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Heavy industries, from steel and molecules to the Cloud

Florence Hachez-Leroy

The expression ‘heavy industry’ appeared with the acceleration of industrial development from the nineteenth century onwards, alongside the notion of so-called ‘light’ industry. The distinction was based on the levels of investment necessary for the construction and operation of the industries concerned, sectors associated with the production and transformation of raw materials such as mining, metallurgy, electrometallurgy, paper-making and first-stage chemical processing industries. As their techniques evolved, certain other industries came to qualify for this ‘heavy’ industry classification, for example the IT industry in the twenty-first century. If the category offers certain facilities of analysis for economists and financial experts, from the point of view of the history of technology it is difficult to give a coherent account of a field which covers industries of a highly heterogeneous nature. Amongst metals, historiography has paid particular attention to the study of the iron and steel industry. After all, the uses of ferrous metals are both ancient and extremely important in quantitative terms. The history of paper-making is another sector with a long history and a rich bibliography. In both these cases, the geographical territories covered are vast ones, corresponding with the diversity of the techniques employed and the relative ease of their application. Unlike these two sectors, that of non-ferrous metals has so far elicited fewer studies and many of these are quite recent. The chemical industry is another special case. The exceptional variety of production techniques and of products, especially since the 1950s, and in a broad range of spheres of consumption—civil and military, foodstuffs, industry, agriculture, textile manufacture, cosmetics, health products, etc.—has given rise to much research, even if important areas still remain unexplored.

The field is a vast one so we have decided here to take an overview looking at different points and raising some questions. The technical history of heavy industries has often been presented from the point of view of the discoveries that marked its development (Kranzberg, Pursell, 1967; Daumas, 1978; Gille, 1978; Caron, 1985). But this prism of innovation is not adequate to account for the history of technology, in which the examination of usages must play a preponderant role. Nor does it do justice to the question of these industries’ environmental impact, sometimes of a catastrophic nature. After a reminder of the classic historiography on the question, we shall briefly examine the new approaches addressing usages and the environment, going on to conclude by looking at industrial archaeology where questions raised are often the same, today, as those raised by the history of technology.

Heavy industries, inventors and innovations

The history of the production of iron, cast iron and steel can be written with an approach centred on the history of innovations and inventors—Beaumont Neilson’s hot blast, Bessemer, Martin, Paul Héroult’s electric furnace—seen as so many historic milestones in the construction of the chronicle of iron and steel production techniques (Edgerton, 1998). At the beginning of the nineteenth century, the process of improving the quality and output of the metals, which began in the eighteenth century, continued in the United Kingdom, encouraged by the development of metallographic sciences (C. S. Smith, 1978). A whole series of improvements were introduced to production processes, such as the use of hot blast in the furnace or the recovery of gases at the top of the furnace in order to reinject them.

Iron and steel making are seen as one of the pillars of the profound technical changes that took place at the end of the eighteenth century. It was also a sector at the heart of the industrial crisis

that commenced in the 1970s. Historical research has been carried out at different levels—local, national, regional and comparative—alongside monographic studies on particular firms or sites (Gille, 1964; Kahlow, 1991). The international and world-wide approach to the sector has been able to underline the remarkably early date and the fluidity of exchanges at technical, financial and human levels (Moreau, 2005; Barthel et al., 2019). This sector was of particular interest to historical research during the second half of the twentieth century. A first wave of studies, during the 1950s and 1960s, was able to nourish a specialised periodical like the *Revue d'Histoire de la sidérurgie*, concentrating on the modern and late modern eras. A second wave was provoked by the crisis of the late 1970s in Europe and the United States. Then the 1990s saw more studies being carried out on the sector as a whole or on particular firms, inspired here by the *Business History* approach, and dealing with the contemporary period (Kipping et al., 2001; Kipping, 1996, 1997; Lindner, Pestre, 1996). Finally, at the beginning of the twenty-first century, global approaches covering the modern and contemporary periods began to be undertaken (Evans, Rydén, 2005; Dilmann et al., 2015).

The rolling technique, very important in this sector, has been particularly studied at the national scales. An overview published in 2012 on the continuous hot casting between 1920 and 2000 was able to show its transfer from the United States to Europe then its improvement at the local level by European plant suppliers, and finally the diffusion of plant designs in the globalization movement, and particularly in Asia (Aylen, Ranieri, 2012). If metallurgical science is dominated by European research until WWII, in the interwar period, the US companies afterward catch up and compete at the highest level. CorTen steel (Corrosion resistance and Tensile strength) developed in 1933 by the US Steel Corporation is a symbol of this expertise. This self-weathering steel, designed for rail applications due to its lighter weight, and applied to the US Steel Tower in Pittsburgh in 1971, knows since the end of the XXth century a strong enthusiasm in architecture and contemporary art all around the world.

The historiography of non-ferrous metals is less abundant and does not deal with different metals on an equal footing (Garçon, 1998; Turnbull, 2008; Bencivengo, 2014). Amongst these non-ferrous metals, the one that is most important in terms of the presence of its ores in the earth's crust and in terms of its uses, aluminium, has been the focus of particular attention since 1986. It is worth noting here that the sector of aluminium production is based on mining activities to extract the bauxite, on chemistry to obtain alumina and also requires the production of considerable electrical energy for electrolysis, necessitating the construction of dams and hydro-electric or thermal power plants. In France, a first series of studies was published from the 1950s on, in the fields of geography and industrial history (Gignoux, 1955; Veyret-Verner, 1956; Chabert, 1973; Morsel, 1973). The history of electrolysis and of the industrial developments of aluminium at international levels was the object of a weighty publication in 1964, written by engineers at Pechiney (Barrand, Gadeau, 1964).

During the same period, in the United States, some work was done on the history of the Alcoa company and on the inventor of the process (Carr, 1952; Cowles, 1958; Edwards, 1955). The centenary of the invention of the Hall/Héroult process, in 1986, saw a renewal of research and new publications, first of all in the United States (Nunn, 1986; Smith, 1988; Graham, Pruitt, 1990) and then, even more, in France, thanks to the creation of a dedicated history institute financed by the aluminium business (Grinberg, 2017). This was the context in which former Pechiney engineers, with the help of professional historians, published a technical history of aluminium production in France (Morel, 1991; Plateau, 2004). Aluminium production techniques are original in so far as the process is still basically the same as in 1886, the improvements brought to this process being introduced through new building materials, and through the shape of the electrolytic cells and how materials are introduced into them. Since this time, France has been in the lead on this question (Carbonell et al., 2012). The monopolistic structure characteristic of this branch has encouraged monographic and sectorial approaches (Grinberg,

Hachez-Leroy, 1997; Hachez-Leroy, 1999; Lesclous, 1999, Le Roux, 1998). From 2000 on, the geographical areas covered have been enlarged to cover northern Europe, Latin America, Japan and Africa, but with approaches, in these cases, that often belong to economic history (Romainville, 2009; Fridenson, Hachez-Leroy, 2017).¹

The building of steam engines required by the industrial development of the second half of the nineteenth century led to considerable progress in the realm of mechanical engineering (Burstall, 1965). Internal combustion engines and petrol-driven engines, steam locomotives and railway rolling stock, machine tools of ever greater efficiency and ever larger dimensions, like the steam hammer developed in about 1840 by François Bourdon, hoisting devices such as port cranes (about 1850 for steam-powered ones)... many of these suggest how certain machines were tending to become gigantic. New apparatus was developed, like the overhead crane used towards the end of the 1890s for lifting heavy items. New equipment was also developed for railway building, like the steam-powered excavator (first patent in 1859) or devices for tunnelling, such as tunnel boring machines (1845 for the Frejus railway tunnel). After the Second World War, a similar development took place where the creation of networks of pipelines was concerned with the invention of combined machines that could dig trenches and lay the pipes. And progressively, where engineering workshops were concerned, machines were driven by hydraulic systems and then by electricity, offering improved regularity and greater power. Rolling mills that flattened slabs of metal, served by teams of workers introducing the slabs successively on either side of the rolls, were replaced during the 1940s by hot and cold rolling mills comprising successions of stands enabling thick and voluminous slabs of metal to be formed more rapidly. Continuous process rolling mills which first appeared in 1909 for producing rails were again improved in the 1950s, particularly for aluminium, with the invention of continuous casting of liquid metal, producing thin sheeting at a much faster rate. Progress here was encouraged by aeronautical inventions, such as the development of Concorde at the end of the 1960s, and by the growth of food packaging for mass markets. At the end of the nineteenth century, electrical engineering also emerged as an industrial sector in its own right, with the earliest institutions for electrotechnical training appearing in Great Britain and the United State. The whole field was transformed from the 1950s by the development of punched card techniques and then microelectronics, facilitating the automatization of work processes.

The case of the chemical sector illustrates the difficulty of offering, since the Second World War, a synthesis of its technical history, whereas such synthetic accounts can be found for the nineteenth century and the period up to 1945 (Haber, 1958 and 1971; Ihde, 1964; Liebenau, 1984; Brock, 1993; Sakudo, 2011; Langlinay, 2017). Dominated by German firms up to 1914, the sector subsequently became more competitive and many industrial research laboratories were set up. The American industry, which originally depended on German raw materials and German patents, became independent during the First World War and was able to develop its own products (Hounshell, Smith, 1988; Ndiaye, 2001). Monographic studies of different firms and of their R & D departments give an idea of the complexity of the research undertaken and of the industrial processes (Cayez, 1988; Bertrams, 2007; Bertrams et al., 2013). Historical research at national levels underlines the mobilities between West and East, as illustrated by the case of Hou Tê-pang, who had a grant to study chemical engineering at the Massachusetts Institute of Technology and obtained his doctorate at the University of Columbia in 1921 (Reardon-Anderson, 1986). On his return to China, he contributed to the development of the chemical industry there, but still maintained close contacts with the community of American chemical researchers. In 1922 the Golden Sea Research Institute of Chemical Industry, the first such laboratory in China, was founded. The large number of biographies of chemists underlines the importance attached by historians in the past, and today too, of identifying the inventors of

¹ Fridenson and Hachez-Leroy, 2017, in particular the articles by Grégoire Awono Zinga on Cameroon, Hajime Miwa on Japan and Marcelo Rougier on Argentina.

discoveries (Dumas, 1965; Defries, 1970; Viel, 2006). Such research has the merit of underlining the uninterrupted circulation of knowledge between scientists ever since the eighteenth century. More recently, work has moved on from what can be a rather hagiographic approach to a cultural appreciation of the profession as a whole (Grelon, 1991; Fell, 2000; Knight and Kragh, 1998). A handful of publications try to give a global vision of the sector in the years since 1945 (Bensaude-Vincent, Stengers, 1993, Travis et al., 1998; Bensaude-Vincent, 1998; Galambos et al. 2006).

The chemical sector is undoubtedly the one where the field of innovations has been the largest because possible applications cover all human activities: health, food, transport, agriculture, etc. In the first quarter of the twentieth century, the major intermediate synthesis processes, such as ammonia or nitric acid, are developed on an industrial scale while developed synthetic fertilizers are designed. In the second half of the twentieth century, the new processing methods for the oil transformation disrupt research. Plastics chemistry and medicinal chemistry products are the result. Gradually, the distinction between general chemistry, inorganic chemistry and organic chemistry (based on coal and petroleum) gave way to a classification by concepts and methods: Molecular and Biological Chemistry, Materials Chemistry and Chemistry of Interfaces. Within molecular and biological chemistry, fine chemistry stands out: it concerns complex products with high added value (dyes, cosmetics, flavours, pharmacy, phytosanitary). Materials chemistry includes part of the former organic mineral chemistries. The field is still interested in metals and alloys, but also in polymers with innovations such as polymer alloys and biodegradable materials. Interface chemistry brings together all the phenomena located at the interface of two media: liquid-solid, solid-solid, solid-gas. In this, heterogeneous catalysis holds a very important place in many industrial processes: refining, petroleum chemistry, synthesis of polymers, fertilizers, etc. (Ihde, 1964; Bensaude-Vincent, Stengers, 1993; Lowe, 2016).

Two other sectors are worth considering here, paper-making and communications technologies. The first witnessed an important technical change towards the middle of the nineteenth century with the substitution of wood for textiles as its raw material and the important influence of electrical energy. The relative simplicity of paper-making meant that at first the paper mills were modest and numerous, before larger production plants became necessary (André, 1991, 1996 et 2013; Amsalem, 1983; Angus, 1976). The commerce in paper pulp has seen a specialisation of geographical zones on a world-wide basis, between tree growing regions, pulp production and paper manufacture itself.

Techniques of communication, the second field to be mentioned here, are at the origins of a whole new branch of heavy industry with the development of computer technology and, more particularly, of the internet (Abbate, 1999; Le Crosnier, 2008). The transport and storage of data now requires impressive infrastructures and today mobilises enormous capital investment, comparable to that invested in the transportation of electrical energy. Transatlantic cables, satellites and underwater data-centres... all these aspects of the industry are still evolving. The end of the twentieth century was marked by the expansion of digital techniques and digital objects, which have led to major changes in contemporary society (Carnino, Biagini, 2010). The algorithm has become a technical object which historians of technology must now take into consideration and where novel issues of conservation are being raised (Di Cosmo, 2017; Abiteboul, Dowek, 2017, Di Cosmo, Hachez-Leroy, 2018).

Forms of organisation and modes of production

By their very nature, heavy industries are capital-intensive firms, which must take measures to secure their supplies of raw materials and to develop their markets. From the late nineteenth century on, there were phenomena of arrangements and agreements between producers at both national and international levels. In France the examples are called cartels, in Germany *Konzernen*, in the United States trusts and in Japan, *zaibatsu*. According to the sector concerned, these organisations have turned out to be both solid and lasting. Their dominant positions have

been vigorously combatted in some countries, such as the United States, with the Sherman antitrust act voted in 1890. In Europe, it was only after the Treaty of Rome of 1957 that the countries of the European community could come to any sort of agreement in combatting trust organisations. Lawyers were particularly interested in these forms of arrangement during the inter-war period and then again in the years prior to the Treaty of Rome. There was debate as to the positive or negative effects of such organisations for other firms and for consumers. Historians became interested in these forms of organisation, particularly at the initiative of Akira Kudo and Terushi Hara at the 18th Fuji Conference at Tokyo (Kudo and Hara, 1992). Analyses showed that the forms of arrangement that were most solid were those that were formalised in oligopolistic sectors such as aluminium or cellulose, and that the organisations here could last for several decades. Switzerland served as home to many of them. At the turn of the twenty-first century the European Union established significant powers to combat this phenomenon of trusts, which have resurfaced not only in industrial sectors but also in the service industries and banking (Schröter, 2013, Hachez-Leroy, 2015).

Where their internal organisation is concerned, companies have alternated between a movement towards vertical, upstream integration, prior to the First World War and then downstream integration after the Second World War, before giving way to the mode for externalisation and sub-contracting from the 1980s, under the influence of the growing financialisation of capital. Corresponding with a concentration on ‘core business’, tasks seen as peripheral, such as transport services, logistics or accountancy, are increasingly entrusted to outside firms. In France, between 1984 and 2003, the proportion of firms that sub-contract work grew from 60% to 87%. Certain sectors, such as aeronautics or the motor car industry, has already been practising this sub-contracting for a long time (Baudry, 2003). The construction of homogeneous political and economic spaces such as the European Union, eliminating internal customs barriers, has had a considerable impact on the organisation of industrial production, particularly where heavy industries are concerned. Already, prior to the Second World War, European firms could often be distinguished from American ones by the fact that they were still family-owned and family-run, like the Krupp, Siemens, Vickers or Schneider companies. European countries could also be distinguished from the United States by a strong tradition, from the nineteenth century, of state intervention and programmes of nationalisation. German railways were nationalised in 1880. This interventionist tradition declined but at rates that varied from one country to another, after 1945. The construction of the European Union was accompanied by measures which had a strong influence on the iron and steel industry, the arms industry or aircraft construction. Many large-scale European companies now share out their supply and production activities between different countries, according to financial considerations such as the cost of labour or rates of taxation. Supply of raw materials or of energy is no longer the main consideration.² And this phenomenon is by no means limited to Europe. The liberalisation and globalisation of the economy which began in the 1970s, was also based on commercial exchanges between firms, representing between a third and a half of all the commercial exchanges in the world. The different stages in the manufacture of goods, like services, are shared out between companies’ different sites (Michalet, 2004). Regulations and world-wide governance can no longer be free from the weight of multinational companies and, in particular, those involved in heavy industries, internet included. At the turn of the twenty-first century, the relations between the different players—states, companies, governmental and non-governmental international organisations—around legal questions and questions of power relationships became considerably more complex.

Usages and the environment

The history of usages and users represents a field that is not yet properly addressed for the industrial products of heavy industry, whether these are finished products or semi-manufactured

² *Entreprises et histoire, L'entreprise européenne*, 33 (2003/2).

ones (Scranton, 1997; Oudshoorn and Pinch, 2003; Chatriot et al., 2004; Chauveau, 2006; Oldenziel, Hård, 2013). Where metals are concerned, this involves the history of alloys and of metallography. For steel, research has mainly been concerned with imposing structures such as bridges or buildings, or some smaller ones such as tin cans for food (Bruegel, 2002; Mioche, Woronoff, 2006). In the case of aluminium, there are no detailed studies allowing us to understand the main stages and conditions in the development of transformation techniques such as wire-drawing or stamping or the processes used for giving aluminium a special surface or colour. As a general rule, the history of ferrous and non-ferrous metallic alloys over a long period and at international levels remains very sketchy (Cobb, 2010; Chemello et al., 2019). Approaching the question from the market side has offered a more global vision of technological developments, englobing the technical, cultural and social aspects of the materials studied (Friedel, 1983; Meikle, 1995; Hachez-Leroy, 1995; Schatzberg, 2003). Developing new products or new substances also means measuring the industrial risks involved (Boulet, 2006; Varaschin, 2007; Chambless, 1985) and creating customer confidence, for better or for worse (Østby, Zachmann, 2011; Oreskes, Conway, 2010). At this point, technological history meets up with environmental history and its mechanisms (Smith, 1997; Boyd, 2001; Fressoz, 2012). Heavy industries are the ones with the heaviest environmental impact. Pollution, occupational diseases and the harmlessness of foodstuffs are questions to be found throughout the productions and products of heavy industry (Lefaux, 1968; Needleman, 1991; Hombourg et al., 1998; Massard-Guilbaud, 2010; Buzzi et al., 2006; Hachez-Leroy, 2013; Exley, 2013). The applications of chemistry are immense, but in studying certain controversies, case studies allow us to work our way back from the product to its manufacture and its design (Schuck, 1978; Rainhorn, 2012; Pessis et al., 2013; Snow, 2017; Blanc, 2007). This is the case, for example, with bisphenol A in babies' feeding bottles or additives in foodstuffs such as nitrites (Meikle, 1997; Vogel, 2009; Hachez-Leroy, 2019). These new perspectives offset the positive vision of technological history, one that is often too positive (Sheller, 2014).

The contributions of industrial archaeology

From the 1950s, industrial archaeology began to open new research perspectives and new ways of understanding the history of technology (Buchanan, 1972, Daumas, 1980). Heavy industries here present some emblematic cases, particularly in terms of scale, complexity and environmental impact, such as the mining and metallurgical region of Essen in the Ruhr or the copper producing region of Chile (Preite, 2011; Woronoff, 2015). The high visibility of such sites has given rise to some stimulating thinking about the notion of technical and industrial landscapes, as part of the broader notion of the cultural landscape, developed by UNESCO (Preite, 2005; Michon, 2008). The preparation of nomination files for UNESCO world heritage inscription has to be more and more detailed and has served as an opportunity for reconsidering the history of technology in a more global approach, comparing different geographical spaces without being under the sole influence of western references. In the context of the definition of criteria of outstanding universal value, the question of technical history is an essential one, as is the question of the effects of this history. And how to take into consideration question of environmental pollution or industrial waste products? (Preite, 2018; Beazley, 2007) The UNESCO inscription of the site of the nuclear tests in the Bikini atoll (2010), like the inscription of the German and Czech zones where uranium was mined and transformed (2019) give food for thought about the history of technology and its representations (Albrecht, 2017). The images of industry and of technology and their place in society are also topics that can renew our approach to the history of technology (Woronoff et al., 2002; Pierrot, 2010). The confrontation of archival sources and field observations can enrich our knowledge of technology and the way we understand it (Fluck, 2008; Pillet, 2009; André, 2017). And the issue of preserving material traces also offers plentiful opportunities for developing our know-how around technical history. What should we keep, and how? The conversion of industrial buildings to new uses is a crucial issue that raises many

questions (Douet, 2012). What hierarchies can we establish between sites that can be altered or should be kept as found? What must be kept ‘absolutely’, in order to maintain a site’s legibility? How can changes to the built fabric be kept reversible? There are important debates as to the constitution of collections of technical objects of the same sort, or preserving them *in situ* (Ballé et al., 2010). Does a steam engine tell the same story when it enters a museum collection? And what of the ‘authenticity’ of a machine-tool when we know that the very essence of industrial operation is to maintain, to repair and to improve machines throughout their useful life (André, 2005; Buffa, 2015). Interrogating the object itself is also a fertile approach (Amouretti et al., 1984). This is the case with paper manufacture, for example. The analysis of watermarks provides information about the history of the paper’s production and the techniques and people involved in the industry (Coural, 2011).³ The intangible heritage and oral archives are two vital aspects for nourishing the contemporary history of technology.⁴

Finally, digital tools are today renewing our interrogations about technical objects and their study, whether this is primarily in view of interpreting the objects for the general public, through 3D models or enhanced reality, or, rather, for conserving the object by the creation of data bases, for example (Laroche, 2009; Benoit et al., 2009; Saou-Dufrene, Barbier, 2014). The gigantic dimensions of the sites of heavy industry often entails to the use of digital techniques to interpret how these sites functioned and to keep the memory of them when their physical conservation is deemed impossible. Technical complexities and their understanding can be preserved and communicated by these digital tools (Fischer et al., 2017).

To conclude, it is useful here to underline the fact that heavy industries are all part of the contemporary phenomenon of globalisation of the economy, particularly since they now benefit from the unprecedented development of inexpensive maritime transportation for large and heavy payloads (Daudin, 2003). Nine billion tonnes of merchandise were transported by sea in 2015, compared to one billion in 1960 and 4 billion in 1990.⁵ Most raw materials and agricultural produce are now carried in containers and the size of container ships has risen from a capacity of 1 700 TEU in the 1960s to 11 000 TEU since 2006.⁶ Tankers could carry 5 000 tonnes of crude oil in the 1950s but by the 1970s, with ultra large crude carriers, this had reached a capacity of 500 000 tonnes. Cargo ships, liquefied natural gas carriers, ore carriers, oil tankers, phosphate carriers, container ships and other bulk carriers... the ships are now specialised and have multiplied to the point of representing today the principal transportation mode for raw materials (80% in 2012), oil still the leading such product, followed by mineral ores (Levinson, 2006; Solly, 2007; Rodrigue, 2017).

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³ On this subject, see the website dedicated to the history of paper: www.memoryofpaper.eu.

⁴ *Les témoignages dans les musées industriels - Entre mémoire et patrimoine* (Liège, Maison de la métallurgie et de l’industrie de Liège, 2016).

⁵ United Nations Conference on Trade and Development, *Review of Maritime Transport 2018* (New-York, United Nations, October,3, 2018).

⁶ TEU: twenty-foot equivalent unit = length of a container.

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