Introduction

Imagine a business whose main products derive from raw materials that are not only inexhaustible, but also free. The vast majority of those products, whether used in manufacturing or in provision of services, whether they are deployed by accident or by design, have no adverse environmental consequences whatsoever. And the companies that make and sell the products are profitable, long-lived, and yet operate outside of the limelight. We all know that things that sound too good to be true usually are. But in this case, the industry exists and, indeed, has existed since the late nineteenth century. Generally neglected by scholars and little known among the general public, the industrial gases industry produces and sells a range of products, many of them simply components of the air such as oxygen, nitrogen, neon, argon, and krypton. These and the other products of the industry in turn underlie every manufacturing process in the modern world and also play a role, directly or indirectly, in many service industries. This is the first time that the story of the development of the "invisible industry" from its origins to the present has been told in its full technological, business, industrial, and international dimensions.[1]

[1] The phrase "invisible industry" comes from a pamphlet produced by an industry trade association. See IOMA, *The Invisible Industry: The Story of the Industrial Gas Industry* (Cleveland, OH: IOMA, 1997). There is one full-length published history of the industry, i.e., Ebbe Almqvist, *History of Industrial Gases* (New York: Kluwer Academic/Plenum, 2003). Almqvist, however, focuses on technical issues and on individual firms rather than on an integrated, archivally based treatment of the development of the industry over time. Other literature focuses on specific companies. See, for instance: Andrew J. Butrica, *Out of Thin Air: A History of Air Products and Chemicals, Inc., 1940–1990* (New York: Praeger, 1990); Hans-Liudger Dienel, *Linde: History of a Technology Corporation, 1879–2004*

Of course, not all stories that have yet to be told are worth telling. But this one is. Even before recent financial and economic crises stimulated heightened interest in business history, management studies scholars were trying to unpack the secrets of firms that have been successful over the long run, companies that some have claimed were therefore "built to last."[2] Exploring the history of the industrial gases industry allows us to push the concept of corporate longevity much further, elaborating on it while at the same time testing its limits. Populated by relatively few firms, the majority of which have lasted a very long time indeed, the industrial gases industry provides a rare case in which it is possible to reconstruct the dynamics of competition and cooperation, of organizational experimentation and consolidation, and of technological development and innovation among the industry's component companies over the long run. But telling this story also allows us to challenge the implicit assumption of many that the companies were "built to last" from their inception. Instead, we look at companies that, building on air as their key product, *constructed* corporate longevity. We also examine closely the dynamics of an industry in which some of the companies that were "built to last" and managed to construct longevity over more than a century suddenly ceased to exist as independent companies in the early twenty-first century.

David Landes, in his classic work *The Unbound Prometheus*, is perhaps the most prominent of many scholars who identify a "Second Industrial Revolution" that began in the late nineteenth century.[3] According to this widely accepted interpretation, the characteristic industries that emerged during this era, in particular organic chemicals and electrical generation and equipment, were very different from those of the first Industrial Revolution, primarily because of their fundamental reliance on theoretical understanding as a prerequisite for technological development and for production. In other words, science was not just useful; it was essential. This meant that scientific knowledge not only had

(Basingstoke: Palgrave Macmillan, 2004); and Jörg Lesczenski; *100 Percent Messer: The Return of the Family Firm* (Munich: Piper, 2007).

[2] Cf. James C. Collins and Jerry I. Porras, *Built to Last: Successful Habits of Visionary Companies*, 3rd ed. (London: Random House Business, 2000).

[3] David S. Landes, *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present* (Cambridge/New York: Cambridge University Press, 1969; 2nd ed. 2003). See also Joel Mokyr, *The Lever of Riches: Technological Creativity and Economic Progress* (New York: Oxford University Press, 1990), especially chapter 6.

to exist before production was possible, but also that scientifically trained personnel were central to production processes. What is more, ongoing research and development were also necessary, which entailed close links with universities. For that reason, before too long, most companies in such industries began operating in-house dedicated research and development laboratories staffed by university-trained scientists and engineers, a trend that started in the German chemical industry and soon spread to other countries and industries.[4]

Although only one generalist historian of economy, business, and technology in the late nineteenth and early twentieth centuries, Vaclav Smil, deals with it at any length at all,[5] the industrial gases industry shares some of the key characteristics of the classic industries of the Second Industrial Revolution. Scientific understanding, for one thing, tended to precede industrial development, often by some considerable length of time. During the late eighteenth century, scientists isolated and identified the two main components of air, oxygen (about 21 percent of the atmosphere by volume) and nitrogen (about 78 percent). Although the potential usefulness of oxygen for medical treatment in particular was recognized almost immediately, medical doctors and scientists did not develop sophisticated and effective oxygen therapies until much later. One prominent exception to this generalization was the atmospheric gas compound known as nitrous oxide (N_2O), identified at about the same time as oxygen and nitrogen, in the late eighteenth century. Most commonly known as "laughing gas," nitrous oxide did in fact find an application fairly quickly, but initially only as a recreational drug for the amusement of a small number of wealthy individuals. It was not until considerably afterward, beginning in the 1880s, that it began to be deployed as an anesthetic.[6]

In other words, there were few commercial uses for the gases at first, although demand for oxygen for "limelight" for the theater grew in the latter part of the nineteenth century. As was the case in the development of understanding, producing, and using electricity, then, the issue was not

[4] See, for instance, Ernst Homburg, "The Emergence of Research Laboratories in the Dyestuffs Industry, 1870–1900," *British Journal for the History of Science* 25 (1992), pp. 91–111; David Noble, *America by Design* (Oxford/New York: Oxford University Press, 1977).

[5] Vaclav Smil, *Transforming the Twentieth Century: Technical Innovations and Their Consequences* (Oxford: Oxford University Press, 2006).

[6] I. O'Sullivan and J. Benger, "Nitrous Oxide in Emergency Medicine," *Emergency Medicine Journal* 20 (2003), p. 214.

just how to generate applications so that there would be markets for the product, but how to manufacture the primary good in quantity and to "package" and distribute it.[7] Arthur and Leon Brin patented one process for producing oxygen in 1880, and it formed the basis for one of the earliest firms established in the industry, Brin's Oxygen Company, founded in Britain in 1886. Twenty years later, Brin's renamed itself British Oxygen Company, or BOC, which already in the early twentieth century was one of the leading firms in the industry, a position it retained into the twenty-first century.

The Brin brothers' process was far too limited in its potential output to allow for a breakthrough into modern, larger scale production. The processes that set the industry standard – based on then-contemporary scientific knowledge and fundamental to industrial gases production technology even now – were developed in the latter part of the nineteenth and early twentieth centuries and involved liquefaction of components of air. Carl Linde was the first off the starter's block with his 1895 patent for a process for liquefying air.[8] The company that exploited the process, named after the German inventor and academic himself, is now one of the largest industrial gases producers in the world. Not longer after Linde's breakthrough, the Frenchman Georges Claude came up with a rival process for air liquefaction. He, too, founded a company that exploited the process, Air Liquide, which is also one of the world's largest industrial gases producers. Both the Linde and the Claude processes were developed by engineers with considerable scientific training. Both used cooling technology and distillation and hence were "cryogenic" processes. Both became commercially viable by the early part of the twentieth century by virtue of additional developments in rectification (air separation) technologies, and variations of them (although with substantial incremental improvements and on a considerably different scale) are still in use today in most of the industry's air separation units (ASUs).[9]

[7] On the scientific, technological, business, and social development of the electrical industry in the late nineteenth and early twentieth centuries, see Thomas Parke Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore, MD: Johns Hopkins University Press, 1983).

[8] German patent number 88824, 5 June 1895.

[9] For an overview, see Linde Engineering, "Cryogenic Air Separation: History and Technological Progress" (2008), available at: www.linde-engineering.com/process_plants/air_separation_plants/documents/L_History_e_100dpi_08.pdf [accessed 14 October 2009].

Still, even as the modern industrial gases industry came into existence at the end of the nineteenth and beginning of the twentieth centuries with the development of production technologies with much larger potential output than the Brin process offered, markets for its products remained limited. Technical breakthroughs in the development of equipment for the use of oxygen and acetylene for cutting and welding and related applications were only just beginning, and it would take some time for the widespread adoption of oxyacetylene torches and welding techniques in a variety of key industries that would make industrial gases, if not yet a big business, at least a healthy and viable one. The three firms mentioned so far – BOC, Linde, and Air Liquide – were at that time still quite small, and, although the latter two had already achieved technological dominance, the three were far from the only players in this still tiny industry.

In the course of the century or so that followed these humble beginnings, things have changed dramatically. Once restricted to limited if sometimes lucrative markets for limelight and some medical gases, the industry now produces specialist gas mixtures for a huge variety of applications in oil refining and recovery, electronics manufacture, hardening of metals, food processing, health care, and steelmaking, just to name a few. There are many companies still active in the industry, but, by 2007, four firms, two American-based and two European-based, accounted for at least two-thirds and by some estimates up to 75 percent of the world market in industrial gases. The four controlled an even healthier share – up to 89 percent – of the European market.[10] All four of them, moreover, counted among the largest in their respective countries, with the two American-based companies ranking in the U.S. *Fortune* 500.[11]

[10] Dr. Peter Vocke, Linde AG, "The world market for industrial gases," presentation in Munich, 8 October 2007; Interview with Aldo Fumagalli, SOL spa, Monza, 10 June 2009. For the 75 percent estimate of global market share for the top four firms, see Thorsten Winter, "Messer-Industriegase für größte deutsche Raffinerie," *FAZ* (15 May 2010), p. 47. Cf. similar estimates of the global market structure for gases at the end of the first decade of the twenty-first century in "Global Analysis: Decidedly Ahead," *Gasworld* (May 2008), pp. 40–42; Francesca Ross, "Global Analysis: Bullish Global Growth in 2007 and Beyond," *Gasworld* (May 2007), pp. 28–30; Nancy Seewald, "Industrial Gases: Another Year of Optimism," *Chemical Week* (3 March 2008), pp. 17–19; Rüdiger Köhn, "Flüchtig, aber grundsolide," *FAZ* (3 December 2007), p. 25.

[11] For 2013 rankings for the United States, see: http://money.cnn.com/magazines/fortune/fortune500/ [accessed 1 November 2013].

How did the industry develop from a group of fringe players into one featuring some of the world's largest companies? What factors explain its internationalization? How was innovation managed and encouraged? What were the business strategies of key firms in the industry, and how and why did they change through time? These are the main questions we explore in the chapters that follow. Before we engage with them, however, we need to delve just a little more deeply into defining just what it is we are investigating – the industrial gases industry and its constituent companies.

Oxygen from the air provided the invisible but quite lucrative foundation on which the industrial gases industry was built, and it and other components of air, including nitrogen, argon, xenon, neon, and krypton, remain the industry's core products to the present day. For this reason, too, the cryogenic ASU remains the industry's central and most characteristic artifact. Beginning in the early twentieth century, other, nonatmospheric gases became part of the product palette of firms in the industry as well, starting with acetylene and eventually extending to single-element gases such as hydrogen and helium, as well as multiple element gases such as carbon dioxide, and eventually including specialist gas mixtures such as Corgon (carbon dioxide and argon) and Varigon H2 (hydrogen and argon).[12] It is important to emphasize, too, that there are a range of gases, technical and otherwise, that have never belonged in this industry, including, for instance, steam, coke-oven gases, and natural gas. Steam and coke-oven gases differ from those produced, sold, and handled by the industrial gases industry by virtue of the fact that they can be produced easily and economically by those who use them without the specialized expertise that firms in the gases industry possess. Natural gas, on the other hand, requires different expertise in exploration, drilling, and other processes that industrial gases companies do not possess.

In any event, unlike many others, this industry cannot be defined exclusively in terms of the products that it produces, sells, and handles. In fact, some companies in the industry, especially the small "mom and pop" firms founded in particular in the 1920s and 1930s to help supply the boom in oxyacetylene cutting and welding, actually *purchase* all of their "product" from owners of ASUs because they do not have the capital necessary for the investment in such hardware. Their *real* product, then, is not the gas itself, but instead often resides in a combination of

[12] Corgon and Varigon are trade names of Linde Group. See www.linde-gas.com/en/products_and_supply/shielding_gases/index.html [accessed 1 November 2013].

gases expertise, logistics capabilities, and related hardware, such as gas cylinders.

However, not only are there companies in the industry that do not produce gases, but the reverse has also been true. Especially in the first two-thirds of the twentieth century, there were major producers of atmospheric industrial gases that had very little to do with that industry. In 1962, for instance, the top five companies in the world producing oxygen gas were, in rank order, BASF (West Germany), Sasol (South Africa), Anic (Italy), and American Cyanamid and DuPont (both USA).[13] None of them was part of the industrial gases industry. All of them had purchased their ASUs from a European company (Linde, Air Liquide, and German-based Messer were the key players here) or from the American-based industrial gas plant manufacturers, such as Air Products or the Union Carbide Corporation Linde Division (later Praxair). The products of these ASUs, however, would have been consumed internally and would therefore not have counted as part of the industrial gases market. This pattern continues to a lesser extent even to the present day, although, as we shall see later in the book, there has been a trend since the 1950s for large companies outside the gases industry to outsource gases supply to firms within it.

In any event, what defines this industry, then as now, is not so much the product it sells to its customers – which is sometimes manufactured by companies outside the industry and which in any case cannot be differentiated from the products of competitors (since, in the end, oxygen of a given purity is still just oxygen regardless of who makes it). Instead, the industrial gases firm as it emerged by the late twentieth century was characterized most fundamentally by the combination of distinctive products, logistical capabilities, and the service it provides to its customers. Here, although products, services, and safety figure more prominently than in many other industries that are involved with transport of goods, logistics do loom large, with the development of other means of distribution in the course of the twentieth century (such as on-site plants, pipelines, and so on) especially significant, although the firms in the industry remain some of the heaviest users of roads in the world.

One important cause of such heavy road usage lies in the profoundly local/regional nature of production and distribution processes in the

[13] Note/Transcript from *Nachrichten aus Chemie und Technik*, 7 March 1962, p. 67, in Corporate Archives of BASF AG, Ludwigshafen [hereafter CAB], G1101-1105.

industry, which in turn constitutes another of its key characteristics. Air, the most important raw material for its core products, is available everywhere, but, owing to the very high weight of cylinders relative to the weight of their contents, evaporation and leakage, and expensive fuel costs of transport relative to the price of the product, it is not economical to transport atmospheric gases, especially oxygen, beyond more than 400 km. And that distance was shorter still through the 1940s due to older cylinder construction technologies and much more limited use of liquid gas transport, which enabled increased distances, but which still had its limits owing to evaporation and fuel costs.

On the other hand, we also need to underscore that the firms in this industry are and were far more than mere shipping and transport companies. Even the smallest company in the industry, after all, must be highly skilled in the distribution of this particular set of products, something that involves considerable expertise in handling and, especially for cylinders but also for liquid transport and storage, a number of specialist safety capabilities. There are other areas of specialized expertise needed as well. If, for instance, a company owns one or more ASUs, as many in the industry (especially medium and large firms) do, it must in addition pay particular attention to capital and energy costs. In 1982, for instance, the Swedish gases producer AGA (which was later acquired by Linde) estimated that the costs associated with an ASU broke down on average as follows: 50 percent capital, 10 percent labor, and fully 40 percent energy.[14] Moreover, the most successful firms in the industry have been characterized by substantial interest in innovation. This often involves working closely with customers – some large, but many quite small – to devise specialist solutions to particular manufacturing or handling problems. Many firms in the industry have also invested heavily in research and development.

Finally, it is characteristic of most of the largest firms in the industry that they not only sell and distribute gases, operate ASUs, and pursue innovation, generally in close collaboration with their customers, but the largest players also generally design and build air-separation plants and related equipment that require extensive specialist engineering capabilities. The pioneers of the modern industrial gases industry, Carl von Linde (he was ennobled in 1897) and Georges Claude, were first of all scientists and engineers, and the companies they founded were first and foremost highly sophisticated engineering firms. These firms only

[14] AGA, *Annual Report 1982*, pp. 8–9.

subsequently developed competences in storage, logistics, and customer service in order to sell the products of their machines and plants. Air Products also started as a specialist plant-building firm in the United States in 1940 and then gradually moved into the gases market itself. Its first forays into the international arena by the early 1950s, initially into the United Kingdom, repeated this process of development, starting first by cooperating with a British engineering firm exclusively to produce plants and then branching out into gases sales and distribution in the UK.[15]

In the chapters that follow, then, one theme that drives the narrative is the tension between the local, regional, and small-scale dictates of production technology, distribution, and customer services, on the one hand, and the internationalizing dictates of large-scale capital investment and technological capabilities, on the other. What are the factors shaping the local/regional dimension versus the international dimension, and how have these changed through time? How have companies managed this tension over time? Along the way, we also consider the role of another tension in the strategy of gases firms: the evolving relationship within leading industrial gases firms between production of plant on the one side and production and distribution of gases on the other. The former is scientifically and technologically challenging but highly volatile in terms of markets and features relatively low profit margins. Production and distribution of gases, on the other hand, tend to be relatively pedestrian in science and engineering terms, yet quite stable in terms of markets and feature relatively high profit margins. How and why have the largest firms in the industry managed these two apparently contradictory businesses, and how has this relationship changed over time?

This book thus covers a complex and ever-changing industry over the course of well over a century. The story we tell involves a number of large players (and many smaller ones) with increasingly international activities and interests, but with the simultaneous need, regardless of size, to produce at the local and regional level and to operate in close

[15] See the Air Products Ltd. company magazine, CryoGen, especially the edition *CryoGen Looks at 25 Years of Air Products* (Walton-on-Thames, 1982); Butrica, *Out of Thin Air*, especially pp. 74–76, 105, 161–164, and 177–179; Interview with Dexter Baker, 28 October 2008, Allentown, Pennsylvania. For a detailed consideration of Air Products' entry in the United Kingdom, see Ralf Banken and Ray Stokes, "'The Trauma of Competition': The Entry of Air Products Inc. into the Industrial Gases Business in Britain and Continental Europe, 1947–1970," *Business History* 52 (2010), pp. 1047–1064.

cooperation with individual customers, some of whom are quite small. We therefore had to make some choices about how best to explore this history; this has involved limitations, some of which have been self-imposed, and some have been imposed on us by constraints of time and other resources. Although many firms in the industry will be mentioned along the way in particular contexts, we will focus our attention throughout on the strategies and activities of the major players in the industry, including AGA, Air Liquide, BOC, Linde, Messer, Union Carbide Linde Air Products/Linde Division (UCC, which later became the independent producer Praxair), and Air Reduction Company (Airco). Moreover, Air Products, as one of the few late entrants into the industry and a firm that was extremely important in shaking up markets in Western Europe in the 1960s and 1970s, will figure prominently as well, while at the same time the Japanese firm Nippon Sanso and its role in Japanese and eventually other markets will also come into the account. This is, in other words, the history of the construction of an industry, but with its dominant firms and their actions at the heart of it. The side effect of this focus is that attention to small and medium-sized firms, which continue to play an important role in the industry, is scant, although there will be some attention paid to some of them, such as SOL in Italy and some others. The concentration on larger firms, though, has the benefit of allowing detailed investigation of the interplay in strategy, innovation, and action among the largest players in what was from the beginning an oligopolistic industry. It also enables analysis of the processes of consolidation (primarily through acquisitions) and increasing levels of internationalization that took place within the industry, especially since the 1970s.

A second choice we made in order to provide coherence and focus to the narrative has been to concentrate primarily on the operation of these firms in markets in Western Europe and the United States, although Japan and its markets, followed by China and other emerging industrializing countries, will form an increasingly important part of our story as well, especially in later chapters. We decided on this general limitation because we need to focus on key developments throughout the entire history of the industry's development. There is no question, for instance, that until after the Second World War, Western Europe, the United States, and, increasingly more so, Japan, were by far the most important markets in the world, and they remain among the most significant to the present day. What is more, these markets developed differently from one another in important ways, and detailed exploration of developments in them will enable sustained consideration of the relationship between the