairs led to the fully glazed cutlers' shops on the first and second floors; part of the first floor was of brick arched construction, supported by iron columns and beams, to provide an additional hull in the centre, between the stairs. At the back of the hulls, between the troughs and drums, cast iron columns were also employed to bear the loadbearing brick walls of the main building above.

In front elevation, the two distinct functions of the building were clearly expressed: the grinding hulls by large, shallow arched windows with individual doors to the yard on the ground floor, and the workshops on first and second floors by smaller, more closely-spaced casement windows. The verticals of hearth flues and the steam engine stack ran the full height of the façade, organising it into three bays with a 2-3-3 rhythm. To allow workbenches along both north and south walls, each of the cutlers' shops was also provided with a hearth centred on the internal partition, leading to separate ridge chimneys.

About the yard could be found the customary appurtenances of swarf pit, ashes shed and WCs under the stairs. Other works functions, such as time office and weighing machine, would have remained at the parent site.

This type of wheel–containing a mixture of uses and powered by an engine shared with other processes–effectively superseded the public wheel, flourishing in the confined space of smaller urban courts and existing works' yards. [figs. 4.111, 4.112] The late nineteenth century form of Leah's Yard, built within the same strip pattern of plots on the west side of Coalpit Lane and still in existence today is an important surviving example of the once ubiquitous mixed-use workshop complex with its own small steam engine. Its significance lies not in the quality of its building or the integrity of its parts, but in being the cumulative sum of an episodic, fragmented process of development and reinterpretation. This began in the early 1700s, with the construction of a house on the street frontage (set back from the current building line and visible on a plan of c.1770-80), soon augmented by utility buildings in the garden plot behind.[307] [see fig. 3.1, chapter 3] Around the beginning of the nineteenth century cutlers' shops were built against the newly formed lane known as 'Backfields', these being the earliest buildings that remain on the site today, although much modified and with an extra storey of accommodation. [see fig. 2.72, chapter 2] With the front and back of the site in

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306 SCA SYCRO 141/B Shepherd, Fowler & Robinson's valuation of Ecclesall Bierlow (1842) plan no. 3, Coalpit Lane, Tillotson owner, including 'enginehouse & shops'. The building of a new stack probably reflects the installation of a larger engine. Also see Flockton valuations (1840) p. 55; CA206/2284 'block plan' 24 ft. to an inch.
307 SCA FBC SheS286S. See also FB26 pp. 48-49, FB54 supp. pp. 74-75, which allow the plan to be dated to a ten year period.

place, the yard became the focus of development, based on a linear, drive-through principle that was retained until the subdivision of the site into front and back parts around 1841.[308] [fig. 4.113]

During this period, the primary use of the site was as a horn-works under James Morton (for the preparation, cutting and pressing of hafting material for cutlery and other decorative uses), a trade that needed little specialist infrastructure. By the 1870s Morton had relocated, replaced by a number of smaller firms manufacturing cutlery, silverware and horn, presumably tenants of a single owner who was responsible for the subsequent courtyard development. This was achieved by taking land behind the Sportsman's Inn public house, demolishing the existing south side of the yard and in its place creating a three-sided range of differentiated structures around a larger square yard. In doing so, the format of the site changed from a linear thoroughfare to an enclosed turnaround entered from the front.[309] [figs. 4.114, 4.115] It was at this point that the steam engine was introduced, at the end of the east wing of the new buildings, line shafting dispersing power around the yard and through a high-level opening to the existing long range of workshops to the north. By this time reservoirs were unnecessary, and only the external chimney stack (now missing its circular shaft) and a large storage tank built on the eastern courtyard wall betray the presence of steam power.[310] [see fig. 4.56 above] At the southernmost end of the site the ground floor appears to have been designed as a grinding hull with large north-facing lights and provision for shafting along the windowless rear wall.

Other trades housed in the warren of interconnected workshops included steam-powered die stamping (practised by the new owner of the premises from 1892, Henry Leah and Sons), cutlery, pocketknife and spring-knife manufacture, silversmithing, electroplating, knife-hafting and horn and bone merchanting. This diversity characterised the period from the 1870s onwards, during which time anywhere from six to eighteen separate trades occupied workshops here.[311]

It was not until the twentieth century that the final form of the buildings was fixed, but each successive change was made with reference to the preceding arrangement, and closely integrated with the retained elements, so that the transformation of the works was gradual, underpinned by a continuity of use and form. In this sense, the progress over 150 years can be seen more as a mutation of the original plan than as a series of distinct redevelopments.

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[308] For the names and dates of occupants see Giles (1998) pp. 1-2. Aside from the earliest phase, the author's interpretation of the development is generally in agreement with the RCHME report, NBR No. 95122.
[309] A block of WCs was built in front of the rear entrance and the street archway bricked-in. The arrival of an engine tenter on the site in 1884 probably indicates the completion of this redevelopment.
[310] The Lancashire boiler was housed under the yard, accessible by gratings set in the ground and from the network of basements that run beneath some of the later structures.
[311] See, for example, the trade directories for the years: White (1876) p. 130; Kelly (1883) p. 69; White (1895) p. 205; Kelly (1922) p. 76.

Chapter 5: Steam and steel–the development of the Don Valley

Abstract

By the middle of the nineteenth century, many of the steelmakers that had formerly been based in the town of Sheffield were relocating to the outskirts and the advantages of large, open sites with greater potential for expansion. Both Sandersons and Jessops (the subjects of chapter 3) made the decisive move out of town during the 1840s and subsequently rose to become two of the world's largest steel manufacturers.

The major landowners were quick to realise the potential of their suburban holdings, none more so than the Duke of Norfolk who owned much of the land to the northeast of the town, along the Don Valley. The new Sheffield to Rotherham railway line, completed in 1837 and following the course of the river, provided the decisive impetus to development. Along its length, large, carefully planned works with their own private railway sidings quickly transformed the pre-industrial rural idyll into one of the country's largest concentrations of heavy industry.

This chapter demonstrates that early developments such as the Etna Works of Spear and Jackson and Agenoria Works of Peace, Beet were essentially scaled-up and idealised versions of their urban companions; likewise, the Duke of Norfolk's Don Valley development is considered as a 'super estate' modelled on the template of his earlier Sheffield estate developments. Some companies, far-sighted enough to take out options on adjacent plots, soon began to abandon this model, erecting less classically planned assemblages of building better suited to extension and change.

Thus began the era of the great steelworks, fuelled first by the railway boom, then by the international arms race of the latter half of the century. Around 1860 Henry Bessemer made his controversial but important entry into the Sheffield steel industry, establishing his new model works alongside those of Charles Cammell and John Brown.

Arguably the most important development of the mid-nineteenth century was the relocation of Vickers from their large but cramped River Don Works at Millsands to an enormous new site at Brightside (which also became known as the River Don Works), well beyond the Duke of Norfolk's estate. This new complex marked a radical departure from the traditional integrated works plan. Arranged along the main railway line, the works comprised a row of large freestanding sheds, served by a comprehensive network of railway tracks, cranes, and furnaces, while the offices and ancillary buildings (built along the road as usual) were relegated to the back of the site, in a reversal of convention. Of the five main buildings, the most remarkable was certainly the vast crucible steel melting shop, which had been planned on an ingenious new principle to enable monster castings many tonnes in weight. Huntsman's crucible process had here reached its zenith, but its superiority was to be short-lived, as it

was rapidly superseded first by the Bessemer process and soon after by the Siemens-Martin open hearth furnace.

However, in the reconfiguration and extension that followed, Vickers was to demonstrate the advantages of its new approach. The foundations of modern steel industry had been laid, and other firms were quick to adopt the same principles. In these expansive industrial complexes, with their attendant rows of workers' housing, a different type of city was being born, quite different in character to the haphazard yet tightly integrated works and dwellings of the town centre.

Part 1: The first East End works

Wonderful that out of the depths of the Wharncliffe Forest, and near the cave of the devouring dragon of Wantley, there should have arisen a town such as Sheffield, and such vast temples of Vulcan and of Tubal Cain as the Cyclops Works!

Ferdinand Kohn, *Iron and steel manufacture* (1869) p. 86.[1]

The stretch of the Don Valley, running from the Wicker at the northeast of Sheffield to Tinsley and Rotherham beyond, was the last great frontier and development opportunity for Sheffield's heavy steel industries. [fig. 5.1] It offered most of the prerequisites for steelmaking: water could be obtained from the Don itself and also from the canal that meandered alongside until reaching Tinsley where the river became navigable. An abundance of fuel was available locally, especially the high-grade Silkstone coals from the Duke of Norfolk's collieries that populated the valley. Bulk transport–for importing bar iron and exporting heavy forgings and castings–was also close to hand, first by canal and from 1838 by the long overdue railway.

At first, the Duke opposed the planned railway, in the fear that competition from outside would damage the market for his coal in the town. The short sightedness of this resistance was quickly superseded by an appreciation that the railway could unlock the value of what was otherwise an area of low-grade farmland, compensating for any loss in coal revenue. It has been suggested that the Duke's land agent from 1834, Michael Joseph Ellison, was largely responsible for this change of direction, although the extent of his involvement in later estate policy is subject to debate.[2]

That industry had not settled outside the town earlier was mostly due to availability of the predominately urban workforce, who were generally loath to walk the two or three miles to work and back each day. For the same reason, early steam grinding wheels had been obliged to locate close to the town.

Although the products of suburban steelworks differed significantly from those of the traditional cutlery and edge tool trades, some of the fundamental processes and arrangements were very similar, albeit on a larger scale. The crucible process had already reached the upper limit of its capacity, based on the weight of steel a man could handle, and could only be enlarged by the addition of further units. Forging skills were basically the same,

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[1] Room (1995) p. 329. The 'Dragon of Wantley' is a story taken from Percy's *Reliques of Ancient English Poetry* (1765), reproduced in Smith (1865) pp. 129-132; the serpent was reputed to have 'Four and forty teeth of iron: / With a hide as tough as any buff'–a humorous nod to the local industries. The hero, More of More Hall, commissioned a suit of steel-spiked armour at Sheffield, and slew the dragon by kicking it in the backside (its only point of weakness)! Wantley is an alternate name for Wharncliffe in South Yorkshire.

[2] Simmons (1995) pp. 302, 337, suggests that Ellison was actively involved in management, whereas Olsen (1973) p. 338, felt that most day-to-day decisions were delegated to his clerk Marcus Smith.

even when carried out with steam hammers on a larger scale, and the enormous rolling mills for armour plate operated on much the same principle as their smaller siblings, the bar mills.

The relevance of experience on a smaller scale might explain why few firms successfully entered the heavy steel trades without a previous background in the lighter staple Sheffield trades. Examples of this transition included Charles Cammell, who had acted as a travelling representative for Ibbotson of Globe Works (see chapter 3), establishing a business in files at Furnival Street with co-founders Henry and Thomas M. Johnson, before going on to build the giant Cyclops Works in 1845.[3] John Brown had also worked his way up from small-scale cutlery factor, moving into steel with his invention of the conical steel buffer. Mark and Thomas Firth emerged from Sanderson's melting shops to erect the Norfolk Works. Naylor Vickers, as shall be seen, could claim descent from a long steelmaking line. These pioneers of the heavy steel industry were also close contemporaries, demonstrating the importance of experience and opportunity in making the transition.[4]

Often old and new product lines would continue in parallel, sometimes with additions to old plant, otherwise with new facilities capable of different scales of work. This was true of Vickers, for example, who continued their old line in steel bells at Brightside, alongside the larger and more lucrative trade in railway, maritime and ordnance castings.

As a large and complex undertaking, it is not intended to offer a complete picture of the Duke's East End estates, but to concentrate on the key stages of its development through individual cases (Charles Cammell's Cyclops Works, Beet & Sons' Agenoria Works, Spear & Jackson's Etna Works) and approaches to master-planning. For a detailed examination of the legal and economic aspects of the Norfolk Estates, Simmons' unpublished thesis and subsequent article may be consulted; Olsen's well-known essay *House upon house* offers a comparison of the Duke's Sheffield property management with that of the Eton College estate at Chalcots.[5]

Charles Cammell: Cyclops Works (1845-50)

Cammell and Johnson are generally regarded as the first major steelmakers to have settled alongside the railway in the Don Valley, responsible for triggering the subsequent invasion of giant works.[6] [fig. 5.2] The company was first established at Furnival Street in 1837, Cammell having left the employ of Ibbotson Bros., and began to manufacturer steel and files despite

[3] *Journal of the Iron and Steel Institute* (1878) p. 615, obituary of Charles Cammell. Hunter (1869) p. 213. Tweedale (1995) p. 35. Timmins (1977) pp. 173-174. Pollard (1959) pp. 78-79.
[4] The lives of many founders ran almost in parallel, including John Brown (1816-1896), Charles Cammell (1810-1879), Thomas Jessop (1804-1887), Edward Vickers (1804-1897).
[5] Simmons (1995); Simmons (1997); Olsen (1973).
[6] Pawson & Brailsford (1862) p. 124: 'The first of the large manufactories erected in this neighbourhood [on the line of the Midland Railway] was by Mr. Charles Cammell, now the head of the firm of Messrs. Charles Cammell and Co., of Cyclops Steel and Iron Works; and, the building being once opened, the advantages of the contiguity to the railway became so obvious that many other large business premises were shortly after erected there'.

the ongoing commercial crisis.[7] Within a decade the site had been outgrown, and the three partners (including the two Johnson brothers) were obliged to look elsewhere for larger premises. Comparing their pioneering spirit to Messrs. Greaves at Sheaf Works twenty years earlier, Gatty in the revised edition of *Hallamshire* related that:

> *...in 1842, Mr. Cammell became persuaded that their wisest course would be to move their plant to a point at which they could most readily receive their coal and iron, and transmit their finished goods with least inconvenience and expense. It was, however, through many apprehensions of less determined friends, that he proposed the purchase of a lease of four acres of ground, by the side of the railway, from the Duke of Norfolk. The land selected was an open field, and the price accepted for the accommodation was twopence halfpenny a yard.*[8]

The major product lines exploited the growing demand for railway components, evidenced by an early catalogue of the works' output, displaying a wide range of coach and carriage springs.[9] In addition, the firm made 'steel, heavy forgings of all kinds in both steel and iron...and files, upon a very extensive scale', while also retaining traditional lines such as files and straight razors made of cast steel.[10]

While much is made of Johnson and Cammell's visionary boldness, there is good reason to believe this was magnified retrospectively. Evidence from the Arundel Castle Manuscripts suggests that a more tentative start was made: the first application of November 1844 was for just one acre of ground on lease at 1¾d per square yard. Construction was well underway in 1845, and only by August 1846 did the firm request a further 9250 square yards at 2d.[11] By this stage, the firm had already built on 6120 square yards, or 1.26 acres, confirmed by the rental accounts to 28 June 1847 (giving a total area at this date of 15,370 square yards, or 3.18 acres). No plans of the early stages survive, but a geometrical analysis of the 1850 Ordnance Survey measurements suggests a clear sequence of development phases.

The one and a quarter acre plot of 1844 was planned as a symmetrical, self-contained premises without the irregularities of the later works. [fig. 5.3] A front warehouse block (still evident in later views) ran the full sixty-nine yards' length of the Savile Street boundary, behind which extended two perpendicular wings of workshop ranges. In the centre of the resulting rectangular yard, the back of which was left open to the railway (probably closed by a fence wall), stood a freestanding melting shop. In 1846, cementation steel furnaces were added to the rateable value of the works, along with warehouses and file shops; [fig. 5.4] the following year saw the completion of the coach-spring shops, file hearths and internal works

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[7] Henderson (1966) pp. 65-66; Stainton (1924) p. 249. For other biographical details on Cammell, see 'Cammell Laird' (1919); Odom (1926) pp. 164-165; SCL NCRS vol. 13, p. 113; Hollett (1992).
[8] Hunter (1869) p. 213; Stainton (1924) p. 249, suggested that the original plot area had been two acres.
[9] Johnson Cammell & Co. (1847?) *passim.*
[10] Pawson & Brailsford (1862) p. 126.
[11] Simmons (1995) p. 455; ACM S384/564, 630 (2 Nov. 1844, 22 Aug. 1846). ACM LB/A/394. Based on the same length of frontage, a one acre plot would have formed a square in plan, although nothing in the later works' plan indicates that it was built to these proportions.

railway, built on newly taken land alongside the original works nucleus and bringing the total area occupied to 2.75 acres.[12] [fig. 5.5] Even in its nascent form, the Cyclops Works ranked among the town's larger examples, considered by J C Fischer in 1846 to be 'probably the largest among the astonishing number of steelworks', with twenty melting holes (of two crucibles each) and four large cementation furnaces each holding over 200 *centner* of iron (c.10,880kg).[13] He was, however, disappointed to find that apart from its size, there was nothing novel about the works.

By the time of the Ordnance Survey's visit to the works in 1850 the remaining peripheral land had been absorbed, and a long row of shops built along Sutherland Street, taking the site area to almost four acres.[14] [fig. 5.6]

It therefore seems that Johnson and Cammell was initially encouraged to develop their site within the constraints of a preordained estate plan, consisting of large rectangular plots of uniform size set out along the projected line of Savile Street East. Unfortunately, the well-proportioned courtyard works was unprepared for the exponential increase in demand stimulated by new markets: it is said that the Cyclops Works' first order was for ten tons of railway springs, at a time when the maximum output was just one ton in a week.[15]

Johnson and Cammell must have recognised the limitations of their first site almost immediately, and entered into negotiations with the estate (although the letter-books in the Arundel Castle Manuscripts unfortunately postdate this crucial period). To take a second plot of the same size was probably impractical, so it was conceded that the irregular trackside land at the rear could be taken in. From this first slippage it is easy to imagine the progressive reasoning that culminated in the appropriation of the entire four-acre polygonal area.

Development after 1850

From this point onwards, the only opportunity for growth lay offsite, but this did not deter the relatively rapid investment in new plant, first across Sutherland Street to the strip alongside the Agenoria Works (and ultimately absorbing Peace, Ward & Co.'s premises as well), then over the railway to undeveloped land on Carlisle street. Thus, in 1862 the works were said to 'cover about nine acres of land', which just two years later had risen to 'about 15 acres, and about as much more land has been purchased down the line to be more or less built upon'.[16] This last statement was clearly a reference to the large plot at Grimesthorpe Junction, halfway between the main Don Valley estate and Vickers' works at Brightside. In retrospect, this move

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12 Brightside rate book (1846-47) vol. 1, p. 25. ACM LB/A/394 (28 June 1847) 'Rent of 6,120 yards from Lady Day 1846 to Michelmas 1846, £22 6s 0d; [Rent] of 13,351 yards from Michelmas 1846 to Lady Day 1847, £65 0s 0d'.
13 Schib (1951) p. 589: '...warscheinlich das Grösste unter der erstaunenden Menge von Stahlfabriken'.
14 This is contrary to the claim in Pawson & Brailsford (1862) p. 126, that 'In 1845 the works of Messrs. Cammell and Co. occupied four acres, and the covering of this extent of land with a huge manufactory appeared so bold a venture that many were startled, and prognosticated that so rapid a progress could not be sustained', which appears to be an embellishment of the truth in the interests of drama.
15 Hunter (1869) p. 213.
16 Pawson & Brailsford (1862) p. 126; Hunter (1869) p. 213.

may be seen as an unavoidable compromise: too much had been invested in the original works cluster to abandon it in favour of a more distant site, but modern, consolidated premises were urgently needed if the firm was to keep up with its major competitors including Vickers and John Brown whose Atlas Works dominated the northwest side of the railway.

New products demanded new plant and processes, in which Cammell was regularly among the first to invest. Thus by the late 1850s, 'to their other branches of trade, Messrs. Cammell and Co. have recently superadded that of iron manufacture, previously unknown in the town. They convert pig iron into malleable wrought iron for the best qualities of work'.[17] Puddling furnace flues with their characteristic dampers appear in contemporary views; to forge the iron, Nasmyth steam hammers were also brought in at an early date, such that in 1865 there were: 'Not fewer than seventy of this and other descriptions of large hammers...at work in this particular locality, twenty-seven being on Mr. Cammell's premises'.[18] Products by now included 'Patent Buffers, Railway Springs, Ordnance Forgings in Cast Steel, Railway Tyres, Axles, Shafts, &c.' and an extensive range of cast steel rails for both British, continental and American railways.[19] [fig. 5.7]

Cammell's marketing centred upon their claims of cast steel's strength and durability compared to iron, backed up by guarantees and one of the earliest known experimental testing departments. Here, steel coach and engine-springs were subjected to loads exceeding the limits of normal performance, after which they were warranted for one year's use; the heaviest were laminated from sixteen plates and designed to bear up to eight tons. Techniques were understandably crude, taking no account of dynamic loading or the long-term effects of stress, and by no means all of the springs actually withstood testing: in 1851 Fischer toured the works for a second time, and was allowed by Mr. Johnson to test a new spring, 'but long before it had reached its maximum extension through compression, it broke'. This was presumably the cause of some embarrassment to the proprietor, and led Fischer to conclude that their product was inferior to that of Turton & Sons (see chapter 3).[20] Similar analysis of the mechanical erosion of steel rails led the firm to make the claim:

> *We consider it no extravagant prediction, warranted as we are by these experiments to state, that ultimately it will be found that* Steel Rails *will wear* fifty times *as long as* Iron Rails.[21]

Lavish catalogues were used to promote their goods internationally–the 1864 list almost identical in format and content to Krupp's catalogue of two years earlier–assisted by an

[17] Pawson & Brailsford (1862) p. 126.
[18] Smith (1865) p. 50.
[19] Cammell (1864) *passim.*
[20] Schib (1951) p. 723, '...aber weit früher als sie das Maximum ihrer Ausdehnung durch Geradedrüken erreicht hatte, brach sie [i.e. die Feder]'.
[21] Cammell (1864) plate 64.

element of aesthetics to the products themselves, including conical buffers embellished with decorative architectural mouldings.[22]

Almost the reverse could be said of the architecture of the Cyclops Works, whose indebtedness to railway architecture may be clearly seen in views of the works. Characteristic features included tall arched trackside windows, stripped classical detailing, repetition of elements and continuity of monitor roof structures. [figs. 5.8, 5.9] The stratified planning of later phases contrasts with the symmetrical front / back formality of the first Cyclops Works buildings.

By 1865, the company had reached such a size that in March of that year it was reorganised as a Joint Stock Company, although Charles Cammell remained both chairman and manager of the works.[23] Johnson, who had been so prominent in the works at the time of Fischer's visits, had fallen ill and unfortunately 'did not live to reap the coming harvest of enrichment'. This change in the company's fortunes had much to do with their diversification into armour plate, which by 1862 was being manufactured in the rolling mills by laminating large slabs of iron.[24] The technology had been introduced to Sheffield at John Brown's Atlas Works a year earlier, although plate had been rolled in Rotherham from 1853-54.[25] Cammell's first rolling mills appear to have been erected in the vacant yard of the original works, but by 1864 construction work began on the new Grimesthorpe Works.

Cammell was an early adopter in Sheffield of many of the revolutionary new technologies of the later nineteenth century, beginning with the installation of puddling furnaces soon after John Brown's of 1857-58, followed by the Bessemer process and later the Siemens-Martin open-hearth furnaces. This aggressive approach to expansion of plant and product lines, along with the firm's deep involvement in the development of armour plating for battleships (see below), ensured its continued position among the big Sheffield steel manufacturers.

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[22] See Krupp (1862) *passim.*
[23] Hunter (1869) p. 214.
[24] Pawson & Brailsford (1862) p. 128.
[25] Pollard (1959) p. 161.

The Don Valley Estate

Visibly different from the grid system of the urban estates, the Norfolk Don Valley estate has been appropriately described as a 'super-grid', mostly just two blocks deep and running along the relatively level valley bottom on both sides of the linear railway.[26] Only three major transverse roads crossed the tracks on bridges at intervals of about 2000 feet (610m), in between which parcels of land were arranged in contiguous long plots something like a gigantic pattern of burgage strips. Each plot was bounded to the front by a newly formed street and to the rear by the railway lines, with a narrow semi-open conduit to supply water to the proposed works running alongside.

Initial planning of the estate appears to have been based on multiples of single acre plots, and for some time allocation of land continued on the basis of round measurements of area. In most parts of the valley, where distance from street to railway was fairly consistent, this gave rise to uniform frontages of around sixty-five to seventy yards in length, as adopted by the earliest works such as the Etna, President, and the first phase of the Cyclops Works. Indeed, the stretch of Savile Street East which ran between the Etna and President Steelworks can be subdivided into seven such frontages, although demand for specific site arrangements soon quashed any hope of enforcing a regulating grid. Once again, the Duke of Norfolk fostered ambitions for the estate that were incompatible with the requirements of his tenants, only to later abandon them after efforts to regulate development proved unsuccessful.[27]

As the earliest fully-fledged East End steelworks, the Cyclops Works was also the first to break the rules, by 1850 its four-acre site including an irregular parcel of land alongside the Sutherland Street railway bridge. This was developed from the rear, with buildings erected along the skewed boundary, but leaving the frontage to Savile Street clear, suggesting that there was still a hope that a second twenty-two yard façade might be built alongside the first. Ultimately this was in vain, and the street elevation was completed by an extension of the existing warehouse block terminating in a section of screen wall with entrance archway [fig. 5.11]

Other exceptions were to follow: the Agenoria Works of 1850 was erected on a plot of just thirty-five yards in width, while from 1854 John Brown developed a three-acre double width site with central entranceway (located between the Norfolk and President Works). Enlargement and remodelling of later works was to progress with little regard for the symmetry and propriety of the pioneers, as the larger companies swallowed up their smaller neighbours.

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[26] Simmons (1995) coined the term 'super-grid'.
[27] Note the similarity to the development of the Alsop Fields estate, almost a century earlier, cf. Cruickshank (1998) pp. 34-35.

Even so, some controls did remain, enforced by covenants in the lease agreements. When owners of tenements opposite Bessemer's works complained about the installation of 'Tilts and Forges' close to the street, the Duke of Norfolk's agent requested it be relocated to the back of the site by the railway.[28] Minimum heights for steam engine stacks (usually fifty yards, although occasionally lower) were also in force, although their efficacy would have been compromised by the valley's natural topography. Other conventions, such as the general adoption of two storey continuous street frontages, constituted an unspoken standard for building. In addition, the terms of most leases required a minimum expenditure on new buildings (usually £1500) within five years of its being granted, protecting the Duke's interests and preventing speculative hoarding of land and subletting.[29]

After a somewhat slow start in the 1840s, manufacturers' confidence in suburban relocation grew rapidly, encouraged by the success of the early ventures. Within twenty years, the centuries-old agricultural landscape had been transformed into a linear industrial new town, a local guidebook suggesting that:

> *Some idea of the extent of the works in this locality, may be formed from the fact that, on the estates of the Duke of Norfolk alone, about 50 acres have been taken for manufactories, and about 70 acres more for dwellings for the workpeople, while upwards of ten miles of roads have been made.*[30]

Perceptions of the Don Valley works

The histories of early Don Valley steelworks indicate that the Cyclopean imagery with which Sheffield's heavy industries became synonymous did not arise with the initial colonisation of the 1850s, but was a product of the exceptional growth of a small number of firms over the decades that followed. The ambitious monikers of early railway-connected steelworks, accompanied by monumentally conceived advertising views, did much to elevate what were essentially steelworks on the traditional pattern to the status of super-works comparable to Krupp or Le Creusot.

The Cyclops works was appropriately one of the first to indulge in the mythological / classical idiom of naming, soon followed by the Etna (or Aetna) Works, Atlas Works and Agenoria Works all on Norfolk land.[31] Perhaps in the absence of a maker's mark, central to the reputation of cutlers and tool-makers, brand identity became of greater importance, the product inseparable from its place of making in the same way that ironworks' output had

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[28] Simmons (1995) p. 348; ACM LB/D/964.
[29] Simmons (1995) pp. 343.
[30] Pawson & Brailsford (1862) p. 126.
[31] In classical mythology, the Cyclops were the assistants of Vulcan in his forge; one view of Cammell's works depicts a sculpted pair of the creatures flanking a coat of arms above the railway side gateway. Agenoria was the goddess of courage and industry. Other steelmakers chose instead to flatter the landlord by making reference to the Duke of Norfolk and his family (Firth's 'Norfolk Works', Wilson & Hawksworth's 'Carlisle Works'; the 'Howard Works' of William Brookes and Sons).

become associated with its name (Bowling, Low Moor, Butterley, etc.) As a valuable asset, companies would often take their works' name with them to new premises (such as Ibbotson's 'Globe' and Brown's 'Atlas').

At about the same time, the topographical works view also underwent great popularisation; these had been produced in limited numbers since the eighteenth century, but were relatively scarce before the 1840s and only reached a peak in the 1860s and 70s with the more regular production of trade directories and the advent of popular guidebooks, including Pawson & Brailsford's *Illustrated Guide* series. The advent of better street plans and particularly telephone communications saw a gradual decline in the role of the works view from the beginning of the twentieth century.

The main purpose of such views was promotional: for example, J C Fischer of Schaffhausen and Cammell of Sheffield exchanged prints of their steelworks on meeting in London during 1851, Cammell being so taken by Fischer's view that he is reported to have said 'That's where I would like to live'.[32] Such was the success of the large firms' image-making, that much smaller competitors soon strove to emulate the Don Valley aesthetic. In the production of topographical views, the draftsman would often impose a number of 'corrections' and conceits–extensions homogenised to appear integral to earlier buildings, rooflines straightened, furnaces reordered–making comparison with other works difficult.

An engraving of the Alma Works published in 1862, a small courtyard file manufactory embedded in the eighteenth century warrens that lay behind Barker's Pool, could easily be mistaken for an Etna Works-sized concern, with a similar arrangement of parts.[33] [fig. 5.13] Comparing this view to the contemporary Ordnance Survey plans [fig. 5.14] reveals the deceit: the impressive symmetrical façade did not in reality even run the full length of the yard, cut short by neighbouring buildings and with the archway off-centre. Similarly, the receding ranges of linear workshops were actually cranked and broken. A cluster of borrowed cementation furnaces completed the 'puffing'. Similar techniques were used to formalise George Fisher's Hoyle Street file works, this time assisted by scaled-down people for an image of inflated proportions.[34] [figs. 5.15, 5.16] Both works covered less than a quarter of the area of their Don Valley counterparts and had developed organically on geometrically complex sites.

On the other hand, even the larger works were given the same treatment. The well-known railway elevation of the Cyclops Works [fig. 5.10] depicts a unified façade with symmetrical portals and end gables, masking the site's recent development from a smaller nucleus.[35] A decade later, a woodcut reworking of the same view imposed a further layer of distortion and

[32] Henderson (1966) p. 79, note 61.
[33] Pawson & Brailsford (1862) p. 264.
[34] Kelly (1865) p. 73.
[35] Johnson Cammell & Co. (1847?) p. 2 frontispiece.

simplification, now accompanied by a street elevation of equally misleading proportions.[36] [figs. 5.11, 5.12] By 1862, the complementary views had been replaced by a new railway view of the works, incorporating recent extensions across the road.[37] [fig. 5.8] Although topographically more accurate than the former, the new image went further in rationalising the works' plan, straightening geometry and assigning a uniform style to the buildings.

Visitors taking the train to Sheffield would invariably pass through the canyon of steelworks, with its chimneys and furnaces spewing black smoke, and the forges sending tremors through the neighbourhood. Even at night work continued in the heavy forges, mills and cementation furnaces, giving the impression of incessant toil comparable to John Martin's 'Pandemonium'. As some travellers would stay overnight at the station hotel before moving on, the Don Valley came to be their most enduring image of the town.[38]

> *Who would think that here grew the many-leagued oak forests in which Gurth and Wamba roamed?...Now, what with furnaces and forges, rolling-mills, and the many contrivances used by the men of iron and steel, the landscape is spoiled of its loveliness, and silence is driven to remoter haunts.*[39]

Ultimately it was the ability of firms such as Cammell's and Brown's to meet increasing orders and invest in emerging markets that secured their future success, more so than the appeal of their brand or advertising. To this end, effective speculative risk-taking, availability of capital and the scope to expand were most important. No doubt Sheffield's particular and established system of outwork was also helpful, enabling the firms to bridge periods between building campaigns while offering flexibility in an erratic marketplace.

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[36] White (1856) pp. 4, 6 ads. Note that the second view appears to be a later drawing than the 1847(?) railway elevation. The extents of the yard on Savile Street have been severely compressed for the format of the advertisement, and a similar compression may be noted between the two railway views.
[37] Pawson & Brailsford (1862) p. 125.
[38] White (1858) p. 362: '...it was late when we reached Sheffield. I turned at a venture into the first decent-looking public house in *the Wicker*, and was rewarded by finding good entertainment and thorough cleanliness'.
[39] White (1858) pp. 363-364.

Other Don Valley steelworks

On the publication of the 1850 Ordnance Survey sheets of the town, two of the large new works–the Cyclops and Etna–had already been built, and a third, the Agenoria Works, was under construction although not featured on the plan. As dedicated steel and tool manufactories, the Etna and Agenoria Works nevertheless differed little from the early format of the Cyclops Works, comprising a large courtyard space surrounded by workshops with subsequent extensions built in the yard. Steel requirements were similar in each case, and furnaces were provided in similar numbers to the earlier Sheffield-based steelworks (see the Globe, Sheaf Works, chapter 3).

Production units also remained at a similar scale: the basic unit of the hand forge was a spatial constant, and steam-powered forge shops and grinding wheels did not exceed the size of those to be found at many smaller works [fig. 5.17]. Cammell's forge shops differed in being fully open to the yard, sheltered by reverse-pitch canopies (to let out the smoke) on a railway station-like iron framework; flues were integrated into the parapet of the trackside blind wall. A dramatic view down this rear 'alley' exploits the accidental forced perspective of its plan, the cementation cones in the background appearing to loom over the works–both documentary and plan evidence indicates that they were little larger than Sanderson's (chapter 3).[40] [fig. 5.18]

These similarities only began to diverge with the adoption of heavy steelmaking and rolling. Cammell was an early adopter in Sheffield of the puddling furnace, and Brown made this description of steely-iron his primary business. Meanwhile, the tool-centred businesses experienced less growth, some like the Agenoria Works ultimately dissolving (to be absorbed by their larger neighbours), while others such as the Etna and President Works found no need to expand beyond their original sites.

Spear and Jackson: Etna Works (1846)

The progenitors of the firm were responsible for the first independent steel melting furnaces (outside of the Cutlers' Company) in Sheffield at Gibraltar Street in 1766, and in partnership as Love & Spear took warehouses and an 'iron house' at 19-20 Scotland Street.[41] In its slow development the firm was characteristic of eighteenth century Sheffield enterprises, and not until the early 1830s did the partnership find it necessary to look beyond its location in the Crofts. At this time, the need for powered workshops resulted in Spear & Jackson letting the

[40] Compare Fischer's assessment of both from Schib (1951) pp. 528, 589.
[41] In 1766, Love & Manson entered into partnership, later to be reorganised as Love & Spear, see chapter 2. Their Scotland Street premises, owned by 'Geo., Wm. and Benj. Binks' in 1779, were to become the Debtor's Gaol after Spear moved out; see SCA FBC FB52 (1779) p. 84.

established iron foundry and fender shops of Stuart & Parkin in Savile Street, and leaving behind their Gibraltar Street furnaces.[42] [fig. 5.19]

By now, Spear & Jackson had begun to manufacture steel tools and to that end the Savile Works already included a grinding wheel, converting furnaces (or 'steel houses') and various workshops. To these, the new occupants added cast steel furnaces and file shops, completing the core elements that would later form the backbone of their subsequent Etna Works. A sawmill on the site may also have been of use for making tool handles.[43] The premises were an untidy accretion of ramshackle structures erected over the years for different purposes, and must have served their purpose in functional terms only.[44] Steel furnaces straddled the middle of the site, with the walled street front left largely clear, and the grinding wheel on the riverbank. [fig. 5.20] The location of Savile Works was determined more by its proximity to the river Don than for its transport links; only when the Wicker Station was built directly opposite the works in 1838 did it become a desirable situation in terms of connectivity.

An advertisement of 1849 informs that Spear & Jackson had 'removed from Savile Works', and three years later the company are described as 'merchants, and steel, file, saw, ledger blade and machine knife, &c. manufacturers, Ætna Works'.[45] The circumstances of the move of c.1846 are not known, but it can most likely be ascribed to an increase in trade (perhaps stimulated by the fortuitous arrival of the railway) along with the development of new product lines: certainly by the 1850s they were manufacturing the gardening forks and spades for which they became best known. [fig. 5.21]

In adapting the model established by the Cyclops Works, Spear & Jackson created perhaps the most characteristic and representative of the early Don Valley steelmaking complexes, soon to be followed (and closely paralleled) by the similar President Works, Queen's Works (later Atlas), and beyond the Norfolk Estate by the Regent Works. [figs. 5.23, 5.24]

The plan of the Etna Works was basically a revision of the urban courtyard type, retaining most of its key characteristics. The office and warehouse acted as the 'public front' and it was here that the 'architecture' was concentrated. Its 66½-yard frontage, almost the same width as that of the Cyclops Works (and later the President Works), featured a central pavilion with a flat-arched entranceway in the rusticated ground floor, three-bay first floor with a central triple-opening window, surmounted by a simple pediment. To each side, plain two-storey wings

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[42] Pigot (1834) places Spear & Jackson at 'Saville Street', while the previous year the file manufactory was at Cupola Street in the Crofts, occupied by 'John Spear & Co.'; White (1833); Hawley (1992) p. 96. Stuart moved to Roscoe Place in 1834-35, replacing Jobson: see SCA CA VS(L)1 (1834-34) p. 81. For Spear & Jackson's Gibraltar Street premises, see rate book, Sheffield lower (1834-35) vol. 1b, p. 288.
[43] SYCRO 141/B Flockton valuations (1853) pp. 221-222, 'Valuation of freehold property in Saville Street, Sheffield, belonging to Mrs. [Caroline Jane] Stuart'. This valuation made some years after Spear & Jackson had left the site nevertheless records the buildings that had been erected during their tenancy.
[44] No advertising images of the Savile Works are known, and Flockton wrote down half the total value of buildings on the basis that 'to realise the value of the land a considerable portion of the buildings would probably have to be taken down'.
[45] White (1849); White (1852).

formed a neutral backdrop to Savile Street (which by 1850 effectively terminated at the Etna Works, each tenant being responsible for paving their own stretch) with ground floor windows raised above door level, reduced to horizontal slots for privacy. [fig. 5.25] Behind this secure façade and unseen from the street was the expected courtyard, in this case much longer than its urban predecessor. Both sides were built up with ranges of workshops (incomplete in 1850 when the first plan was made), terminated at the back of the site by the cementation furnaces and private sidings. Down the middle of the yard, freestanding workshops were also derivative of the smaller courtyard works type. Within these assorted furnaces and shops, the full range of tool production was undertaken, if not arranged in such a strictly progressive sequence as at the Sheaf Works.[46] Instead, each part was subservient to the wider planning of the site, similar to the smaller works where space was at a premium and pragmatic considerations such as the efficient movement and storage of fuel, materials and waste were more important than the spatial integration of production stages.

The difference in scale between the urban and suburban works did, however, have ramifications to planning, and the significantly larger Don Valley works rapidly evolved an aesthetic quite different to the busy accretions of the town. While the long street frontage offered greater scope for architectural display, the classical language of the Etna Works operated at a more fundamental level, embedded in the organisation of the plan. Most immediately noticeable is the strong mirror symmetry of the works, of which the front elevation gives a foretaste. On passing through the central archway into the yard it became immediately apparent that the major axis did not run the length of the site, but was abruptly cut short by the projecting bay window of the time office, above which a clock tower presided over the front yard as a constant reminder to the employee of his place in the time-regulated operation of the works. From this point on, the physical axis was bifurcated, following the route of the paired railway lines that entered the site through archways in the perimeter wall, to service the longitudinal rows of shops on the long side boundaries. On the other hand, the compositional axis remained on the centreline of the site, passing through the clock tower, the symmetrical grinding wheels and their engine stack, and completed by the array of four cementation furnaces, forming a theatrical backdrop to the composition.

Although not as rigorous in its formality or refined in its details as the neoclassical complexes of Ledoux, the intent and effect of the Etna Works is much the same. Certainly to a Sheffield workman or industrialist, the meaning of its various parts and their arrangement would have been known intuitively, constituting an *architecture parlante* that Ledoux could only dream of.

Although the Etna Works' original configuration was altered to admit additional processes and extra capacity, compared to its heavier steelmaking neighbours the basic plan remained remarkably stable, the only group of buildings still clearly recognisable in early aerial views of the valley. [figs. 5.22, 5.30] Extensions to the plant proceeded on a small scale, piecemeal

[46] See appendix 5.2, for a description of a visit to the works in 1890.

basis, and as late as 1900 a new dedicated twelve-hole crucible furnace was built on nearby Greystoke Street (see chapter 2).

Beet, Sons & Griffith (later Peace, Ward & Co.): Agenoria Works (1850)

Although it has attracted little attention compared its larger neighbours, its history mired in obscurity, the Agenoria works of Beet & Sons (later Peace, Ward & Co.) conveys more succinctly than other examples the fixity of the urban steelworks type as first transplanted to the Don Valley. In addition, a schedule of both buildings and fixtures (even including some fittings) provides an unusual level of detail, allowing comparisons with its town-based equivalents to be made.[47]

Beet, Sons & Griffith had managed to obtain land that had previously been reserved by Spear & Jackson for a possible extension to the Etna Works, and who had been paying an agricultural rent on the plot to secure first refusal since the establishment of their works in 1846.[48] Griffith, a co-partner in the Beet family business for less than five years, was probably brought in as a sleeping partner to provide the necessary capital.[49]

With an area of just over one acre (4845 square yards, or 4051m^2) the site was nevertheless smaller than most others alongside the railway, with a frontage of only thirty-five yards. Only the short-lived Queen's Works of Armitage, Frankish & Barber had been of similar extent, occupying one acre of land (although the site as acquired by John Brown contained three acres in all).

From front to back, the sequence of buildings was as might be found at a smaller urban steelworks: behind the main warehouse and caretakers' cottage facing Savile Street East extended file cutting shops, forge shops and stable to one side, with additional hand-forges and a steam-powered grinding wheel opposite. The steelmaking buildings were pushed to the very back, comprising a steelhouse with two cementation cones facing a ten hole melting furnace with coke shed and auxiliary work rooms.[50] [fig. 5.26]

An engraving of the Agenoria Works published in 1862 (but possibly made some years earlier) is of particular interest for its lack of adherence to the scale and proportions of the actual premises. [fig. 5.27] This disparity between plan and topographical view highlights the difficulties experienced by contemporaries in defining the new type–the site is dramatically

[47] William Flockton's valuation is the only one known of a Don Valley steelworks of this kind, and therefore offers the industrial historian invaluable evidence not available elsewhere. SYCRO 141/B (1861) pp. 305-308.
[48] Simmons (1995) pp. 338, 449. SCA ACM S384/620, 626 (July 1846, May-July 1850); ACM LB/B/370, 374, 388, 410, 648. The land was obtained for just 2.7d per square yard, a much lower cost than was later charged on the same street once works had been established.
[49] Peace (1999?) p. 164, notes that Griffith left around 1854-55.
[50] SCA Walker Deeds 538 (1855) 'The Plan referred to on the Deed of Copartnership between the undersigned partners [Thos. Beet; W J Beet; Henry Peace; Benjamin Schofield, Jr.] dated the 3rd day of July 1855'. Note that Timmins (1977) p. 178, misread '10 holes' as '70 holes', assuming the works to be much larger. See schedule SYCRO 141/B (1861) p. 305, 'Ten Melting Furnace Holes'.

foreshortened along its length, the steel plant, grinding wheel and warehouse compressed to resemble a conventional courtyard arrangement.[51]

Fixtures and fittings within the works were typical of what might have been found in any medium-sized manufactory of the time. The corner 'cottage' occupied by the works' supervisor was reasonably well furnished for its size, with pictures of local interest upon the walls–a portrait of the Duke of Norfolk, views of the town of Sheffield and the School of Art. In the dining room was not only the usual dining table and Windsor chairs, but also a card table and 'two spittoons', suggesting its use by works' management as a place of recreation.[52]

Nearby, the furnishings of the private office created a different impression, designed to impress clients with evidence of efficiency, reliability and international trade. Glass cases and rows of pigeonholes suggested orderliness and pride in the business; a large iron safe by Milner's would have held the company's valuables while suggesting security;[53] while upon the walls hung framed maps of London, America and Russia, the main seats of trade. Also present was the ubiquitous almanac, an item commonly found in the humblest cutler's shop.

Workers arriving in the morning would first have to pass through the archway alongside the cottage, under the scrutiny (symbolic or actual) of the management, before entering the timekeeper's office to check in. Fully glazed and presiding over the weighing-machine, this was also where all of the keys to the works were kept. Wages, on the other hand, were collected from the table knife warehouse at a specially designated 'pay place'.

For the attendants of the two (later four) cementation furnaces, shifts could be long, evidenced by the bed provided in the watch-house to relieve overnight duty. Other fixtures in the furnace building included a desk, bins for scrap (cut ends and test pieces) and stays for securing the long bars of steel awaiting conversion.

The crucible furnaces conformed equally to type: the pot room was fitted with stone troughs for water, a metal clay-treading floor and a stone bench for pot-making. Shelves for freshly made crucibles were reached by ladder, while more shelves for drying could be found in the melting shop. Here the fixtures included the usual metal flooring, two 'tressels' and a large annealing grate.

Grinding wheels and file shops were equally unremarkable, although it is interesting to note the means of water supply to the works, conducted via 'piping and pumps' from the Royds Mill dam, and used both to power the engine and for general purposes.[54] It may be reasonably

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[51] Pawson & Brailsford (1862) p. 148.
[52] An 'ale gantry' in the kitchen leaves little doubt as to the refreshments served during card games.
[53] Made by the well-known Milner's Safe Company Ltd. of London.
[54] SYCRO 141/B, Flockton valuations (1861) pp. 305, 306: '...with the privilege of a water supply from Royds Mill dam for Engine purposes on payment of 3s per Horse power & of a share of the cost of certain works...' This is

assumed that water provision for other Don Valley works was arranged on a similar basis, and that the Agenoria Works lay on the same overground water channel as the Cyclops and Etna Works to either side.

Perhaps because of its unusual size for a tool manufactory (or else the withdrawal of Griffith from the partnership) the occupants of Agenoria Works were not fortunate in business. In 1855 two new partners–'Henry Peace of Sheffield file manufacturer and Benjamin Schofield clerk and traveller'–were brought in, and the entire 'material, stock in trade and tools of John Brown' from the file and steel manufactory at his old Furnival Street Atlas Steel Works was purchased (presumably at a knock-down rate, to boost their merchanting turnover).[55] However, within three years the business collapsed with Henry Peace declared bankrupt in April followed by Thomas and William Beet in July. This was not the end of Peace's involvement as trade directories indicate that by the following year Peace, Ward & Co. had reoccupied the premises, even winning a medal for their cutlery exhibit at the 1862 London exhibition.[56] However, by 1866 the new company had also become insolvent and the Agenoria Works disappeared from local directories, ultimately to be taken over by Cammell.

The Duke of Norfolk's 'model village'

To the northwest of Carlisle Street and directly alongside the swathe of heavy industry, the Norfolk Estate's residential sector was an ambitious attempt to emulate the model towns of Robert Owen and others, but built on a speculative basis. Before the 1889 Sheffield Bye-Laws, the 1890 Housing of the Working Classes Act, and the subsequent establishment of the first municipal housing schemes, Sheffield's housing provision had been entirely privately funded and maintained, with few controls on specifications and planning.[57] What controls did exist were generally the responsibility of the landlord, and the Dukes of Norfolk had made several earlier attempts to foster planned development of a minimum standard, the reversionary value of the properties built on relatively short leases (typically 99 years) being foremost in their minds.[58] The extent to which organised urban planning remained central to the Don Valley estate, and particularly its associated housing at Pitsmoor / Brightside, has nevertheless been often overlooked by historians.[59]

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corroborated by a letter of 7 Feb. 1850 to Firth's regarding the Norfolk Works offering a water supply from a 'conduit' on the same terms, see SCA ACM LB/B/308.

[55] SCA Walker deeds 538 (3 July 1855) description to accompany plan. In 1854 Brown had decided to leave his dispersed Sheffield premises for the Don Valley, Tweedale (1986b) p. 15.

[56] Peace (1999?) pp. 164; Melville (1859); White (1860).

[57] Hebblethwaite (1987) pp. 144-150; Harper (1978); County Borough of Sheffield (1889).

[58] Simmons (1997) p. 416-417. Shorter terms of 90 to 98 years were also made to allow co-ordinated reversions, while in exceptional cases leases of 63 and 21 years were granted (generally on premises).

[59] Olsen (1973) pp. 333-357, dealt mainly with the Alsop Fields estate, and suggested that the Dukes had all but given up on estate management after its 'relative failure'. Simmons (1997) pp. 403-431, gives a more balanced view, but

In its basic plan, there are echoes of James S Buckingham's 'Victoria' (1849), with orthogonal rows of dwellings divided by diagonal streets, public buildings and churches situated at the more important nodes.[60] The geometrical generator was an isosceles triangle (almost equilateral) with its base equal to the large grid of the adjacent industry defined by Sutherland Street and Carwood Road. These primary roads climbed the steep valley side to converge at a central hub of six streets, the main terraces of housing following the contours in streets of decreasing length towards the centre. It was undoubtedly the extreme gradient of the land that led to the abandonment of the hitherto ubiquitous grid, the vertical distance from base to vertex of the triangle being almost 140 feet (42.7m) giving an average rise of one in ten.[61] [fig. 5.28]

On the main axis of symmetry, and at the focus of six convergent main streets, was erected All Saint's Church (c.1869), financed by Sir John Brown whose Atlas Works it presided over.[62] Such was its intended centrality to the community, located at the heart of the residential district, that the nave was aligned with the geometry of the estate plan, rather than the usual east-west orientation. Behind the church a radial group of school buildings clustered around the apse, emphasising the connection between religion and education (built on land also given by Brown). As Sheffield was a centre of non-conformism, other churches, halls and meeting houses of various denominations (including Methodist and Congregationalist) and their associated schools were laid out at significant nodes of the plan.

Predating the industrial villages of Port Sunlight (from 1888) and Bournville (from 1894) by several decades, the development evolved in parallel with Titus Salt's mill community of Saltaire near Bradford (1851-71). However, a comparison of Salt's axial classicism and the half-formed radiant plan at Pitsmoor suggests there was little exchange of ideas between the two. One similarity is the treatment of public houses, absent from Saltaire and relegated to the bottom of the valley at Sheffield, a town not otherwise noted for its temperance.[63] An earlier parallel (but on a smaller scale) may be found in the workers' housing (c.1814) of the Plymouth Iron Works at Pentrebach near Merthyr Tydfil, Wales, and colloquially known as 'the Triangle'. Here rows of two storey terraces enclosed a central triangular space, the whole complex located near to the ironmaster's house.[64] [fig. 5.29]

The estate plan was never completed, although there is some doubt as to the original intent–a hexagonal plan would have been possible, but may have succumbed to the realities of topography and pre-existing roads. Ultimately a looser form of planning prevailed, abruptly cut

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[60] Buckingham (1849) *passim.*
[61] This was ameliorated by the diagonal streets (Sutherland Road and Lyons Street) to around 1 in 12.5, and by the long diagonal of Ellesmere Road to 1 in 22.
[62] Odom (1917) From its position on the valley side, All Saints' became a notable landmark of the district, its pointed steeple visible for miles. Before completion of the building, services were held in a room at the Atlas Works. The church was demolished along with most of the housing in 1978; it is not to be confused with All Saints' Parish Church, Ecclesall, where John Brown was buried.
[63] Simmons (1995) p. 346, cites examples of the estate strongly resisting the use of dwellinghouses as beerhouses; ACM/LB/D/769; N/926.
[64] Darley (1976) p. 17.

off in some parts by field boundaries, and showing signs of growth by accretion. Even in the formal triangle some plots remained undeveloped, into which industry began to spill over, notably the Harleston Iron Works shown on the OS Plan of 1905 (extant).[65]

From the air, the strong geometry of the housing and its relationship to the linear form of the Don Valley industries is clear. [fig. 5.30]

[65] Vine (1936) part 3 'Stevenson Road'. 1:2500 OS Plan (1905) Yorkshire sheet 294.04.

Part 2: Hiatus–Bessemer versus the Sheffield steelmakers

> *This strange monster, "truly unique among organic forms," breathes through his nether parts, feeds, spits, roars and flames through his nose, which, like his breast, strangely enough grows above his back, while his shoulder lies beneath the middle.*[66]

Perhaps no invention had a more profound effect on the perception of industry in the nineteenth century than the Bessemer converter, with its futuristic (even zoomorphic) appearance. Even though the quality of steel it produced was no better than crucible cast steel, and it was quickly eclipsed by the more economical Siemens-Martin open hearth furnace, Bessemer's 'pneumatic' process caught the public imagination from its first announcement, becoming a subject on which no modern gentleman could afford to remain ignorant.[67]

Like Huntsman a century before him, Henry Bessemer (1813-1898) did not come from a background in steelmaking and had no formal training. He could best be described as a 'professional inventor', taking out over 100 patents during his life beginning at the age of twenty-five, but he was also a remarkable self-publicist.[68] His first great commercial success was the development of a bronze powder, produced by machine to undercut the expensive handmade gilding powders then available, from which he made a large enough fortune to fund his later speculative inventions. Further successes followed, with a sugarcane press and various improvements in glass manufacture, [fig. 5.31] before the outbreak of the Crimean War in 1853 turned his attention to armaments.

Having developed a rotating shell suitable for use in existing smooth-bore guns, it became evident that the common cast-iron gun barrels were not strong enough for the heavy shells planned by Bessemer, and consequently he began to investigate methods of casting ordnance in stronger metals. He began with an attempt to redesign the staple 'Sheffield method' equipment, the cementation and crucible furnaces–an episode curiously absent from his autobiography. The former became a gravity-fed, blast furnace-like structure, converting a mixture of 'iron bars, hoop, plate or scrap' with charcoal in vertical tubes; the latter was a circular array of melting holes with a central casting pit into which the crucibles were automatically 'tapped' from the bottom into a single large casting, all surmounted by a large

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[66] Howe (1895) p. 341, note 'p'.
[67] Bessemer's famous paper read to the British Association on 'The manufacture of iron without fuel' was fully reported in the next day's *Times* (14 Aug. 1856). *The Engineer* (31 May 1867) p. 491, considered crucible steel to be 'still the cast steel *par excellence*', due to the 'uncertainty in the kind of metal produced in the Bessemer vessel'.
[68] Much of the following history is taken from Bessemer's autobiography which, although in many ways a post-rationalised account, remains one of the best general sources on his life. Bessemer (1905) *passim*.

tapering stack giving the appearance of a Hoffman kiln.[69] Patents were taken out, but the designs attracted scant attention from the steelmaking establishment, busy developing their own solutions to the problem of large castings.[70] Bessemer's fascination with circular and centric systems was a recurrent theme throughout his life, in this case resulting in the impractical solution of a casting shop capable of producing only one size of gun, but soon to become the governing principle of the Bessemer shop.[71]

Significantly, it was through his work with crucibles that the 'pneumatic' process was born. The first 'converter' was simply a single 40-pound crucible with a perforated lid, through which a blowing pipe was inserted below the surface of the molten steel, brought to fusion in a conventional melting hole.[72] On applying the blast of air (or rather its oxygen), both impurities and carbon were rapidly burnt away in a violent reaction, resulting in molten malleable wrought iron of a quality suitable for foundry work. Increasing the carbon content of the charge (towards cast iron) or decreasing the 'blow' time gave a more steely product with the properties of crucible cast steel, but with the potential to be made of cheaper materials in much greater quantities.

From its first successful trials, the converting vessel passed through a number of prototypes, the idea of a rotating converter (to simplify the charging and 'tapping' processes) emerging in 1855, but only achieving its characteristic form with bottom tuyeres (the apertures through which the blast enters the steel) about three years later.[73] [figs. 5.32, 5.33] The early experiments and demonstrations were made at his bronze factory in St. Pancras prior to the establishment of the Sheffield Works in 1857 and his low-key Greenwich Works of c.1865.[74]

Following the enthusiasm that greeted its public announcement, Bessemer was besieged by ironmasters competing for the limited number of franchises at first made available, but this was dramatically cut short by the unexpected failure of the process in the hands of the first licensees. The chemical explanation of this problem and its solution is covered elsewhere; the impact it had on confidence was catastrophic, and led directly to Bessemer's involvement in Sheffield. Unable to revive commercial interest in the process, its inventor decided that the only remaining course of action was to convince the Sheffield industrialists of its value by undercutting their cast steel in the marketplace. Provocatively, the location chosen was the steelmakers' own backyard, alongside the railway in the Don Valley.

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[69] Clearly, Bessemer was attempting to bypass the use of highly-paid teemers, a job that demanded skill and strength, and was subject to regulation by unions; the same motive may have encouraged his development of the pneumatic process. Hoffman patented his annular brick kiln in 1858, see Hammond (1978) p. 181-188, plate 2.
[70] 'Patents class 72' (1905) p. 4, Bessemer, H. (18 June 1855) no. 1384.
[71] Bessemer personally designed and drafted most of his inventions, developing a clear aesthetic that cannot be entirely explained by functional requirements. From his design for a glass factory, to the solar furnace which preoccupied him throughout his life, centricity and a certain robust style permeate his work.
[72] 'Patents class 72' (1905) p. 7, Bessemer, H. (17 Oct. 1855) no. 2321.
[73] For a fairly comprehensive survey of the converter's development, with drawings taken from the patent specifications, see Carnegie (1913) pp. 132-136.
[74] Mills (1998) pp. 11-14, suggested that the Greenwich premises–not mentioned by Bessemer in his autobiography–may have allowed him to 'experiment and work out of the way of prying eyes of manufacturers based in the north of England' and close to his home in Denmark Hill.

Henry Bessemer: Bessemer Works (1857)

Bessemer's decision to set up not in Sheffield's centre, but in the midst of its largest and most modern works could be interpreted as a snub to the outdated 'Sheffield method' steelmakers and an example to his 'progressive' neighbours. The Carlisle Street site was on the opposite side of the tracks to his target audience, undeveloped to either side, and quite different in appearance: 'a neat white brick range of buildings with sandstone dressings, and a tall chimney as the usual landmark'.[75] [figs. 5.34, 5.35] The contrast of white (glazed?) brick with its smoke-blackened red brick surroundings aimed to distinguish the model works as a beacon of progress, in a brave attempt to defeat the Sheffield grime. Security was also a prime concern, as Bessemer retrospectively explained:

> *In thus opposing the old-established steel trade in its very midst, we ran the risk of "rattening," or a bottle of gunpowder in the furnace flues, by which the workmen of Sheffield had earned for themselves an unenviable notoriety, and we had reason to consider ourselves fortunate that we escaped.*[76]

In this case, however, security did not mean secrecy–the works were to be a shop window for Bessemer's patent process, open for any interested industrialist to visit. The venture was funded by Bessemer and his partner Robert Longsdon who, 'with his intimate knowledge of architecture', also contributed the design of the buildings. [fig. 5.36] They were joined by Messrs. Galloway of Manchester (who had taken out the first license on the process, and built most of the equipment including the converters), and Bessemer's brother-in-law William Allen was brought in as resident manager. The first tilting converter went to work in 1858, operated by hand and disgorging its contents upon completion of the 'blow' into a casting ladle attached to a counterbalanced hydraulically-lifted crane. [figs. 5.37, 5.38] Once full of molten iron, the ladle would be turned around by a hand-operated cog to deliver streams of metal to individual ingot moulds (like Huntsman's but considerably larger) arranged in a semicircular casting pit. Upon cooling, the ingots were processed in the usual way, forged and rolled to the required section. This 'original single little one-ton vessel' was followed about two years later by a pair of four-ton converters.[77]

In its arrangement, the classic 'English' Bessemer shop owes something to the concept of the gravity-fed corn mill. Pig iron and spiegeleisen are melted in cupolas at the top, run down a

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[75] Bessemer (1905) chapter 12. It is interesting to note Bessemer's recognition of the chimney's symbolic role, much as the 'solid steel column...representing the world's production of Bessemer steel in the year 1892' (published as figure 107 in his autobiography) appropriated architectonic imagery to communicate an abstract concept of industry. [fig. 5.39]

[76] Bessemer (1905) chapter 12. The example of Bessemer probably inspired Reade (1896) pp .301-302, to describe the fictional manufactory of Henry Little, the hero of his novel *Put Yourself in His Place*: 'a portion of the building [was] to be constructed so that it could be easily watched night and day...He went into the suburbs for his site, and bought a large piece of ground [and] warned the builders it must be a fortress, as well as a factory; but, at Henry's particular request, he withheld the precise reason. "I'm not to be rattened," said he'.

[77] 'Progress of Bessemer' (1867) p. 491. The first tilting converter was 'still occasionally used' in 1867, at which date the four ton vessels were 'continuously at work'.

charging funnel into the supine converter mouth, then down again into the ladle before reaching its lowest point in the casting pit (from where it would be lifted by crane back to ground level). An engraving of Bessemer's own plant exhibits all of the basic elements: the shower of flames and sparks from the converter in full blow (left) being directed up a masonry hood to a chimney outside, while the ladle receives molten steel from the opposite vessel (right), controlled by a man at the 'pulpit' (left foreground, see below); a cupola furnace can be seen through the arch in the rear 'proscenium' wall, while on the metal shop floor a pair of cranes cover the active areas of the casting pit. [fig. 5.40] Given Bessemer's imaginative use of imagery elsewhere, it is unlikely that the pseudo-sacred setting of the converters was arrived at by chance, the strong axial symmetry and dramatic use of layered space, overseen by the 'priest' at his elevated mechanical altar, all contributing to the air of ceremony that surrounded proceedings. Potential licensees were dazzled by the phantasmagoria of the blast, reassured by the obedient nodding of the vessels and the calm efficiency with which the stream of ebullient metal entered the mould.[78]

The Bessemer blow's innate theatricality meant that it quickly became an established favourite of the steelworks tour: on occasions of visiting royalty, observation platforms were set up above the shop floor for an optimal viewpoint.[79] [fig. 5.41] Following the violence of a 'heat', the slow choreographed movement of the converters on their trunnions and the pirouetting of the casting ladle and ingot cranes was nothing short of a mechanical ballet. Meanwhile, behind the proscenium of the converter extract hoods and back wall of the shop, the raw servicing of the process went on almost unnoticed, where cupola furnaces melted charges of bought-in pig iron and spiegeleisen.

Bessemer's converter and its supporting infrastructure occupied a liminal position between the tradition of artisanal steelmaking skills and the mechanised future towards which its inventor tirelessly strove. Although Bessemer's stated aim had been to produce cast malleable iron 'wholly without skilled manipulation', the process could not be entirely automated: the endpoint of a 'blow', for example, could only be judged by a highly experienced eye, and it was not unknown for the 'blower' to be better paid than the shop foreman.[80]

Thus the Bessemer process was a foretaste of the mechanised and integrated production lines of the early twentieth century, despite the process itself being a simple metallurgical operation first developed in an adapted crucible furnace. It was this futuristic idea of the production process that caught the public imagination, the converter and its accessories taking on an almost zoomorphic character.

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[78] It is a foretaste of what Banham was to term 'mechanolatry', or the worship of the machine; Banham (1960) caption to pl. 119.
[79] Barraclough (1976) fig. 91, showing the 1889 visit of the Shah of Persia to John Brown's Atlas Steel Works.
[80] Lodge (1999) p. 174, gives the example of the Stocksbridge Works in the 1880s.

Introduction of the Bessemer process into Sheffield works

John Brown: Atlas Works

John Brown was the first to 'cross the line', both metaphorically and literally, having been introduced to the process on a visit from Colonel Wilmot, Superintendent of the Royal Gun Factories, who is said to have persuaded Brown and his partner Ellis to accompany him on a tour of their neighbour's works.[81] In Bessemer's words:

> *They seemed much interested in watching the great change which took place in the flame and sparks emitted as the process proceeded; but when the eruption of cinder, and the accompanying huge body of flame, were seen to issue from the converter, they were greatly astonished. In about twenty minutes the flame had dropped, the mouth of the huge vessel was gradually lowered, and a torrent of incandescent metal was poured into the casting ladle. Up to this moment they merely expressed surprise at the volume of flame, the brightness of the light, and the entire novelty of the process. But no sooner did they see the incandescent stream issue from the mouth of the converter, than their practised eyes in an instant recognised it to be fluid steel, and they themselves were "converted," never to fall back again into a state of unbelief.*

As the first licensee in Sheffield, Brown's reputation and his success with the process meant that others soon followed his example, notably Charles Cammell who established casting pits at the Cyclops Works and after 1865 at Penistone.[82] [fig. 5.42]

Brown's first Bessemer shop consisted of two three-ton converters, built before the definitive patent specifications of 1862. Instead of being arranged 'in such a position with reference to each other that the flame and flashes emitted therefrom shall be projected in opposite directions, the said vessels being capable of discharging the converted metal into a ladle placed between them', they shared a common axis of rotation with the cupolas placed to one side, an arrangement common in later American plant.[83] The waste of iron resulting from the distance it had to travel from cupola to converter mouth militated against this arrangement being widely used, and Brown's second shop, illustrated by *The Engineer* during 1867, returned to the classic plan. Comprising a pair of ten-ton converters at opposite ends of a 'really magnificent' near-circular casting pit, it was the largest facility to have been built by that

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[81] Bessemer (1905) chapter 13. Brown moved alongside Bessemer's works from 1859, producing steel at this plant from 1861. Tweedale's suggestion that Brown built his works in Carlisle Street before Bessemer would appear to be incorrect. Simmons (1995) p. 443; Tweedale (1986b) p. 16.
[82] Stainton (1924) p. 249, noted that Cammell's 'iron and steel works at Penistone were secured in 1865', covering an area of 25 acres; the change to limited company status in 1864 may have been to fund this investment.
[83] Patent specification Bessemer, H. (8 Jan. 1862) no, 56. A description of this Bessemer shop, published by Percy (1864) pp. 821-824, is reproduced as appendix 5.3.

date, reputedly designed entirely by Bessemer himself and built in Sheffield by Walker & Eaton.[84] [figs. 5.43, 5.44] By now, the blowing engines (housed outside of the main building) provided compressed air not only for the blast, but also power to turn the converting vessels and raise the casting ladle and two cranes by hydraulic rams. Control of the process was divided between the men in the casting pit, who turned the cranes and ladle, and an operative in charge of the hydraulics, 'placed above his fellows, in a kind of watch-tower', more usually known as the 'pulpit'.[85] [fig. 5.45] The valves and pipework communicating with the equipment were concealed in the plinth and beneath the shop floor.

Converter capacities rapidly grew as operators gained experience, from Bessemer's first one-ton model (1858), through Brown's three-ton (1861), Cammell's four-and-a-half ton (c.1863), and Brown's ten-ton (by 1867). Outside Sheffield, converters were also operated at locations better known for their ironworks such as Barrow-in-Furness (Hematite Iron Company), Crewe (London and Northwestern) and Dowlais.[86]

While Sheffield's Bessemer shops tended to conform to the dual converter type as described in the patent specification drawings (Bessemer's British patents lasted until 1876, fourteen years after the defining specification), elsewhere new configurations arose almost with every new works–particularly so in America where a greater emphasis was placed on the mill-like operation of the plant, the converters hanging in a complex, vertically-orientated sequence of spaces expressed in the irregular roofline and varied fenestration of most Bessemer sheds. [fig. 5.46] Here, as steelworks grew in scale and competitiveness, ever more complex arrangements of cranes, gantries and railway tracks evolved. The plant of the Bethlehem Steel Works, Pittsburgh, seems strangely unsuited to its housing, tracks winding in and out of the shell–a rational, cruciform mass of building–part of an overall works layout that bore strong similarities to that of its British equivalent, Vickers. Inside, the equipment was essentially that developed by Bessemer, but with the converters in a linear arrangement of four, fed from the rear by a network of mobile ladles and wagons; the multiple levels are evident in a painting of the interior. [fig. 5.47] Important improvements were also made by Alexander Holley at Troy, NY, whose modular converters with easily replaceable linings and tuyere-bottoms were claimed to be twice as productive as the original.[87]

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[84] 'Bessemer plant' (1867) pp. 479, 487, 490. 'Patents class 72' (1905) p. 73, Bessemer, H. (8 Jan. 1862) no. 56. 'Progress of Bessemer' (1867) p. 491, suggests that although the vessels nominally held ten tons, the actual capacity was fifteen.
[85] 'Bessemer plant' (1867) pp. 479. Jeans (1880); Jordan (1878). The pulpit and its controls are described in the January 1862 patent as above.
[86] Other examples by 1867 were known at Wednesbury (Lloyds, Foster & Co.), Ebbw Vale, Gorton, Tudhoe (nr. Durham), Glasgow, Bolton and Cheltenham. See Lord (1945-47) pp. 163-180.
[87] See *Engineering* (10 Aug. 1866) p. 89, co. 3, 'Bessemer Steel Making'; Carnegie (1913) p. 136. Holley had purchased the U.S. rights to the Bessemer process in 1863, building the first American plant at Troy two years later. He was also consultant and planner to many others, including the Bethlehem Steel Works. The replaceable bottom was patented in 1868.

The international development of the Bessemer converter plant and its multitude of variants is beyond the scope of this study,[88] suffice to say that just as the house-built steam engine gave way to portable models (culminating in the mobile steam locomotive), so the Bessemer shop rapidly developed into an assortment of differentiated parts operating in concert, requiring only a roof for shelter. In some cases even the loadbearing walls were dispensed with to give a fully permeable ground level, as at Rhymney where a startlingly simple iron-framed canopy with independent cladding panels anticipates twentieth-century functionalism. [fig. 5.48] The introduction of increasingly complex devices, such as the mobile ladle-crane, reduced the design of the site and its buildings to a flow-diagram. [figs. 5.49, 5.50]

Architecturally, the Bessemer converter prompted the beginning of a new era: no longer was the furnace a determinant of spatial configuration. Like the machinery inside a textile mill, it came instead to occupy a fixed relationship, needing only a space of sufficient volume to enclose the whole. The resulting shed was serviced from the outside, raw materials being brought in at one end and ingots distributed from the other, so the works yard ceased to be a central amenity, becoming a peripheral zone.

On a larger scale, the planning of these sites resulted in an alienation of the steel industry from the town that was not only physical, but also perceptual: the identity of the post-Bessemer works was ambiguous, its activities concealed beneath undifferentiated roofs and behind blind walls. In contrast, the old units of production had served as mnemonic symbols, their multifarious configurations cohering into a legible urban landscape. While the Don Valley had attained the critical mass of a town, with its associated housing, shops and entertainment, it was never to become a *locus* in its own right, but remained an attenuated trail of urban debris.

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[88] Barraclough (1990) offers a good summary of its progress; a well-known early twentieth century account appeared in Carnegie (1913) chapters 14, 15; also see Sexton and Primrose (1912?) chapters 27, 28; Howe (1895).

Part 3: Vickers' River Don Works

The first River Don Works, Millsands (1826-62)

In 1826, the newly formed partnership of Naylor Vickers (Naylor having left his erstwhile partner Sanderson in possession of the facilities at West Street and Attercliffe Forge, see chapter 3) constructed a water-powered rolling mill at Millsands, fed by Edward Vickers' Town Mill supply.[89] The Town Mill had been Sheffield's principal corn-mill since medieval times, and Edward Vickers was of the third generation of his family to work as millers at the site.[90] The shift from corn milling to steelmaking reflected the growing profits to be made in Sheffield's speciality industries, and the increasing scarcity of good water-powered sites for rolling mills and tilts.

Soon after the rolling mill began work came the first opportunity for expansion, with the acquisition in 1829 of Jonathan Marshall's neighbouring steelworks, including both cementation and casting furnaces. [fig. 5.51] This steelmaking capacity was augmented by the tilt and forge at Wadsley Bridge also under Marshall's ownership, essential if the firm was to compete with other large integrated concerns, such as the Sandersons.[91] [fig. 5.52] It is difficult to confirm how much of the Marshall site was retained: an image from the 1830s shows an idealised courtyard arrangement, quite unlike any configuration of the works before or after. The depiction of Marshall's front warehouse block (with two storey wings) seems reasonably accurate, but the steelmaking plant behind was, in reality, far less orderly.[92][fig. 5.53] In any case, augmentation of the works' capacity began almost immediately with twenty more crucible holes built on the Marshall site; during the 1840s this pattern continued on adjacent land, with two blocks of eighteen melting furnaces added between 1845 and 1846, and four new converting furnaces in 1851.[93] During the boom decades, steel was not only supplied to the local trade, but also exported in considerable quantities, suggesting that Vickers' early growth followed a similar pattern to that described in chapter 3.[94]

For the Great Exhibition of 1851 the firm submitted 'an admirable model of a converting furnace' along with 'models of [cast steel] furnaces, rolling mill and forge', which given the

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[89] SCA FBC FB171 (1826) pp. 8, 34, 59-60 'Levels taken for Ms. Vickers & Brother. 6mo. 10 1825 to ascertain the fall there was at this time between the Bye Wash on Town Mill Goight stone sill and the water in the River Dun as it is now opposite an intended Rolling Mill in their land at Millsands'; p. 103 'Ground agreed to be purchased of Wm Vickers in Millsands by Wm Hoole measd. for him 3mo. 8 1826' (indicates Town mill dam and 'New Rolling Mill').
[90] Hey (1998) p. 151.
[91] It is not clear that the Marshall family entirely surrendered their interest in the steelmaking plant, as the Wadsley Bridge forge remained in their ownership as late as 1870. Crossley (1989) pp. 6-7.
[92] Compare Scott (1962) fig. 2; SCA ACM SheS1495L (1781) 'A plan of Millsands in Sheffield'; 1850 OS plan. Perhaps the view represents a proposed arrangement that was never put into practice. As late as the Goad Fire Plans of the 1890s, elements of the old Marshall steelworks may still be identified on the site.
[93] SCA Sheffield rate book SL (1831-32) vol. 4b, p. 311. Timmins (1977) p. 58, table 3:2.
[94] An early reference to Vickers' steel in America appeared in an advertisement for John Deere, walking plough manufacturer: 'We have on hand a large quantity of CAST STEEL which was manufactured expressly for us, at the River Don Works, Sheffield, England, by Naylor & Co., and imported by us, which were are converting into Plows, at a trifling increase of cost over the common articles generally in use'. Reference from: www.deere.com/en_US/compinfo/media/pdf/johndeere_archives/walkingplows.pdf (1 Jan 2003).

timing may have been originally commissioned for design purposes.[95] The jury recorded the Millsands Works as employing 150 workers at the time, and that its eight cementation furnaces and ninety double melting holes in nine buildings could produce 2300 tons of steel per annum, or 'about a sixteenth part of the whole quantity of steel made in Sheffield'.[96] However, more major additions were made in the boom years of the 1850s, with two further converting furnaces between 1851 and 1853 and the remaining 72 melting holes and bell foundry in 1853-4.[97]

These latter furnaces were the direct result of Vickers' licensing of a new steel-moulding process, developed by Jacob Mayer of Bochum and patented in Britain by Ewald Riepe in 1854, for the manufacture of cast steel bells.[98] This deceptively simple method (often referred to as the Riepe process) employed calcined fireclay–in Vickers' case pulverised spent crucibles–packed around a wooden pattern to a depth of about three-eighths of an inch and backfilled with ordinary sand.[99] The resulting moulds had the advantage of being cheap, infusible and not susceptible to chill the steel as cast iron moulds might. As sole licensees, Vickers soon found a ready market for their cast steel church bells, a familiar item made of a 'modern' material, which appealed to the Victorian ideals of progress and novelty.[100] [fig. 5.54]

Likewise, the orchestration of the casting process within a building specially designed for the purpose was a spectacle that became an instant attraction in the town, in spite being fundamentally nothing more than a scaled-up version of the century old crucible shop. [figs. 5.55, 5.56] Two principal rows of holes ran along opposite sides of the tall, timber-roofed melting shop, and racks of drying crucibles hung from the rafters. Additional holes were built back-to-back with the former, inclosing a two level clay-drying space closed by hatches (similar to Huntsman's 'clay place', chapter 1). A contemporary illustration of the Millsands foundry captures the balance of order and chaos involved in the skilful and dangerous job of teeming up to 176 crucibles into a single tundish (a funnel-like container used to keep a constant head of metal).[101] [fig. 5.57]

These changes had been introduced by Tom Vickers, the son of the founder, who had received his training in Germany and took over the technical side of the business from 1856 at the age of just twenty-two. While steel bells were an excellent advertisement, more important innovations were to follow, which would seal the firm's future success.

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[95] Percy (1864) p. 768, '*Converting furnace* [note 5: 'An admirable model of a converting furnace may be seen in the Museum of Practical Geology. It was presented by Messrs. Naylor, Vickers & Co., and previously appeared in the International Exhibition of 1851.'] This model has not been traced. Also Ellis (ed) (1851) p. 615: 'Naylor Vickers & Co'.
[96] Ellis (ed.) (1851) vol. 3, p. 10. Jeans (1880) p. 19.
[97] Timmins (1977) p. 58, table 3:2.
[98] Scott (1962) p. 14. Vickers' first successes were reported to have been in 1855.
[99] 'River Don Steel Works' (1867) p. 383.
[100] Thousands of these bells were cast and exported around the world, such as an 1860 example for the San Francisco fire station which required the contents of 105 crucibles; Barraclough (1984) vol. 2, p. 51. A full ring was installed at St. Marie's church in Sheffield. It is, however, generally acknowledged that their sound was inferior to traditional bronze bells. Examples may be seen at the Sheffield Millennium Galleries and at various other locations.
[101] Pawson & Brailsford (1862) pp. 122-124, fig. 'Steel bell casting,–Messrs Naylor, Vickers and Co., Don Works'.

Some idea of the tremendous growth of the firm over this period may be gained from the evidence that by 1855 the output of the River Don Works had almost doubled from its level of four years earlier. While additions to the site were necessarily organic in character, the River Don Works was to follow the precedent established by Greaves' Sheaf Works (chapter 3) in placing the various stages of the steelmaking process as sequentially as possible, given the constraints of the site.[102] From the five cementation cones at the northern end (discussed in chapter 2), an 1858 panorama from the opposite bank of the Don took in [fig. 5.58] 104 crucible steel melting holes (all double pots) arranged in three buildings, the largest of which also housed the bell foundry; an 'unfinished' bell tower for testing of the product; a steam powered rolling mill, tilt and forge with two large stacks; the earlier water-powered mill, and finally stables, outbuildings and a pair of houses for the site superintendents.[103]

At its peak, the complex was one of Sheffield's most comprehensive integrated sites, occupying 11,650 square yards of freehold land (9740m²) and valued in excess of £60,000.[104] The buildings were more utilitarian than for show, the most distinguished being the warehouse and offices of Marshall's former works dating from the 1820s or earlier; a new office built later on Bridge Street took the form of a small and unusually restrained classical box, belying the firm's status and prosperity. [figs. 5.59, 5.52]

The second River Don Works, Brightside (1862-66)

For over a decade after Cammell, Spear & Jackson and Brown had removed to the Don Valley, Vickers remained at the Millsands premises in which they had invested so heavily. By the end of the 1850s, however, it became clear that their Sheffield location had been outgrown and that relocation to the suburbs and railway was the only viable way forward.

Unlike the majority of Don Valley steelworks, Vickers were not tenants of the Duke of Norfolk, but took land further downriver towards Tinsley, the property of the Earl Fitzwilliam.[105] This had a number of benefits, being adjacent to the railway but beyond the already fragmented Norfolk Estate, allowing Vickers to develop twenty acres of consolidated land, with optional additional space nearby. In contrast to the Norfolk Estate's 'husbanding' of land, which led to a volatile patchwork of different sized plots with works constantly jostling for position, Fitzwilliam allowed large quantities of land to be leased for future developments–ideal for rapidly expanding and ambitious firms as Vickers.[106]

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[102] Marshall's steelworks at the southern end of Millsands were retained much as found, and therefore cannot be considered as part of the overall progression. Significantly, the works' view of the 1850s [fig. 5.59] presents this 'inherited' portion as a separate image (top), divorced from the new complex (bottom).
[103] SYCRO 141/B Flockton valuations (1857) pp. 269-270. Marshall's works site seems to have housed an extra pair of cementation furnaces and up to 58 further melting holes (at least twenty of which were added after Marshall's time), not included in Flockton's valuation.
[104] Flockton's valuation appears to have been made for the purposes of mortgaging the works, as in 1866 the company was still 'burthened with a mortgage of £60,000'. Scott (1862) p. 16.
[105] Pawson & Brailsford (1862) p. 126.
[106] Simmons (1995) pp. 427-428.

It was at first intended to retain the old River Don Works for bell-making and the smaller steel castings 'for which they have become famous', but within three years of the new Brightside works opening they were disposed of.[107] This marked a new and unforeseen change in Vickers' fortunes, as the demand for heavy castings and steel (railway) tyres manufactured to Tom Vickers' patents paved the way for the incorporation of the firm in 1867.[108] It was nevertheless some years before the company returned a profit on their new plant, which had cost some £204,000 in construction.

The establishment of new works at Brightside was not only expensive, but a considerable gamble: it came at a time when many in the industry had turned their attention to the promise of bulk steelmaking, most notably the Bessemer process, but also Siemens' nascent open hearth method of producing steel direct from the ore.[109] Yet Vickers chose to consolidate on their success with crucible steel–indeed, the new River Don Works could produce nothing else but castings of this material. The traditional array of cementation furnaces was notably absent, as steel was made by the cheaper and more effective method of melting bar (wrought) iron along with charcoal and manganese oxide, as pioneered by Heath and Mushet.[110] Around the same time Krupp had also dispensed with blister steel in favour of the Bessemer process to feed his crucibles, 'showing an example to the backward pot-steel melters of Sheffield'.[111]

The street front was built up with low two-storey offices, warehouses, model shops and stables, forming a continuous range along the building line. Behind this conventional frontage (which could almost be seen as a screen wall to the street), however, the production buildings departed from the expected classical symmetry and grouped units of the first generation Don Valley works. Contemporary observers struggled to find an appropriate language with which to describe the phenomenon–in 1867 *Engineering* reported 'the works are divided into five large and separate masses of building...connected in all their parts by railways'.[112] The 'masses' were in fact little more than the large sheds that would dominate the entire valley within a few decades, although still displaying some of the characteristics of earlier steelworks buildings. [fig. 5.60] Their language of sheer brick walls minimally articulated by piers, supporting repeated iron and slate gable roofs, also owed something to the recent emergence of utilitarian railway architecture. Indeed, the transport connection went beyond the design of

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[107] Pawson & Brailsford (1862) p. 124; 'River Don Steel Works' (1867) p. 383.
[108] Scott (1862) pp. 14-16.
[109] 'Patents class 72' (1905) p. 24, Siemens, F. (2 Dec. 1856) no. 2861; p. 132, Siemens, C. W. (20 Sept. 1856) no. 2413; Scoffern (1857) pp. 360-363, 366-367; Bessemer, as above.
[110] Mushet (1840); Scoffern (1857) pp. 357-360; 'River Don Steel Works' (1867) p. 383, 'The old malt-kiln-looking converting-furnaces are being gradually abandoned, and the best Sheffield works now melt down the wrought iron direct'. Percy (1864) pp. 776-777, noted that: 'In 1839 a patent was granted to William Vickers for the direct production of cast-steel by melting 100lbs. of borings of iron, or wrought-iron scrap, with 3lbs. of black oxide of manganese and 3lbs. of best ground charcoal. The use of cast-iron scrap is also claimed, and the proportions specified are 28lbs. of the scrap, 2lbs. 3oz. of the oxide of manganese, and 3lbs. of charcoal'. The relevant patent was dated 25 June 1839, no. 8129.
[111] 'Progress of Bessemer' (1867) p. 491; this harsh judgement came from the English journal *The Engineer*, reflecting the general impression that Sheffield had become the seat of retrogressive unionism and 'closed shop' trade practices (particularly at the height of the 'Outrages' scandal).
[112] 'River Don Steel Works' (1867) p. 383.

the buildings: an aerial view of the works (published in 1879) is remarkable for depicting what would traditionally have been regarded as the back of the works, facing the Midland Railway, with the street façades hidden from view.[113] [figs. 5.61, 5.62, 5.63] Not only had the railway eclipsed the road in importance, but it was now beginning to infiltrate every corner of the works, branches from the sidings weaving their way between, through and underneath the serried ranks of sheds, crossing at turntables and proliferating into further spur lines. [fig. 5.64]

In responding to the new condition of the railway, the River Don Works followed the example of Cammell's Cyclops Works, although Vickers took the system much further than its predecessors. Where the Don Valley works of the 1840s and 50s made a clear distinction between the railway as means of transport, and the works as site of production–generally segregated by solid brick walls–the River Don Works was among the first to achieve a convincing synthesis of the two.

Building from scratch also allowed Vickers to arrange the works more rationally than at Millsands, once again following a schematic progression across the site, even if this did not literally reflect the sequence of the various manufacturing processes. From east to west, the first shed housed crucible-making, iron cutting and mixing; the second was dedicated to the crucible furnaces themselves; the third was an iron foundry with moulding shops; the fourth a tyre mill and machine shop; while the last contained a number of Nasmyth-type steam hammers. [fig. 5.65] All of the sheds were arranged on a common building line, as close to the sidings as possible, and in most cases with space for future expansion behind. Primary railway lines ran along the alleys between buildings, and behind the long range of street-facing buildings, to form a continuous loop; heavily serviced and peripheral functions also occupied these interstitial zones–coal bins, boilers, cranes, chimneystacks and gas producers for the hammer shop.

Much of the difference between this and earlier works may have been due to the role of Edward Reynolds, the works' engineer, in the integrated design of the premises. Whereas most steelworks buildings were 'designed' by the builder-mason in conjunction with the client and / or surveyor, Vickers seem to have reconsidered everything from first principles, with Reynolds responsible for a number of innovative features (as well as, presumably, the general planning). Seventeen hydraulic cranes could be found throughout the works, but unlike those connected with the Bessemer works, these were actuated by natural waterpower. [fig. 5.66] Designed to reduce dependence on individual steam engines, the high-pressure system took water from the Don and raised it by a pumping-engine to a one-acre reservoir half a mile away and at an elevation of 240 feet. This head of water delivered a

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[113] Taylor (ed.) (1879) p. 218. This was in direct contrast to the other works' images that appeared in the same publication (e.g. Etna Works, p. 281; Suffolk Works, p. 265; Atlas Works, p. 233; Regent Works, p. 221).

consistent pressure of 110lbs./sq. in. at the works below, working the cranes, pumps, a blowing-fan and eliminating the need for boiler-feeding machinery.[114] This was water-power on a different scale to that of the well established watermill, and might have inspired a new generation of hydraulically-powered works, had it not been for the cheapness and ready availability of coal in the South Yorkshire region, offset against the cost of infrastructure and limited sites for reservoirs.

The new works also allowed an expansion of the product line, with further developments in the use of the Riepe process, including method of casting several steel railway tyres onto a 'tree', that were then machined out on lathes. Vickers also continued to cast steel bells at the new works. A ring of eight (including one recast in 1874) is still in regular use, originally hung within a Vickers-designed and fabricated framework.[115]

The zenith of crucible steel

Of the five original structures, the most remarkable was the enormous crucible steel melting shop that stands out so clearly from the others in topographical views of the site. The scale of operations at Brightside meant that the design of the new crucible furnaces was on a radically different principle to the traditional Sheffield furnace, although still based on the long established coke-fired process. Instead of individual melting holes arranged in groups with separate flues housed in a monolithic stack, Vickers' idea was to eliminate the stack altogether, removing all obstructions–physical and visual–from within the vast space of the melting shop to enable complete surveillance and co-ordination of the process. As a contemporary observer explained:

> *...it is of the utmost importance in a melting-house where large castings are to be made that every man has a clear view from his melting-hole to the place of casting, and the foreman founder should be able, in the same way, to see, from a single point, every melting-hole from which steel is to be brought for teeming. The melting-house at the River Don Works is in this respect perfect, and, by an almost military organisation of the workmen, a single casting of 25 tons weight may be poured from 576 pots, holding 100lb. each, within the space of five minutes, or at the rate of one every half-second.*[116]

Taking the cue from Bessemer's earlier attempt to 'industrialise' the artisanal skill base of steel melting, each oval section hole of two pots fed into a large under-floor flue leading to an external chimney resembling a steam engine stack. Similarly, the traditional cellar covered by

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[114] 'River Don Steel Works' (1867) p. 384. The availability of constant hydraulic power was also used in a novel 'water-jet pump', in which a powerful jet of water injected into the centre of a pipe created a pressure differential that drained water from a sump out of the works. See 'Hydraulic crane' (1867) p. 508, figs. 1-9; 'Water-jet pump' (1867) p. 407, figs. 1, 2.

[115] These are installed at St. Mary's Church, Moseley. Web: http://www.stmarys.moseley.btinternet.co.uk/bells.htm; 10/06/2003.

[116] 'River Don Steel Works' (1867) p. 384.

a brick arch was abandoned in favour of an entire lower level framed in iron and serviced by railway tracks, with iron floors to the casting shop above.[117] [figs. 5.67, 5.68]

To the same end, a novel form of roof construction was introduced (remarkable enough for *Engineering* to dedicate a short article to it) by which the 30,000 square feet (2787m^2) of roof was supported on just 'four pairs of double columns in addition to the [outer] walls'.[118] Between these and the outer wall spanned 50-foot (15.2m) box girders, fabricated of single lengths of iron–a feat of engineering at the time–and supporting the iron roof trusses. [fig. 5.69] Unlike the other shops, the melting-house roof was not composed of a number of unidirectional elements, but took a basilica-like form: a wide central nave reflected the movement of the travelling crane that serviced the casting-pits, with six transverse 'side-chapels' containing the rows of floor-level furnace holes. [fig 5.70] All roofs had continuous ridge ventilators, in addition to which regular skylights punctuated the flanking bays.

In making these fundamental changes to the established furnace type, some concomitant functions were inevitably lost, including the vital spaces for dry clay storage, pot making and drying. This, however, suited Vickers' rationalisation of the whole process, and the manufacture of crucibles–although still undertaken on site–was effectively reorganised as a separate industry with its own separate building and dedicated workers.[119] Production was mechanised, and drying carried out at temperatures in excess of 100°C over a month in the vast 'drying-house', capable of housing 30,000 crucibles.[120]

Working was also now carried out in shifts both day and night, the latter unheard of since the secret nocturnal heats of Huntsman's day. At busy times, employing half of the available holes around the clock, over a thousand crucibles might be needed every day.[121]

From the scale drawings of the basic crucible hole, the dimensions of the shed structure and the number of furnaces reported to have been built at various times, it has been possible to reconstruct the interior layout of the melting shop before the installation of gas-fired holes (and later open hearth furnaces). Professor S Jordan stated that the shop was initially designed on a perfectly 200-foot square plan in bays of 50 feet, and to contain 384 double holes.[122] In actuality, a shortened three-bay version was built, with 288 holes (200ft x 150ft) suggesting 96 holes per bay. The main chimneys were placed at the corners of each bay, so

[117] Scott (1962) p. 19, confused the description of the single-flue coke-fired holes with the later Siemens regenerative crucible furnaces installed in the same building.
[118] 'Girders' (1867) p. 407, fig. 1.
[119] Jeans (1880) p. 338. E Reynolds, works manager, stated 'whereas common practice covers the 'cellar' by a brick arch...beneath which the pots are made, we have iron floors, and make the pots in a separate building'. Similarly innovations were made to the crucible pot, with the addition of plumbago to the mix (previously avoided in Sheffield practice) and the introduction of an extra large 100lb pot for special jobs.
[120] 'River Don Steel Works' (1867) p. 383.
[121] Hackney (1875) p. 384; Jeans (1880) p. 338, see account of E Reynolds.
[122] Jordan (1877); Jordan (1878).

that the three bay shop was served by eight stacks (Jordan's configuration would presumably have had ten), or 36 holes per stack.[123] Arranged back-to-back about a central flue, the banks of furnaces left space along the centre of the shop for an alleyway 50 feet in width, where the casting would have taken place.[124] [figs. 5.71, 5.72]

The key to the structure was its expandability: from the outset Vickers intended that it should be 'built so as to admit of future extension', a consideration almost entirely absent from earlier steelworks design.[125] This explains the redundancy of the end chimneys, each with half the intended number of furnaces; in the event of expansion, half a bay could be added at a time, providing 48 additional furnaces with just one extra stack. Soon after 1866 Vickers put the theory into action, bringing the total capacity to 336 holes (or 672 crucibles) enabling a steel marine shaft of 22 tons to be cast on the premises–so large that it was used without subsequent forging.[126] The extra stack can be seen on a contemporary engraving, at the Brightside Lane end of the melting shop's west side. [fig. 5.73]

No contemporary views of the interior are known (the *Illustrated Guide to Sheffield* having been content to reproduce the engraving of steel bell casting from 1862 alongside the new works' view), although photographs of the reconstruction of the building taken from basement level depict some of the remaining structure, including what may be remnants of the under-floor flues, structurally integral to the framework. [figs. 5.70 above, 5.74] Many of the original coke-fired holes had already been replaced by gas-fired crucible furnaces (1872) utilising Siemens' regenerators to save fuel, and the rest gave way to open hearth furnaces soon after, seen in the plans of 1897.[127] [fig. 5.64]

The dispersed layout of the works and its comprehensive railway network certainly assisted later expansion, but the changes of planning cannot entirely be ascribed to technological factors, as steel was still made by the basic coke-fired crucible process. Important lessons had been learnt from the overcrowded Millsands works, and room was allowed for the extension of plant (as, for example, the space behind the crucible shop). While their location to Brightside had taken them beyond the preferred development areas of the day, it was to prove an inspired decision as demand for heavy industrial premises increased.

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[123] Illustrated in the works' view from Taylor (ed.) (1879) p. 218. The length of the building does not permit a single row of 72 holes, so they must have been arranged back-to-back, an efficient way of sharing the flue structure.
[124] Traces of the structure about this central alleyway are discernible on the 1897 plan of the works. 'Vickers' Works' (1897) 8 Oct. p. 432.
[125] 'River Don Steel Works' (1857) p. 384. Cf. Naylor & Sanderson at West Street, chapter 3, where the melting shop was built with no scope for extension.
[126] Taylor (ed.) (1879) p. 220
[127] See *Engineering*, vol. XIII (5 Jan. 1872) p. 8: 'Messrs. Vickers...have just put down all the necessary appliances for working a number of furnaces with gas on the Siemens patent principle'.

Armour plate, ordnance and the international arms race

Sheffield's great East End steel firms, notably Vickers, became key players in the first international arms race, fought largely between England and Germany in the 1860s. The development of new technologies in armour plating for battleships and heavy guns stimulated an unprecedented growth of Sheffield's steel industry, mirrored in Europe by that of Krupp and others.

The railway boom, although lucrative, was relatively short-lived and Vickers struggled to make enough profit to justify the cost of their new premises. Increased government spending on military equipment, triggered by the Crimean War, provided a new market and one which Vickers was well equipped to exploit. Their first success was in the manufacture of gun barrels (as Bessemer had also been attempting) using the existing technologies of large castings and lathe-turning that had been developed in the tyre mill. A new gun assembly plant, complete with 'goliath crane' and soaking pits for heat treatment was erected alongside the original site. [figs 5.75, 5.76]

By 1868 the firm had begun to produce heavy castings for the marine industry, developing a market in drive shafts and screw propellers; in parallel, the crucible steel furnaces were upgraded with the replacement of some holes with gas-fired holes on the Siemens regenerative process, and later superseded by new Siemens-Martin open hearth furnaces capable of meting over twenty tons of metal direct from the ore.[128] [fig. 5.77]

Armour plate proved a highly lucrative market for a handful of Sheffield's largest steelmakers, who could afford to invest in the necessary plant and premises. The development of John Brown's Atlas Works stands as testament to the meteoric rise of the few firms to embrace the new technologies, expanding far beyond its original three acre site to cover much of the Don Valley estate between Sheffield and Grimesthorpe. [figs. 5.79-5.84]

Vickers only entered the armour plate market in 1888, much later than John Brown (1861) and Charles Cammell (1862), although the River Don Works was quick to adopt the Harveyising process (c.1891-92) for hardening steel plates.[129]

The Harveyising furnace was a modification of the conventional cementation furnace (described as such in Harvey's patent specifications) specially adapted to handle large masses of armour plate.[130] The single large 'chest' was a mobile platform on rails, onto which the plate was loaded from straight from the rolling mill, bedded down in sand. [figs. 5.78] Charcoal was packed above the upper face to be hardened and the top closed with a layer of sand firebricks. The car would then be rolled into the furnace shell itself, bricked in and fired

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[128] Tweedale (1986b) p. 68; report in Barraclough.
[129] Pollard (1959) p. 161; 'Armour plates' (1911) pp. 578-582; Harvey's British patents of: (29 Sept. 1891) no. 16,529; no. 16,544; (17 Dec. 1892) no. 23,312.
[130] Abridgement class furnaces &c. (1891) p. 269: Lake, H H [Harvey, H A] (29 Sept. 1891) no. 16,544. *Cementation furnaces* [sectional drawing included, not to scale].

for several days. On completion, the furnace would be broken open, and the case-hardened plate rolled away to be heat treated and tempered. For this operation Harvey had developed a mobile sprinkler capable of evenly cooling one side of the plate, and licensed by the large Sheffield works. From here the plate passed to the planing shop to receive its final finish.

Vickers' armour plate facility was developed across the road from their principal site, the herringbone pattern of Harveyising furnaces easily identifiable in plan, [see fig. 5.64] connected by rail to the plate rolling mills, reheating furnaces and planing shop. The operations in the plate mills, particularly rolling the red-hot plates, were among the most spectacular in the metal industries, and became an essential fixture on the 'tour' of Sheffield made by visiting gentry. [figs. 5.85-5.88] Even Queen Victoria was taken to see plate being rolled at the Cyclops Works on her final tour of the town in 1897. [fig. 5.89]

Despite their late entry into the ordnance market, Vickers specialised to a greater degree than their established competitors and were soon offering fully-assembled mobile howitzers, naval gun turrets, and armour plate, soon becoming the largest supplier of weaponry to the British government.[131] In a similar way, Charles Cammell's firm entered into the naval construction industry as Cammell Laird, with shipyards at Birkenhead and Tyneside.[132] By the opening of the twentieth century, steel was no longer the focus of Vickers' business, having been eclipsed by military hardware, shipbuilding and eventually the emerging market in aircraft.

Vickers are, in a sense, the longest surviving of Sheffield's steelmakers, having passed through a number of incarnations during the last century. The first major acquisition resulted in a new company of Vickers, Sons & Maxim, followed by a merger with Armstrong-Whitworth (Newcastle) in 1927 to become Vickers-Armstrongs. Nationalisation led to the formation of British Steel, but after its demise the River Don Works continued to operate under the banner of Sheffield Forgemasters. Understandably, very little of the 1860s works can be seen today, but some of the large nineteenth century sheds still provide accommodation for more modern steelmaking equipment.

The architecture of Vickers' later gun and plate works epitomised the extruded medium-span shed type that persisted throughout the twentieth century, reaching its apotheosis in buildings such as the Steel, Peech & Tozer's 1917 Templeborough mill at Rotherham (spared demolition to become the lottery-funded 'Magna' centre adapted by Wilkinson Eyre Architects). Drawings published in *Engineering* indicate the balance of structural prowess and economy found throughout the Vickers works; despite the ready availability of steel and technical understanding of its high performance, the relatively high cost of the metal precluded its use in the works' buildings. Instead, the well-tested solution of riveted wrought

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[131] Porter and Watson (eds.) (1910) pp. 285-329; Sansom (1970).
[132] Warren (1998); Hollett (1992).

iron sections prevailed, spans kept to a practical minimum to save material and accommodate the ubiquitous travelling cranes. [fig. 5.90]

When steel did begin to be adopted for construction purposes it was in higher-cost commercial buildings, usually concealed behind traditional masonry cladding (such as at Selfridges department store, London) and most critically in the multi-storey proto-skyscrapers where performance outweighed cost. Bulk steel, produced by the post-Bessemer methods in the traditional iron-making regions, dominated the lower end of the market, including that of constructional steel. Sheffield, although wealthy in its own modest way, could boast no such pioneering use of the metal with which its name had become synonymous, and 'steel city' remained primarily an exporter rather than a beneficiary of the material advances it had helped to make.

Conclusion

The site must have been one of great natural beauty...until modern methods of trade, mining, and manufacture converted it into one of the grimiest of human ant-heaps.

The Builder (1897) vol. 78, no. 2853, October 9, p. 273.

Sheffield has had an image problem for well over two hundred years, with most visitors finding little of beauty or magnificence in the smoke-blackened, irregular and often alien forms of the town (see appendix 6.1). Admittedly, it is not an attractive place in the conventional sense. The impressive classically planned estate proposed for Alsop Fields by James Paine in the 1770s never materialised, emerging instead as a muddled assortment of utilitarian structures. Nowhere does one find anything to compare with the green squares of London or the generous crescents of Bath; even the scale and detail of Manchester's brick and terracotta warehouses is absent. To understand why Sheffield appears to be so architecturally impoverished, it is necessary to examine the particular conditions surrounding its development.

The uniqueness of its location has already been discussed. It is probable that Huntsman's crucible process evolved here not only because of the inventor's determination to succeed, but because it could not have done so elsewhere. Indeed, for many years after it had been systematised in theory, attempts to establish the process elsewhere failed, or proceeded independently on different principles as with Fischer and Krupp. To bring skilled hands from Sheffield was not enough; for some time it was believed that the secret lay in Sheffield water, and many barrels were exported before its inefficacy was demonstrated. A precarious balance of conditions encouraged and sustained the town's tremendous growth into a global industrial centre, and Sheffield's steel and cutlery industries created an urban setting as distinct from other towns as was the baroque city of Rome with its myriad churches.

Its relative isolation and unique industrial processes also gave rise to building types found nowhere else, comparable to an urban Galapagos Islands. The temptation to draw evolutionary analogies is strong, with species of buildings responding to their environment and developing individual characteristics conditioned by use, but here one must take care. While Sheffield's built environment may appear to have been an extension of the 'mass heredity' that Abercrombie suggested characterised its inhabitants (see introduction), its development was more a consequence of the transmission of ideas. The design of a building is not involuntarily influenced by that of others, but is the result of a selective decision-making process, conditioned by context. The family of steam grinding wheels, for example, can be classified according to size, plan and site layout, but there is no evidence for any one example giving rise to another without a return to first principles and generic forms such as the steam engine or jack-arched floor construction. Less successful examples do not necessarily disappear, but persist and furthermore can be adapted to totally different uses.[1] While spaces can be better suited to certain activities, it is rarely to the exclusion of others; even the functionally specific cementation furnace cone managed to be profitably converted to a storeroom.

As demonstrated by many of the case studies, industrial buildings could be as much a reflection of the social aspirations of their originators as a response to purely functional requirements. To understand the meaning of the town, one must look beyond causal relationships of form and function, towards the social, constructional and aesthetic elements of type.

The significance of type

Typology and its application to architecture has been the subject of much debate, particularly during the 1980s when architectural practice and theory briefly met (with limited success) under the banner of postmodernism.[2] It is not the author's intention to adopt any particular theoretical stance, but it may be helpful to recall Rossi's description of the city and its artefacts as a work of art, or the 'human thing *par excellence*'.[3]

Throughout this study, typologies have been used primarily as a tool for interpretation and reconstruction, rather than being seen as the outcome of an analytical process. The aim is not to discover the typological basis of buildings, but to assess the relative importance of the diverse parameters and relationships in any particular instance, and identify tendencies towards a model or archetype. In certain cases, such as the development of the steam-powered grinding wheel where the first fifty years of development can be mapped out with some certainty and the geographical limits of development are narrow, the relationships are clear and direct. In others, such as the courtyard works, temporal definition is less clear and influences may come from further abroad. Local correspondences are still likely to take precedence, but iconic forms can be equally powerful generators, as was the case with Boulton's influential Soho Works and its many imitators.

Industrial buildings are arguably more prone to typological conformity than other building types, as the relationship between form and performance is usually extremely close. For the same reason, they also tend to undergo more rapid mutations as the balance of design criteria can change suddenly, the most common cause of which is technological change

[1] A clear example of the indeterminacy of form is found in the Pond Forge Mills, built as a public wheel on the template of the Park Wheel, but later used as a warehouse, crinoline wire mill, electricity generating station and telephone exchange.
[2] Architect/theorists such as Aldo Rossi, Robert Venturi and Leon Krier attempted to systematise architectural design by the application of type. While Rossi's theory of the city offered the most promise, the resulting architecture was at best a disappointment.
[3] See Rossi (1982) *The architecture of the city*.

where the requirements of a new process gives rise to novel and untested solutions. Even so, the solution may often be found in established forms, exemplified by Huntsman's appropriation of the brass furnace type, or the modification of the glass cone to cementation steelmaking. Elsewhere, technological developments affect the scale and social organisation of an established type, such as the application of steam-power to cutlery grinding, or the integration of the various steelmaking processes in the larger out of town works.

Aesthetics come into play mainly in those areas where social perceptions of value are concentrated, such as the warehouse which was the seat of wealth, filled with the manufacturer's valuable stock. In the most elaborate examples, architectural form is boldly used to symbolise affluence (see Globe Works, Sheaf Works, chapter 3), but even the more humble domestic-scaled blocks exhibited an order and neatness that suggested pride and solidity (as Sanderson's, Jessop's, also chapter 3). Of course, solidity and impregnability were also functional requirements–barrels of tools wrapped in oiled paper were both valuable and flammable–but the care taken in the composition and detail of the buildings exceeds any purely pragmatic need.

Scale and form in the Don Valley

The first works of the Don Valley demonstrate the persistence of typological form in the face of changing scale and technology. Here, the courtyard form as developed within the established street patterns of the town was at first simply scaled up and applied to the blank canvas of the undeveloped fields. Key plan elements and their placement were to all intents the same: the ornamented front range with its gateway, the 'dirty' processes confined to the back of the site, its sides built up with workshop ranges, and freestanding sheds erected within the space of the yard (often including the source of motive power). The yard itself was similarly used for the movement and storage of goods and fuel, with the railway at first treated as another kind of road, entering through gated archways and following the conventional circulation patterns of the horse-drawn cart. Only later did the rails begin to pervade the entire works, becoming integral to some processes and moving over, under and through the buildings as at Vickers' River Don Works.

Alongside these developments came the realisation that just like the wider rail network, the works need not be bound to historic centres of production, but could develop on the principle of the sidings, growing in complexity and connections, and unlimited in size and geometry. The naturalised flow of railway lines began to determine the layout of the works buildings, prompting a departure from the classical plan favoured in the town. On the construction of Vickers' extensions to their Brightside works, the internal railway even crossed the road to connect the two adjacent sites.

This template of the Don Valley steelworks predated even the Bessemer process, so to accommodate the increasing areas required for heavy steel manufacture, major alterations in the works typology were needed. Sites once composed of discrete units arranged around courtyard spaces were progressively rebuilt with much larger iron-framed sheds to form continuous blocks of covered space. Within and beneath these lightweight shells operated the network of cranes, rails and heavily serviced furnaces that constituted the modern steelworks. [fig. 6.1] The experience of the Don Valley steelmakers even found its way back to Sheffield's larger established urban premises such as the Sheaf Works where, by the late nineteenth century, the earlier modular plan had given way to an accretion of sheds and semi-open canopies sheltering rolling mills and steam hammers.[4]

In moving to a larger scale of production steelmakers were confronted with the same problem that had driven them out of the town only a decade or two earlier. The freedom and space of the Don Valley had rapidly given way to blanket coverage: some firms managed to absorb their less successful neighbours, but this could not be considered a viable stratagem for growth. As few firms wanted to give up their situations near to the town, multi-site operations again became a reality, although this time connected by railway sidings instead of by road.

By the early 1860s, the shortage of new land in the Don Valley led some firms such as Vickers to bypass the Norfolk Estate, establishing larger works further out at Brightside. In time, the compromise was to pay dividends, allowing the River Don Works to emerge as a tightly integrated assemblage of modern plant while its competitors were forced to build separate 'divisions', often some distance from the original works. The latter approach was not entirely the compromise it may seem, as many processes were in any case confined to specialised and self-contained plant; similarly, parts of Vickers works operated as near-autonomous premises, despite belonging to the wider complex. A more pronounced example of this tendency away from total integration may be seen in Spear & Jackson's construction of an old-style cast steel furnace close to their main Etna Works premises as late as 1899.

The persistence of type

Aside from the practicality of certain scales of production, there are other compelling reasons for the establishment and persistence of type in industrial buildings. More than in other building types, the sites of production exhibit a close, even symbiotic, relationship between form and performance, in some instances blurring the boundaries between building and machine. Structures governed by such tightly prescribed parameters will naturally exhibit a greater affinity than more loosely organised types, although even within families of functionally identical forms, such as the cementation steel furnace, a large number of variants can exist, often evolving independently in different regions. This suggests that typological conformity is guided by other motives beyond the simple form-function relationship.

[4] See the 1889 OS sheets, by which time most of the site was covered by building and many of the earlier steel furnaces demolished.

To understand the development of industrial building types, a parallel may be drawn with the emergence and maintenance of the processes they housed. Before the adoption of modern scientific method and the widespread transmission of knowledge in documentary form, manufacturing techniques were developed and maintained on an iterative basis, passed on from master to apprentice. As seen in the early steelmaking practices (chapters 1, 2), not everything was 'understood' in a rational sense, so anything that worked was recognised and remembered mnemonically, by pattern and appearance. Such pattern-recognition based behaviour was used in the grading of blister steel by the quality of its fracture and grain, [see fig. 2.6] and judging the temper of steel by its colour.[5] There is reason to believe that the fundamentals of construction and site layout were governed by similar principles of pattern recognition and judgement, as minor deviations could easily result in the compromise or failure of a process.

Upon these predetermined, essentially 'vernacular', foundations could then be overlaid strata of specific design decisions, which included rule-based operations of symmetry and scale, contextual responses to topography and nearby buildings, and the interrelation of closely connected processes such as cementation and crucible steelmaking, or grinding and tilting. The design of premises was often undertaken by the individuals who were to operate them, such as Huntsman's cast steel furnaces or Bessemer's converter, or else those experienced in the trade as in the case of Makin's plans for the Cutlers' Company steel furnace.

Other forms were determined less by function than through an organisational concept that had become part of the collective understanding of what constituted a workplace. For example, the basic principles of the courtyard steelworks were universal, but capable of considerable variation to suit specific sites and associated processes. There was no clear archetype, but the concept of the courtyard works was held together by a number of intertwined parameters: the basic units (furnace, shed, warehouse, etc.) and their relationship; the movement of people and materials; security and definition of the private realm.

Within the family of potential forms, some sites did come to be regarded as 'model' examples, particularly where their contextual response was replicable as on the regularly planned estates, or adjacent to river or canal. In the absence of intellectual property rights for the design of premises (unless, like Bessemer's steelworks, the shop layout was governed by a patented process) these model works were copied (sometimes blatantly) and adapted, giving rise to distinct species.

Industrial buildings were not alone in their strong adherence to type: public, commercial and domestic buildings were often based on classical pattern-book examples, motivated by ideals of display and propriety. Vernacular structures were built using long-practised methods and

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[5] Engineer and Machinist's Assistant (1853) p. 167; *Journal of the Society of Arts*, no. 131, vol. 3 (Friday 25 May 1855) p. 495 'Tempering of steel'. Recognised colours included 'straw yellow' for tools, 'brown yellow' for hatchets, 'light purple' for saws and 'dark purple' to 'dark blue' for springs.

locally available materials and techniques, in addition to reflecting the beliefs and social rituals of their users. With functional buildings, however, there were more compelling reasons behind the subscription to tried and tested formulae, such as performance, efficiency and above all economy. Commonly, these criteria would overrule preferred local construction methods and the desire for architectural expression, unless they could be accommodated without conflict and at no additional expense. The resultant appearance of crude construction and raw utility is mainly responsible for the unpopularity of industrial forms in the urban context, and only recently have observers begun to appreciate their honest 'minimalism'.

Phases of industrial development

Buildings of the Sheffield metal trades went through characteristic development phases, sequential in their emergence but not strictly chronological in their use, and with long periods of concurrence. While there is no clear date or rule by which to differentiate one phase from another, the following stages may be helpful in understanding the nature and similarities of the various case studies, characterised as:

1: Rural domestic/farming; proto-industrial (Huntsman, Shore).

2: Urban domestic; proto-industrial (Cutlers' Company, small crucible furnaces, backyard hearths and forge shops).

3: Urban industrial:

   a. Standalone buildings (Public grinding wheels, Castle Hill furnace).

   b. Long/open yard (Kenyon, Sanderson).

   c. Enclosed courtyard (Jessop Park Works, Globe Works).

   d. Courtyard with freestanding buildings (Arundel Works, Butchers' Works).

4: Dedicated suburban industrial:

   a. Large courtyard (Cyclops, Etna).

   b. Large freestanding group (Sheaf Works, Vickers, Jessop Brightside).

   c. Accretion of sheds/total coverage (later Don Valley works, Brown Bayley).

   d. Freestanding super-shed (Templeborough steelworks, modern Don Valley).

Over time, individual sites often progressed from one category to another, and hybridisation was common. Thus Huntsman's works could be described originally as belonging to the rural domestic type, progressing by 1819 to the long/open yard form (by which time Attercliffe had become semi-urban) and ultimately rebuilt at Coleridge Road as an urban courtyard type, gradually augmented by the accretion of sheds.

Within the broad categories of works types, finer distinctions can be made, such as those subspecies that constitute the family of steam-powered grinding wheels:

Public wheel, large steam powered (Soho, Union, Park).

Public wheel, medium steam powered (Nursery, Bees' Wax).

Semi-public wheel, medium to large (Sheaf, Sykes, Sheaf Island, Washington Works).

Private wheel, small to medium (many examples after 1830).

While the definition of types is useful as an analytical tool, it can give rise to artificial distinctions that do not necessarily represent categories understood by contemporaries. For this reason, references to all but the most generic of forms (such as the courtyard or linear site) have been generally avoided in the main text.

Concepts in the design of industrial premises

Alongside the morphological types identified above, from the mid-eighteenth century a number of recurrent abstract concepts can be identified in the design of industrial sites, present to varying degrees in the majority of the case studies. These can be summarised as:

- A rationalising design principle, beginning with a simple site layout that does not necessarily establish a clear strategy for future growth. Buildings are arranged geometrically, often in regular groups or exhibiting mirror-symmetry. Subsequent additions attempt to complement the original arrangement as far as possible, or else to create a new composition incorporating elements of the old. Successive layers tend to obscure the clarity of the early phases, although the generative logic of the plan often survives, as at Sanderson's and Jessop's steelworks.
- A desire for flexibility in land ownership and leasehold conditions, most evident in the planning of sites within an estate structure, but also where the field geometries of peripheral areas are assimilated by the expanding town. In many cases, including Huntsman's steelworks, the Park Grinding Wheel, Nursery Steam Wheel, Butcher's Eyre Lane works and the Sheaf Works, important design decisions were made on the basis of land ownership, and site layout influenced by existing boundaries. While construction of premises on fragmented plots of different ownership could result in compromise, it often represented the only available expansion strategy, and was for most a risk worth taking. At the Park Wheel and Butcher's Eyre Lane, land intended for streets ultimately passed into the control of the tenant, creating larger than usual premises. Piecemeal acquisition of adjacent properties could yield the same results, but was a slower and less certain route

- The cultivation of specialised construction techniques not generally found outside of the local area, and practiced by a small number of local builders. Areas of expertise ranged from the construction of cementation and crucible furnace structures, with their complex vault geometry and critically important proportions, to more prosaic local 'vernacular' forms, such as the universal casement windows and ventilation grilles found at many of the town's grinding wheels.
- An increasing awareness of the aesthetic potential of industrial processes, emerging in parallel with Burke's ideas on the sublime and the appropriation of industrial subjects by artists. Through the metalworking scenes of Joseph Wright of Derby, John Martin's infernal visions and Turner's celebration of steam-power, industry became a popular subject of the eighteenth century, attracting the interest of the educated and wealthy traveller. It was, in a sense, a void waiting to be filled: the symbolic imagery of alchemy and mysticism had fallen out of favour, and the dry, tabular content of the emerging sciences left little room for emotion.

There is limited evidence that Sheffield's industrialists consciously exploited the aesthetic potential of their premises, although Belford (1997) has hypothesised that such motives were often present.[6] Certainly by the introduction of the Bessemer process, the aesthetic potential of industry was keenly appreciated and even employed in the commercial promotion of the technology. This unlikely aesthetic of light, heat, noise and smell, sometimes at almost unbearable levels, was integral to Sheffield's character, inspiring revulsion and fascination in equal measure. If the city can be considered a work of art, Sheffield's stark contrasts and fractured forms heralded the modern age of conflict, pollution and consumption. It was an image that no visitor to the town could ignore, and a sign of things to come.

The future of the [post-] industrial city

Preservation and reuse of Sheffield's surviving industrial buildings has not been a great success. Most had been demolished by the 1990s, and many of those that remain are under threat. Deprived of the economic and social environment for which they were designed, such specialised forms cannot continue in their original use, while their non-conformity with modern building regulations means that sympathetic adaptation is difficult to achieve.

Meanwhile, the conservation industry often struggles with the evaluation of industrial buildings as they seldom conform to the formulae of 'originality' and high design that characterise other pre-eminent examples of particular building types. Important industrial buildings are more likely to have evolved over a period of decades, with no single designer or overarching 'vision' to lend coherence. This does not, however, detract from their value and in recent years more has been made of the interest and inevitability of change and growth over time, and the

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[6] Appealing as Belford's suggestion is, there is unfortunately little evidence to support the compositional treatment of steelworks buildings, the layout of which can generally be understood in functional and typological terms.

organisational relationship between early and late versions of a building type. Nevertheless, many important buildings have already been lost, and those that are upheld as exceptional examples of their kind are often atypical, as in the case of Abbeydale Works.[7]

Likewise, many of the typical 'mesters' yards' of Sheffield are neither original (having been formed from earlier premises), nor the product of small masters. By its very nature, the creation of a yard represented a capital injection and centralised management, and the owners often saw their premises as an investment akin to the smaller public grinding wheels. Butcher Works and Leah's Yard are often cited as key examples of this type, but both were the result of cumulative growth, and in Butcher's case just one part of an organisation spanning multiple sites.

In contrast to the empty and decaying 'genuine' workshops in the town, the reconstructed workshops of the 'little mesters' at Kelham Island Industrial Museum resemble the cages of an anthropological zoo, in which the last specimens of artisan–extinct outside of captivity–are preserved.[8] Here, in a 'reconstructed' internal street scene built to resemble an unspecified row of workshops, visitors can find relief from the display cases and presentation boards of the museum itself and watch the mesters at work, or buy examples of their wares. Thankfully, the authentic flavour of the tableau stops short of outfitting the mesters in their traditional garb, and traditional hand-tools sit alongside modern lathes and electric kettles, but otherwise the deceit does little to encourage public perception of the Sheffield trades as a vital and continuing industry.[9]

It is equally regrettable that most industrial building today conforms to the shed type, driven by a general unwillingness to depart from formulaic designs. Even offices have succumbed to this environmental apathy, floating in a sea of car parking, not unlike the defensive (even hostile) planning of the public grinding wheels.

What remains of the specialised steel industry in Sheffield has develcped the modular approach pioneered by Vickers to its logical conclusion. Blind and isolated sheds lie scattered about a wasteland of fences and traffic roundabouts, a landscape almost impressive in its scale and desolation. [fig. 6.2] At the other extreme, rare examples of enlightened patronage have produced buildings such as David Mellor's Hathersage cutlery factory, which sits comfortably in the tradition of artisan led small -scale manufacture. The generator of its circular form, the plan of an old gasometer, is also reminiscent of the earlier reuse of

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[7] Abbeydale is possibly unique in combining steel melting with traditional scythe and tool manufacture at a water-powered grinding and tilting works on a courtyard plan,

[8] This is not intended to detract from the craftsmen whose skills are still those practiced and refined over the years, but to demonstrate that in the absence of supporting infrastructure and complementary trades, there is little hope of their continuance.

[9] Similar workshops are accommodated more comfortably at Abbeydale, where craftsmen work alongside local artists. Ironically, in the age of the private motorcar, Abbeydale has become a well-located workplace with ample parking provision.

foundations in the construction of new works, such as Francis Huntsman's crucible furnaces and James Dixon's Cornish Place (see chapters 1, 4).

Industrially influenced design of a different kind can be found at the National Centre for Popular Music (NCPM) designed by Branson Coates Architects, like many lottery-funded projects now sadly unoccupied. The four stainless-steel clad 'drums' with rotating roof cowls owe an obvious debt to the Bessemer converter, while their symmetrical arrangement is reminiscent of the arrays of cementation furnaces that once populated the town. [fig. 6.3] However, the affinity to functional building does not extend beyond the surface aesthetic, and in plan the NCPM is fundamentally an 'object' building, albeit one squeezed onto its small site.[10]

In 're-branding' the city for the twenty-first century, there has been a tendency to write off its industrial past as a source of embarrassment. But regeneration, however necessary and laudable, is often at the cost of social amnesia, as the commercial interests of development conflict with (and usually prevail over) the underlying structures of urban identity. As the developers move in, archaeologists are often given one chance to discover and record any significant remains before the site is mechanically excavated and the ground into hardcore.[11]

In the absence of new industrial tenants, buildings fall out of use and become dilapidated and dangerous, in which state they are eventually demolished as public hazards and 'eyesores'.[12] At best their interiors–which invariably do not comply with modern regulations–are lost, usually along with roof structures, rear elevations and outbuildings, to be replaced by standard serviced floor-space concealed behind a façade stripped of function and meaning. Where buildings are reused, heritage-aware town planners can unwittingly encourage the creation of a historic town centre that never was, embellished with Victorian pillar-boxes and reproduction bollards.[13] Such tragicomic episodes, no more common in Sheffield than elsewhere in Britain, indicate a lack of will and imagination to address what are admittedly difficult situations.[14]

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[10] At a lecture held at the Showroom, Sheffield (2000), Nigel Coates of Branson Coates Architects, explained that the plan of the NCPM was inspired by the double-symmetry of Andrea Palladio's Villa Rotunda. In this sense, the building is more an extension of the classical vocabulary than the organic planning of industry.

[11] This was the case recently at Millsands, where although Marshall's eighteenth century furnace may be preserved, the remains of Vickers' first River Don Works were partially recorded and then pulverised when time and money ran out. Mechanical diggers and deep basements mean that remains that have survived successive rebuilding campaigns are now being lost to future generations.

[12] In Sheffield, the local newspapers periodically highlight such buildings, branded 'eyesores' and 'blots', alongside artists' impressions of the promised future replacements, designed to mollify the public resistance to change.

[13] Historically sensitive interventions of this kind have increased in popularity, and tend to blur the boundary between old and new, unintentionally skewing the interpretation of past forms. It is not intended, however, to suggest this is a recent phenomenon; at Sheffield's Georgian Paradise Square, the original ground floors of fully-glazed shop fronts were replaced by imitation townhouse façades in reclaimed brickwork during the 1960s refurbishment by local architects Hadfield Cawkwell Davidson.

[14] The public perception of landmarks and significant buildings often differs from the official evaluation. After the part demolition of Morton's cutlery workshops on West Street, a protester scrawled the words 'Our history gone forever!' on the site-boards. [fig. 6.4]

There have consequently been few success stories over the last five years, as more of the structures that gave the city its identity have been demolished or altered beyond recognition. This does not just apply to buildings, but to streets, districts and the wider landscape, and perhaps most acutely of all to the skilled workpeople who built and occupied them. Without apprentices and the amenities of that 'great workshop' to which the city was once likened, they too will inevitably vanish. The tragedy is not simply a consequence of global economics, but is accelerated by a lack of the cultural will to subsidise and patronise, as many people have become willing to do in other areas (such as organic food production, the fine arts, etc.) As hand-crafts are acquired principally through practice, not theory, once lost there is no way to recover these skills, demonstrated by the example of the Islamic swordsmiths and their long-forgotten expertise in forging Damascus steel (see chapter 1). Our own cultural future will be impoverished by their loss.

There is no ready solution to this dilemma, and it is expected that the following decades will see the loss of many more historically important processes and structures. Perhaps by drawing attention to what has already gone (in most cases before the opening of the last century), those important elements of our cities that remain may be better understood, cultivating a more positive appreciation of their worth to the collective identity even where the culture and economy that supported them has disappeared. More generally, it is the author's hope that further insights into the present built environment and its development will be found in the specific histories and character of the rare and unusual building types that once flourished here.

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