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An Element of Controversy

The Life of Chlorine in Science, Medicine, Technology and War

Edited by Hasok Chang and Catherine Jackson

from research by undergraduate students at
University College London

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Back cover illustration: Chlorine gas, courtesy of the Department of Chemistry, University College London. Photo by Gretchen Siglar.

Contents

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Obstacles in the Establishment of Chlorine Bleaching

Manchi Chung, Saber Farooqi, Jacob Soper and Olympia Brown[1]

1. Introduction

The bleaching power of chlorine was already noted when Carl Wilhelm Scheele first isolated it in its elemental form in 1774: when suspended in chlorine, "blue litmus paper became almost white; all vegetable flowers—red, blue, and yellow—became white in a short time; the same thing also occurred with green plants."[2] The renowned French chemist Claude-Louis Berthollet in the 1780s took the lead in applying this knowledge to use chlorine as a bleaching agent for industrial processes. By 1790 Berthollet's procedure was formally endorsed by the *Bureau du Commerce*, the body responsible for national economic policy, which called for its industrial implementation.[3] From these developments one might imagine it was a quick and straightforward matter to apply chlorine-based bleaches to all sorts of practical purposes, launching a practical tradition that continues down to our own use of chlorine-based household bleaches. However, as it turns out, the use of chlorine bleaching did not get established very quickly. This is puzzling especially for the textile industry, where the economic utility of a better bleaching process was obvious.

[1] Catherine Jackson carried out some additional research for this chapter.
[2] Scheele [1774] (1930), p. 31. In Chapter 1, Section 2 we have discussed in some detail Scheele's work on chlorine, which he called "dephlogisticated muriatic acid".
[3] Berthollet [1789] (1790) was his first major publication relating to chlorine bleaching; we have discussed Berthollet's view on chlorine ("oxymuriatic acid" for

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Traditionally, the bleaching of linen was a long and drawn-out affair.[4] The need for bleaching arose because of the natural oils in the flax that make up the linen. Bleaching involved washing out this oil, and discharging it completely from the cloth. The first step in the process was "bucking" (boiling to remove the fats). The next step was washing with soap, then souring (acid treatment) to neutralize the alkali in the soap, followed by rinsing and water extraction. Finally there was "grassing", or "crofting", which involved exposure to sunlight, which was the most time-consuming stage in the entire process. Each of these stages required repetition up to four of five times, and the total length of time needed to get linen bleached was usually two to five months, and could be as long as 10 months for very heavy goods.[5] Because the crofting process depended on the weather, the process was considerably extended when carried out during the winter months. It also involved considerable manual labour because the cloth had to be kept moist and turned to ensure that it was evenly bleached. The slow bleaching process created a significant bottleneck in the production of textiles in general. It was also wasteful, as fields where the fabric was spread out were unavailable for agricultural production during the best growing season. As imported cotton began to replace linen and the production of cotton fabrics grew, the benefits to be gained from the development of a quicker and more economic method of bleaching also escalated.

As it turns out, the application of chlorine to the bleaching of textiles was not a simple consequence of Scheele's observation of the bleaching properties of the gas. Even after Berthollet's work, it was not a trivial matter to convert his experiments on the bleaching properties of chlorine into a practically useful procedure. The development of a viable industrial process took many years and involved the scientific and commercial expertise of a large number of people. Even more difficult to overcome than the technical problems was the challenge of making manufacturers adopt the new procedure. Even the French government's official endorsement of Berthollet's work was not sufficient. Despite Berthollet's very considerable efforts, chlorine bleaching did not become

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him) in Chapter 1, Section 3, and also in Chapter 2, Sections 3 and 5. For the *Bureau*'s endorsement of Berthollet's process, see Smith (1979), p. 126.

[4] For a description of the traditional method of bleaching linen, see Pratt (1989), p. 23, and Home (1771), pp. 285ff.

[5] Smith (1979), p. 115.

widespread in France until after the end of the Napoleonic Wars in 1816.[6] That delay was partly a consequence of the upheavals of the French Revolution, but a similar time lag in Britain, albeit shorter, suggests that non-political factors were also involved.

In this chapter we give an account of the origin and early development of chlorine bleaching in France and Britain, and attempt to answer the puzzle about its slow and erratic uptake. Our discussion builds on the extensive research by several historians, including Sydney Herbert Higgins (1924), Archibald and Nan Clow (1952), A. E. Musson and Eric Robinson (1969), and John Graham Smith (1979). We begin in Section 2 with some methodological considerations critical of the traditional accounts of the development of chlorine bleaching. In Section 3 we tell the story of Berthollet's development of chlorine bleaching and the obstacles to its adoption in France. In Section 4 we trace the movement of that technology to rapidly industrializing Britain, where a close interaction of science and entrepreneurship led to easier acceptance. In the two contrasting stories, we will highlight the very different social, political and economic contexts in Britain and France in the last decades of the eighteenth century.

2. The need for a new perspective on chlorine bleaching

Traditional accounts of chlorine bleaching tend to be framed in a combination of the "linear model" of technological innovation, and technological determinism. The linear model conceives that new scientific knowledge, in this case the chemical understanding of chlorine that Scheele and Berthollet developed, directly causes the development of technology based on it. Technological determinism sees the scientifically developed technology going on to determine changes in society. Historians of technology have, until relatively recently, considered that new technologies, notably the steam engine, were the main driving forces behind the creation of centralized manufacturing processes and the consequent generation of vast wealth in the Industrial Revolution.[7] Although this might be the most intuitive way to look at how science

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[6] Smith (1979, pp. 159–160) describes the slow uptake of chlorine bleaching in France.

[7] Clow and Clow (1952, 1958) exemplify this view, as does Chapman (1972) in more specific contexts.

produces effects in society, it ignores important feedback loops, through which social, economical and political influences affect technology or even basic science in the "reverse" direction. In traditional accounts, the development of chlorine into a usable bleaching agent by Berthollet is imagined to have been followed almost immediately by its practical application in the textiles industry.

Higgins's *History of Bleaching*, published in 1924, contains a whole chapter on "the use of chlorine as a whitening agent", which gives an extensive account of the history of the industrial application of chlorine in the textile-bleaching industry.[8] Higgins clearly favoured a linear and deterministic account, according to which advances in the chemical sciences led directly to improvements in technological applications, which in turn directly saw radical changes in industry:

> Chemistry has had its innings. It had completely revolutionised the industry and enabled it to turn out the quantity of material which was demanded of it. The bleaching industry has been developed along with the chemical industry by such men as Tennant and Bealey, so that chemical knowledge has been brought fully to bear on it.[9]

Higgins criticizes other commentators who do not adhere to this traditionalist approach. For example, he quoted an unidentified "modern writer" as stating that "the chemist . . . has been somewhat apt to . . . think that all difficulties which arise in practice can be solved purely by the application of knowledge of the chemistry of the processes involved". Higgins, siding with the authority of science, disagreed completely and gave this vehement reply:

> This statement conveys an entirely wrong idea of the development because we have seen above that every step taken by the chemists had the authority of chemical science. Before science was applied to industry, farmers were boiling down plant ashes, steeping it in buttermilk, and spreading it on the grass; but chemists introduced sulphuric acid, pure soda, chlorine compounds etc., into the industry and made the modern bleaching industry.[10]

Perhaps it is not surprising that Higgins's account sounds methodologically outdated, as it was written in the 1920s. However, it is interesting to reflect on the persistence of the linear model. While D. W. F.

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[8] Higgins (1924), pp. 73–95.
[9] Ibid., p. 114.
[10] Ibid.

Hardie assured us in 1952 that "it is a facile and utterly false assumption that the history of chemical industry is merely that of the application of the discoveries and theories of pure chemistry and physics to technology", the linear model of technological development has persisted in many histories of chlorine bleaching long after it was generally expunged from histories of the steam engine.[11] Clow and Clow's account of 1952 was quite explicit on this point. To express their view on "the relationship between chemistry and bleaching", they quote the 18th-century chemist Thomas Henry: "Bleaching is a chemical operation." In the paper quoted by Clow and Clow, Henry lamented the lack of willingness on the part of industrialists to acquire knowledge of relevant chemical principles.[12] In 1979, John Graham Smith considered that the introduction of chlorine had been a "revolutionary advance . . . establishing the bleaching industry on its modern basis" and was "rightly framed as one of chemistry's chief contributions to the Industrial Revolution".[13] Smith's revolutionary imagery was adopted by Alastair Durrie in an essay published in 1987, in which he sought to explain the "radical and rapid transformation of bleaching technology brought about by the discovery and development of chlorine" in the north-east of Scotland.[14] Even economic historians Chris Freeman and Luc Soete have looked to emphasize the direct one-way influence of the science on the technology in bleaching: "The case of bleaching differs . . . since it was directly based on advances in chemistry".[15] S. D. Chapman similarly noted that the new bleaching technique required "specialised knowledge of chemistry."[16]

It is questionable that the development of chlorine bleaching, any more than any other new technology, followed such a straightforward route from the laboratory directly into mass industrial usage, leading to technological applications which in turn caused dramatic changes in society. Recent developments in the area of social studies of science and technology point to a more rounded picture of technological development in general. As we will see, the development of the chlorine bleaching

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[11] Hardie (1952), p. 606.
[12] Clow and Clow (1952), p. 198.
[13] Smith (1979), p. 113.
[14] Durrie (1987), pp. 14–15.
[15] Freeman and Soete (1997), p. 40.
[16] Chapman (1972), p. 25.

industry was shaped not only by the technical aspects of the processes involved, but also by social and economic factors. It was not a rapid advance from laboratory science to large-scale commercial success. There were many problems in its evolution, as well as a host of social and economic influences that helped to shape the development of chlorine as a widely used bleaching agent.

What is the alternative to a linear and deterministic framework for understanding the development of the chlorine bleaching industry? A different perspective on the chlorine bleaching story is given through the lens of the "social shaping of technology" (SST). Here the historical context of technological development is understood as "patterned by a range of 'social' and 'economic' factors as well as narrowly 'technical' considerations".[17] This leads to a deeper understanding and a more complex narrative in contrast to the relatively limited analysis that historians such as Higgins would give. The introduction of chemical knowledge may have been one of the more important contributing factors for the expansion of the chlorine bleaching industry, but it was not the only influence that was present in its development. SST explores a range of organizational, political, economic and cultural factors, which form a web of understanding of how a technology is established. Society influences the technology and arguably also the science involved. But SST is also not another term for social determinism, in which society is seen as the sole determinant of technological outcomes. Rather, SST draws a multi-dimensional picture — neither technologically deterministic nor socially deterministic, but recognizing mutual influences between science, technology and society.

3. Chlorine bleaching in France

The story of industrial chlorine bleaching begins with Berthollet's publication of his memoir on chlorine in 1785, which included an account of the bleaching properties of a solution of chlorine in water (called "chlorine water").[18] Smith suggests that Berthollet's interest in the chemistry of chlorine was triggered by his election to the position of

[17] Williams and Edge (1996), p. 865; see also Mackenzie and Wajcman (1999).
[18] Berthollet [1788] (1897); we have discussed this paper in detail in Chapter 1. See Lowry (1936), pp. 213–215, for a concise discussion of Berthollet's work on chlorine water.

chemical advisor to the *Bureau du Commerce* and superintendent of the state dye-works in Gobelins in 1784,[19] but Berthollet's involvement in the debates surrounding chlorine's elementary nature (discussed in Chapter 2) suggests that his motivation was not solely utilitarian. Berthollet published the outcome of his research on bleaching in the *Annales de Chimie* in 1789, and published his treatise on the art of dyeing two years later in 1791.[20] Even before this, Berthollet's procedure had attracted attention from the *Comité d'Administration de l'Agriculture*, of which his close colleague Antoine-Laurent Lavoisier was a leading member, and by 1790 it was formally endorsed by the *Bureau du Commerce,* which called for its industrial implementation.[21]

Berthollet explained the bleaching ability of chlorine in terms of oxygen transfer, a reference to Lavoisier's new chemistry. Previous theories of bleaching had attributed the loss of colour to a loss of phlogiston, but Berthollet associated the loss of colour with the affinity of colouring particles for oxygen. In his theory, the more easily a substance provided oxygen to the colouring particles, the more effective it was as a bleach. Since Berthollet considered chlorine to be "oxygenated muriatic acid" (or, "oxymuriatic acid"), as discussed in detail in Chapter 2, it would have seemed a natural candidate as a bleach: "the [bleaching] properties of the oxigenated muriatic acid [chlorine] are owing to the oxygen that is taken from it by the substances on which it acts [so that] by a continued action, it destroys colour".[22] Berthollet's practical work did not at any stage cause him to question this explanation of the scientific basis of bleaching.

Despite its obvious technical promise and its promotion by a powerful scientist who provided both experimental and theoretical arguments supporting it, chlorine bleaching was slow to be adopted in France. There were problems with new equipment, and the results were initially unreliable.[23] The process was difficult to control: if the solution was too

[19] Smith (1979), p. 118.
[20] Berthollet [1789] (1790), and Berthollet (1791). Both of these publications were quickly translated into English, the *Elements* warranting a second edition to incorporate the practical instructions of a dyer.
[21] Smith (1979), p. 126.
[22] Berthollet [1789] (1790), p. 34.
[23] See Pratt (1989), pp. 25–27, for a description of these problems and their solutions.

weak, the fabric yellowed on later washing; if it was too strong, the fabric was damaged. Moreover, the use of chlorine presented significant health risks to workers in the new industry. One major difficulty was that chlorine gas escaped from the chlorine-water, producing choking fumes. This made Berthollet's original bleaching process dangerous and unpleasant. C. Pajot Descharmes, one of those who attempted to develop Berthollet's 1789 process, described the miseries he experienced:

> Running of the nose, asthmatic affection of the breast, headache, tears and smarting of the eyes, bleeding at the nose, the sensation known by the name of the teeth set on edge, pains in the small of the back, and even spitting of blood, are the ordinary inconveniences to be expected, when the pure oxygenated muriatic acid [chlorine] is used as is prescribed in the *Annales de Chimie*.[24]

Berthollet's key innovation at this juncture was to add potash to chlorine water, in an attempt to neutralize the toxic effects. Not only was the intended effect achieved, but the bleaching action unexpectedly became more powerful. Solutions to other problems also followed, such as protective gear for workers and the introduction of means of measuring the strength of the bleach. The new chlorine–potash bleaching liquor became quite usable and Berthollet, with the help of François-Joseph Bonjour, was able to convince the *Bureau du Commerce* that chlorine bleaching could be developed for industrial use. Berthollet demonstrated his methods to members of the Javelle Company, who then attempted to obtain a patent for their adaptation of Berthollet's method. The French government refused the patent once it had been shown that their product "*Eau de Javelle*" was not original. It was in fact almost identical to the solution created by Berthollet when he added potash to chlorine water in order to alleviate the smell of chlorine gas escaping from the solution.[25] Berthollet inadvertently prepared this more effective bleaching solution, which the Javelle Company created by dissolving chlorine in a solution of potash.

Technical difficulties were not the only kind of obstacles in the establishment of chlorine bleaching. Smith points out that the new

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[24] C. Pajot Descharmes, *The Art of Bleaching Piece-Goods, Cottons, and Threads of every description*, trans. by William Nicholson (London, 1799), p. 64; quoted in Smith (1979), p. 143.

[25] Pratt (1989), p. 26. According to Parkes (1815, pp. 57–58), Berthollet himself carried out the analysis that established the chemical similarity of the two solutions.

technique threatened to undermine the traditional artisanal nature of the French bleaching industry.[26] Berthollet's insistence that the practice of chlorine bleaching was "capable of execution only by people instructed in chemistry" was perceived to exclude the lay-artisans who constituted the majority of the industrial workforce at the time.[27] Berthollet's one-time assistant Bonjour tried to establish a chlorine bleaching plant at Valenciennes near the Belgian border, but faced overwhelming opposition from the local croft bleachers which eventually put him out of business.[28] According to Roger Hahn, the high-handed attitude of scientific innovators like Berthollet generally came up against the "grievance of the artisan", who felt threatened by the apparent exclusivity of the new technology. Lavoisier had recognized the nature of this grievance early on, and his "strategy for saving the Academy was founded upon the belief that the attacks of the artisans arose principally from their natural desire to participate in governing science and the arts".[29] In a similar way, the proponents of chlorine bleaching became increasingly careful to demonstrate that the new bleaching process was "destined to go absolutely hand in hand" with traditional methods.[30]

Berthollet was unflagging in his campaign for chlorine bleaching. In addition to publishing all his results and techniques, he also traveled around France demonstrating his procedures for all who asked to see them. James Watt, who saw one of Berthollet's demonstrations of chlorine bleaching during a visit to Paris, and he offered to secure a British patent for Berthollet on his return to England. Berthollet refused, stating that he had no desire for personal gain but merely wanted science to advance. Berthollet's lack of interest in profiting from his science was well documented. Dominique-François Arago wrote that Berthollet was "quite happy to see others profiting from his discoveries", while his biographer Auger commented that "apart from his genius, Berthollet was best known for his lack of interest in money."[31] No doubt Berthollet's occupation of what Fourcroy described as "one of the best paid scientific

[26] Smith (1979), p. 178.
[27] This comment, made by Berthollet in 1788, is quoted in Smith (1979), p. 143.
[28] Partington (1962), p. 507.
[29] Hahn (1971), p. 231.
[30] *Le Journal de Normandie,* quoted in Smith (1979), p. 142.
[31] Arago and Anger quoted in Crosland (1967), p. 99 and p. 101 respectively.

posts in the country" made it possible for him to communicate his knowledge freely, without thought for the money to be made from the process.[32]

One might imagine that Berthollet's considerable ingenuity and selfless dedication would have been enough for the establishment of chlorine bleaching. On the contrary, the development of the new bleaching technology came to an abrupt halt during the French Revolution. After Berthollet's success in disseminating knowledge about chlorine bleaching in the short period since 1785, the Revolution presented considerable challenges to its further development. Many of the main figures in the French bleaching industry had their attention diverted to the fighting or in politics, and others ran out of supplies or had their equipment destroyed.[33] Parisian science was highly centralized, taking place under the auspices of national bodies such as the *Bureau du Commerce* and the *Académie Royale des Sciences*. While the *Académie* functioned as a "central collecting point for new scientific work",[34] the *Bureau* also fulfilled an important role in providing patronage to those involved in scientific activities. As Roger Hahn comments: "In the face of the dominance of publicly sponsored institutions, the impact of voluntary associations of scientists and research in private industries [was] inconsequential".[35] Berthollet's exploration of chlorine bleaching was well supported by the *Bureau du Commerce*; its sponsorship protected Berthollet from the pressures of commercial competition, and enabled him to disseminate knowledge of the new bleaching process to a wide audience. The *Bureau* received a large number of appeals concerning chlorine bleaching throughout the 1780s and as late as 1790.

Unfortunately for Berthollet, the French Revolution threatened the dominance of old central-governmental institutions, forcing the relocation of science in France from state-funded, centralized institutions into the private sector for a time. The *Bureau du Commerce* was abolished in September 1791. The *Académie* fared no better. Already in November 1789 the Duc de la Rochefoucauld d'Enville addressed the *Académie* on the need for a new regime with greater proletarian involvement, away

[32] Fourcroy, quoted in Smith (1979), p. 118.
[33] Smith (1979), p. 134.
[34] Crosland (2002), pp. 242–243.
[35] Hahn (1971), p. 315.

from "arbitrary ministerial control".[36] This reaction against exclusiveness was a problem for the development of chlorine bleaching, which Berthollet argued was only operable by those knowledgeable about the relevant chemistry.[37] No provision was made for any widespread instruction in chemistry during this period, and the majority of the industrial workforce therefore lacked the necessary skills to participate in the new bleaching industry.

Although the *Académie* had always tried to "justify it existence in the public eye and to the state, its paymaster" by supporting projects with utilitarian value, the intellectual elite was believed to have used patronage to perpetuate their own views.[38] Seen from this point of view, the *Académie*'s guidance of scientific activity constituted an unwelcome "imposition of theories".[39] Jean-Denis Lanjuinais even went so far as to describe academicians as a "literary aristocracy wielding a despotic authority that could not be tolerated in an age of liberty".[40] Lanjuinais particularly objected to the fact that French academicians were paid and he contrasted this situation with that in Britain, where "its academies receive neither tokens nor stipends; nevertheless they flourish, and their academicians are, I dare say, even more useful than ours".[41] This perception of "frivolous expenditure" by the *Académie* was heightened by the discovery in 1791 of anomalies in its accounts.[42] The *Académie* was dissolved in October 1793, following a period of financial disorder during which it became increasingly difficult to provide support to the Academicians.

It seems that during the Revolutionary period the only significant establishments involved in chlorine bleaching were privately funded. The most successful bleaching company in France at this time was F. A. H. Descroizilles's factory at Rouen in Normandy, north-west of Paris, which was supported by the patronage of the brothers de Fontenay, wealthy textile merchants with an interest in bleaching. By 1802, Descroizilles

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[36] Quoted in Hahn (1971), p. 167.
[37] See Smith (1979), p. 143.
[38] Crosland (2002), pp. 324–325.
[39] Fox (1992), p. 134; see also Crosland (2002), p. 270.
[40] Hahn (1971), p. 198.
[41] Ibid., p. 196.
[42] Ibid., p. 227.

was running the "finest Berthollian bleaching works in France".[43] Even F. J. Bonjour and J. J. Welter, Berthollet's protégés at the *Bureau*, pursued their interests privately. Welter was decorated in 1819 with the Legion of Honour for his contributions to chemical industry, a significant part of which was his role in chlorine bleaching. Robert Fox describes the flourishing bleach industry in Mulhouse, a semi-autonomous region that was relatively unaffected by the Revolution.[44] In 1801, two residents of the region, Nicolas Dollfus and Alexandre Jaegerschmid, patented a new method of making chlorine.[45] This case illustrates two interesting points. First, during these times of turmoil, new ideas by relatively unrecognized individuals were not likely to receive funding from the government. Second, the use of patents (which were introduced in 1791) suggests the growth of a commercial culture, reflecting trends in other parts of Europe and contrasting with the spirit of publicly sponsored research, which Berthollet displayed. However, in the long-term French context, such private ventures were ineffective in establishing a whole industry. As Smith notes, even by the 1820s chlorine bleaching had by no means displaced traditional methods entirely in France.[46]

4. Chlorine bleaching in Britain

Chlorine bleaching actually first took hold in Britain, rather than France where the basic technique was first developed and officially promoted. At the height of the Industrial Revolution in Britain, which was in large part driven by developments in the textile industry, there was a clearly felt need for a more efficient method of bleaching. Bleaching was needed not only to make white cloth, but to prepare properly any cloth to be dyed.

The demand was high. There is research to suggest "an increasing trend for the British consumer towards buying cotton clothing throughout the eighteenth century".[47] The mass market was fed by the thriving textile

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[43] Descroizilles's success was hard-won, as described by Smith (1979), pp. 128–129. One of Descroizilles' innovations was the development of a system for measuring the strength of bleaching liquor using a device he called the Berthollimètre, a fore-runner of the modern burette.
[44] Fox (1992), p. 140.
[45] Smith (1979), p. 177.
[46] Ibid., pp. 177–178.
[47] Lemine (1991), p. 100.

industry already present in Britain. Freeman and Soete report: "between 1760 and 1790 there was a huge growth in Britain, specifically the cotton output". This was due to the significant effects of the mechanization of the textile industry, through important innovations such as the spinning jenny, the power loom and the water-frame.[48] As the production of textiles increased, so did the need for a large-scale bleaching industry. This drive from the textile industry to develop chemical bleaching techniques is in keeping with the general observation by Clow and Clow that "during the Industrial Revolution, much of the expansion of the chemical industry was conditioned by the prodigious growth of the textile industry."[49]

Before chemical compounds entered the bleaching industry, much of the cotton and linen that was manufactured in Britain was sent to be "finished" in Holland and Ireland. Compared to England and Scotland, these two countries were producing a far superior product that was sought after throughout Europe. After an initial attempt to import skilled workers from Ireland, Scotland decided to take more radical measures to address the problem. The Board of Trustees for Manufacture, Fisheries and Improvements in Scotland recommended: "sending [Scottish] bleachers to Ireland to study Irish methods . . . , by subsidizing the laying down of extensive bleachfields and by awarding premiums to Scottish academic scientists for researches . . . on various bleaching processes."[50] This kind of state reward for research into more efficient bleaching methods was intended to make Scottish bleachers more competitive with respect to their Irish and Dutch counterparts.

Cotton and linen manufacturers also had to contend with a different kind of dominance within the textile industry — the woollen and silk manufacturers. Before chlorine compounds were utilized for whitening linen and cotton cloths, woollen and silk products were the textiles of choice for the finer items of clothing such as hosiery. This was due to the fact that the bleaching techniques, before the introduction of chlorine compounds into the industry, favoured woollen and silk products giving it a whiter finish than the cotton and linen equivalents.

The need for better bleaching methods was intensified by the severe increases in land rental prices that occurred just before and after

[48] Freeman and Soete (1997), p. 37.
[49] Clow and Clow (1958), p. 256.
[50] Clow and Clow (1952), p. 173.

1800.[51] Traditional methods of bleaching utilized crofting, where the cloth had to be exposed to the sun in expansive stretches of fields. This created competition for land between the agricultural industry and the bleaching industry. This problem was amplified due to the dramatic increase in the amount of linen and cotton goods that needed to be bleached. Therefore, a large and larger amount of land initially had to be given over to crofting.

For all of these reasons, when a promising new process of bleaching came to the attention of British industrialists, they were willing to see the process of development through the numerous difficulties that beset it. Even before chlorine had entered the picture, there had been steps taken to decrease the time needed to bleach linen and cotton goods in response to the increased output of the manufacturers. When cheap mineral acids became available, this "enabled bleachers to reduce the time of souring to about a twenty-fifth of that formerly required. But even this increased rapidity of bleaching was not adequate to cope with the output of the mills, soon to be increasing by millions of yards annually."[52]

In the attempt to develop chlorine bleaching, there were many technical challenges to be overcome. Too high a concentration of chlorine inevitably damaged the cloth that was being bleached. Bleaching liquor made using potash also damaged the cloth, which made many textile manufacturers resistant to its use. The poisonous nature of chlorine was all too familiar to the early pioneers of chlorine bleaching who tried to harness it in its volatile gaseous form. Furthermore, although the use of chlorine compounds gave better results than traditional forms of bleaching, it was more expensive due to the necessity of using costly alkalis. Finally, the difficulty and expense of transporting bleach in liquid form hindered its large-scale, centralized manufacture. Still, there were entrepreneurs willing to devote the resources and time needed to develop a commercially viable form of chlorine-based bleaching agents, because in part they could see that the traditional forms of bleaching were simply too slow to suit the "modern" demands of the cotton and linen manufacturers. This is not to deny that the chemical knowledge employed for this purpose was impressive, but chemistry alone would not have sustained the strenuous work of developing chlorine bleaching.

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[51] Montague (1992), p. 21.
[52] Clow and Clow (1958), p. 247.

In the last section we noted that having state support was initially not sufficient to establish chlorine bleaching in France, and that the state support diminished in any case in the midst of the Revolution. In Britain, there never was much sustained support from the state for chlorine bleaching, or for most other technological innovations. As some of the early chlorine-based bleaching agents were quite expensive to produce, and as research was not funded by the state, scientists and entrepreneurs had to make their own investments, and be concerned about protecting these investments. The lack of state support was a source of frustration for innovators. Francis Home had lamented this state of affairs in his treatise on bleaching in the middle of the 18th century, with an admiring eye to France: "I look on it as a loss to Great Britain and to arts and manufactures that we have no academy instituted by Public authority. . . . [W]hat a trifling sum to France is the yearly expence [sic] of the Academy of Sciences and yet of what benefit has it been to the arts and manufactures of that country".[53] The Royal Society of London was separate from the government despite having a Royal charter, and was not in a position to fulfill key aspects of the role of the Paris *Académie.* Home presumably wished for the provision of substantial financial support for science. He also envied the public discussion of technological innovation fostered by the *Académie* in Paris, arguing that "nothing promotes an art faster than the communication of those who practice it; nothing retards it more than a selfish spirit of keeping it a secret".[54] Interestingly, the development of chlorine bleaching in Britain during the last quarter of the eighteenth century challenges Home's belief in the greater productivity of co-operative scientific activity. It was in Britain, in an atmosphere of intense industrial competition, that chlorine bleaching was transformed from a laboratory technique to a large-scale industrial process.

The Royal Society of London was not the main meeting place for those whose interests combined science and industry, despite the willingness of Sir Joseph Banks (President from 1778 to 1820) to include working technologists amongst the fellowship, exemplified by the election of James Watt in November 1785. Instead, provincial societies such as the Lunar Society of Birmingham and the Manchester Literary

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[53] Home (1771), p. 394; in the first edition of 1756, see p. 329.
[54] Home (1756), p. 324.

and Philosophical Society provided a forum for those interested in the systematic improvement of industrial products and processes.[55] Although the need to preserve secrecy about the details of industrial processes must have restricted communication between the members of these societies, they provided access to the company of like-minded individuals and a useful network of connections. In the British context, the development of chlorine bleaching was largely left in the hands of men seeking economic success, rather than academic accolades or the altruistic satisfaction of public service. Instead of direct support, the British government only offered a system of patents, providing a legal safeguard for the innovators. In terms of modern sociology of science, Berthollet may have been behaving according to the norms of communism and disinterestedness that Robert Merton attributed to scientists, but the behaviour of the British pioneers of chlorine bleaching were more in line with Ian Mitroff's "counter-norms" of solitariness and self-interestedness, values that are the polar opposite of Mertonian norms, but which are institutionalized just the same.[56]

In the remainder of this section we trace the establishment of chlorine bleaching in Britain, focusing on the work of three key figures: James Watt (the same Watt so well known as the improver of steam engines), Charles Macintosh, and Charles Tennant. The work of these pioneers was characterized by a close interaction between science and entrepreneurship, which fostered the coordinated development of new technology and profitable commercial processes. Practical techniques for the manufacture, distribution and use of chlorine-based bleaches were developed by chemists *and* industrialists working in close co-operation. As A. E. Musson and Eric Robinson state: "In bleaching . . . there is abundant evidence of close links between men of science and of industry, between laboratory and workshop — so close, indeed, that research and development were often almost merged together and there was hardly any gap at all."[57] Sometimes the fruitful interaction took the form of a partnership between scientists and industrialists. In other cases, the separation between the scientist and the entrepreneur (with the engineer somewhere in the middle) was not so clear, and we find it more con-

[55] See Schofield (1957) on this aspect of the Lunar Society.
[56] Merton (1973); Mitroff (1974).
[57] Musson and Robinson (1969), p. 336.

venient to think of some of the key figures in the story as "scientist–entrepreneurs". Many of the scientists involved had commercial as well as scientific expertise, and many of the industrialists had at least some knowledge of practical science.

James Watt (1736–1819) is an interesting case. He was clearly not lacking in scientific ideas, as evidenced in his well-founded claim to have arrived at the composition of water as a compound of hydrogen and oxygen.[58] However, on many occasions he humbly sought advice from those who were more engaged with science (or rather, natural philosophy or chemical philosophy, in the terminology of his time). For example, Watt mentioned a chlorine-based bleaching liquor in a letter to Joseph Priestley written shortly after his return from Paris in late 1786, asking whether Priestley could enlighten him about how the liquor might work. As key members of the Lunar Society, Watt and Priestley routinely had this sort of scientific–technological interactions. And Watt was also actively engaged in the business side of his work, though certainly guided by his business partner Matthew Boulton, another key member of the Lunar Society.

The story of chlorine bleaching in Britain begins with a letter from Berthollet to Charles Blagden, Secretary of the Royal Society, in March 1785, describing his preliminary experiments on the chemical properties of chlorine, including its bleaching power. This letter did not mention the potential for using chlorine to bleach textiles, but Musson and Robinson claim that Blagden and other British scientists probably "soon acquired knowledge of Berthollet's subsequent proposals for its industrial application, by reading his published papers or by personal contact".[59] It was, however, not until Watt visited Paris with Boulton in late 1786 that British scientists and entrepreneurs definitely witnessed Berthollet's bleaching experiments.[60]

According to Samuel Parkes, Watt already had some interest in the technicalities of bleaching before this visit.[61] Impressed by Berthollet's demonstration, Watt wrote to his wife Annie from Paris, asking her to

[58] See Muirhead (1846).
[59] Musson and Robinson (1969), pp. 261–262.
[60] Ibid., pp. 262, 264–265.
[61] Parkes (1815), p. 55, footnote.

pass the news on to her father, James McGrigor, a Glasgow-based dyer.[62] McGrigor worked together with James and Annie Watt from 1787 to 1789 to improve the bleaching method, no doubt assisted by Watt's continuing correspondence with Berthollet.[63] By 1788, Watt had also sent his son to work in a printing and bleaching firm in Glasgow. Watt and McGrigor struggled to maintain a monopoly over the new process, in contrast to Berthollet's own openness, which often threatened their attempts at secrecy.

Watt and McGrigor were of course not the only people in Britain who recognized the commercial importance of bleaching. Apparently "disappointed at their commercial prospects at home",[64] Bourboulon de Boneuil and others, formerly of the Javelle Company in France, set up a company in Liverpool. But when they applied for an exclusive licence to manufacture *Eau de Javelle* in Britain, it was refused on the grounds that the product was not novel.[65] When Watt learned of the Javelle Company's plan to make public demonstrations of the new method in Liverpool, he suggested to McGrigor that they establish priority by making, demonstrating and, if possible, selling their own bleaching liquor.[66] A British patent was also refused to the Javelle Company, largely on the evidence of Watt, who claimed that he had, "for more than a twelvemonth, been in possession and practice of a method", which was "the very same" as the Javelle process.[67] William Henry identified Watt as a "powerful auxiliary in preventing the monopoly of the foreigners"; this is a factor also recognized by Pratt, whose study of the Javelle Company notes "a rising tide of establishment thinking against anything French" just before the French Revolution.[68] As it turned out, Watt and others need not have worried so much. *Eau de Javelle* was expensive to make, and it was also rather impractical because its bleaching power

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[62] Musson and Robinson (1969), p. 263. His name is given as "MacGregor" by Partington (1962, p. 508) and Crowther (1962, p. 159).
[63] See ibid., pp. 265–273, for a description of the early stages of this collaborative effort.
[64] Partington (1962), p. 508. Partington's assessment of their motives may be generous. According to Smith (1979, p. 131), Bourboulon was on the run from charges of embezzlement!
[65] Pratt (1989), p. 26.
[66] Musson and Robinson (1969), pp. 274–275.
[67] Letter from Watt, dated 23 February 1788, quoted in Henry (1815), p. 423. See also Musson and Robinson (1969), p. 258.
[68] Henry (1815), p. 424, footnote; Pratt (1989), p. 27.

diminished over time. Although it achieved some success in domestic use, it was never suitable for large-scale industrial applications.

Meanwhile, in Manchester the physician and industrial chemist Thomas Henry (1734–1816) had been investigating the chemistry of bleaching.[69] As early as 1781 he described bleaching as a "chemical operation", and recommended the use of muriatic (hydrochloric) acid in place of vitriolic (sulphuric) acid in a joint paper with A. Easdon.[70] By 1788, he was attempting to develop a chlorine-based bleaching liquor but ran into technical difficulties, which led him to consult Watt. As his son William (1774–1836), renowned chemist himself, explained in 1815: "next to Mr. Watt, Mr. Henry was at least equally early with any other person in applying the discovery to practice". William Henry went on to refer to a "number of letters" between Watt and his father in 1788, "in which each of those gentlemen disclosed, unreservedly to the other, the progress of his experiments in this new art".[71] However, Musson and Robinson suggest in their analysis of this correspondence that it is "doubtful whether Watt gave Henry much help on these problems". In any case, Henry continued to work on the economic and chemical problems of developing the new bleaching technology, by now in partnership with the Manchester dyer John Wilson.[72]

Before long, a large number of people were actively involved in attempting to produce bleach commercially, and competition was fierce. In April 1788 McGrigor had a perturbing visit from George Macintosh, the proprietor of a dyeing business. Macintosh reported that his son, Charles, "a very good Chymist", had just written to him describing a bleaching process similar to the one developed by Watt and McGrigor, using hydrochloric acid to produce chlorine. Charles Macintosh (1766–1843), who would later go on to achieve fame for his invention of waterproof cloth, was indeed a well-trained chemist. Having learned his chemistry from William Irvine in Glasgow and Joseph Black in

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[69] On Henry and his family, see Farrar (1997).

[70] Thomas Henry, "On the Advantages of Literature and Philosophy in General, and especially on the Consistency of Literary and Philosophical with Commercial Pursuits", read to the Manchester Literary and Philosophical Society, 3 October 1781, *Manchester Lit. & Phil. Soc. Memoirs* (1785) i: 7–29, cited in Musson and Robinson (1969), p. 252. The paper with Easdon was published in the same volume, pp. 240–242.

[71] Henry (1815), p. 422, quoted in Musson and Robinson (1969), pp. 258–259.

[72] Musson and Robinson (1969), p. 300.

Edinburgh, Macintosh was particularly well placed to understand the relevance of chemistry to industry.[73] McGrigor was concerned that Macintosh would quickly discover the advantages of using sulphuric acid and salt to prepare chlorine. His fears were entirely justified — in July he wrote to Watt to say that Macintosh had done just that.[74] Macintosh was motivated to explore the use of sulphuric acid by his existing connections with the sulphuric acid works at Prestonpans. His interest in bleaching continued and in 1797 he entered into partnership with Charles Tennant, James Knox and Alexander Dunlop to exploit a new bleaching process based on the use of lime instead of potash.

Charles Tennant (1768–1838) was quite a significant force in Macintosh's partnership. Although not widely remembered now, Tennant was a very well-known figure in his time, and well into the 19th century. In William Walker's *Memoirs of Distinguished Men of Science 1807–1808*, published in 1862, Tennant was given 4 pages of coverage, quite comparable to the 6 pages given to Watt. Of more general interest is the fact that Walker's list of "men of science" did not exclude industrialists like Tennant and Watt. Tennant was born in 1768, son of John Tennant, a farmer and Steward to the Countess of Glencairn. He was educated first at home, by his mother, who was described by Walker as a "very able woman".[75] His education continued at a local parish school and after leaving school he worked as a bleacher in Wellmeadow. Having learned this trade, he went on to establish a bleachfield at Darnley, near Glasgow, with a partner, Cochrane of Paisley.[76] Tennant was convinced that the bleaching methods he had used in Darnley could be significantly improved using the study of chemistry, at the time very much in vogue both at home and across the Channel. He began studying chemistry in earnest, with a careful eye on uses for his Darnley bleachfield.

The next part of the story is less clear. It seems that Tennant was inspired by a demonstration of bleaching by Watt in Birmingham in 1787, and began his own studies into the bleaching liquor.[77] Quite how young

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[73] See Hardie (1952) on Macintosh's early training and family background.
[74] See Ibid., pp. 292–295, where the McGrigor–Watt correspondence is discussed in detail.
[75] Walker (1862), p. 187
[76] See the entry on Tennant in the *Dictionary of National Biography*, by Arthur Hardner.
[77] For a mention of Watt's demonstration, see Clow and Clow (1952), p. 186.

Tennant in Scotland came to hear of the demonstrations of Watt in Birmingham is a little uncertain. We do know that Watt was working with his father-in-law, James McGrigor, who was then resident in Glasgow, and it may be that McGrigor and Tennant were in communication with each other. At any rate, Tennant's initial innovation was the use of lime instead of potash, which dramatically reduced the cost and also minimized the damage sustained by the cloth. The basic idea might have been obvious enough, but Tennant was, or at least claimed to be, the first to solve the technical problem of lime's insolubility in water.[78]

One technical problem remained, however. The new product remained unsuitable for long storage, and thus for transport. Tennant and Macintosh arrived at the idea of giving far-away manufacturers licences to use their process for a fee, instead of buying their product. So in 1797 Macintosh undertook a tour of Lancashire, giving demonstrations of the new liquor and offering licences for its manufacture at a cost of £200. The scheme worked very well, for the bleachers reported savings to their own industry of £1,000–£2,500 per year, with the bleach repeatedly proving successful. This is an interesting example of a technical problem being solved by entrepreneurial skill; the licensing scheme was a simple and effective social method for circumventing the storage problem.

Unfortunately for Tennant, Macintosh and company, their brilliant entrepreneurial solution was stymied by a new entrepreneurial problem. In 1798 a group of Lancashire bleachers began to use Tennant's process without purchasing a licence. They claimed that the process pre-dated Tennant's licence, although it was clear that they had not used it themselves previously.[79] Tennant took them to court, but lost. The verdict against Tennant was partly based on the evidence presented by some of the Lancashire bleachers, most notably Robert Hall and Hugh Foy, who had actually had a part in developing the process Tennant used. Tennant pursued his case to the Crown Court in 1802, and lost again. But the legal battles do not seem to have left long-lasting bitterness between Tennant and the Lancashire bleachers, as they awarded him a commemorative plate for his work in the improvement of bleaching.

The outcome of the legal appeal was somewhat immaterial at any rate, as Tennant and Macintosh had in the meantime come up with a

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78 See Musson and Robinson (1969), pp. 321–326, on Tennant's bleaching liquor, and the legal challenge to his patent discussed below.

79 See ibid., p. 323.

different solution to the basic problem. Seeing that the licensing scheme was not as lucrative as they had hoped, they turned back to the application of science. In 1799 Tennant took out a patent for a dry bleaching powder, which was manufactured by the absorption of chlorine gas into dry lime. Therefore a number of historians assert that Tennant was the inventor of bleaching powder, but Macintosh subsequently claimed the invention as his own. In Hardie's view, given the innovative nature of the process (it was "the first gas–solid reaction to be technically exploited") and Tennant's record of somewhat dubious priority claims, it is more likely to have been the work of the highly trained chemist than the entrepreneur.[80]

Regardless of the accurate distribution of credit, the introduction of bleaching powder was a decisive moment in our story. It was instrumental in breaking down the resistance of British bleachers to chlorine bleaching. In order to develop the commercial potential of the new product Tennant established a new chemical works at St. Rollox, just north of Glasgow, which made him an extremely wealthy man. For a brief period (1802–03) Tennant even exported bleaching powder to France, where it was not manufactured until 1819.[81] Bleaching-powder production also helped the revival of sulphuric acid manufacture, alongside new chemical manufactures based on salt and chlorine, enabling Tennant and others to transcend their role as bleach manufacturers to found new chemical industries.[82]

5. Conclusion

There were many difficult technical challenges involved in the transformation of chlorine bleaching from basic science to useful technology. The major innovations included Berthollet's addition of potash to reduce toxicity, Tennant's replacement of potash with lime to reduce cost, and the Tennant–Macintosh invention of bleaching powder to solve the storage-transport problem. It would have been quite difficult for chlorine bleaching to be developed without a certain amount of chemical

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[80] Hardie (1952), p. 610, which also describes how Macintosh ceased to be one of Tennant's partners.
[81] See Smith (1979), pp. 158, 160.
[82] For a comprehensive, if biased, account of Tennant's influence on the broader development of the chemical industry in Britain, see Tennant (1947).

knowledge, but the product that came out of Berthollet's laboratory was very different from the product that bleachers such as Tennant were patenting for large-scale commercial use. It should also be noted that the technological developments were made in the absence of any understanding of chlorine and its properties that modern chemistry would regard as correct.

Our investigations of the origin of chlorine bleaching have also revealed significant and interesting differences between the British and the French contexts. The oft-cited contrast between French state control and British private enterprise is indeed important. However, during the turmoil of Revolutionary re-organization in France the centralized support structure for science and technology generally faltered, leaving the establishment of chlorine bleaching suspended despite Berthollet's considerable efforts. Differences in the general shape of the two economies mattered, too. Compared to Britain, France remained a more agrarian economy, and the Revolution also enhanced the power of the artisan class, which feared that industrialization would undermine their livelihood. Britain was already significantly industrialized, and its workforce adapted more spontaneously to new kinds of employment; new industries in Britain developed in response to consumer demand rather than government initiative.

Overall, the case of chlorine bleaching fully exhibits the complex interactions between science, technology and society. Traditional accounts of the development of chlorine bleaching based on the linear model and technological determinism are shown to be inadequate. First of all, we should recognize that the great impetus for the development of chlorine bleaching was demand: the bleachers felt the push from the linen and cotton industries as their output increased significantly through the last half of the eighteenth century, with a growing mass-market eager to buy the goods produced. And it was scientific–entrepreneurial partnerships that proved successful in developing chlorine bleaching into a usable form, and these close collaborations also resulted in greater acceptance of the new technology amongst textile manufacturers. Such partnerships abounded in Britain during this period and, although not all were successful, they were powerful agents for change which operated substantially through informal provincial networks and not under the auspices of the government or metropolitan societies like the Royal Society.

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