

# Manufactured Gas Plant Remediation



## A CASE STUDY

Allen W. Hatheway  
Thomas B. Speight

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*Dedicated*

*To*

***Leon John Willien***

*(1885–1945)*

*B.S. Ch.E., 1910, Rose Polytechnic Institute*

*And*

***Judith Speight***

*(1944–2017)*

*Mother, Teacher, and Friend*



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# Preface

The manufactured gas industry was a going concern more or less worldwide for a period of nearly two centuries. During this period, the industry evolved steadily and often quite rapidly, as gas was manufactured for a wide variety of uses, and while it was learned that gas could be made from virtually any naturally occurring natural organic material, coal was the most commonly employed for the first one hundred years. Eventually, coal gas production volumes were outstripped by the carburetted water-gas process and also by later versions of oil gas, and the introductions of surplus oil refinery residuals such as propane. Today's environmental remediation of derelict gasworks requires careful historic operational research into which of the considerable number of gas-manufacturing processes were utilized at a particular derelict site, since the various historic processes can leave differing types, quantities, and locations of contaminants.

As convenient as the term “manufactured gas” can seem, it is nonetheless problematic. This term became prominent mostly at the end of the gasworks era in order to distinguish the various types of gas made from coal or other materials from the “natural” gas, which had previously been restricted to the Midwest where it was available, but which pipelines built to support the industries of the Second World War could now carry to the nation's other industrial centers. Nineteenth- and twentieth-century gasmen—the engineers, chemists, laborers, tradesmen, regulators, and businessmen who made the production and supply of gas their trade—referred to it in their professional writings as coal gas, blue gas, water-gas, carburetted water-gas, illuminating gas, combustible gas, fuel gas, and in scores of other ways, but generally not as “manufactured gas.” Their consumers commonly called it city gas or town gas. Either group could as easily refer to the product of a gasworks simply as “gas.”

In Massachusetts, the “gasworks era” essentially began with the first launch of the Boston Gas Light Company in 1823, although it did not actually produce any gas until 1829. The era came to a rather abrupt end in the 1950s, with gas companies taking advantage of the sudden advent of natural gas in Massachusetts. Some gasworks lived on in a sort of twilight for roughly another two decades, retained in auxiliary roles for dealing with sudden peaks in demand.

The gas industry also helped to fuel the rise of the modern global chemical industry, with its tar and other residuals, when sold as by-products, providing the raw materials for pharmaceuticals, laboratory reagents, explosives, fertilizers, antiseptics, and even graphite for pencil leads, to name but a few of the hundreds of finished chemical derivatives. Inevitably, some of these residuals went to waste and were released to the environment, whether through conscious and routine disposal of waste materials, through leaks from plant equipment, or from discharges of wastewater to the soil or to ponds or streams.

The gas industry in Massachusetts came of age in the 1840s and early 1850s, during the same era as the initial generation of public water and sewer systems. Although sewer systems lagged behind water and gas systems, all three were driven by much the same reason—rapid urbanization on an unprecedented scale, driven primarily by enormous industrial growth. Indeed, Boston and many other cities and towns had gas service before they had municipal water service. For example, Boston had gas service beginning in 1829, but a regular public water supply system was not established until the opening of the Cochituate Aqueduct in 1848. The London water supply companies, particularly the New River Company established in the early seventeenth century, provided the distant ancestral model for the infrastructure of later utilities, including early gas companies, as discussed by Leslie Tomory in his *The History of the London Water Industry, 1580–1820*.<sup>\*</sup> In the practical sense, however, as water, sewer, electrical, and other utility services developed in the United States, these services were modeled more or less explicitly on the gas industry's later and more evolved

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\* Tomory, L. *The History of the London Water Supply*. Baltimore, Johns Hopkins University Press, 2017.

example, with long-term planning for infrastructure, schedules of standard fees, municipal contracts or ownership, regulatory oversight to ensure quality of service, and the like.

These three services, water, sewer, and gas, rapidly became part of the indispensable infrastructure of the Massachusetts city. While the sewer systems were usually left to the municipalities of the day to manage, mismanage, or ignore, during this period, water and gas were in the 1800s generally provided by private business ventures, “public utilities” only in the sense that they would serve those members of the public who could afford it. The richest market for gas in the state—and one of the richest in the country—was metropolitan Boston, which was at the time one of the nation’s great centers of industry as well as finance and international trade. The balance of the state, however, included several large cities such as Worcester, Fall River and Springfield, and several dozen substantial manufacturing towns such as North Adams, Taunton, and Webster, nearly all of which had at least one gasworks.

While primarily an urban undertaking, the gas industry was not limited solely to large cities, and found fertile soil outside of the major urban areas in smaller towns and “factory villages.” Massachusetts, in general, was the national model for dispersed industrial activity during the Industrial Revolution, with small factory villages founded at what seems like every useful river or stream site with a waterfall or enough flow and velocity to warrant the investment in a dam and works to convert water power into mechanical energy. By the 1850s, manufactured gas technology had evolved to the point that small private gasworks and gas “producer plants” could be used to power sites where water power was not available, and to fuel processes for which water power was not a suitable power supply. By the 1880s, many of these factory villages had their own gas companies, however, large or small.

Today’s environmental remediation of derelict gasworks, driven by risks to public health and ecological resources, requires careful historic operational research into which of the considerable number of gas-manufacturing processes were utilized at a particular derelict site, since the various historic processes can leave differing types, quantities, and locations of contaminants.

This is not a trivial issue, for a lack of attention to establishing the operational history of a derelict gasworks, or of a long-demolished and abandoned or repurposed gasworks site, invites mistakes in the planning and implementation of a remedy. These mistakes can produce lasting effects, since most gasworks-related contaminants such as coal tar or cyanide compounds do not degrade except on a geologic timescale, and remain dangerous to human health and ecological resources at and near former manufactured gas plant (FMGP) sites.

Legal and financial responsibility for the contamination of former gasworks and related sites—if not formal “Potentially Responsible Party” status under environmental laws—commonly but not invariably devolves on the utility companies which are frequently the corporate successors of the gas companies that operated the gasworks, either because the utility still owns the former gasworks and uses it for other purposes, such as an electrical substation, or because environmental laws and regulations or civil litigation provide successor property owners with recourse against the entity that “made the mess.”

The same need for “full disclosure” of historic site features is equally important to on- and off-plant gasworks dump sites, areas of discharge of toxic gas liquors (wastewaters), dumps of unwanted gashouse residuals and wastes, such as tar, tar oils, ammonia, naphthalene, purifier box wastes containing cyanides, heavy metals and some tar oils, formed the basis for subsidiary industries that fueled the revolution in industrial chemistry during the late nineteenth century. These materials were generally known by the gas industry and related industries during the nineteenth century to have potential toxic effects.

Our book attempts to bring forth the history of all of these influences in the Commonwealth of Massachusetts, and to knit these elements to the physical and geologic nature of the state, for gas-making’s are toxic to the natural environment and to human health. We hope that the reader will be aware of the single most important aspect of derelict manufactured gas and coal tar sites as an environmental imperative; the associated residuals and wastes are toxic to animal, plant, and human life, and, once discharged to the ground or to bodies of surface water or ground water, are virtually indestructible by way of natural earth processes, creating threats with half-lives measured

in geologic time. Several of the more common polycyclic aromatic hydrocarbon (PAH) compounds present in coal tar, such as benzo(a)anthracene, benzo(a)pyrene, and dibenzo(a,h)anthracene, have been identified as carcinogens or as promoters of cancer.\* Additionally, the basic chemical structure of the coal tars is complex, potentially including between from 500 and 3,000 distinguishable PAH compounds, plus hundreds of other potential organic and inorganic impurities; all variable for each instance of gas production, being as short as hours or days in duration.

Our main purpose in compiling this book was to bring of to the ongoing public health and environmental challenges of “coal tar”-related contamination found across a state with a historically prominent manufactured gas industry. To that end, our goals were threefold. First, we wished to recount in at least a broad overview of the history of the manufactured gas industry in Massachusetts for its own sake, since this complex and interesting story has effectively never been told.

Secondly, we hoped to provide a historical and technical reference for those remedial engineers, scientists, and environmental regulators who work with gasworks and other coal tar sites as they are in the twenty-first century, which for the most part revolves around the assessment, remediation, and redevelopment of environmentally contaminated land.

Thirdly, on account of recognition of the real “environmental risks” associated with coal tar cleanup, we discuss historic and modern technical knowledge associated with the history, operation, assessment, and remediation of gasworks and other coal tar sites. The awareness of which, the authors hope, will assist in mitigating risks to human health and the environment. This book will hopefully fill some gaps in the knowledge on all accounts, as well as to ensure some degree of open discussion over how site and waste characterization is conducted.

To that end, we begin with a discussion of the things at the center of the industry, the making of gas and the nature and operation of gasworks, before expanding our discussion outwards to discuss the history of gas companies, some of their trials, tribulations and business practices, the historical regulation of the gas industry in Massachusetts, health or environmental problems associated with the gas industry during the nineteenth and early twentieth centuries, the uses of gasworks by-products, the health and environmental hazards posed by toxic by-product residuals, the regulatory framework for gasworks in the post-1970 “environmental era,” and some of the challenges and strategies associated with the remediation of gasworks.

While the most comprehensive part of our discussion deals with gasworks, we also discuss tar refineries, gasworks waste dumps, producer plants, and other gas-related facilities in considerable detail, and our discussions and conclusions regarding human and environmental hazards encompass these sites as well as gasworks.

While the contents of this book focus on the manufactured gas industry’s history and environmental legacy in Massachusetts, the sense of the authors is that in these respects Massachusetts is a microcosm and representative example of the worldwide historic manufactured gas industry, and that the lessons learned in Massachusetts have global relevance.

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\* Agency for Toxic Substances and Disease Registry, Toxicological Profile for Polycyclic Aromatic Hydrocarbons, August 1995.



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Hatheway is from an early family (1638) of the Commonwealth and resided at Belmont and practiced at Cambridge in the 1970s and 1980s, and holds a Massachusetts Professional Engineer's license.

Speight is a native son who has turned his academic background and fascination with regional history into a hands-on environmental remediation career. Speight is a native of the Springfield area, specializes in site assessment and remediation, is registered as a Certified Hazardous Materials Manager, and takes an avid interest in investigating historic industrial processes and facilities. Speight would particularly like to thank Peter Levesque, late of Pioneer Environmental, Inc., Valerie Tillinghast, LSP, for critically reviewing drafts of several chapters, without which this book would be much the poorer, Kevin O'Reilly (for the constant reminders about beginning with the end in mind) and the other staff of O'Reilly, Talbot & Okun Associates, Inc., Gary Weiner, PE, for some of the best advice a young engineer could hear, Dr. Philip Pajakowski, Dr. Francis Mason and the late Professor John Windhausen of the History faculty at Saint Anselm College for their mentoring and encouragement during his education and employment, and James Buckley for endless informal lessons in utility plant operations. Speight also owes boundless gratitude to his parents, Edward and Judith Speight, and to Allison Terry for putting up with him during this process and for general aiding and abetting, to Bryan Karsis, who helped with everything to do with the North Shore, Stephanie Godin for help sorting out maps of Boston, and especially the final proofreading, to Heather Spaulding and eternal thanks to John Wardle, Grant Sharkey, Michael Watt, and John G. Mellor for general inspiration.

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Hatheway has practiced for 57 years and holds American licensure as a Civil and Geological Engineer, Geologist, and Engineering Geologist. He has held command leadership in the Association of Environmental and Engineering Geologists (AEG) and the Engineering Geology Division of GSA and is a Fellow and Life Member of ASCE, a Fellow of the Geological Society (London) and is a retired Colonel of Engineers (United States Army).

**Thomas B. Speight** has practiced as an environmental consultant in Massachusetts and neighboring states for the past 13 years, with experience in site assessment, remediation and redevelopment, including former manufacturing facilities and Brownfields. Speight is a Certified Hazardous Materials Manager and provides business, industrial, and institutional clients with consulting services for wastewater, air emissions, hazardous materials storage, and waste management. He holds a bachelor's degree from Saint Anselm College in Manchester, New Hampshire.



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# *Section I*

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## *Fundamentals of Manufactured Gas*



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# 1 Gas and Gasmaking in Massachusetts

What's past is prologue.

**William Shakespeare**  
*The Tempest, Act 2 Scene 1*

Massachusetts was the setting for the most diverse application of competing gas-manufacturing processes in the nation. This situation is not surprising; the Commonwealth was the first tightly organized manufacturing economy of the nation, and its degree of urbanization was intense, requiring gaslighting both for quality-of-life purposes and for factory lighting, and later, for its primary 20th century use as a domestic and industrial heating fuel. Money was plentiful in the Commonwealth and it was coupled with the combined infusion of trade, technology, and culture with Great Britain and Europe. The result was a considerable variety in gasmaking processes, each one having the potential to leave a different hazardous environmental imprint on each site. To further complicate matters, many gasworks employed more than one process, either simultaneously or in succession, each with a variety of forms and quantities of residuals and wastes waiting to be discovered below and around each of today's derelict gasworks sites.

## 1.1 INTRODUCTION AND OBJECTIVE

In this chapter, we introduce the variety of gasmaking processes, the general development of the manufactured gas industry of Massachusetts, and the sources of their toxic residues that today plague their derelict sites. The best appreciation of the history and of the environmental threat of bygone manufactured gas plants and of their toxic residues, is to anchor a first impression on the types of manufactured gas that have been employed in Massachusetts. This story varies from state to state and country to country, in terms of the magnitude of effect of each gas process, and so here is how we see the interplay between the various processes. While today's toxic threat uniformly represents severe threats to humans and to the environment, and, in all cases calls for rigorous and continued attention, there are distinct differences in how these threats impact public health from place to place.

The gas industry in Massachusetts employed a wide variety of processes over its 150-year history. In roughly chronological order, the major processes included:

Wood gas (also known as resin gas; rosin gas) (1820s–1840s)

Coal gas (1820s–1950s)

Early animal and petroleum-oil gas (1820s–1840s)

Spirit gas (gasolene gas) (1850s–1950s)

Water-gas also known as “blue” water-gas or “fuel gas” (1880–1950s)

Carbureted water-gas (CWG) developed by T.S.C. Lowe in the 1870s, patented, and later widely marketed by the United Gas Improvement Company of Philadelphia (c1880–1885, 1890–1950s)

Candle power-enriched coal gas (mid to late 19th century)

Hydrocarbon-oil-enriched water-gas (attempts to circumvent the Lowe patents for CWG) (c1880–1885, 1890–1950s)

Coke-oven gas (1899–1950s)

Acetylene gas (1900–1920)

- Producer gas (1890s–1960s)
- Second-generation high-Btu oil gas (1930s–1960s)
- Substitute natural gas (1930s–1960s)
- Reformed refinery gas (1930s–1960s)
- Synthetic natural gas (1930s–1960s)

Of these, coal gas and CWG were used most extensively, with the latter type coming to dominate the gas industry in Massachusetts between the mid-1890s and the late 1940s. An example of a coal gas process chain is shown in [Figure 1.1](#). Oil gas, in which oil was used instead of coal as the process feedstock, appeared in two distinct forms. “Early” oil gas had a heyday among about a dozen small communities in the late nineteenth century before being eclipsed by CWG, and the more sophisticated “second-generation” high-Btu oil gas appeared in the late 1930s and 1940s.

Appendix A includes tables that present the general types of manufactured gas process that have been employed in Massachusetts, the general chronology of their employment, and a sequence of major gas industry-related historical events.

## 1.2 NAVIGATING THE GAS-MANUFACTURING PROCESSES EMPLOYED IN MASSACHUSETTS

Despite the wide variety in the size, layout, and process structure of gasworks during this period, particularly with respect to changes over time, some common features remained constant. Appendix B includes selected examples of images depicting gasworks site layouts.

Each gasworks had at least one *retort house* or *generator house* as shown on [Figure 1.2](#), which respectively housed the coal gas retorts or the water-gas or CWG generators. These were the most crucial structures at the gasworks because they were where the gas was actually made. These buildings were decidedly Spartan affairs, with massive brick masonry walls, unadorned structural ironwork, simple slate-shingled monitor roofs for ventilation, and naturally far more thought given to fireproofing and durability than to aesthetics or comfort. Still, some thought was occasionally spared for ornate exterior brickwork, as seen on the façade of the retort house at the Boston Gas Light Company’s Commercial Point gasworks ([Figure 1.3](#)). The Amesbury Gas Light Company’s generator house ([Figure 1.4](#)) is by contrast decidedly humble.

Separate structures—at least one, and as many as seven or eight—housed the apparatus for clarifying and purifying the gas by various means. *Clarification*, followed by *purification*, involved separating tar and other atomized particulate impurities, and liquids from the gas, along with the removal of undesirable gases such as hydrogen sulfide (*sulphuretted hydrogen*, in the parlance of the day) and ammonia. These devices were referred to variously as *condensers*, *washers*, *scrubbers*, *washer-scrubbers*, *purifier houses*, *purifier boxes*, *clarifiers*, and the like.

*Gasholders*, the most visible symbol of the gasworks era, were large, cylindrical water-sealed storage structures for the finished gas; every gasworks had at least one and most had a minimum of two. The gasworks was also a maze of aboveground and underground plumbing, including gas mains, water and wastewater pipes, sumps, valves, drains, meters, tanks, tar wells, and other structures.

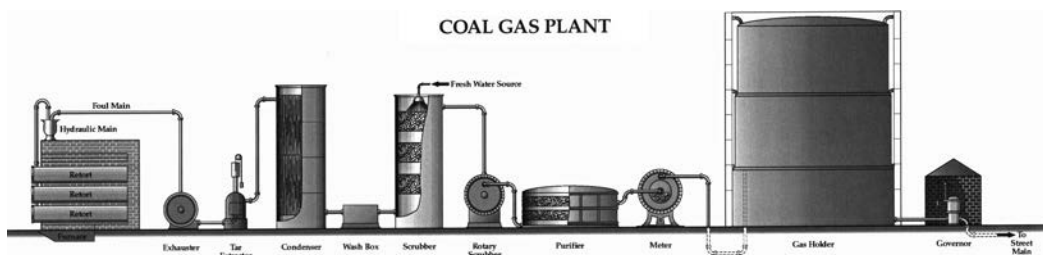
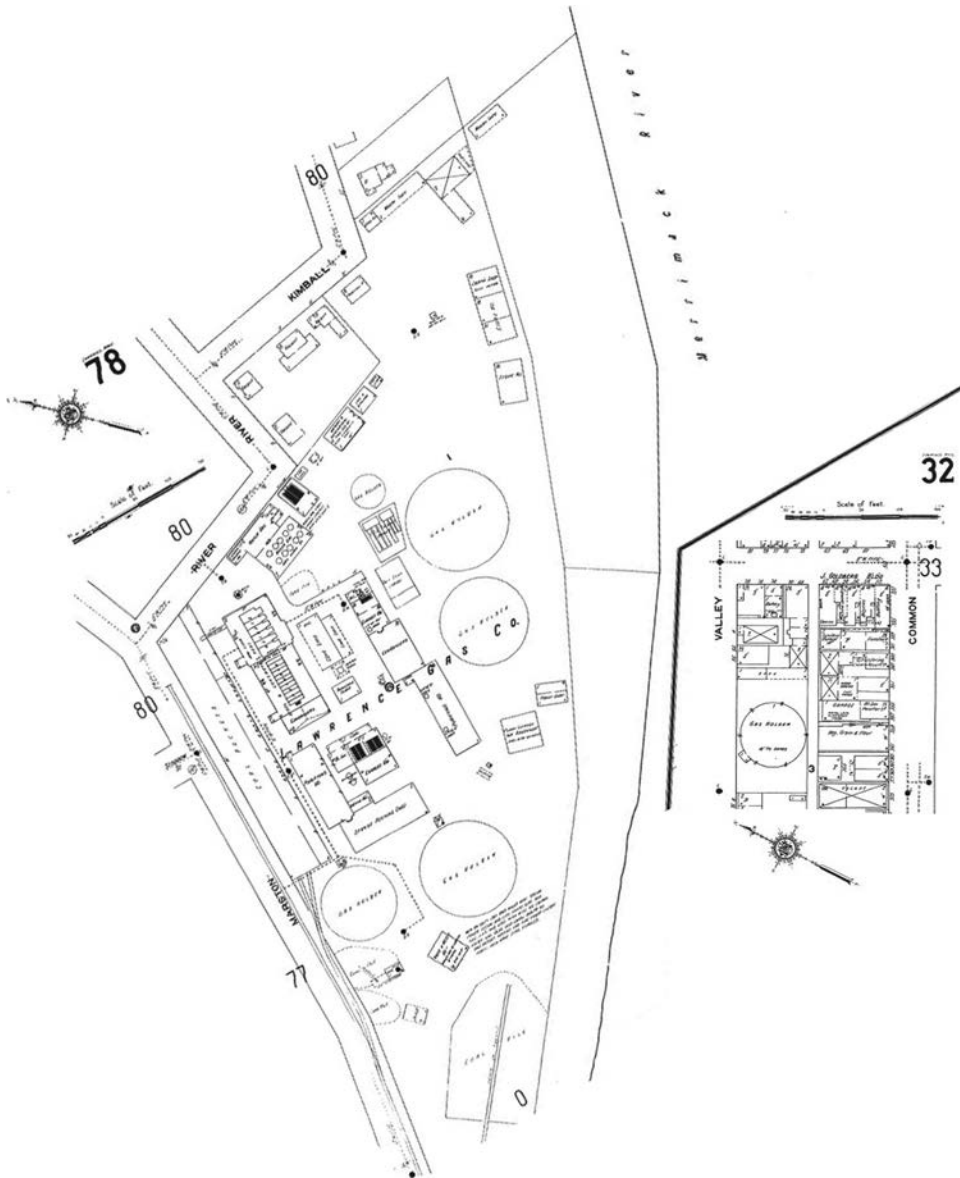


FIGURE 1.1 A typical coal gas manufacturing process chain.



**FIGURE 1.2** A historic layout of the Lawrence Gas Light Company’s plant, after a 1911 Sanborn map.

These basic components—the retort house, the clarification train, the purifiers, and the gasholders—were the main infrastructure of a gasworks. In addition to these, however, there would often be buildings for meters and governors to monitor and control gas pressure and flow, office buildings, pipe-fitting sheds, machine shops and other workshops, an extensive coal yard, stables, a railroad siding or wharf for taking deliveries of coal, and almost invariably a large boiler plant to supply steam or hot water for innumerable purposes around the gasworks, and living quarters; it was common for the plant to have at least an apartment (if not a house) for vital staff such as superintendents, and some works (notably Boston Gas Light Company’s Commercial Point plant) also had barracks for less exalted personnel. A small gasworks in a town such as Amesbury might have only a combined water-gas generator house and office, purifier building, and gasholders in a yard less than an acre in size, but a large gasworks could extend over several city blocks and include dozens of large structures (Figures 1.5 and 1.6).

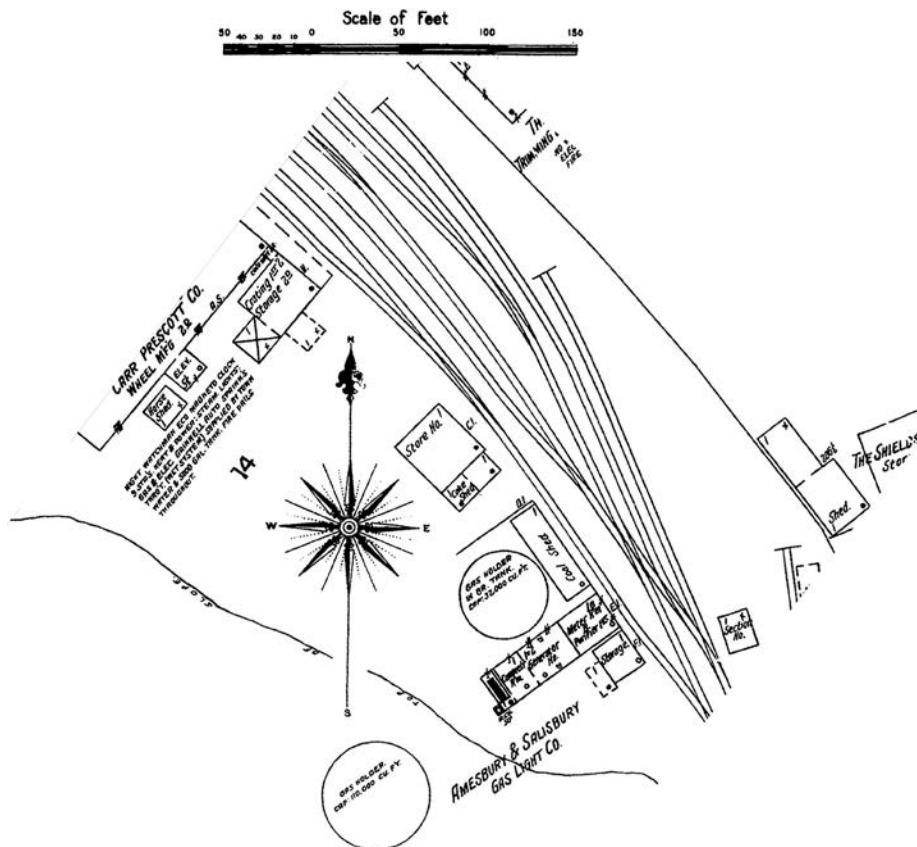


**FIGURE 1.3** Exterior view of the Commercial Point gasworks retort house in Dorchester, 1887.

Any or all of these structures could be—and most likely were—altered, added onto, and replaced at some point, since many individual gasworks remained in constant use for nearly a century, and most for well over 70 years. The degree to which some aspects of the industry changed over time is illustrated in the first chapter of George Wehrle’s 1919 *American Gas Works Practice*, an instructional manual for gas engineers and other people involved in the industry. Unlike most gas manuals, which tended to focus strictly on the engineering aspects, Wehrle’s first chapter was a survey of the



**FIGURE 1.4** Exterior view of the Amesbury Gas Light Co. generator house. (Barber, Earl H. *Report on the Amesbury and Salisbury Gas Company, January 5, 1920*. Baker Library Historical Collections, Harvard Business School. Earl H. Barber Papers, Vol 1 Case 14.)



**FIGURE 1.5** Sanborn map—a map showing a small CWG plant, in this case the Amesbury and Salisbury Gas Light Company’s plant.

industry’s history, then about a century old, and juxtaposed pictures of past and present gasholders, coke-handling equipment, retort operations, and even business offices to convey how much the gas industry had grown in even a few decades.<sup>1</sup>

A large gasworks would often attract related industries making use of some of the gas-generation residuals, and would also spawn dumpsites for the unrecovered portion of the residuals, the outright toxic wastes, the toxic gas liquors, and the inert solids of production-damaged gasworks bricks, ceramics, as well as plant trash.

As it is, an accurate assessment of a derelict gasworks requires a *site and waste characterization* based on a proper identification of these components, understood in the sense of the process flow and, be of all, the manner in which the toxic residuals and wastes were typically handled and managed, to include the location of gas-liquor waste effluent discharge points and the location of the *gasworks dumps*.

During the early years of gas manufacturing in the United States, the method of manufacturing and feedstock selection was largely governed by two main infrastructure factors:

1. Local availability of gasmaking feedstock
2. Its transportation from source to gasworks

Gasmaking began in the United Kingdom with coal, but Massachusetts’ native coal resources are limited to meager strata (measuring from mere inches to 23 feet in thickness) of poor-quality material



**FIGURE 1.6** A 1912 L.J. Richards map showing the Springfield Gas Light Company's works. (L.J. Richards & Co., Atlas of the City of Springfield and the Town of Longmeadow, Massachusetts, 1910, plate 1. Map courtesy of the State Library of Massachusetts.)

(too low in the volatile content necessary to yield gas, or even to be good fuel) underlying parts of Bristol County, and under parts of Plymouth and Norfolk Counties, as well as parts of adjacent Rhode Island, deeply buried under a vast sandy plain with few outcrops.<sup>2</sup> Aside from its difficult topographic/structural exposures, the coal is a poor sort of anthracite, some of which is known to approach graphitic slate. This coal was long conceded to be a wholly inferior gas coal incapable of economic competition with the early imports of coal from Nova Scotia, Appalachia, and Newcastle, England.

The lack of good coal did not noticeably hinder general economic development prior to the middle of the nineteenth century; timber was abundant and provided adequate fuel for most processes, either as wood fuel or as charcoal. As industrial processes became more sophisticated and technologically demanding, the increased use of steam engines for railroads and stationary steam plants rapidly exhausted the timber supply and forced New England businessmen to turn to alternative fuels.

Gas generation in Massachusetts began with wood (such as pine “fatwood”), shale oil, or even whale oil for gasification feedstock, but the real boom of the industry came in the 1840s and was fueled overwhelmingly by coal. Gasworks located along the integrated rail net could then receive the gas coal (particularly bituminous varieties containing volatile content already known for superior qualities in gasmaking). By the 1840s, Massachusetts was steadily importing large quantities of coal on a continuous basis. Much of this coal came by sea, whether from the United Kingdom, Nova Scotia, or up the coast from Virginian or Pennsylvanian ports supplied by Appalachian mines. The Boston and Worcester Railroad, the Western Railroad, the Grand Junction Railroad in the Boston area, and

several others were fully up and running by the late 1840s, and allowed coal to be rail shipped from newly developing coalfields, away from navigable waterways. As coal became more readily available, industries sprang up to make use of it.

Perhaps rather surprisingly, the need for specialists familiar with gasworks was not usually a significant handicap. Beginning during the 1830s and 1840s, the availability of itinerant journeymen gas engineers and consulting firms specializing in gasworks design and construction, notably Boston's own prolific but short-lived Blake and Darracott, formed in 1848, and the appearance of a professional literature of technical journals contributed to the rapid spread of gasworks technology.<sup>3</sup> Gas engineers from the United Kingdom, whether visiting as consultants or as permanent emigrants, played an important role in the early decades of the gas industry in the United States.<sup>4</sup>

While the complex parts of a gasworks (e.g., the ironwork of a gasholder or the firebrick of retorts) required special manufacturing, most of the plant could be built of relatively standard and readily available building materials, such as mortar or concrete, bricks, and iron pipe using local laborers and craftsmen directed by a specialist engineer. Lack of specialized knowledge was therefore not usually a severe handicap in the development of gasworks outside major urban areas; if local specialists were not available, the experts could be brought in on contracts or simply hired away from existing works, as was the case during the establishment of the Worcester Gas Light Company during the 1850s.

In the early days of the industry, many university professors of the sciences also found themselves caught up in the gas industry in some capacity, for chemistry in the early nineteenth century was almost entirely of the applied sort, and segued readily into chemical engineering. Benjamin Silliman Jr. of Yale was one such, although he is likely better remembered for his expert witness work and his poor advice to mining concerns. At the other end of the spectrum, the Commonwealth's first Inspector of Gas Meters was the formidable polymath William Barton Rogers, a professor of chemistry, geology, and physics and the founder of the Massachusetts Institute of Technology, whose last words before expiring during a speech at MIT's 1882 commencement were "bituminous coal."

Where actual experienced "gas engineers" could not be found (whether "practical" men who learned on the job or "graduate" engineers who had attended college), new ones could sometimes be trained up from nothing. The nascent English and American professional engineering discourse produced several generations of learned treatises, manuals, and guidebooks on gas engineering that could be used by both experienced professionals and dilettante novices alike. This bootstrapping process became less common in the later nineteenth century, with the growth in engineering education in the United States after the Civil War to support manufacturing and civil developments.

The first of these gas engineering manuals was Friedrich (anglicized to Frederick) Accum's *Practical Treatise on Gas Light*, published in at least four editions in English, German, and French) between 1808 and 1820, which helped spread gasmaking technology outside of its original London enclave. The last of the influential publications was arguably Jerome J. Morgan's *A Textbook of American Gas Practice*, published in 1931. One particular publication, William Boughton King's *Treatise on the Science and Practice of the Manufacture and Distribution of Coal Gas*, published in three editions between 1871 and 1913 and often known simply as "King's Treatise," served as the primary reference of the gas industry in the English-speaking world and well beyond for a good half century. Literally hundreds of other, less all-encompassing books were also published on more focused topics, such as Samuel Wyer's 1906 *Producer-Gas and Gas Producers*.

Gasworks manuals of this sort were intended to be self-contained references for the aspiring or practicing gas engineer, whether the "practical" engineer (self-taught or with knowledge gained through work experience) or, after the 1861–1865 Civil War, the college-educated "graduate" engineer. These manuals typically covered in at least broad strokes all the major aspects of operating a gasworks, from coal handling and selection through design of gasholders and retorts, the quality control testing of gas in a chemist's laboratory, and general business management. Large gas companies often had departments for each of these facets of the gasworks' operations, but many small-town gas companies had staffs consisting of only a few laborers plus a superintendent who wore a

great many hats (including engineering, bookkeeping, marketing, and distribution), and who likely spent a great deal of time checking his well-thumbed copy of King's Treatise.

For the self-improving "practical" engineer, several institutions offered home-study courses in gas engineering and distribution. The best known of these was the "Catechism of Central Station Gas Engineering," sponsored by the American Gas Light Association through its Trustees Gas Educational Fund, and offered between 1899 and the early 1920s under the leadership of A.E. Forstall. This course of study was tailored to the upwardly mobile technical staff of a gas company, and was sufficiently comprehensive that it even included a section on resuscitating persons overcome by gas fumes. After the cancellation of this program in the early 1920s, Columbia University took up the gauntlet with a two-year, 24-lesson program developed by the noted Jerome J. Morgan, then a Columbia University professor of chemical engineering and one of the most influential gas engineers of this day.<sup>5,6</sup>

### 1.2.1 WHY GAS PROCESS IDENTIFICATION MATTERS SO MUCH IN REMEDIATION

For a given FMGP site, the owner's choice of gas-generating process sets the stage for the general layout of the gasworks, of its process flow, and with it the characteristic gashouse residuals and wastes that were generated in accordance with the usual nature of each gas-manufacturing process. For this reason, [Tables 1.1](#) and [1.2](#) serve to portray our sense of detection and to chronicle the appearance, duration, and demise of each of the processes that we believe to represent the creation and general nature of the toxic residues and wastes from gasmaking in Massachusetts. [Table 1.1](#) establishes the processes of gasmaking in a chronological sense; [Table 1.2](#) deals with important changes and innovations in the technologies of gasmaking; many of which overlap, between the various processes. The authors note that there were literally hundreds of different processes for making gas, some of them quite innovative and others "mutton dressed as lamb," while others existed mostly on paper. [Table 1.2](#) presents those of which the authors are aware, including the ones that entered widespread use, but others likely exist.

During this time, there were dozens of different base processes for manufacturing gas, worldwide; most of them were variations on four basic methods: coal gas, oil gas, water-gas (also known as "blue" gas, suitable only as a fuel gas), and the "carburetted water-gas" process developed and patented by the pioneering gas engineer T.S.C. Lowe in the 1870s, an influential process, which set the standard in quality, efficiency, and reliability for gas manufacturing after the 1880s and which was not only widely marketed by the United Gas Improvement Company of Philadelphia, but also just as widely imitated, often well past the point of patent infringement. CWG could be used as both an illuminating gas and a fuel gas. The proliferation of variant processes, most of which appeared during the late nineteenth century, appears to be due, in equal part, to innovations by plant gas engineers, who often had to design their own equipment, and the desire either to obtain or to circumvent an existing patent on a specific process, for example, the innumerable spins on the CWG process intended to circumvent T.S.C. Lowe's patents, notably including the so-called Flannery process installed by the Bay State Gas Company in 1888, at its then-new gasworks on made land at the end of the Calf Pasture peninsula in the Dorchester portion of lower Boston Harbor. The Flannery process was a dual deception, imported from New York City, with the twin apparent goals of avoiding the perception of the Commonwealth's effective ban on "water-gas" and putting in place a Lowe patent-skirting oil-enriched CWG plant.

[Table 1.1](#) presents a rough sequence of the various gasmaking processes used in the Commonwealth. A summary of other technological developments is included in [Table A.1](#) in Appendix A.

### 1.3 WOOD GAS (ALSO KNOWN AS RESIN GAS, ROSIN GAS, FATWOOD GAS)

The first Massachusetts feedstock was "rosin" or the resinous portions of timber, most likely evergreen from the western part of the state or Maine. Similarly, resinous "fatwood" from the heartwood of pine trees was contemporaneously used in early MGPs in the Southern United States in a similar capacity. By the mid-1830s, the first state-spanning railroads and canals were completed

**TABLE 1.1**  
**Sequential Employment of Gas-Manufacturing Processes of Massachusetts**

Dates	Process Name	Usual Application	Remarks
1828–1830c	Wood/rosin gas	1828: First of any gas produced in Massachusetts Commercial town lighting gas	1760: Douglass (pp. 62–64) reports thriving wood rosin industry in New Hampshire. <sup>168</sup> Wood varied by species in its gas output. Rosin was the favored gas retort feedstock.
1830c	Coal gas	Commercial town lighting gas	Believed to be the first arrival of English gas coals to Massachusetts.
1830–1850	Early oil gas Whale oil; some mineral oil	Commercial town lighting gas	1830: Roasting of natural oils, such as whale oil, by the (whale) Oil Gas Co., Bankside Works River Hull, Hull, England. <sup>170</sup> 1852c: Dr. Abraham Gesner produces “coal oil” from keragenous shales of New Brunswick.
1850–1890	Coal, oil, and petroleum oil gas	Small-town commercial illuminating gas Yields of 1590 cf per 100 lbs. Pennsylvania crude oil	Typically generated in horizontal iron retorts filled with lumps of fire brick, with raw gas mixed with steam passed over red-hot charcoal. Coastal ship traffic brings in crudely-refined petroleum from NE Pennsylvania.
1860s–1894c	Oil-enriched water-gas	Commercial town gas	<ul style="list-style-type: none"> <li>• Developed as commercial illuminating gas.</li> <li>• Large number of Lowe-patent-skirting processes (1873–1894).</li> </ul>
1860c–1900c	“Spirit” (also known as “gasolene”) Gas plants; mainly for illumination	Early gas-lit hotels Institutions Mansions Military posts Various remote places such as lighthouse	<ul style="list-style-type: none"> <li>• Began with production of “light oils” from early fractional refining of America’s first oil, from NE Pennsylvania.</li> <li>• Popular in areas outside of commercial gas distribution territory.</li> </ul>
1870–1890	Petroleum oil gas, Massachusetts	Commercial illuminating gas broadly available in Massachusetts	1870: The year in which most Massachusetts towns featuring gasworks were reachable by Pennsylvania refined petroleum, as well as external gas coals. 1890: General year in which CWG was available patent-royalty free and competitive to all other gas processes operating in Massachusetts.
1886	L.P. Lowe oil gas	Commercial town lighting and fuel gas	<ul style="list-style-type: none"> <li>• First universally practical oil gas process for illumination.</li> <li>• Developed by Leon P. Lowe (1861–1931) elder son of T.S.C. Lowe, at Lynn, Massachusetts.</li> <li>• Not actually employed at Lynn; demonstrated at Colorado Springs and widely used in California, as the Pacific Coast Oil Gas Process.</li> </ul>

(Continued)

**TABLE 1.1 (Continued)**  
**Sequential Employment of Gas-Manufacturing Processes of Massachusetts**

Dates	Process Name	Usual Application	Remarks
1889c	"Pure oil gas" flurry in western Massachusetts	Small-town gas plants were attracted to conversion from wood gas Williams town	Likely upon arrival of rail connections with the Pennsylvania refineries; naphtha is implied as the common feedstock, commentary to the effect that such gas would not distribute well under low-temperature winter conditions.
1890–1940	Water-gas (fuel gas) (also known as <i>blue gas</i> ); via Producer gas plants and gas producers Note: <i>Water-gas</i> is distinct from <i>carbureted water-gas</i>	Industrial fuel gas Gas engine fuel Installed in factories and at various points of usage; comprehensive lists of locations never kept in the United States	<ul style="list-style-type: none"> <li>• Temperature-cracking of superheated steam into its two burning gases, H<sub>2</sub> and CO.</li> <li>• Typically low illumination and Btu energy value, but yet capable of providing energy for industrial processes requiring heat.</li> <li>• Could be generated from all manner of organic feedstock, including breeze of coal and coke.</li> </ul>
1890c–1940?	Pintsch Railway Oil-Gas Last operating Pintsch Plant owned and operated by the Pintsch Compressing Co. [USA], of New York City) shut down in 1950; Hatheway finding	Lighting of Pullman, dining, mail, and baggage cars	<ul style="list-style-type: none"> <li>• Old Colony and Boston and Albany Railroads.<sup>170</sup></li> <li>• Illumination of passenger, dining, mail, and baggage cars.</li> </ul>
1890–1940	Acetylene (carbide) gas lighting	Institutions Mansions (either self-contained lamps or gas engines) Military posts "Crossroads" towns	<ul style="list-style-type: none"> <li>• Phenomenon identified by Edwin Davy in 1836; mostly a curiosity prior to early 1890s.</li> <li>• Mainly in remote institutions, mansions, and cross-roads towns.</li> <li>• Widespread in rural Massachusetts (1890–1940).</li> <li>• Feedstock price rise in WW-I.</li> <li>• Less frequent in Boston; only where commercial gas not available.</li> </ul>
1891–1972?	Carbureted water-gas (CWG)	Town lighting gas Industrial fuel gas; unlike water-gas, could be used as illuminating gas; generating sets could be started on short notice and shut down without damage	<p>1891: Introduced to Massachusetts at Fall River</p> <ul style="list-style-type: none"> <li>• Sole origination by T.S.C. Lowe.</li> <li>• Patented 1873–1875.</li> <li>• Kept from usage in Massachusetts by Boston GLC, on false contention of toxicity.</li> <li>• Massachusetts CWG ban broken in 1889.</li> <li>• Afforded economies compared to coal gas, through smaller plant with longer life span and reduced manpower requirements.</li> </ul>

(Continued)

**TABLE 1.1 (Continued)**  
**Sequential Employment of Gas-Manufacturing Processes of Massachusetts**

<b>Dates</b>	<b>Process Name</b>	<b>Usual Application</b>	<b>Remarks</b>
1905	Coke-oven by-product gas	Produced in Massachusetts mainly at Everett "merchant" plant	Gas marketed by New England Gas & Coke Co. to Massachusetts Pipeline Co., holding company of Boston distribution.
1908–1936	Blau gas appears, flourishes in rural areas, and as a shop gas	Remarkably safe, high-Btu oil gas delivered in steel LP cylinders	Not a sign of this in all of Massachusetts yet though present on Long Island, Maine, and in the Midwest. Controlled by Blau Gas of America, 1917: NYC, on German patents; C.H. Tenney (Boston) became custodial owner.
1914	Central station concept	Introduced at Fall River in its new role as a Central Station	Adaptation of the 1902 west Coast trend of concentrating gas generation at one central plant and relying on advances in higher pressure distribution using district gas holders.
1914	Vertical coal gas retorts	Introduced at Fall River as part of its new role as a Central Station	Vertical retorts introduced labor savings while capitalizing on smaller footprint generating capacity.
1920–1940	Petroleum gas as high-Btu petroleum gas Reformed refinery gas substitute natural gas	Commercial town gas where petroleum feedstock was favorably priced by rail transport	Mainly precursor process variants capable of producing high-Btu gases not previously available or demanded of and by service.
1925c	Supersized 11-foot diam. CWG sets	Introduced at Fall River Central Station	Capacity of 3,500,000 cfd (24-hour); example of the largest CWG sets ever built (U.G.I. Cone Top).
1929–1955	Hi-Btu reformed refinery gas; used to mix with other gases to achieve necessary Btu delivery	Commercial town lighting, cooking, and heating gas	Often involved purpose-modified CWG sets, as a means of avoiding plant equipment expenditures for the short envisaged use duration; often led to excessive generation of gas liquors and tars.
1947–1972	Hi-Btu reformed refinery gas; used as substitute natural gas (SNG)	Means of gradually supplying gas with equivalent Btu of the soon-anticipated arrival of natural gas	Often involved purpose-modified CWG sets, as a means of avoiding plant equipment expenditures for the short envisaged use duration; often led to excessive generation of gas liquors and tars.
1953–1955	Natural gas arrives for distribution	Tennessee Gas Transmission Co. (TGTG) Texas Eastern Gas Transmission Co. (TEGTC)	1953: TGTG supplies NE Massachusetts. 1955: TEGTC supplies E. Massachusetts, including Boston. Both were delayed at least two years by wrangling in Washington, DC.

*Source:* Compiled by the authors from various sources.

**TABLE 1.2**  
**Oil Gas Processes Known to Have Been Employed in Massachusetts**

Dates	Name	Considerations
1817–1850	Standard British Practice	Whale oil was retorted in iron pots (retorts) to produce illuminating gas; difficult process fraught with pot burnouts.
1854	O.P. Drake's Patent Hydrobenzole Carbon Gas Generating Apparatus Company, Boston, Massachusetts	Prices ranged upward from \$150 for six-light kit. 1862: was being marketed by Ferris & Co. as "Automatic Gas Apparatus."
1874	Butler Process	"On the 10th of January last Captain Butler put the gas works into the Suffolk Glass works, at Boston, for melting glass, and no heat ever before used at the works, equals that now made from petroleum gas, as all the glass manufacturers in New England, who have visited the works, will testify." (AG-LJ, July 2, 1874, 8–9)
1877	Hanlon Improved (Petroleum) Process	Installed at Lexington, Massachusetts as an oil-enriched water-gas process, in circumvention of the Lowe patents and also in continued operation in contravention to the Commonwealth ban on CWG. (AG-LJ, June 16, 1877, 234) Subject of 1889 patent-infringement litigation by UGI, against the New Haven (Connecticut) GLC as the Hanlon Leadly process; court found for UGI. (AG-LJ, July 15, 1889, 102)
1882c	Equitable Process Boston Gas Light Co. North End Station	For enrichment of coal gas to higher mixed-gas c.p.; known to have involved naphtha and crude oil as feedstocks. (July 19, 1909: <i>The Boston Gas Supply During 50 Years</i> , by Capt. Wm. McKay, Boston, Massachusetts; AG-LJ, July 19, 1909, 282–289)
1883	Providence & Boston RR	Had a Pintsch Gas Works in place; actual location not yet confirmed (2013).
1890	Boston and Albany RR	Adopts Pintsch lighting for 1,000 rail cars; plans for five gas plants.
Early 1890s	Oil gas processes were in use in western Massachusetts	Pre-1890–1910: Naphtha gas in use at Amherst. Apparently where rail service from Pennsylvania could deliver feedstocks at a cheaper cost than coal; an example is the Chicopee Falls gasworks sponsored by the Dwight cotton mills.
1892	Pintsch Plant Near Charles River	"Petition 1519. Petition of the Pintsch Compressing Company for license to lay a one and one-quarter inch hose across the draw-way in the Boston & Lowell railroad passenger bridge on Charles River in the cities of Boston and Cambridge."
1899	Pintsch Plant Boston, South Station	Established at junction of Summer Street & Dorchester Ave., South Boston; South Station Terminal, Boston.
1908–1936	Blau gas	Blau gas was produced under license from the Blau Gas Co. of America, using German patents and licenses; AWH has not yet found any evidence of its use in Massachusetts.

Source: Compiled by the authors.

and the thought of importing American gas coal from the Appalachian regions of West Virginia and Pennsylvania could be entertained, since prior to the development of an inland railroad network, coal's bulk and difficulty to transport in bulk limited coal usage to the seaport towns, where water transport made shipping costs bearable. The Springfield Gas Light Company used rosin for a brief period from its founding in 1848 until a switch to coal in 1850.<sup>7</sup>

In general, gas distilled from wood resin or from resinous wood was surely present, here and there in the world, during and from the time of the first reported coal gas. Such a feedstock was present

wherever evergreen (nondeciduous) stands of native timber were available. In Massachusetts, the only limitation to this supply was the general clearing of land for farming and for logging of commercial timber as a favored construction material for the burgeoning waterpower industry of New England, having arrived and well in place for the better part of a century before manufactured gas became a general possibility in 1810. The very fact that Boston, as the commercial/intellectual center of the Commonwealth, did not choose to support a gasworks until 1823, and even then in a faltering fashion, until 1829, gives us a reasonable starting date for the limited development of wood gas (1828) in Massachusetts.

It is our contention that wood and its resin, as a feedstock for manufactured gas in all but the shipping-port towns, began to be replaced by either coal or oil, at about the same time, and that the coming of railroads was the general agent.

## 1.4 COAL GAS

### 1.4.1 BIRTH OF COAL GAS

As with many successful technologies, coal gas had many “fathers.” The extraction of gas from coal was known at least as a laboratory phenomenon as early as 1609, thanks to the experiments of Jan Baptist van Helmont, who coined the term “gas” (from the Flemish word *gheist*, or ghost) in his *Origins of Medicine*. For the most of the following two centuries, however, the phenomenon remained essentially a laboratory experiment or party trick; for example, an English clergyman, the Rev. Dr. John Clayton of Wigan, Lancashire used gas flames as an entertainment at dinner parties during the 1690s.<sup>8</sup> By the end of the eighteenth century, several experimenters were working on the uses of coal gas. The Dutch professor Jan Pieter Minckeleers lit his classroom at the University of Louvain with coal gas in 1783, and appears to have been the first to use coal gas for lighting. Archibald Cochrane, the eccentric ninth earl of Dundonald in Scotland, lit his house at Culross Abbey with gas during the 1790s but by all accounts appears to have been more interested in the uses of the tar produced by gasification than in the gas itself, and deserves credit as one of the founders of the coal tar industry. A prototype tar plant for the British Tar Company, managed by John Loudon McAdam of “macadam” pavement fame, showed initial promise in marketing the tar as an alternative to both pine tar and copper for sheathing wooden ship hulls against barnacles and teredo worms. Worm-proof copper plating (the ideal alternative) was always expensive and the supply of pine tar was then pinched, as imports from the traditional American, Russian, and Baltic suppliers were cut off by Napoleon Bonaparte’s Continental System and the difficulties with the United States. The effort ultimately foundered due to meddling by vested interests in the Royal Navy’s dockyards.<sup>9</sup>

Although Cochrane can be credited as the father of the coal tar industry, the credit for developing gaslighting into one of the premier technologies of the nineteenth century belongs to a fellow Scot named William Murdoch, sometimes spelled Murdock. Murdoch’s undertakings began in 1792 at Redruth in Cornwall, where he worked as a master mechanic and practical engineer for Boulton, Watt & Company, developing steam engines to operate dewatering pumps and hoists in tin and coal mines. He began with lighting his own Redruth home (as the company’s site representative) with a small cast-iron retort, followed by several small-scale projects including street lights at the Boulton & Watt works in Birmingham in 1797 and at a cotton mill at Salford, Lancashire in 1805. In 1812, Murdoch partnered with Friedrich Albert Winzler, an entrepreneuring German émigré to the United Kingdom who went by the Anglicized name Frederick Windsor, to found the London and Westminster Chartered Gas Company in 1812, illuminating Westminster Bridge on New Year’s Eve of 1813. Although Windsor and his partner Thomas Sugg, a plumber and pipefitter, had lit a section of Pall Mall in 1807, their joint effort in 1813 is generally credited as the first commercial use of gas street lighting.

The first documented user of coal gas in the United States other than experimental or demonstrative purposes was the Rhode Island merchant David Melville, who in 1806 used coal gas to

illuminate both his house and a lighthouse at Beaver Tail, Rhode Island.<sup>10</sup> The first use of coal gas for street lighting in the United States was Baltimore in 1816, where it was introduced by Rembrandt Peale and his brothers, who had observed Murdoch's success while on a trip to London. Boston followed in 1823 and New York in 1825.

Massachusetts' first gas company, the Boston Gas Light Company, was nominally launched in 1823 but it was not until 1828 that the company purchased land for a gasworks in the North End of Boston, in the vicinity of Hull Street, Snow Hill, and Commercial Street. The first gas light, fueled by a mixture of wood resin and Nova Scotia coal, was lit in Dock Square on January 1, 1829, but progress thereafter was slow—10 years later the city streets had just 20 gas lamps, but this grew to 180 by mid-1839 and 4,312 by 1868, coinciding with the early stages of the Back Bay land-making project.<sup>11</sup>

“Town gas” plants established prior to the late 1870 almost invariably relied on the world-standard horizontal coal gas retorts, with the exception of a very few oil gas plants, which used crude or minimally refined crude oil as fuel the gasmaking feedstock. These first- or second-generation plants were not very large by later standards, since there was less demand for domestic illuminating gas prior to the large-scale boosterism stemming from the American national centennial of 1876, and use of gas for cooking fuel had not yet become common, but even so it was not unknown for a plant to spend half a night and all the following day making enough gas to keep the lights and stoves running during the next evening. The massive urban growth of the late 1800s—Boston's population tripled between 1860 and 1900—led to a corresponding increase in gas demand and production.

#### 1.4.1.1 Pyrolysis

Most of the gasmaking processes used by the manufactured gas industry were some form of controlled pyrolysis, or thermal decomposition. Pyrolysis (from the Greek *pyro* for fire and *lysis* for separating) describes the process of decomposition of organic matter at high temperatures but in the absence of oxygen, which if present would result in simple combustion. The term is also sometimes used in more modern times for reactions excluding halogens as well as oxygen, but for the purposes of this text the absence of oxygen is the crucial point. It should be noted, however, that there was always some irreducible minimum of oxygen present in the retort, derived from the water content of the coal and as certain of the ‘waters of hydration’ present in the various minerals and other chemical constituents of coal and which could be released by heating. Some inevitable minor combustion would occur during the initial stages of working off a charge of coal, but this would end as the oxygen was rapidly exhausted.

As the coal was heated in the retort, a number of overlapping chemical reactions began to occur, some of which are opaque or difficult to distinguish and many of which were not well understood during the gasworks era, so the following is a much-simplified description.<sup>12</sup> While coal is given as the example here, the same reactions would occur if oil were being used instead.

As the heat rose in the retort, the structure of the coal particles would begin to collapse as chemical bonds ruptured. The gases trapped in the coal, such as methane, ethylene, carbon dioxide, hydrogen sulfide and other gases began to off-gas, followed by the breakdown of some of the aromatic compounds into smaller, volatile hydrocarbons with low boiling points such as benzene, toluene, ethylbenzene, styrene and naphthalene. Once the temperature in the retort passed their boiling points, quantities of even heavier hydrocarbon molecules, ranging from polycyclic aromatic compounds such as phenanthrene to high molecular weight asphaltene compounds, would volatilize and be drawn off in the gas stream. These heavier compounds would later condense and form coal tar. The gradual breakdown of the organic structures in the coal meant that the release of trapped gases and production of low molecular weight hydrocarbons was more or less continuous throughout the process. Using coal crushed to a certain particle size was also advantageous as it reduced the amount of “trapped” internal volume in a given particle and made the process more efficient.

The rate and quality of gas production from a charge of coal would thus tend to describe a bell curve over time, with relatively little gas made in the period immediately after charging as the coal heated up, most of the gas (and the highest quality gas) made during the early and middle period of the cycle as the coal decomposed and allowed a spike of off-gassing and volatilization, and lesser quantities of lower quality gas produced towards the end of the charge period, until essentially all the volatile material had been yielded from the coal and the residue in the retort (fixed carbon and refractory minerals) had been more or less completely converted to coke. This point was usually determined by the plant engineering staff based on knowledge of the retorts, the coal used, and past analytical testing.

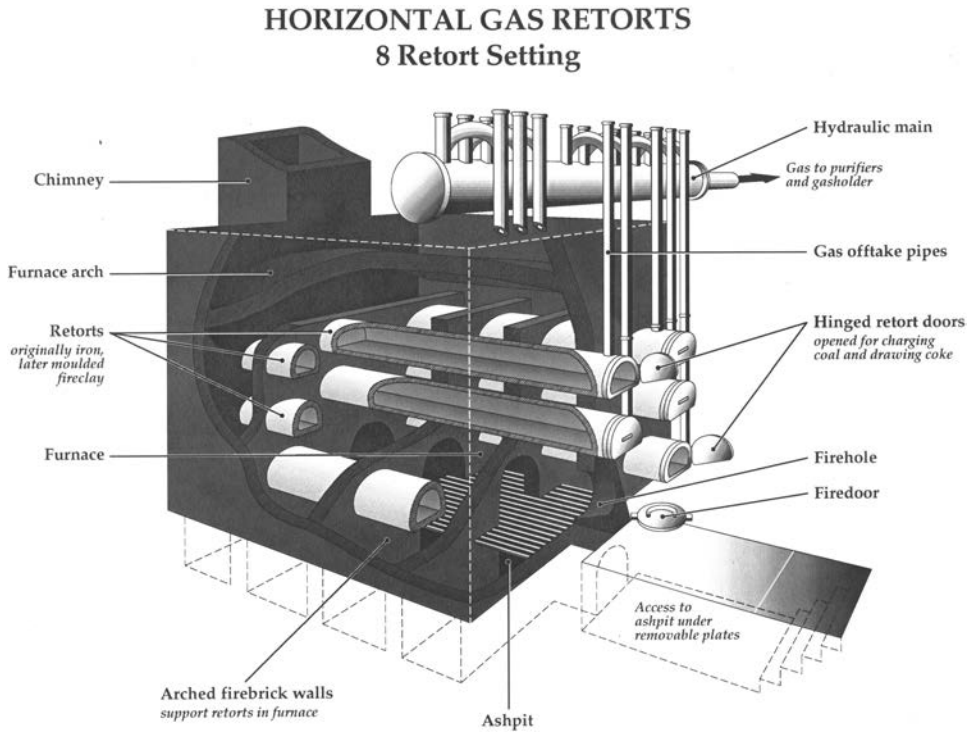
As a general rule, for a ton of gas coal at a coal gas plant, typically about 65%–70% of the material was converted to coke, about 15% by mass to gas, and the remainder to tar, gas liquor, and other byproducts or wastes.<sup>13</sup>

The process in water-gas systems was different, and also varied according to the feedstock used in the process (coke, anthracite, bituminous coal, or oil). Generally speaking, the water-gas process relied on hydrous pyrolysis, where materials are heated to decomposition in the presence of water, in conjunction with steam cracking to break down hydrocarbons into smaller compounds. The water in this case was provided by the superheated steam introduced into the generators.

#### 1.4.2 COAL GAS RETORTS

The centerpiece of coal gas works was the retort house, where the gas was actually made. Retorts were oven-like structures constructed of masonry, arrayed in individual “benches” housing six, eight, or ten retorts (i.e., a “bench of sixes”). Some writers and engineers followed British usage and called a bench a (“bed,” signifying one to nine separate retorts heated by one furnace) with the term “stack,” or “set” in the United Kingdom, signifying a row of individual beds). Retorts were usually described as being “D-shaped” in section, with the flat side being the bottom of the retort, and with a typical cross section of approximately 2 feet wide by 18 inches high, and a length of usually between 10 and 20 feet. Toward the end of the century, retorts eventually came in innumerable varieties: double-ended, single-ended, “slopers,” horizontal, and even vertical designs, all of which had differing thermodynamic and mechanical characteristics. As of 1911, however, horizontal retorts remained the most numerous, even at some of the nation’s largest coal gas works; a survey by the United States Department of Agriculture found of 91 of the largest gasworks in the nation, each with a minimum annual “make” of 20,000,000 cubic feet of gas, 82 plants used horizontal retorts, seven used inclined retorts, and only two employed the then-new vertical retorts.<sup>14</sup> Single-ended retorts marked the beginning of the Massachusetts gas industry, replaced by double-ended retorts in some of those plants adopting mechanical charging and discharging machines; generally only after about 1890. Both ends were closed with massive iron-door *lids*, luted (sealed) with moist potter’s clay and mounted to an iron “nostril” or casting that included an uptake pipe through which the gas exhausted for collection, into the hydraulic main (Figures 1.7 and 1.8).

Individual *charges* of gas coal, ranging from 500 to 1,200 pounds of material, were loaded into the retorts and subjected to four or more hours of intense heat provided by underlying fire-box furnaces (or, from the 1890s, in some cases, regenerative furnaces; collecting *sensible* heat) located beneath the retorts, together known as “settings,” rather like the arrangement of a bread oven heated by a firebox. For most of the nineteenth century, these settings were fueled with inexpensive coal (as distinct from the select coals used in the retort charges themselves) this was gradually replaced by the use of gas-fired burners, and some firms adopted oil-fired settings. As one example, the Westfield Gas Light Company (later Westfield Gas & Electric, after 1899) for many years used a coal gas process in which the retorts’ furnaces were fueled by crude oil rather than by coal.



**FIGURE 1.7** An isometric cutaway rendering of a “bench” of horizontal retorts.



**FIGURE 1.8** Interior of the Commercial Point retort house, showing stokers charging a retort in the 1880s.

Volatized oil could be added to the gas stream to “enrich” it by increasing the hydrocarbon content and thereby boosting the candlepower value of the gas. This was most commonly done at a later stage of the process, but it was not unknown to set aside one retort in a bench for generating oil gas right from the start, thereby enriching the gas generated by the other retorts to which it was manifolded.<sup>15</sup> Volatile-rich *cannel coal* was also used, being added to the regular gas coal at a ratio of about 1 pound cannel to 10 pounds regular gas coal.<sup>16</sup> The use of *naphtha* (a contemporary generic term for a variety of low-volatility, low-gravity petroleum oils or tar light oils, not the least of which were the *drip oils* recovered from the gasyard and distribution-pipe *drips*) or other higher volatility petroleum oils generally eclipsed the use of cannel coal by 1900, and the use of *benzol* (common group name for coke-oven light tar oils) in turn eclipsed naphtha in first decades of the nineteenth century.<sup>17</sup>

Given the tendency of gasworks to grow and evolve over time in order to keep pace with demand and technology, it was far from unusual for one plant to have several generations and types of benches in use at any given time. In 1905, the East Boston Gas Company’s works at Chelsea and Eagle Street in East Boston, was relegated to a surplus-production plant after the creation via amalgamation of the Boston Consolidated Gas Company, had five Weber benches of six’s, two Portland-type benches of six’s, and one Gautier-type bench of six, all housed in a 100-foot by 37-foot retort house, constructed on driven timber piles supporting concrete foundation cross members and floors. The plant also had a newer CWG unit that housed two five-foot diameter “improved Lowe” water-gas sets.<sup>18</sup>

In later years, after about 1890, many gasworks installed *gas producers* adjacent to the benches (usually to the rear), feeding this form of cheaper fuel gas to the underlying furnaces. This allowed for hotter and more precisely controlled temperatures than wood or coal-burning furnaces. The intense heat, of the retorts, in the absence of oxygen, more effectively carbonized and destructively distilled the coal, causing it to volatilize and to release the stored gases such as methane (also sometimes called *marsh gas*) or other gaseous hydrocarbons, which, together, formed the manufactured gas. The gas was collected in a *hydraulic main*, a manifolded pipe system (serving as the first of several tar traps), running above and along a series of benches (together known as *stacks*), which kept the heat of the retorts from igniting the gas by bubbling the gas through a “water seal” that was in practice comprised of tar and condensed *gas liquor*, a mixture of water, ammoniacal compounds, oily or tarry hydrocarbons, and detritus produced by the gasmaking process. The gas lines were eventually trunked together and conveyed off to be cooled, *clarified* (removal of tar and light oils of tar), *purified* of sulfur, cyanide, and other impurities, and stored in a *distribution* gasholder.

Heating coal in the absence of oxygen (pyrolysis) caused the trapped gases, volatile hydrocarbons, tar, and other dissociable constituents to evolve from the coal. Typical working temperatures were well over 1,100°C, and could reach over 2,000°C. Actual distillation typically commenced at 427°C, but retort temperatures typically peaked toward the end of a run as residual heat built up.<sup>19</sup> Gas—the mixture of methane, other gases, and volatile hydrocarbons—typically developed on a predictable sequence, although even during the heyday of the gas era the precise nature of the hydrocarbon distillation was not completely understood, and experts propounded competing theories of the formation of paraffins (alkanes in modern terminology), and other compounds.<sup>20</sup> W.J. Atkinson Butterfield, a gas engineer with the mammoth Beckton gasworks in London, the world’s largest single gasworks throughout this period, and later a consulting chemist to the gas industry, described a typical working-off of a charge:

In the manufacture of gas from ordinary good gas coal, when about 11,000 cubic feet of gas, having an average illuminating power of about 14 standard candles, is made, the fraction produced during the first half-hour, amounting to about a seventh of the total volume, will be only about 10 candle gas. During the next hour and a-half, the candle power of the gas made will be 17 to 18, and the production nearly one-half of the total. During the next hour, the make will be nearly a fifth of the total, but the candle

power only about 14. The remainder of the gas will be only 8 to 10 candle. These figures are, of course, only rough approximations, and the description of coal, the heat, and the pressure in the retort, may cause great variations from then. They are applicable only to a high heat, and consequent rapid working off of the charge.<sup>21</sup>

Production of gas was often as much an art as a science. For example, even by the end of the First World War, it was customary in ordinary operations to judge the temperature of a retort by the shade of red the iron “nostril” to which the retort’s hatch was mounted turned, rather than by an instrument. Walter M. Russell’s 1917 *The Operation of Gas Works* includes a table of such colors and their associated temperatures as his Appendix VIII. “Bright cherry-red,” for example, was held to be approximately 1,100°C.<sup>22</sup> Certain constant rules could, however, be applied. Gas produced at higher heats and higher operating pressures in the retorts, although with generally higher yields per ton of coal, would be of inferior quality, the native hydrocarbons having been destroyed by the higher heats, and would require more intensive enrichment to attain a necessary candlepower.<sup>23</sup> Excessively high operating temperatures could also create severe problems for later stages in the process; one frequent complaint was that very high temperatures altered the formation of the tar, causing the lighter fractions to come off too quickly and leaving the heavy pitch fractions behind to clog the hydraulic main—in effect distilling the tar before its time.<sup>24</sup> Injecting an inert gas, such as superheated steam (largely CO<sub>2</sub>), into the retorts could increase yields; as developed in the 1860s, this process may have helped inspire the even broader use of CWG technology.<sup>25</sup>

This coal distillation also produced vast quantities of a noxious liquid, commonly known as ammoniacal liquor and comprised of coal tar, (itself a complex and highly variable mixture of hydrocarbon PAH compounds) together with water, sometimes small amounts of carbolic acid (phenols), sulfur compounds derived from the sulfide and sulfate minerals native to the coal, and its characteristic ammonia gas and ammonium liquid, derived from the nitrogen in the coal. The solid residue of the coal, known as *coke*, was a spongy, lightweight mass comprised predominantly of carbon and geologic refractory silicate minerals, and was valued as a prime smokeless fuel for sale or for use at the plant. At the end of the processing period, which could be four to eight hours, the retort was opened, emptied of its coke, and immediately recharged.

Pile foundations (both traditional timber and injected fluid concrete; a foundation type developed at and widely utilized at Boston) were typical of many large buildings in the Boston metropolis due to the large areas of filled tidal flats and other made land, as well as the famous Boston *Blue Clay*, a highly compressible glacial rock flour. These factors together would make for dubious foundations unless the soil was geotechnically reinforced. Gasholder foundations also sometimes required massive buttressing, shown previously in [Figure 1.9](#). In one instance, the Hartford City Gas Light Company’s engineer, John Pooler Harbison, expressed his frustration with gasholder foundations at an annual meeting of the American Gas Light Association:

I doubt whether there are many men in this room who have not had more or less experience with leaky tanks. [...] I am unfortunately (or otherwise) located where there is a rise and fall of 27 feet in the water level and hence the ground is made ground, so-called. I have had a good deal of difficulty with tanks. I have four tanks – one 60 feet in diameter, one 75 feet, and two are 90 feet or more. In two of those tanks, I have already put in a lining of four inch brick wall on the inside, and, of course, have lessened the space that it is desirable to have between the inside of the tank and the holder. One tank that is now leaking (it is 94 feet in diameter and 24 feet deep) has caused me to consider the question of putting in an iron or steel lining instead of a brick one; it is split from top to bottom, having been built on made ground, and up to this time I have not been able to make it tight.<sup>26</sup>

#### 1.4.2.1 Gas-Generation Working Conditions in General

Although coal gas technology changed a great deal over its century and a quarter of history in Massachusetts, certain features remained constant. Working in a coal gas plant was a challenging and



**FIGURE 1.9** An 1887 image showing foundation buttresses for a gasholder at Commercial Point.

fatiguing labor environment, a constant cycle of heat, noise, and backbreaking toil, with the added hazard of possible gas leaks or explosions; the closest modern approximation would be a foundry.

Even in the last decade of the gasworks era, operating temperatures in a gashouse were commonly well over 100°F. One reporter touring the Springfield, Massachusetts Gas Light Company's plant in 1950 was appalled to encounter conditions of 125°F and a choking atmosphere thick with coal and soot particles, and the entire building shaking with the discharges of the massive water-gas sets, which sounded like bomb explosions. The reporter commenced his description thus:

We got as close to the Biblical hell yesterday afternoon as we ever expect to get this side of eternity and we are convinced that the fellow who wrote the description of hell in the Book must have worked in a gas house or approximation sometime during his career.<sup>27</sup>

Gasworks also typically worked around the clock, every day of the year. This Regime was essential not only to meet the unceasing demand for gas, but also to prevent cycles of heating and cooling from propagating disastrous and destructive thermal stress fracturing and cracking of retorts and of their surrounding firebricks, which could render an entire bench useless until it could be rebuilt.

Given the manpower-intensive nature of gasworks operations, working conditions and process control in a gasworks are not easy to separate. Operating a gasworks well and safely required an intimate combination of careful precision and brute strength; as many of the manuals on constructing and operating gasworks noted, the production of good gas depended on good process control in the retort house or generator house, with an emphasis on running charges of coal of the correct weight and composition for a specified time at a particular temperature. If the retort crew was not on the ball, so to speak, the charge could be light or the run deficient in some other respect, which would create problems that ramified through the rest of the gasmaking process.

The retort house was not just a difficult working environment—it could be downright lethal. At each recharging of a retort, gas remaining in the retort from the previous charge had to be flamed off with a hand torch or length of burning rope before drawing the coke, adding regular bouts of open flame to the workplace hazards. The air in the retort house was thick with superheated steam, raw gas (which could contain up to 1%–2% hydrogen sulfide, 0.1% of which is almost instantly lethal if inhaled), vapors containing tar, sulfuric acid, hydrochloric acid, and hydrogen cyanide, all capable of ruining the workers' lungs—the severity of this problem is attested to by the repeated warnings in most gasworks manuals that interior mortar and metal surfaces in the retort house needed to be painted to prevent corrosion.

In plants with benches of single-ended retorts, the glowing hot coke was drawn directly onto the working floor in front of the retort or into a wheelbarrow on the floor, an obvious safety hazard. Double-ended retorts were a welcome later innovation, since they allowed the coke to be pushed out the back of the retort rather than drawn toward the stoker. In either case, the freshly drawn, glowing hot coke would immediately burst into flame once it came into contact with oxygen, and needed immediately to be quenched with cool water drawn from external pipes or hoses. The quenching saved the coke for use or sale, but in doing so, also produced additional quantities of gas liquor, the plant's ubiquitous effluent, sometimes as much as half a ton of water per ton of coke quenched, much of which drained into the yard's soil or drains and contributed to the ubiquitous soil and groundwater contamination at such sites (Figure 1.10).<sup>28</sup>

Workplace injuries were a constant feature—London's South Metropolitan Gas Company lost 10 employees killed on the job between 1892 and 1896, and 30 employees were left unable to work by workplace injuries in the year between November 1896 and December 1897.<sup>29</sup> It is small wonder that employment as a gasworks stoker could pay fairly well—except in poor economic times, generous wages were often the sole attractive feature about the job.

These conditions, more so than most working environments even during the nineteenth and early twentieth centuries, would quickly “make old men out of young ones.”<sup>30</sup> Many did not stay old men for very long; workers typically lost significant weight over time and suffered chronic respiratory trouble such as bronchitis or tuberculosis, and skin troubles such as eczema, boils, chronic rashes, and warts. Cancers of the stomach, lung, scrotum, and skin were common; other coal-related trades such as chimney-sweeping and makers of fuel briquettes similarly encountered elevated rates of



**FIGURE 1.10** A 1936 photograph vividly depicting the drawing of a spent charge of red-hot coke into the retort house, amid a cloud of smoke and gas.

scrotal cancer, which earned the nickname *pitch cancer*.<sup>31</sup> It should be no surprise at all that some jobs at gasworks, such as stokers, were notorious for having a rapid and steady turnover. This put an additional onus on the plant management to get newcomers in line as quickly and effectively as possible.

The difficult conditions in which gasworks crews toiled were not always taken seriously by “management.” C.E. Brackenbury, in his *Modern Methods of Saving Labour in Gasworks* (London, 1901), writing in the wake of considerable labor turmoil in the United Kingdom, bemoaned that gasworks employees remained so resistant to progress and so prone to strike despite their wages being comparable to skilled workers. With some understatement, he notes that the gashouse workers labor was “admittedly, in some cases, physically onerous.”<sup>32</sup> It is therefore no coincidence that most of Brackenbury’s suggestions lean toward major capital investments in mechanical stokers, inclined retorts, and other alternatives to manual labor.

Gas companies and their employees commonly took great pride in having “never let the lights go out” despite the grueling labor and myriad other challenges, and on the whole strikes by gashouse workers were few and far between. One of the rare exceptions, showing what could happen when things were pushed too far, was a 1919 strike by employees of the Worcester Gas Light Company that left the city without gas service between August 27 and September 9. A similar strike in Lowell in 1921 was prompted by the gas company when it announced a reduction in wages. The strike lasted several weeks, but the gas company brought in strike breakers from other cities and maintained gas service, and the striking workers eventually admitted defeat, with many of them asking for their old jobs back.<sup>33</sup> Along with the general postwar climate of economic and political turmoil, the cause of the strike was apparently worker complaints about safety concerns that led to a number of workmen being injured and the resentment of a number of lavishly paid agents from the Sparks Detective Agency being kept on duty at the plant. Although the role of the Sparks agents is unclear, such “detectives” (most notably the notorious “Pinkerton men”) were often hired on by business interests during periods of labor unrest to serve as security, antiunion agitators, and hired muscle.<sup>34</sup>

#### 1.4.2.2 Walter Russell’s Enlightening Description (1917)

As the gas industry evolved, significant changes progressively mitigated many of the hazards of earlier days, such as replacing the drawing of coke onto the work floor with double-ended retorts that let the coke be pushed out the other end, or the use of mechanical stokers.

Walter M. Russell’s *Operation of Gas Works*, published in 1917, was one of the most widely circulated standard gasworks manuals in the United States during the early twentieth century; it also was the first exclusively American operational gas-manufacturing handbook.<sup>35</sup> Like most such manuals, Russell’s text covered contained virtually every topic from fuel quality control (a laborious process involving equal parts manual labor and wet chemistry) to record-keeping, plant maintenance, gauge selection, chemical engineering, and personnel management. Russell wrote his book while serving as manager of the Emporia, Kansas, Gas Co., and originally published it in 1916 in a preliminary format through the *Gas Age* journal. He later migrated to Rhode Island in 1918 and then to Boston in 1919, (Table C.1) where he was employed in the technical management of three holding companies and their subsidiary gas companies.

Russell’s overarching theme was quality control. He emphasized consistency and precision; setting heats were to be rigorously maintained, retorts were to be drawn and charged on an exact schedule, with precise amounts of coal, and the quality of the coal intake and gas make were to be closely monitored for consistency in order to avoid unwanted variation in the pressure, quantity, and quality of gas. He advocated a meticulous regime of record-keeping by supervisors and specialists, with production logs, inspection reports, and other documentation with the aim of identifying trends, problems, or incipient flaws or damage to the system.

John Harrison Blake (1808–1899), an influential gas engineer of the early days of the Massachusetts gas industry, likely knew firsthand exactly the sort of problem Russell was attempting to correct.

Blake described one such problem in 1866, which he attributed to laziness on the part of the gas house crew:

Occasionally it is the case, on a Sunday, when the consumption is small, that the retorts do not require to have their contents withdrawn, and a new charge of coal put in; the gas-holders are full. Now, I have known it to be the case that the workmen would not withdraw their charges, leaving it for the morning watch, who came on at six o'clock, to draw those charges; and during those latter hours, the gas which has been generated by the coal and which has gone into the gas-holder and mixed with the other gas, has scarcely had any illuminating power at all. I have, in my experience, occasionally, found, on Monday, that the gas was of an inferior quality, and in seeking to know why it was so, I have discovered that neglect on the part of the workmen; and I have tested such gas in experiments which I have made, keeping in a charge for twelve hours, and ascertaining the quantity of gas generated during each one of those twelve hours, when four hours would be sufficient, drawn off each hour a portion of that gas, and found that that generated during the latter part of the time had scarcely any illuminating power.<sup>36</sup>

Heavily informed by early efficiency experts such as F. W. Taylor and Frank and Lillian Gilbreth, Russell cites time-and-motion studies and the need for organization and discipline, noting that the phrase “gas house gang” previously had long been used as a derogatory term.<sup>37</sup> In his view, gas-house labor was a worthy trade and “A good stoker should be able to draw and charge 1,100 lb. of coal into three retorts, in 10 elapsed minutes, where the coke is pulled into buggies or onto the floor. If a good stoker fails to do this he is either loafing, wasting effort or has not the right tools.”<sup>38</sup> To shift this amount of material, and a similar amount of coke being drawn—by hand, in 10 minutes, and under such grueling conditions of temperature and respiratory strain is no mean feat by any measure.

Oddly, Russell makes no direct mention of the rail-guided mechanical charging/pulling devices that had been fully perfected since the 1890s. Russell instead details for the reader the steps of charging and drawing retorts by hand, possibly because these may have been common in smaller gasworks during Russell’s day.

Russell split no hairs about the difficult working conditions—embraced the now perennial concept of “safety first” (also a common topic of the many contemporary workplace publications of the United Gas Improvement Co. [UGI])—and advised that each employee have a locker in which to stow clean clothes, washing facilities, a comfortable place to eat, and plenty of ice water during warm weather. Drinking alcohol on the job was so common, particularly in the scorching-hot retort house, that Russell recommended that plant superintendents regularize the practice by allowing men to drink in order minimize the impact, suggesting that external cold-beer runs be made at scheduled times, since attempting to ban alcohol entirely only led to its secret consumption. Workers who let their intake interfere with their work would, of course, be fired. Not all gasworks managers were so accommodating; in 1889 the conspicuously abstemious Osirus Emerson McMillin of the Laclede Gas Light Company in Saint Louis, Missouri posted a sign by the plant entrance warning that any employee caught drinking on the job would be fired on the spot, and followed up on his promise.<sup>39</sup>

### 1.4.2.3 Later Developments in Coal Gas Operations

While coal gas systems were larger, more expensive, more labor intensive, and required greater upkeep than water-gas systems of equal output capacity, coal gas remained in widespread use through the end of the gasworks era, alongside newer technologies, and several major coal gas plants were built or extensively rebuilt well after CWG had become generally accepted (recall that coke or anthracite were the technically-appropriate feedstocks for CWG). Right to the end of the gasworks era, coal gas had several features that made it highly attractive to gas companies with the resources and market to undertake construction. Bituminous coal—even choice grades of gas coal—was cheaper to buy on the open market than suitable coke or anthracite, which were in high demand by other industries. Since a coal gas process produced coke and light oils such as benzol and naphtha, a combined-process plant could use these products as feedstocks for its water-gas

systems, a self-sufficiency not to be sneezed at given how the price of naphtha crept steadily up under the Standard Oil monopoly over the nation's petroleum industry. In the late 1860s, certain grades of naphtha, sometimes also referred to as "benzine," were almost a waste product, and there was a national surplus of naphtha.<sup>40</sup> Although the hydrocarbon ranges and physical characteristics of naphtha and benzol were generally similar, as mixtures of mostly aromatic hydrocarbons with boiling points less than 200°C, the loose but general distinction between the two was generally that naphtha was a refined petroleum product and purchased from an oil vendor, while benzol typically was the light-oil by-product of the gasworks itself. Lastly, the residual products of a coal gas system were generally more usable and salable than those of a water-gas plant, which produced inferior tar, no light oils, and insignificant amounts of ammonia; a plant that relied exclusively on CWG could therefore not expect to realize as much revenue from the sales of the recovered portion of the gasworks' residuals as with a coal gas plant.

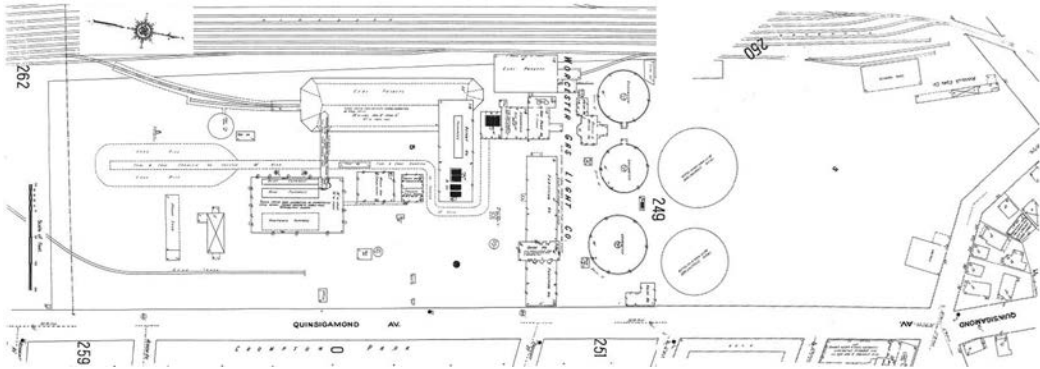
#### 1.4.2.4 Case Example of a Modern Coal Gas Plant—Worcester, Circa 1910

Charles Dudley Lamson, the longtime engineer and superintendent (later, President) of with the Worcester Gas Light Company, wrote at length about the improvements that had been made in gas technology in a 1909 gashouse missive entitled *A Pound of Coal*, first read before the New York Society of Gas Lighting and thereafter published as a pamphlet.<sup>41,42</sup> Lamson recalled his early days with the Boston Gas Light Company during the early 1870s, noting, "Very good gas was made. The yield per pound of coal was small. [...] Four and one half feet of gas per pound of coal was considered very good for a month's working." Lamson had managed the Boston Gas Company's Commercial Point gasworks during the "Boston gas wars" of the 1880s, at which time it was usual to only reckon a gasworks' efficiency and overall output quality on a monthly basis; in later years, it was common to conduct these assays on a daily or even shift basis to ensure quality and efficiency.

The plant Lamson described bears little resemblance to the Worcester company's comparatively crude first gasworks of the 1850s, located on Belmont Street in the Lincoln Square area, much as once-bucolic Worcester had grown into the second city of the Commonwealth during the same period. By the early 1900s, the Worcester company had relocated its works to Quinsigamond Avenue, near the city's rail yards (which remain extant), and had converted its original Lincoln Square gasworks to a district gasholder station (now a medical school building) to support distribution to more distant parts of the gas company's growing service territory. Although the gasworks did not at the time make use of sloped or vertical retorts, this version of coal gas-generation technology was, in all other respects, the pinnacle of that particular technology prior to the extinction of the manufactured gas industry in the 1950s.

Lamson also waxed enthusiastic about the modernization in gasworks layout and design that had come about with the advent of the twentieth century and which was to be found in Massachusetts. A new retort house was built at the Quinsigamond Avenue gasworks in 1908, modeled on a similar unit built several years previously at the Lowell Gas Light Company's plant; both retort houses were built by the same gas engineering and construction company, the Riter-Conley Manufacturing Company of Pittsburgh, Pennsylvania. In a good example of how even incremental improvements in gas technology could improve the resulting gas, the old retort house at the plant provided ~4.95 feet of 14 candlepower gas (70 candle/feet of illuminating power) per pound of coal, while the new retort house produced 5.95 feet of 17 candlepower gas (101 candle/feet), a 20% increase in the amount of gas made and a 30% increase in the resulting total lighting value. A candle-foot is a rule-of-thumb measure for the total illuminating power of the gas, estimated as feet of gas made multiplied by candlepower.

The Quinsigamond plant employed a distinctly new and complex residuals-consumption process, in which the energy-rich waste products of each stage of the gasmaking process were used to help fuel another stage, such as using "waste" heat to help keep retorts hot. In addition, most of the heavy work of moving coal into the retort house, charging retorts, and clearing the coke was now done by heavy machinery rather than by laborers—the whole retort house was staffed by only two men per



**FIGURE 1.11** A layout of the Worcester Gas Light Company’s Quinsigamond Avenue plant circa 1910, after Sanborn.

shift, a remarkable advance for a coal gas plant, where earlier plants of this process type had usually required dozens of laborers (Figure 1.11).

Rather surprisingly, Lamson flew in the face of a prevailing trend at the time of using gravity-fed retorts, and specified double-ended horizontal retorts, rather than the new German-cum-English *sloped* (also known as *slopers*) and vertical retorts. Each retort was a D-section unit 15-feet long, taking a 950-pound charge of coal every seven hours, and lined with Riter-Conley’s proprietary “Ricon” silica fire “clay” ceramic material, capable of withstanding the rigors of heats in excess of 2,800°F, but with a normal retort temperature of 2,000°F. These high-tech ceramics of the day withstood hotter temperatures but the elevated heat of the raw gas gave trouble with the rest of the system. The whole bench was *recuperated*, with the intake air for the bench preheated by being piped past the hot exhaust ducts in order to reduce the energy demand for heating the air to the point of combustion. The new retort house had one stack of ten *benches of eights*, with set-aside space for a second stack of the same size to be added later.

The throughput process of coaling began on the topmost floor of the new retort house, which housed bunker feed-volume for 600 tons of coal, constantly brought in by mantrolley and crane-mounted grab bucket at the works rail spur. By Lamson’s order, the coal was not crushed until just before being brought into the retort house, where it was reduced to a sieve size of not less than 1¼ inches. From the bunker space, the coal was transferred by chute to a pocket for one of the two charging machines, pulled up on the retort house guide rails. Coal appeared via electrically powered, half-ton overhead mechanical scoops. In one motion, the scoops entered the front-door mouth-space, pushed the spent and now blazing-hot coke out the rear opening and onto a conveyor belt, while depositing the incoming fresh charge.

Newly expelled coke was quenched on the spot (thus not improving on this major source of toxic *gas liquor* at one of its several plant sources), then the drained and dried coke was parked nearby, for direct feedstock for each of the single gas producers built to fire each bench of retorts in place of the coal fireboxes of earlier years. These were not Lowe-type units, but simply produced uncarbureted “blue” gas, the popular fuel gas discovered in the 1860s, and enjoying a great and enthusiastic worldwide resurgence for industrial fuel gas generation from about 1907 onwards. The use of producer gas for firing the retorts, in conjunction with recuperation of stacks to make use of waste heat, offered significant economies in manpower and fuel coal, as well as some efficiency in gas produced.

Lamson noted “any other form of cheap fuel may be used” for making producer gas, if the coke supply somehow became limited, since the producer gas was used only in the plant and was not mixed with gas being sent to the consumers. The producers and their charges of coke were heated by a portion of recovered waste gases from the main flue of the retort stack—in other words, hot

exhaust—and the “blue” gas from the producers was used as the main source of fuel to fire the retort furnaces of each of the two main benches. Waste gas was also used in place of the steam normally used in the “blow” cycle of a producer system, which Lamson credits for the producer systems not producing usual gasworks waste stream of coal-residue clinkers at the plant furnaces (stemming both from retorts and the ubiquitous plant steam boilers).

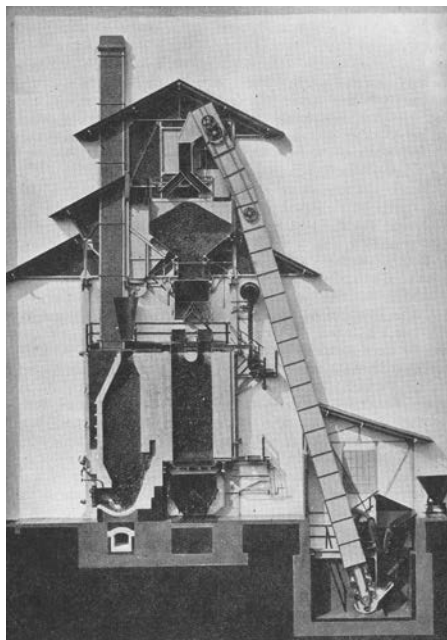
The first innovative Worcester *horizontal trough-retorts* described in Lamson’s paper produced 1.5 million cubic feet gas with an illumination value of 17 candlepower and a calorific (heat) value of 627 Btu per day, for a total daily make per pound of coal of 5.90–6.00 feet, or 13,328 cubic feet per ton of coal.<sup>43</sup> Between 13 and 14 gallons of tar was produced for each ton of coal; this was a couple of gallons more than was typical for the time for other coal-carbonization processes. Lamson credited the efficiency of the new system to the careful thermal balancing of the retorts, which were evenly heated along their whole length, having only a slightly elevated gas-pressure buildup occurring in the retorts. Pressure was as crucial to gasworks efficiency as temperature and coal selection; the internal pressure of a hydraulic main was ideally maintained at 0.5–1.0 inches of water column (0.018–0.036 PSI) less than the external barometric pressure, which enabled the gases to disassociate from the coal more easily, although using ambient pressure rather than a slight negative pressure produced higher quality gas.<sup>44</sup> His plant production efficiency was felt due to the consistent, but not excessive, operating temperatures, since very high temperatures could crack (destroy) the essential hydrocarbon illuminants generated in the released raw gas, and thereby reduce the candlepower of the gas.<sup>45</sup> As well, the desired results also were due to the carefully-timed-cycling of optimal amounts of coal with each charge, with minimal headspace in the retort, so as to sequester and draft-remove the raw gas early in its generation.

### 1.4.3 VERTICAL RETORTS

Vertical retorts were a relatively late innovation in the coal gas field, originally developed in Germany and first appearing in the United States at Derby, Connecticut in 1907.<sup>46</sup> The inspiration for these systems appears to have been a combination of the success of sloped retorts in coal gas works, and the influence of high-capacity by-product coking plants of the Otto Hoffman and Koppers types, as discussed later in this text. The UGI, Glover West Corporation, and Woodall-Duckham Company all produced variations on the general design concept of gravity-driven movement of coal and its coke product.

Vertical retorts were functionally much the same as horizontal or sloped reports, being a masonry compartment into which coal was packed, closed at each end by an iron lid. In most cases, the coal was mechanically loaded at the top by a “larry” or automated hopper, which saved much manual labor. The coke could be easily decanted from the bottom by opening the hatch and allowing it to drop out under gravity, assisted as necessary by a mechanical ram or plant personnel with the dubious pleasure of hand-barring the coke loose enough to fall freely. As the prominent gas engineer J.J. Morgan noted in 1922, the retort was often curved or offset near the bottom to avoid having the whole weight of the coal charge resting on the lid.<sup>47</sup> Some vertical retorts, like the 24-retort Glover-West system operated by the Springfield Gas Light Company, operated on a continuous-feed basis rather than in batches, steadily feeding coal in at the top and decanting coke on the bottom.<sup>48</sup> These posed some challenge in making sure the retorts were always optimally full, but provided the benefit of a steady output of gas.

The operation was thus fairly simple, but the construction was far more complex than a bench of conventional retorts. Vertical retort houses were typically constructed primarily of steel rather than masonry, with a complex system of overhead gantries, elevators for moving the coal, and rail tracks running both above and below the retorts, for delivering the coal and removing the coke. Their cost and complexity notwithstanding, vertical retort systems were generally well received for their ability to produce large volumes of high-quality coal gas without relying on enriching oils, to process larger amounts of coal since (in the case of continuous-feed retorts) there was no downtime



**FIGURE 1.12** A cross section of a vertical retort system. (From Morgan, J. J. 1931. *A Textbook of American Gas Practice*. 2nd ed. Maplewood, NJ: J.J. Morgan, Vol 1, p. 212.)

for drawing and charging, and with less gas lost to waste during the charging process. Vertical retorts were also able to fit within the limited footprint of an urban gasworks. They also offered considerable savings in manpower, since they could be operated with only two men per shift, and some upkeep, as the periodic injection of high-pressure steam into coal charges would decrease the amount of scurf (residues of carbon fused to the interior of the retorts) that accumulated without adversely affecting the quality of the coke, and with beneficial results for the gas.<sup>49,50</sup> The continuous-feed retorts also remained essentially at the same temperature for as long as they were in use, avoiding the fluctuations in temperature during drawing and charging that gradually degraded the brickwork of the retorts.

By 1915, at least five Massachusetts gas companies were operating vertical retorts (Springfield, Malden and Melrose, Fitchburg, Brockton, and Fall River).<sup>51,52</sup> In many cases, these replaced older coal gas units, and in at least one documented instance, the Fall River company elected at least temporarily to stop making water-gas at all due to increases in enriching oil costs, and to simply make up the difference with its new coal gas unit.<sup>53</sup>

Together with new units constructed as additions and upgrades to existing gasworks, facilities such as the new Worcester retort house and the Fall River Gas Works Company's new plant represent close to the pinnacle of design for coal gas systems, with the technology refined to the point that it could successfully compete with water-gas and remain economically viable into the later years of the gasworks era (Figure 1.12).

### 1.5 EARLY OIL GAS IN MASSACHUSETTS (1820–1890)

The historical record of oil gas is less formal and detailed than for the other major process groups, and the process was in large part overshadowed by the popularity of coal gas and CWG. A good deal of this relative obscurity stems from the generally smaller and less urban of the first oil gas plants and their relatively brief life span. Given that the production of whale oil was a significant product of the New England fishing industry, it is reasonable to suppose that whale oil was used for

production of illuminating gas within the same general time period, and was likely in use during the 1820s. Petroleum oils such as kerosene and crude oil replaced nonpetroleum oils during the 1840s and 1850s. References to gas being made with oil from the period prior to about 1840 should generally be understood to refer to animal (e.g., whale or fish) or vegetable oils.

By the 1850s, oil gas had developed into a more or less mature technology, capable of providing illuminating gas to a factory village or small town. By 1880, the combination of routine Pennsylvania oil-field refining, the presence and early prominence of the Standard Oil Company, and the connective interstate railroad network would bring together the ability of any town gasworks to indulge in oil gas production. Although in some respects technically superior to coal gas, the cost of the oil feedstock appears to have prevented oil gas from expanding in scale or popularity to keep pace with the growth of coal gas.

Oil gas was produced at a minority of Massachusetts gasworks—fewer than a dozen at any given time, and with a heyday during the 1880s and 1890s. Most of the oil gas companies were located in small, relatively isolated towns, such as Amherst, Gardner or Leominster, or were factory-owned gasworks that chose to sell some of their gas to the municipality and public, such as the case of the Chicopee Manufacturing Company’s plant in Chicopee Falls. The earliest petroleum oil gas operation in Massachusetts, as determined by the authors, was the pre-1875 gasworks at Stoneham, believed to have been particularly sited to take advantage of rail transportation. Two of the earliest oil gas franchises, located in Lee and Great Barrington in Berkshire County in the westernmost part of the state, failed circa 1890 when the towns switched to electric streetlights and deprived the firms of their primary customers.

The number of oil gas companies in Massachusetts peaked at 11 in 1892 (Table 1.2), but began a swift and irreversible decline in 1894; after 1903 only three Massachusetts gas companies made oil gas.<sup>54</sup> The “mass extinction” of the late 1890s is due to a number of companies abandoning oil gas, with its high feedstock cost, in favor of cheaper CWG, with its low capital costs and significantly larger production capacities. The switch to water-gas (both Lowe’s CWG [Table 1.3] and the many Lowe-patent-skirting Oil-Enriched Water-gas processes introduced before the Lowe patents expired [Table 1.4]) was frequently heralded by a company tripling or quadrupling its gas output within the first several years after the conversion. The last oil gas company in the Commonwealth, the tiny Stoughton Gas Light Company, closed its doors in 1915.<sup>55</sup>

The technology of the many patented oil gas processes was quite simple, and without the degree of variation that developed in coal gas, oil-enriched water-gas, or CWG technology. Crude oil or partially refined petroleum distillates were fed into a heated retort at a controlled rate and dripped or sprayed onto an iron plate or grating in the absence of oxygen, resulting in the destructive distillation of the oil in essentially the same chemical process as coal gas production. The resulting gas was then *clarified* (via condensers, washers, scrubbers, or their combinations) for removal of most of the resultant aerosolized tar articles traveling with the raw gas, then *purified* using the standard methods of the day, for example, oxide boxes. The furnaces that heated the retorts were commonly fired with cheap bituminous coal, wood, or other inexpensive fuel.

Oil gas produced significantly higher candlepower and fuel value for a given volume of gas, but at a significant cost; the rate for oil gas was typically three times the dollar value per thousand cubic feet, due in large part to the high cost of oil compared to coal. The chief advantages, in addition to the high quality of the gas produced, included the relatively small plant necessary and the lesser manpower requirement in comparison with a coal gas works. Oil gas also generally did not need purification other than a wet scrubber, but was usually diluted with a percentage of air to limit the smoking of the gas, which could damage walls in houses and foul streetlight housings with soot.<sup>56</sup> The principal disadvantage was the high cost of feedstock, which effectively precluded large systems—production accounts provided by gas companies to the Board of Gas and Electric Light Commissioners between 1885 and 1922 show that oil gas plants only rarely exceeded 1,000,000 cubic feet per year in their output, and most never exceeded the million cubic foot per annum threshold during their operating lives.<sup>57</sup>

**TABLE 1.3**  
**Known Oil Gas Plants of Massachusetts (Listed Alphabetically, by Location)**

Dates	Location and Name	Considerations
1890–1910	Amherst Estate of E.P. Dickinson Cor. College & Dickson Streets, East Amherst	Naphtha oil gas; fired by coke. 1910: The Amherst Gas Company at a special meeting voted to install a water-gas plant in the building lately purchased from the estate of the late E. P. Dickinson in East Amherst. The estimated cost will be \$35,000. The use of water-gas will necessitate an enlargement of the gas mains. The building now used for making naphtha gas will be devoted to storage purposes. (1910, LH&P, c, p. 439)
1890	HQ at Boston Shaw Petroleum Oil-Gas by Orient Gas & Water Co.; understood to have been promoting plants throughout Massachusetts	1890: Capital stock \$1,000,000. President Wm. E. Merrill; Treasurer Hiram Blaisdell. Superintendent Construction: Wm. B. Frank. A Construction and Operating Company under the Shaw Petroleum Process. <i>Brown's Directory</i> , 1890, p. 146.
1909	North Adams Location undetermined No compelling evidence yet has been discovered that such a plant was built	<i>North Adams: C. P. Mosher and F. M. Cook, representatives of the Liquid Gas Company of (Boston) Massachusetts may locate a plant in this city.</i> ( <i>Light</i> , v. 10, December 1909, p. H) 1909: <i>The Liquid Gas Company of Massachusetts is organized.</i> <i>First to buy and sell natural gas liquid gas or compressed gas and air or to compound or manufacture the same from oil coal water and any other ingredients and to distribute it in tanks or other receptacles or containers.</i> (Capitalized at \$500,000, Incorporated December 16, 1909) (Annual Report of Massachusetts Board of Gas & Electric Light Commissioners, pp. 7–8, Public Documents of Massachusetts, no. 35) 1909: The liquid gas is manufactured and stored in steel bottles for shipment by the Liquid Gas Company of Massachusetts, Danvers, Massachusetts. L. Wolf, the inventor of the process has located in Boston, and is the consulting engineer of the company. ( <i>American Machinist</i> , April 22, 1909, p. 651) 1916: Corporation Dissolved. (Special Acts of 1916, Massachusetts, Chapt. 12, p. 86)
1947–1953	Cambridge Cambridge Gas Light Co. Substitute Natural Gas (SNG) Location undetermined but likely within the greater gasyard, north side of Kendall Square and Massachusetts Ave.	1947: Begins distributing Hi-Btu oil gas from converted CWG sets; design by Hall M. Henry, NEGA Service Corp., Cambridge. (1950, <i>Proc.</i> , AGA, p. 416-et seq)

(Continued)

**TABLE 1.3 (Continued)**  
**Known Oil Gas Plants of Massachusetts (Listed Alphabetically, by Location)**

Dates	Location and Name	Considerations
Pre-1981	<p>Cambridge                      M.I.T.                      Fischer-Tropsch Gas Synthesis Reactor                      Actual campus location undetermined</p>	<p>One of the many U.S. DoE experimental gas reactors, designed and operated without attention to related PAH site contamination; Prof. G. A. Huff, a well-known manufactured gas personality, was involved.</p>
1896–1904+	<p>Chicopee Falls                      Chicopee Mfg. Co.                      Eastside of river, adjacent to the plant discharge tailwaters</p>	<p>1870: F.W. Beers, <i>Atlas of Hampden County, Massachusetts</i> plate 32 Petroleum Oil-Gas; furnace fired with anthracite.                      1876: <i>The Lighting of (Woolen) Mills</i>.                      We should not omit mentioning as a practical evidence of the opinions of manufacturers as to the comparative merits of the two systems of lighting that many of the largest mills have changed their old coal gas works to those for petroleum gas.                      Among them we may mention the Washington (Lawrence, Massachusetts), Wamsutta (New Bedford, Massachusetts), Chicopee (Massachusetts), Naumkeag (Salem, Massachusetts), Assabet (Maynard, Massachusetts), China, Webster and Pembroke Mills, (Suncook, N.H.) and the Indian Orchard (Massachusetts).                      The well-known character of the treasurers of these mills gives great weight to their example.                      (National Association of Wool Manufacturers, <i>Bull.</i>, January–December, 1876, pp. 254–272)</p>
1909–1916	<p>Danvers Home of Liquid Gas Co. of                      Massachusetts Location undetermined</p>	<p>1909: <i>The Liquid Gas Company of Massachusetts is organized</i>.                      First to buy and sell natural gas liquid gas or compressed gas and air or to compound or manufacture the same from oil coal water and any other ingredients and to distribute it in tanks or other receptacles or containers.                      (Capitalized at \$500,000, Incorporated December 16, 1909)                      (Annual Report of Mass. Board of Gas &amp; Electric Light Commissioners, pp. 7–8, Public Documents of Massachusetts, no. 35)                      1909: The liquid gas is manufactured and stored in steel bottles for shipment by the Liquid Gas Company of Massachusetts, Danvers, Massachusetts                      L. Wolf, the inventor of the process has located in Boston, and is the consulting engineer of the company.                      (<i>American Machinist</i>, 22Apr, 1909, p. 651)                      1916: Corporation Dissolved. (Special Acts of 1916, Massachusetts, Chapt. 12, p. 86)</p>
Pre-1887	<p>Fall River                      Montaup Mill                      Location undetermined</p>	<p>Pre-1877: Had industrial oil gas illuminating plant 1877.<sup>171</sup></p>
Pre-1887	<p>Fall River                      Shrove Mill                      Location undetermined</p>	<p>Pre-1877: Had industrial oil gas illuminating plant 1877.<sup>172</sup></p>

(Continued)

**TABLE 1.3 (Continued)**  
**Known Oil Gas Plants of Massachusetts (Listed Alphabetically, by Location)**

Dates	Location and Name	Considerations
Pre-1887	Fall River Slade Mill Location undetermined	Pre-1877: Had industrial oil gas illuminating plant 1877. <sup>173</sup>
Pre-1887	Fall River Wamanoag Mill Location undetermined	Pre-1877: Had industrial oil gas illuminating plant 1877. <sup>174</sup>
1888	Gardner Gardner Gas Co. 35 Logan Street @ Chestnut Street; AKA, Jct. of Boston, Barre & Gardner & Vermont and Massachusetts RRs	1888: Organized as oil gas works. 1893: Foreclosed, sold to Mrs Maria L. Ruggles; Worcester. 1904: Naphtha Oil Gas; wood fired retorts. 1953: Serving LP air gas.
1854 to pre-1912	Great Barrington Gasworks	Gashouse Lane at 100 Main Street 1854: Gasworks established; process yet unknown. 1885–1889: Gasworks closed. (Sanborn Maps, 1885 and 1889) 1889: Oil gas plant present. (AG-LJ, May 6, 1889, 599) 1912: Gasworks and its gasholder house had been previously demolished and replaced by Standard Oil Co. warehouse. (Sanborn Map, Jan., 1912) 2008: Known to MADEP; Method 3 Report by Maxymillian Technologies, Pittsfield, Massachusetts.
Pre-1876	Indian Orchard Indian Orchard Woolen Mills Location undetermined	1876: <i>The Lighting of (Woolen) Mills.</i> <i>We should not omit mentioning as a practical evidence of the opinions of manufacturers as to the comparative merits of the two systems of lighting that many of the largest mills have changed their old coal gas works to those for petroleum gas.</i> <i>Among them we may mention the Washington (Lawrence, Massachusetts), Wamsutta (New Bedford, Massachusetts), Chicopee (Massachusetts), Naumkeag (Salem, Massachusetts), Assabet (Maynard, Massachusetts), China, Webster and Pembroke Mills, (Suncook, N.H.) and the Indian Orchard (Massachusetts).</i> <i>The well-known character of the treasurers of these mills gives great weight to their example.</i> (National Association of Wool Manufacturers, <i>Bull.</i> , January–December, 1876, pp. 254–272).
1898– 1904+	Ipswich Ipswich Gas Co. Kendall Oil Gas 18 Hammat Street	1898–1904+: J. R. Kendall oil gas; petroleum oil gas; fired with coal. 1889: Oil gas works present. (AG-LJ, May 6, 1889, 599)

(Continued)

**TABLE 1.3 (Continued)**  
**Known Oil Gas Plants of Massachusetts (Listed Alphabetically, by Location)**

Dates	Location and Name	Considerations
Pre-1876	Lawrence Washington Woolen Mills	1876: <i>The Lighting of (Woolen) Mills. We should not omit mentioning as a practical evidence of the opinions of manufacturers as to the comparative merits of the two systems of lighting that many of the largest mills have changed their old coal gas works to those for petroleum gas. Among them we may mention the Washington (Lawrence, Mass.), Wamsutta (New Bedford, Mass.), Chicopee (Mass.), Naumkeag (Salem, Mass.), Assabet (Maynard, Mass.), China, Webster and Pembroke Mills, (Suncook, N.H.) and the Indian Orchard (Mass.).</i>  The well-known character of the treasurers of these mills gives great weight to their example. (National Association of Wool Manufacturers, <i>Bull.</i> , January–December, 1876, pp. 254-272)
Pre-1889 to post-1891	Lee Lee Gas Co. Location undetermined, likely associated with a mill complex	Pre-1889: Established; petroleum oil gas; furnace fired with anthracite and wood. 1889: Present (AG-LJ, May 6, 1889, 599). 1889: <i>The works of the Lee (Mass.) Gas Light Company were almost totally destroyed by an explosion that occurred on the evening of the 23d. ult. The plant will be restored at once.</i> (AG-LJ, August 5, 1889, 175) 1891: <i>There is some talk of shutting down the gas plant at Lee, Mass.</i> (AG-LJ, November 16, 1891, 709)
Pre-1877	(East) Lexington (now Arlington) Lexington Gas Light Co.	Pre-1877: Established; petroleum oil gas; fired with anthracite. 1877: "We are informed that the Hanlon Improved Process (petroleum) has been put in by the Lexington (Mass.) Gas-Light Co." (AG-LJ, June 16, 1877, 234)
1887	Citizens Steam & Gas-Light Co.	1883: Est. by T.S.C. Lowe, as a fuel gas plant, in contravention to the Massachusetts prohibition on CWG for lighting purposes; site was that of the previous Citizens' Steam and Gas Light Co. 1887: Believed to have been the prototype installation of the L. P. Lowe oil gas process, later installed at Colorado Springs (1887) and which thereafter became the Pacific Coast Oil Gas Process upon Lowe Jr.'s arrival at Pasadena, California, about 1889. 2014: Parking lot for North Shore Community College.
1873–1902	Leominster Leominster Gas Light Co. Between Main & Mill Streets adjacent to Evergreen Cemetery	1873–1902: Unspecified oil gas process. 2000–2010: prodigious amount of site-subsurface NAPL; at least a 1-meter-thick horizon; treated by IESI recovery of >50,000 gallons tar NAPL as well as treatment of ~4E6 gallons contaminated groundwater.

(Continued)

**TABLE 1.3 (Continued)**  
**Known Oil Gas Plants of Massachusetts (Listed Alphabetically, by Location)**

Dates	Location and Name	Considerations
Pre-1876	<p>Maynard Assabet Woolen Mills            Location undetermined</p>	<p>1876: <i>The Lighting of (Woolen) Mills. We should not omit mentioning as a practical evidence of the opinions of manufacturers as to the comparative merits of the two systems of lighting that many of the largest mills have changed their old coal gas works to those for petroleum gas. Among them we may mention the Washington (Lawrence, Mass.), Wamsutta (New Bedford, Mass.), Chicopee (Mass.), Naumkeag (Salem, Mass.), Assabet (Maynard, Mass.), China, Webster and Pembroke Mills, (Suncook, N.H.) and the Indian Orchard (Mass.).</i>  <i>The well-known character of the treasurers of these mills gives great weight to their example.</i>            (National Association of Wool Manufacturers, Bull., January–December, 1876, pp. 254–272)</p>
1951–1975	<p>Lowell, no. 1            Lowell Gas Light Co.            Lowell Gas Co. (1949)            Colonial Gas Co. (1980)            775 Dutton Street</p>	<p>1951: Changed production to oil gas.            1951–1975: Intermittent oil gas production.</p>
Pre-1879 to 1891	<p>Middleboro            Amesbury Electric &amp; Patent Flooring Co.            Gasworks            Middleboro Gas Co.            Off Center Street &amp; RR</p>	<p>1879: Shows on Geo. H. Walker Map.            1888: Was using unidentified oil gas process.  <i>(Light, Heat &amp; Power, 1888, 179)</i>            1889: Bay State Gas Co. acquires plant and franchises of the Middleboro (Mass.) Gas Company.  <i>(AG-LJ, January 28, 1889, 114)</i>            Oil gas works present.  <i>(AG-LJ, May 6, 1889, 599)</i>            1891: Foreclosure sale; works to be demolished.</p>
1876	<p>New Bedford            Wamsutta Woolen Mills            Location undetermined</p>	<p>1876: <i>The Lighting of (Woolen) Mills. We should not omit mentioning as a practical evidence of the opinions of manufacturers as to the comparative merits of the two systems of lighting that many of the largest mills have changed their old coal gas works to those for petroleum gas. Among them we may mention the Washington (Lawrence, Mass.), Wamsutta (New Bedford, Mass.), Chicopee (Mass.), Naumkeag (Salem, Mass.), Assabet (Maynard, Mass.), China, Webster and Pembroke Mills, (Suncook, N.H.) and the Indian Orchard (Mass.).</i>  <i>The well-known character of the treasurers of these mills gives great weight to their example.</i>            (National Association of Wool Manufacturers, Bull., January–December, 1876, pp. 254–272).</p>
1922	<p>Plymouth            Plymouth Gas Light Co.            Dayton Oil Gas            Howland Street</p>	<p>1922: Installs a Dayton Process oil gas process, to nearly double its daily production capacity; peak shaving alternative Allows for 30-minute startup and production of peak-shaving gas amenable to standard clarification and purification and subsequent admixture with coal gas for distribution.</p>

(Continued)

**TABLE 1.3 (Continued)**  
**Known Oil Gas Plants of Massachusetts (Listed Alphabetically, by Location)**

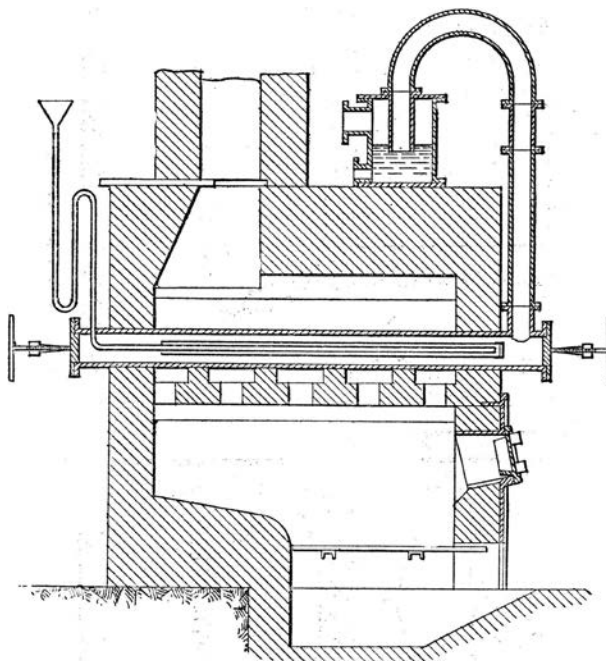
Dates	Location and Name	Considerations
1893– 1896+	Reading Citizens Gas Light Co. of Reading & Wakefield Gasworks Location undetermined	1893: <i>Referring to the dispute between certain gas consumers of Wakefield and Reading, and the Citizens Gas Company which operates in both places, the contention being that the gas was foul beyond the permissions of the statute, we find it stated that “The usual analysis of the gas and test for candle power impurities revealed no extraordinary conditions, and no violation of the statutory requirements except in respect of the of sulphureted hydrogen. The gas had an unusually strong and offensive odor; which upon further examination appeared to be due to particularly poor and sulphurous lot of coal which the Company been using. In view of the fact, that, immediately upon notice of complaint, the Company arranged to abandon the use of this coal, of the further fact that the cause of the complaint soon afterward disappeared; no order upon the petition was considered necessary follow in regular sequence reports of the appeals entered and before the Board in several cases all of which hold many points.” (AG-LJ, Apr 10, 1893, 533)</i> 1896: Kendall oil gas; naphtha, with naphtha Enrichment.
1876	Salem Naumkeag Woolen Mills Location undetermined	1876: <i>The Lighting of (Woolen) Mills. We should not omit mentioning as a practical evidence of the opinions of manufacturers as to the comparative merits of the two systems of lighting that many of the largest mills have changed their old coal gas works to those for petroleum gas. Among them we may mention the Washington (Lawrence, Mass.), Wamsutta (New Bedford, Mass.), Chicopee (Mass.), Naumkeag (Salem, Mass.), Assabet (Maynard, Mass.), China, Webster and Pembroke Mills, (Suncook, N.H.) and the Indian Orchard (Mass.).</i> <i>The well-known character of these mills gives great weight to their example. (National Association of Wool Manufacturers, Bull., January–December, 1876, pp. 254–272)</i>
1904	Southbridge Gas Light Co. Oil Gas Works	Pre-1898: Established. 1898: Improved Lowe CWG; anthracite; gas oil Enrichment. 1904: Petroleum oil gas; fired with anthracite/wood.
1910–1915	Stoughton Stoughton Gas-Light Co.	Pre-1904: Established. 1904: Naphtha oil gas; fired with bituminous coal.
1896–1909	Waltham Waltham Gas Light Co.	1896: Kendall oil gas; naphtha feedstock; naphtha Enrichment. 1909: Purchased by Boston Gas Co.

(Continued)

**TABLE 1.3 (Continued)**  
**Known Oil Gas Plants of Massachusetts (Listed Alphabetically, by Location)**

Dates	Location and Name	Considerations
1904	Williamstown Gas Light Co. Oil Gas Works Rear of Depot Street as of 1895, location currently known as the vicinity of 296 Cole Ave.	Pre-1904: Established. 1904: Naphtha oil gas; fired with wood.
Pre-1950	Brockton Gas Light Co. Charles H. Tenney & Co. Grove & E. Union Street Brockton	1950: Was manufacturing and serving its own manufactured gas, to include Inverted U Regenerative Oil Gas; 528 Btu, produced on one Bartlett-Hayward 500,000 cfd Inverted U Regenerative Oil Gas Set. ( <i>Brown's Directory</i> , 1950, p. 151)
Pre-1950	Cambridge Gas Light Co. Subsidiary of NE G&E Association 727 Massachusetts Ave.	1950: Was manufacturing and serving its own manufactured oil gas, 528 Btu, produced on four oil gas sets; three GASMACO 82,000 cfd and one GASMACO 10,800,000 cfd sets; plant holder storage 144,000,000 cf, plus 2,700,000 cf relief; L-P gas standby plant rated at 90,000 gallons. ( <i>Brown's Directory</i> , 1950, p. 152)

Source: Compiled by the authors, from various historic records.



**FIGURE 1.13** A schematic of a Patterson oil gas retort, from 1897, Patterson (UK), from Midlands Association of Gas Engineers (in) British Association of Gas Engineers and Managers (BGEM) *Proceedings*.

The primary residue of roasting petroleum or nonpetroleum oils in the necessary absence of oxygen is *lampblack*, finely divided soot that is a type of “carbon black,” composed primarily of carbon, containing some PAH, such as is routinely found today, discharged or dumped around locations of discharged gas liquors. Although comparatively harmless in and of itself, this carbon material was fully capable of sorbing significant amounts of the far more hazardous polycyclic aromatic hydrocarbon (PAH) compounds, as is the case with today’s granular activated carbon, used in all manner of commercial water-purification applications (Figure 1.13).

### 1.5.1 CHARACTERISTICS OF EARLY OIL GAS WORKS

Almost without exception, those plants and locations that were established from about 1820 to about 1900 appear to be characterized by the following features:

1. Limited access to feedstock supplies meant that until the advent of rail transport in the 1830s and 1840s, oil gasworks could only exist in a port or town receiving and managing some sort of oil such as whale oil or imported kerosene.
2. Relatively small areas and volumes of gas distribution; say, well less than one million cubic feet per annum, and within a radius of one kilometer.
3. Reliance on a common, incoming fuel feedstock available on a local basis for several lines of sale, so that the oil did not have to be imported for the gasworks alone.
4. A small gasworks footprint of, say, a quarter acre.
5. Clarification, purification, and storage capacities similar to a contemporary coal gas plant.

### 1.5.2 GAS OIL SUPPLY IN MASSACHUSETTS

The production of commercial oils from nonpetroleum sources such as refined vegetable matter (e.g., olive oil, cottonseed oil, or linseed oil) and animal sources (e.g., whale oil and cod-liver oil)

was clearly underway in Massachusetts at the time of the start of the Commonwealth's manufactured gas industry circa 1823–1828. Joseph T. Henry's 1873 account of the development of Pennsylvania petroleum (mineral oil) industry does not provide a date for the appearance of refined animal and vegetable oil in America, but whaling had been a regular activity along the east coast of North America since the mid-seventeenth century and the use of open fire potboiling of render whale oil from blubber for illumination was widely known by the first decades of the eighteenth century.

Much of this oil was used for routine domestic sources such as oil lamps, but the use of it for production of illuminating gas was known to have commenced in the United Kingdom circa 1820, during the first decade of the industry's existence.

The increased availability of petroleum oils beginning circa 1850 generally eclipsed nonpetroleum oils for most nonedible uses, including gas manufacturing, prior to 1860. By the 1850s, whale oil's price had become too high and the supply too limited and erratic. The availability of rail transport made it possible to obtain quantities of oil in the interior, away from the port cities where whale oil or imported oils of other types could be obtained easily in bulk.

The production of oil from certain hydrocarbon-rich shale (fine-grained clastic sedimentary rock) materials began in the 1830s and 1840s, using retorts in which the shale was destructively distilled to yield oil. It is possible that the similarity in this process to coal carbonization inspired the use of oil for gas manufacture. According to J. T. Henry's 1873 account, the advent of John Young's retorted Scottish shale coal oil, more popularly known as kerosene, the "great manufacturers of animal oils along our Eastern seaboard were first to take the alarm."<sup>58</sup> The same alarm attended the advent in 1846 of production of coal oils from shale by physician and geologist Dr. Abraham Gesner in New Brunswick, Canada.

This kerosene industry grew rapidly, and until the discovery of crude oil in Pennsylvania in 1859 provided the sole source of petroleum to the United States. Henry notes that:

Near Boston, Mass., Saml. [Samuel] Downer had erected [kerosene distillation] works on a most extensive scale, which cost about half a million dollars, while at Portland, he had other works put up at an expense of \$250,000, for the manufacture of oil from imported coal, and they continued to increase till at the time oil was struck there were not less than fifty or sixty of these establishments in the United States; one of which was in Portland, one in New Bedford; four in Boston; one in Hartford; five in the environs of New York; eight or ten in western Pennsylvania; twenty five in Ohio; eight in Virginia; six in Kentucky; and one in St. Louis.<sup>59</sup>

The original refined source of kerosene also led to the product being commonly referred to as "coal oil" or "shale oil" for many decades afterward, even after its production from crude oil had supplanted shale sources.

### 1.5.3 PETROLEUM OIL GAS IN MASSACHUSETTS (1890–1929)

Where the commercial rail net was capable of delivering cost-effective petroleum, first from Pennsylvania, some of the small- and mid-sized town gas plants found reason to generate oil gas from low sulfur crude oil. Presently, the authors consider the year of general availability of petroleum at other than Massachusetts port towns and cities, to be 1872 (Table 1.3).

### 1.5.4 NAPHTHA GAS

By the late 1860s, the American petroleum industry was producing vast amounts of naphtha, a mixture of various low boiling point hydrocarbons, as a by-product of kerosene manufacture. Naphtha was used in numerous industries, but the supply so exceeded the demand that only a small amount was refined into a solvent-grade product such as the "VM&P" naphtha popular with varnish makers and painters. The production of *gasolene* (the common name for this refined petroleum fraction

before the advent of the automobile) for “air gas” machines such as the Gilbert and Barker units (see Section 1.11.2) was one potential use, but as the Downer company found when they undertook gasolene production in 1863, yields from naphtha with the available technology could be as low as 1.5%, and the product sold for 30–35 cents per gallon, compared to 5 cents per gallon for crude naphtha.<sup>60</sup>

Following a common theme in nineteenth-century industry of finding a use for a waste product, in the late 1860s an oil refiner and marketer named A.C. Rand partnered with Dr. Leonard K. Gale and patented the Gale-Rand process, which had a brief heyday between 1869 and 1873. This was a two-stage process in which naphtha was first volatilized from a liquid to a vapor at a relatively low temperature before being decomposed and fixed as a gas vapor at a higher temperature. The overall result was somewhere between air gas and oil gas, with some of the drawbacks of both. While not the first attempt to make gas from naphtha, the two-stage heating process apparently avoided the besetting problem of earlier methods by reducing the amount of naphtha that simply condensed out of the gas stream. A full-scale test at the Saratoga (New York) Gas Light Company’s works was initially promising but eventually revealed problems with controlling the quality of gas produced, and the Saratoga company returned to coal gas production after two years. Undeterred, the Gas Light Company of America, a syndicate of investors and antecedent of the UGI (established Philadelphia; 1882) bought out the Gale-Rand patents and marketed the process nationwide, so that by 1873 it was in use by gas companies in 14 major cities. Within a few years, however, it was almost completely eclipsed by the development of CWG technology.

Although a landmark in gasmaking technology, the Gale-Rand process does not appear to have been used in Massachusetts. The Boston Gas Commissioners evaluated the process in response to a request from the Legislature in 1875, including trips to the gasworks in Saratoga, and the New York Mutual works in New York City.<sup>61</sup> The Commissioners’ findings were less than favorable—their report to the Mayor’s office noted that the Saratoga Gas Company had given up on the Gale-Rand process and returned to coal gasification, and that the mutual company used the gas primarily as an illuminant booster for blending with coal gas.

### 1.5.5 L.P. LOWE PERFECTS THE CRUDE OIL GAS MANUFACTURING PROCESS, IN MASSACHUSETTS (LYNN, 1887)

Early oil gas had relied on forms of processed or refined natural or animal oils, and consisted of crude attempts to turn the oils into illuminating gases, via the use of various forms of heated retorts; these were forms of vaporization of portions of the “oils,” both animal and mineral. Building on his father’s discovery of CWG, as discussed below, T.S.C. Lowe’s elder son, Leon Percival Lowe, brought forth the same degree of practical utility, and employed his father’s checker-brick linings of vertical, cylindrical *shells* of riveted iron sheets. In a sense, the junior Lowe’s process represents a transition or evolutionary link between early oil gas, CWG, and late oil gas.

L.P. Lowe accomplished the perfected process in about two years, taking place quickly at Lynn, Massachusetts, in 1883, as the tiny Citizens Steam and Gas Light Company in Lynn, Massachusetts, by its own description, producing *nonilluminative* CWG *fuel gas* “more of an experimental nature than anything else” and was selling small quantities of gas at 40–50 cents per thousand cubic feet—a pittance by the standards of the day.<sup>62</sup> This firm’s works were destroyed by fire in 1889 and the business closed before the junior Lowe could bring the oil gas plant into regular production.

The gas was sold as a nonilluminating fuel gas because at this point in time the sale of water-gas and CWG for illumination in Massachusetts (alone, of all states) was still effectively prohibited by statute.

At roughly the same time, Leon Percival Lowe (eldest son of T.S.C. Lowe, an innovative gas engineer in his own right, and founder of the *Progressive Age* gas journal) was perfecting his own Lowe Oil Gas process in that very city at the Citizens’ Steam and Gas Light Company on what was then Beach Street (now Washington Street). This firm was not a full-fledged gas company, but was

essentially a sort of nineteenth-century tech startup, experimenting with water-gas technology and earning its keep by selling steam and nonilluminating gas to adjacent businesses but not to the general public. It may be the case that L.P. Lowe arrived at Lynn initially also involved in the citizens' activity, possibly hoping to transfer that franchise into a general purveyor of oil gas. This firm's works were destroyed by fire in 1889 and the business closed before the junior Lowe could bring the oil gas plant into regular production, as either a fuel gas or as an illuminating gas.

The fire that destroyed the Citizens Steam and Gas Light facility occurred in the same year that the junior Lowe left town and reappeared at Colorado Springs, Colorado, with the same Lowe Oil Gas process that he had developed at Lynn. After successfully setting up his patented oil gas plant for production in Colorado Springs, Leon departed again, to join his father at Pasadena, California (the elder having arrived in Pasadena in 1887). The junior Lowe installed the perfected Lowe Oil Gas equipment at Colorado Springs Colorado and then culminated at Pasadena (1889), California, as what shortly became the *Pacific Coast Oil Gas* process. Between about 1897 and 1912, the Lowe Oil Gas process, by then self-dubbed as the Pacific Coast Oil Gas process, became the standard means of gas manufacturing on the west coast. Oil gas proved popular on the West Coast because petroleum was much more readily available than suitable bituminous gas coal or anthracite. Unlike the tar-water-emulsion-plagued CWG, the distinctly different Pacific Coast process operated efficiently on unprocessed California crude oil, which was characteristically rich in sulfur, although this process produced a burdensome solid residual of *lampblack*, a finely divided carbon powder (Figure 1.14).

The last West Coast gasworks to adopt the process was Seattle, in 1937. The gasmaking apparatus preserved as part of Seattle's Gasworks Park was the latest improvement in the Pacific Coast Oil Gas process, but not before the junior Lowe was stripped of his original patent coverage by Edward Campbell Jones (son of the Edward Stratton Jones, late of the East Boston Gas Light Co.), then of San Francisco and the major antagonist of a bitter 1920 California Federal Court legal battle entered by the Pacific Gas & Electric Co. (PG&E), decided in 1924 in favor of PG&E.

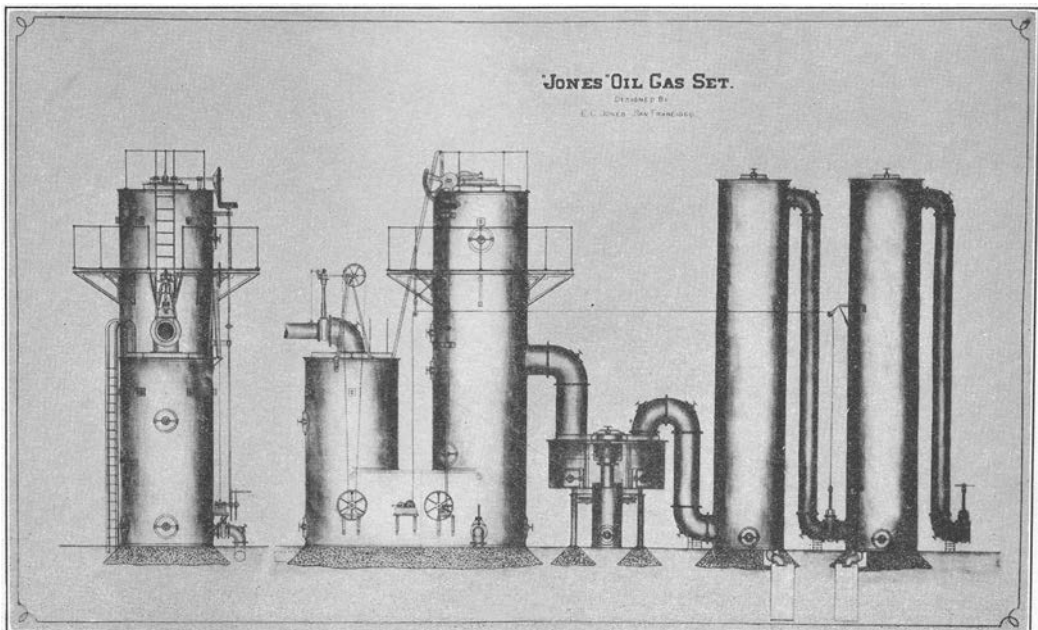


FIGURE 1.14 Schematic of a Jones “Pacific coast” oil-gas apparatus. (From AGI 1909.)

## 1.6 WATER-GAS

The term *water-gas* is often broadly but imprecisely used to refer to a series of several related technologies for making gas. These processes were dubbed “water-gas” because steam played a major role in the gasmaking process. Although the various water-gas processes share fundamental similarities, there are a number of different types of water-gas with important distinguishing features. As was true of coal gas, water-gas was known as a laboratory phenomenon long before it became a viable industrial-scale process, the fundamentals of the process having been identified by the eighteenth-century Italian experimenter Felice Fontana circa 1780, after which it was used as a bench-scale technology for producing hydrogen gas for experiments.

CWG came later to prominence in Massachusetts than in any other industrialized American state, because the legislature effectively banned it from commercial sale as an allegedly toxic gas in 1883, but this ban was repealed in 1890. CWG generally and quickly came to dominate the gas industry in the Commonwealth between the 1890s and the late 1940s. Non-CWG coexisted with CWG until the end of the gasworks era as an industrial fuel gas, because it was very inexpensive to make.

Water-gas processes differed from the coal gas production method; rather than destructively distilling or pyrolyzing coal, water-gas was made in an alternating “blow and run” process, in which a heat-generating, carbon-rich feedstock such as coke or anthracite coal was superheated (the “blow” phase), followed by an injection of steam, (the “run”) some of which then disassociated (cracked) into a mixture of two separate fuel gases, hydrogen and carbon monoxide (which, although known mostly as a toxic contaminant, does have a fuel value), and the neutral residuum, carbon dioxide. The chemical reaction of the steam and coke or coal was endothermic, and gradually reduced the heat of the feedstock until the reaction no longer proceeded efficiently, so the “run” cycle was stopped and another “blow” cycle started.<sup>63</sup> The two cycles repeated until the carbon feedstock was spent and only a clinker remained. This lower energy combined fuel gas was also thinly enriched by whatever hydrocarbons volatilized from the charge of coke or anthracite; the process is broadly similar to steam cracking of crude oil. The hydrocarbon content would be rather more generous if anthracite was used as the feedstock instead of coke. It was also possible to use petroleum crude oil as the feedstock instead of coke or anthracite, but no firms in Massachusetts disclosed doing so in their reports to the Board of Commissioners.<sup>64</sup> Indeed, in the 1930s and 1940s many gasworks modified their later-generation water-gas systems to use atomized crude or residual oil instead of solid fuel, thereby producing *reformed* oil gas to supplement illumination gas during the rising and more and more frequent national labor strikes brought on during this period by the United Mine Workers Union under the direction of its leader John L. Lewis.

Since neither coke nor anthracite contained the same quantity of volatile matter that contributed the hydrocarbon illuminants found in coal gas, water-gas continued to be a *fuel* gas, used for heat alone, and had little illuminating value unless it was subsequently enriched by another hydrocarbon material, as was the whole purpose of generating and distributing CWG.

### 1.6.1 BLUE WATER-GAS

The first and most basic worldwide version of *water-gas* was the so-called *blue water-gas*, developed during the 1860s and largely in Britain, by the German emigrant Siemens brothers. It lacked illumination qualities, but was a useful industrial fuel gas. Although the gas was inferior in heat energy per thousand cubic feet to coal gas, with a calorific value of only 300–335 Btu, compared to a typical range of 500–600 Btu for coal gas, it could be made cheaply enough that the consumer could simply make and burn more gas to compensate for the lesser fuel value.<sup>65</sup> One evaluation, which compared the relative fuel values of several different types of gas, by measuring the amount needed to melt 10 tons of iron, determined that approximately twice as much water-gas was needed,

compared to coal gas, and that although water-gas, CWG, and coal gas were each superior in thermal efficiency to coke, coke remained necessary for mechanical and metallurgical reasons, and remains the essential basic fuel stock of the foundry processes to this day.<sup>66</sup>

Water-gas (blue gas) production was essentially limited to powering large, unregulated, and systematically unrecorded industrial plants, town-utility plants (such as water supply pump stations and fuel gas producers for all manner of DC electric generating stations, or for AC stations in small towns where waterpower was not accessible or sufficient to demand, such as the Shelburne Falls and Dalton electric light plants.<sup>67</sup> For this simple reason, blue gas plants (more properly known as *gas producers* or *producer gas plants*) continue to escape recognition by environmental regulation and remedial attention in Massachusetts.

For the most part, in Massachusetts, as elsewhere, blue water-gas was the most efficient industrial fuel, and these currently unrecorded gasworks could theoretically number about six to ten times more incidences (not by volume of waste, but by locations of gasworks and their gasworks dumps) than for consumer-oriented gas plants.

There were innumerable patent water-gas fuel-making processes, typically referred to by the name of their inventor or patent-holder, for example, “Loomis Gas” after Chicago-based Burdett Loomis, Sr. Although differences in system design might make for greater or lesser efficiency for a given system, the differences between them were often only minor. As the consulting gas engineer Samuel Wyer noted in 1906 in the context of “producer gas”:

The terms Riche gas, Mond gas, Loomis gas, Siemens gas, or Dowson gas are misleading, as the gas is virtually the same in all these instances, and is simply made in producers bearing the respective inventor names. However, the exact (percentage) proportion of the different elements and compounds present in the gas will depend on the type of producer and the nature of fuel used in making the gas.<sup>68</sup>

Wyer also grumbled that:

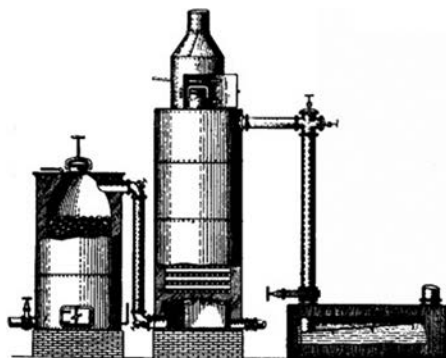
While the number of patents which have been taken out on gas-producers and producer-gas processes is very large, many of the patentees have shown an unusual lack of originality in the principles upon which gas production is based. Many inventors seem to be satisfied by merely modifying details of forms already in use; very few have gone back to the physical and chemical laws upon which gas production is based and, after studying the nature of the various operations, have considered how these could be applied. In some cases, recent patents use only copies of old ideas that had been tried a quarter of a century ago.<sup>69</sup>

There were, however, many abject failures, some of which were proposed by persons who meant well but who lacked the necessary technical knowledge, business acumen, or both, and some of which were basically financial scams. Suffice it to say that for every L.P. Lowe, there were a hundred unknowns (Figure 1.15).

The earliest Massachusetts incidence of a true “water-gas” (as opposed to CWG or oil-enriched water-gas) plant appears to be at Marlborough where it is obliquely noted as being present in 1862, but not yet identified as to its specific process.<sup>70</sup>

Blue water-gas was generally a failure in the utility market, largely due to its lack of illuminating value. Two gas companies attempted to market blue water-gas to the public, the first of which was the Framingham Gas Fuel & Power Company, which began production in 1891, selling nonilluminating water-gas made from bituminous Cumberland coal by the Loomis process for what was then a bargain-basement price of \$0.50–\$0.75 per thousand cubic feet.<sup>71</sup> By contrast, the statewide average cost of coal gas at the time was about twice as much, at \$1.35 per mcf. The Cottage City Gas Company on Martha’s Vineyard launched at about the same time and used a similar process.<sup>72</sup>

A third firm, the American Fuel Company in Chelsea, managed in 1890 to win municipal approval as an opposition company (over the strenuous objections of the Chelsea Gas Light



**FIGURE 1.15** Original Lowe apparatus, a classic example of noncarbureted “blue” water-gas. (From Owen Evans, *Hist. and development of American Water Gas Processes*, Gas Age 1916 p. 70).

Company) and got as far as starting to build a plant and lay mains, before the realization set in that its patent oil-based fuel gas process was a technological boondoggle with little fuel or illuminating value. The fuel gas company missed all of its deadlines and was roundly critiqued by its own belatedly hired engineering consultant, who recommended that the whole plant would have to be rebuilt in order to produce usable gas. After still further delays, and apparently no gas made, or the means to make gas without starting again from scratch, in 1891 the Board remanded the issue to the Chelsea aldermen with the recommendation that “experiments of this nature should be made on private land, and that the public streets ought not to be used for the purpose.” The aldermen promptly revoked the fuel gas company’s permission to operate or lay mains, and the matter was closed.<sup>73</sup>

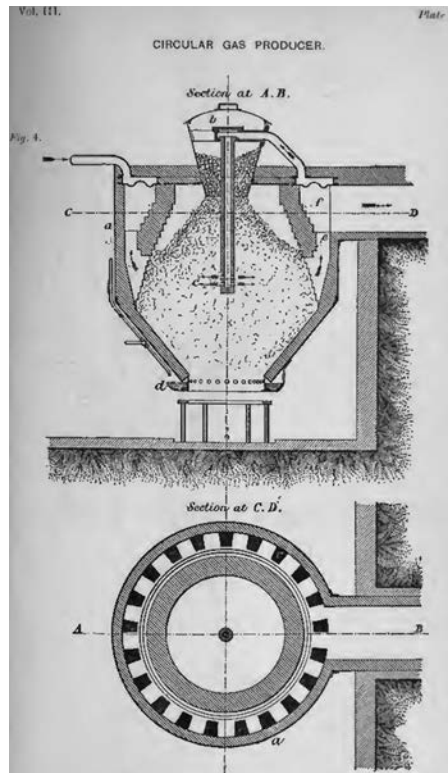
Despite the low cost, the limited usefulness and marketability of this gas—since it was essentially useless for municipal lighting contracts and the residential market without special lighting fixtures such as the “Fahnenjelm burner”—meant gas companies launched to exploit it often struggled for many years before adopting other processes out of sheer necessity. By contrast, however, blue water was such a cost-effective means of producing industrial fuel that it remained in widespread use for factory processes until the end of the gasworks era.

### 1.6.1.1 Producer Gas

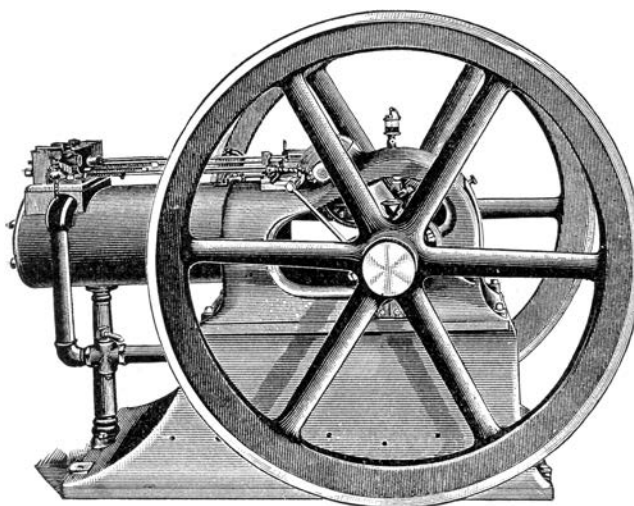
“Producer gas” is sometimes distinguished from “blue” water-gas on the largely semantic basis that the former was the product of air passed through the carbon media, and the latter being the product of steam, but in practice there was little difference. Wyer’s 1906 monograph *Producer Gas and Gas Producers*, however, recognized that there were many different types of gas producers, some of which used air, some of which used steam, and some of which used destructive distillation in airtight retorts—Wyer included the producer gas stage of a by-product coke oven in this category.<sup>74</sup> Most of these were quite simple in contrast to a Lowe or “water-gas” system, often being a single cylindrical unit, with inlet and outlet pipes.

In Wyer’s view, the major common feature of the various types of producer gas was that they relied on incomplete combustion in the producer, with the producer heated by a portion of the gas it produced. More verbosely, Wyer defined producer gas as “the generic name for the gas resulting from the comparatively slow resolution of solid fuel by means of the heat derived by a partial combustion of the fuel itself, the exact composition of the gas being dependent upon the nature of the fuel, the arrangement and the method of operating the producer.”

Producer gas was most strongly associated with heavy industry, particularly the iron and steel industry, where it could provide cheap, controllable process heat for blast furnaces, coking plants, smelters and so on, but could also be found in other industries such as for firing ceramic kilns, steam boilers and gas engines (Figures 1.16 and 1.17).



**FIGURE 1.16** Schematic of a Siemens gas producer, one of the more common producer gas units on the market in the late nineteenth and early twentieth centuries.



THE DAYTON GAS ENGINE.

**FIGURE 1.17** Dayton Gas Engine, of a type commonly fueled by producer gas systems in industrial facilities. (From *Modern Machinery*.)

## 1.6.2 FIRST FUEL GAS DISTRIBUTED IN THE UNITED STATES (LYNN, MASSACHUSETTS, 1883)

It is difficult to imagine the fervor that had suddenly developed in America, over the prospects of blue water-gas fuel that swirled around T.S.C.'s marketing efforts, the startup of the UGI's creation (Philadelphia) and massive intervention (1882) into the potentially unlimited fuel gas market. All of this activity was going on at the same time and same region (Massachusetts), where the Greenoughs were being attacked by the Addicks syndicate at Boston, as discussed in greater detail in [Chapter 4](#), while William W. Greenough had created the legislative furor over the alleged human toxicity of Lowe's CWG. Add to this that creative gas engineers (including Addicks) were quickly installing oil-enriched water-gas variants of Lowe's CWG process, the latter of which was taking all the attention and the heat of its prohibition.

At the present time, it is apparent that Lynn, Massachusetts rightfully claims pride of place for the introduction of water-gas to Massachusetts:

Nov 10, 1883, non-carburetted water-gas was introduced to public at Lynn, Mass., as a solution of the fuel problem, and it fell to my lot to assist in the manufacture of the first strictly fuel for general distribution in this country. Its advent was characterized by the usual flourish that accompanies the introduction of a new thing, and much was promised; in fact too much, for before the works were in operation people were led to believe fuel water-gas at 50 cents per 1000 cu ft. would be much cheaper to burn than anthracite coal at \$6 per ton.<sup>75</sup>

The November event was preceded by a considerable physical expansion of the Pleasant Street Gasworks, announced as forthcoming in the previous July.<sup>76</sup> Evans' careful distinction of the gas as "fuel water-gas" is likely due to the Massachusetts legislature having essentially banned the sale of water-gas for illuminating purposes, as will be discussed later in [Chapter 6](#), and restricted its use to "fuel" uses such as domestic or industrial heating systems.

The authors believe that the design impetus behind the Lynn event was Leon Percival Lowe, the elder son of Professor Lowe, and the person who initiated the first modern oil gas production in 1887, also at Lynn.

## 1.7 CARBURETED WATER-GAS (LOWE)

None of the many patented oil-enhanced water-gas processes had the unique set of patent conditions of the inventions of an American innovation that systematically and flawlessly produced water-gas with the essential qualities of both an illuminant, and, selectively, as a fuel gas. This worldwide improvement was brought forth by the intrepid Civil War Union Army observation balloonist (and celebrated historical founder of the U.S. Air Force), Thaddeus Sobieski Constantine Lowe, and patented (1873–1875) under the exclusive term of CWG. T.S.C. Lowe subsequently sold his patents to the UGI of Philadelphia in 1882.

The heart of the Lowe system was an arrangement of three vertical cylindrical steel "shells," identified as the generator, the carburetor, and the superheater, and collectively known as a "set." Each of these shells was lined with firebrick installed in an open checker-work pattern, in order to provide maximum interior surface area as the actual sites for the cyclically heated gas production reactions. Other essential equipment included fireboxes (the generator) and a high-capacity boiler plant capable of continually supplying large quantities of superheated steam (used both to "crack" water into the required base gases, and to activate the cyclical valves controlling the gas-producing reactions) ([Figure 1.18](#)).

The process began by loading the *generator shell* with a charge of several hundred pounds of feedstock—Lowe originally specified coke or anthracite coal—and heating it to something over 1,000°F while "blowing" air through it until the feedstock was white-hot and the checker brick lining surfaces were thoroughly heated. The air was then valved off and live superheated steam vented into the base of the generator, known as the "run" phase. The steam reacted with the coke and the water

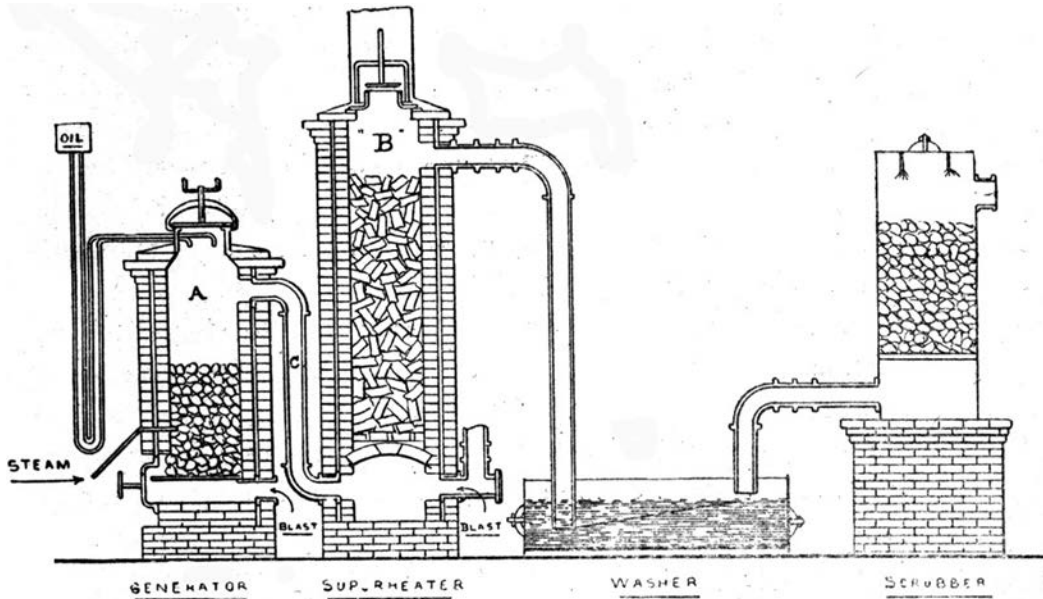


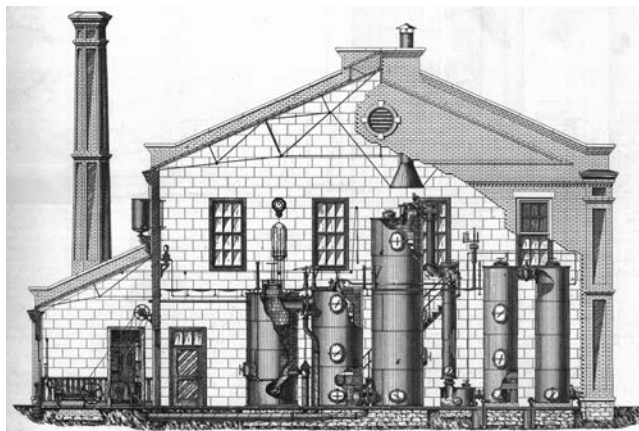
FIGURE 1.18 Schematic of the original Lowe CWG process. (From *Progressive Age*, 1889.)

vapor cracked into carbon monoxide and hydrogen, with the necessary gas-binding carbon supplied by the coke. The gas was then vented into the *carburetor shell* where heated, atomized petroleum “naphtha” was sprayed into the gas stream to enrich it with hydrocarbon illuminants. The role of the third shell, the *superheater*, was to *fix* the volatilized hydrocarbons into the resulting production gas, so that they would not condense out of the stream of produced gas. While the gas was being carbureted and superheated, the generator was being cyclically *blown* again to rebuild heat for another *run*. The timing of the blow and run cycle was usually three to five minutes per cycle, based on experience and the engineer’s judgment. The resulting CWG could be treated much like coal gas, and could be formulated to be usable for fuel gas purposes and, unlike regular water-gas, for illumination.

The Lowe process’s most important feature was the carefully tuned carburation stage that followed immediately after the *blow-and-run cycle* of a water-gas system had generated the raw water-gas. The carburation process added a fine mist of light hydrocarbons, most commonly aerosolized petroleum naphtha or recovered “light oils” from coal gas retorts, to the stream of gas under conditions of controlled temperature and pressure. If properly done, the hydrocarbons would become “fixed” and would remain in suspension as a vapor in the gas mixture for some time, providing the illuminants that raw water-gas lacked. The term *carburation* had shown up in gas technology in the second decade of nineteenth-century Britain, but had not previously been directly associated with a patented water-gas process delivering illumination gas.

Each blow or run phase typically lasted between three and five minutes, and charges of feedstock were normally changed out every 12 hours, depending on demand and charge size and quality. The duration of each cycle was not directly prescribed, but was often selected at the judgment of the plant operator, from as much art as science. The residue left by the feedstock consisted mostly of graphite-like carbon residues deposited on the interior brickwork and known as *scurf*, or of fused lumps of refractory minerals present in the feedstock such as silica, known as *clinker*.

The original Lowe patents specified coke as the required feedstock, with the idea of using a natural by-product of a gasworks’ coal gas units heating the interior of the generator, but anthracite coal was widely used and bituminous coal came into general use circa 1918, as a wartime exigency measure when anthracite or coke were not available. This change created numerous problems, including the production of tar–water emulsions in the system effluent, which greatly increased the



**FIGURE 1.19** A cutaway drawing from an UGI advertisement found in many trade journals over several decades, showing a later-model Lowe system with double superheaters. (From *Progressive Age*, 1894).

quantities of unusable waste products produced by the gasworks, and which also rendered many otherwise potentially salable gasworks residuals useless, leading to increased discharges of these tar materials into the environment, contributing to the typical legacy of tar contamination at gasworks and nearby properties and water bodies.

Since as a matter of convenience the generator was typically loaded with feedstock through its top, which was generally conical, the set was normally installed so that the upper end of each cylindrical shell was flush with the floor of an upper level or a mezzanine within the generator house, often constructed of iron gratings. The set was operated from hand-draw control “arms” at a gas maker’s vertical stand located on the mezzanine, while the rest of the device was accessible from the lower level for, nonroutine actions such as removing clinker, and other shell-maintenance tasks (Figure 1.19).

As the reputation of the Lowe process spread, a great many Lowe CWG plants were quickly installed on a royalty basis, as paid to UGI of Philadelphia, after its purchase of the Lowe Patents of 1873–1875. As an example of the rapidity of the spread of the Lowe process, one contractor specializing in constructing Lowe plants, Henry M. Pierson, claimed to have installed new Lowe systems in nine eastern cities, from Vermont to South Carolina, in 1884 alone.<sup>77</sup>

The acceptance of Lowe technology spread still more rapidly after the UGI bought T. S. C. Lowe’s CWG patents, at the time of the latter’s formation in 1882, but then ran to expiration between 1890 and 1892. Gas apparatus fabricators were thereafter free to build, advertise, and sell their own versions of the “Lowe Process” CWG sets, without permission or royalty payment. By 1910, the Lowe name was virtually synonymous with CWG technology, to the extent that in 1909, of 29 gas companies making CWG in Massachusetts, all but five of them used either the Lowe or Improved Lowe process, including a number of other companies that had initially used other (oil-enriched water-gas patent) equipment.<sup>78</sup>

### 1.7.1 RISE AND UTILITY OF CWG

Less than 20 years into the practical era of *water-gas* (the fuel gas), Lowe’s CWG appeared and quickly came to dominate the American, Canadian, and UK field.

Lowe apparatus was available in a number of standard sizes, with the size of a three-shell set being generally dictated by the size of the generator (Table 1.4). The larger Lowe systems were considerably larger than most other blue water-gas or oil-enriched water-gas systems. By 1917, there were a dozen standard Lowe system sizes.<sup>79</sup> Of these, the four-foot and five-foot diameter units were

**TABLE 1.4**  
**Standard Lowe/UGI Generator Shell Sizes**

Generator Shell Diameter	Daily Capacity in Cubic Feet (24-Hour Period)
3 feet 9 inches	80,000–100,000
4 feet	100,000–125,000
4 feet 6 inches	150,000–175,000
5 feet	200,000–225,000
5 feet 6 inches	225,000–275,000
6 feet 6 inches	350,000–450,000
7 feet 6 inches	475,000–676,000
8 feet 6 inches	800,000–950,000
9 feet 6 inches	1,000,000–1,300,000
10 feet 6 inches	1,265,000–1,600,000
11 feet	1,500,000–1,850,000
11 feet 6 inches	1,650,000–2,000,000

*Source:* After Russell, W. R., 1917, *Operation of Gas Works*, McGraw-Hill Book Co., NYC, NY, p. 209.

Lowe's original models, but remained popular and available for new purchase well into the twentieth century with the nickname of "Baby Lowe" systems.

To give some context for the production capacity of these units, between 1891 and 1906, the Fall River Gas Works Company was able to supply the needs of a heavily industrialized city of over 100,000 residents with four eight-foot six-inch units with double superheaters at its Annawan Avenue plant.<sup>80</sup> Circa 1880, even the original five-foot Lowe sets could equal the ideal daily output capacity of a well-managed bench of eights at a coal gas plant.

The modular nature of these plants was an often-overlooked advantage, because these machines sometimes had to be replaced on rather short notice; in 1917 the Greenfield Gas Light Company had to replace its two quite new four-foot sets (one installed 1907, the other in 1914) with five-foot sets (plus two new condensers and a tar extractor) in order to accommodate the increased demand, which skyrocketed from 15 million cubic feet per year in 1910 to 50 million cubic feet in 1917.<sup>81</sup>

Later refinements further increased the generating capacities of Lowe systems; in 1920, a later version for the 11-foot unit installed at the North Adams Gas Light Company's works, fitted with automatic hydraulic controls, was credited with a capacity of 3,500,000 cubic feet of gas per day, although this was likely a unit with the same diameter but a greater long (vertical) axis.

Table 1.5 introduces the general presence of CWG in Massachusetts, beginning with its development in SE Pennsylvania, in the early 1870s.

## 1.7.2 PRACTICAL ADVANTAGES OF CWG

From a production point of view, the practical advantages of water-gas over coal gas were significant. CWG could be made in smaller plants, manned with only one or two men per shift rather than the dozens of laborers required for a coal gas plant. This was not an insignificant issue; in coal gas manufacture the cost of labor could often account for nearly half as much as the coal, oil, and other materials. The cost of CWG, by contrast, was almost entirely the sum of the preferred feedstock coke and carbureting oil costs, since the labor and plant costs were so much less in comparison with coal gas even though the feedstock and oil were comparatively expensive.<sup>82</sup> Working conditions were not much more pleasant than in a retort house, though; temperatures still routinely exceeded 100°F, the air was still laden with gas, live steam, and fumes, and stokers had to shift ton-weights of coal or coke, although for the most part this material could be wheelbarrowed to a shell-lid in the floor and poured in rather than having to be lifted in scoops as with retorts.

**TABLE 1.5**  
**Known Use of Low Carbureted Water-Gas (CWG) Plants in Massachusetts**

Dates	Location and Name	Considerations
1883	Lynn Citizens Steam & Gas Light Co. This was the first CWG plant to be installed in Massachusetts	1883: T. S. C. Lowe and four other stockholders created a CWG company to distribute fuel gas to be used to supply steam for power at Lynn. The plant was designed to skirt the Legislative ban on CWG for lighting purposes. The second such CWG fuel gas plant was installed by Lowe at Troy, New York. ( <i>Progressive Age</i> , February, 1887, p. 24) 1889: Plant failed economically and was sold for salvage to Lynn Gas Light Co. (F. H. Shelton, p. 254; <i>20th Annual Meeting Proceedings</i> , Cincinnati, Ohio, Western Gas Association; bound with 1896–1898)
Early 1890s	Carburetted water-gas (CWG) gains entry to western Massachusetts	Noted by appearance of the usual second (relief) gasholder on historic site layout maps.
1890	Brookline Gas Light Co. Brighton (Allston) Gasworks	1890: CWG plant shows on L. J. Richards, Springfield, Massachusetts. <i>Atlas of Dorchester, West Roxbury &amp; Brighton, City of Boston</i> , in one vol.; Ward 25. Plate 33 shows fully equipped CWG works.
1892	Chicopee Gas Light Co. 1907: Terminates manufacture of its own gas and buys gas from its new (1907) parent company, C. H. Tenney & Co. (1910, <i>LH&amp;P</i> , p. 475)	1893: <i>The companies in New Bedford, Haverhill, and Chicopee have, during the year past, erected water-gas apparatus, and are now supplying a mixture of coal and water-gas. The company at Athol has also returned to its former practice of distributing only water-gas.</i> ( <i>Progressive Age</i> , 1893, Vol. 11, January–June, p. 215) 1894: L. J. Richards & Co., Map Chicopee Center, Ward 3; <i>Atlas of Hampden County</i> . Some changes in layout. Two gasholders, one larger and one smaller; indicating CWG now present.
Pre-1894	Chicopee Manufacturing Co. Chicopee Falls	1894: L. J. Richards Map of Chicopee Falls, <i>Hampden County Atlas</i> Two gasholders, must have gone over to CWG.
1894	Boston Gas Light Co. Brookline Gas Light Co. Lowell Gas Light Co.	<i>The Boston Gas Light Company and the Brookline Gas Light Company have during the year begun to supply water-gas, and the Lowell Gas Light Company to supply water-gas mixed with coal gas.</i> ( <i>AG-LJ</i> , March 26, 1894, pp. 438–441)
Pre-1904	Amesbury & Salisbury Gas Light Co. Amesbury, Massachusetts	1904: CWG shows on Fifth Sanborn Fire Insurance Map.
Pre-1905	Fall River Gasworks Co. Off E. side of N. Water Street; block with Anawan Street (ENE-WSW) to North, Pond Street (NW-SE) to East and Crab Pond to South	1905: Sanborn Map, 3rd. ed. Now a CWG plant. Many changes. This is the same year in which the Charles Street property was bought and first used to set up the 2,000,000 cf gas holder.
1909	Clinton Gas Light Co.	Historic synopsis (according to the modern Bay State Gas Co. in its pre-1989 properties list): Unknown (1858)–1911: Coal gas. 1909–1930: CWG. 1930c: Terminated production.

(Continued)

**TABLE 1.5 (Continued)**  
**Known Use of Low Carbureted Water-Gas (CWG) Plants in Massachusetts**

Dates	Location and Name	Considerations
1910	Amherst Gas Co.	<p><i>The Amherst Gas Company at a special meeting voted to install a water-gas plant in the building lately purchased from the estate of the late E. P. Dickinson in East Amherst.</i></p> <p><i>The estimated cost will be \$35,000.</i></p> <p><i>The use of water-gas will necessitate an enlargement of the gas mains.</i></p> <p><i>The building now used for making naphtha gas will be devoted to storage purposes.</i></p> <p><i>It was also voted to reduce the price of electric light from 18 to 16 cents per kilowatt hour.</i></p> <p>(1910, <i>LH&amp;P</i>, p. 439)</p>
1910	CWG comes to dominate over coal gas at Boston	<p>1905: Introduction of by-product (merchant) coke ovens of Massachusetts Pipeline Co. at Everett.</p> <p>&gt;1905: Coal gas production was slipping also against coke-oven gas.</p>

Source: Compiled by the authors from various sources.

The CWG process could also produce the same volume of gas using far less fuel and feedstock than a coal gas plant; a mere 500 pounds of coke or anthracite, plus about 55 gallons of carbureting oil to produce 10,000 cubic feet of gas, compared to a ton of coal for the same volume of coal gas.<sup>83</sup> Lowe's CWG process, however, employed volatized naphtha (or a variety of light oils of tar or petroleum) as an intermediate step, making CWG an excellent illuminant, as well as a good heating fuel, capable of the same candlepower and Btu values as coal gas. CWG also offered the advantage that the candlepower value could be adjusted simply by adding more or less naphtha—indeed, Russell references water-gas of up to 28 candlepower, with a corresponding fuel value of 2,550 Btu.<sup>84</sup>

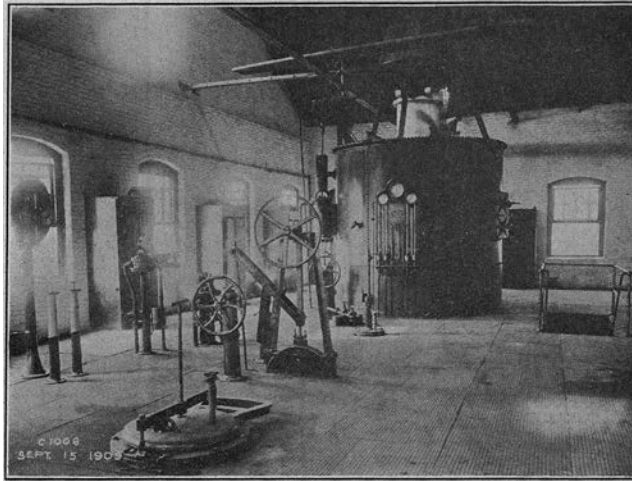
The labor factor could be significant. At one point during the 1880s, the municipally owned gasworks in Philadelphia temporarily transitioned to water-gas, reducing the necessary manpower from 2,000 men to 100, but in a situation that highlighted the machine politics of the era, the city's political machine was in the end unwilling to sack nearly 2,000 presumably loyal voters, and so the water-gas plant was shuttered and the coal gas works returned to use.

A last flare of anti-CWG fervor was emitted by organized gashouse labor, the Knights of Labor, late in 1890, after the newly installed President of the Boston Gas Light Co.; J. Edward Addicks, began to modernize his three large gasworks (North End, Commercial Point, and the Calf Pasture) with steam-powered, automatic coal gas retort stokers: The "Knights" decreed that:

The continued introduction of water-gas is an imposition upon the public; it gives the people an article far below coal gas in illuminating power, and throws a large number of men out of work, without giving the consumer a corresponding benefit in the reduction of gas bill.<sup>85</sup>

Construction of a CWG system was also much quicker than erecting a coal gas retort house. Once the process had gained a measure of acceptance in the gas industry as a whole, CWG equipment could be bought off-the-shelf from manufacturers—though generally under license prior to the early 1890s. With the system components shipped by rail to the gasworks and assembled by millwright crews, the gas system could generally be brought online more or less immediately. By contrast, it could take up to a year to bring a new retort house online.

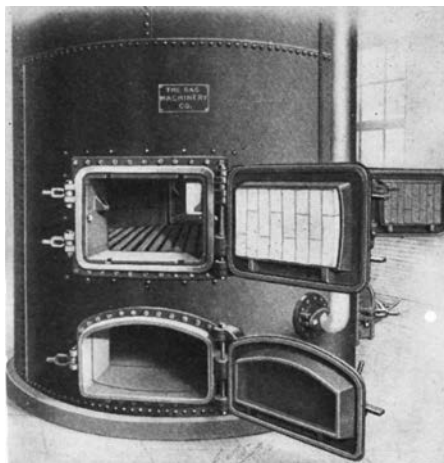
Unlike a bench of coal gas retorts, which had to be brought up to operating temperature slowly and carefully, and then kept at operating temperature, lest the individual firebrick fracture and crack (a problem common to all coke-oven plants, and which also remains common in modern foundries and kiln operations), a CWG plant could be brought from completely offline to full



**FIGURE 1.20** This 1917 picture from W. M. Russell’s *The Operation of Gas Works* shows the operating floor of a CWG generator house, from which workers would pour coal or coke into the “shells” below, in stark contrast to the retort house conditions shown in previous images.

production in an hour or two, and shut down as easily. The fireclay linings of a generator set typically had a useful life of 1,000 hours of running time; although these were relatively short intervals (six weeks if in continuous production); their replacement was a relatively simple task (Figures 1.20 and 1.21).<sup>86</sup>

By contrast, Charles Dudley Lamson, at Worcester in 1909 described the complex process of bringing a coal gas bench up to operating temperature—first the settings were brought up to temperature until the iron *nostrils* of the underlying furnace were red hot, followed by the furnace-fuel-producing *gas producers* being run up to a temperature of 1,200°F over the course of six days (not exceeding 200°F of increase in temperature in 24 hours, to avoid cracking the firebrick of the retort benches) with pressure and temperature carefully balanced, before a single retort could be charged.<sup>87</sup> An additional two weeks might be required to bring a bench up to the proper temperature



**FIGURE 1.21** The humblest part of a Lowe system—the bottom of a generator shell, with doors for removing ash and clinker.

for continuous, 24-hour daily production, after new construction or repairs, allowing up to 15 days for the brick, fire material, and mortar to dry under a controlled heat.<sup>88</sup> For this reason, during periods of reduced demand, coal gas retorts were rarely taken out of use; rather, the retorts were just loaded with reduced charges of coal to spread the reduction in output across all of the retorts.

As it was, coal gas retorts typically needed rebuilding every two to four years just from normal wear and tear; Robert W. Bush, an engineer with the Boston Gas Light Company, noted in an 1893 presentation to the American Gas Light Association that:

[T]he maximum average at Commercial Point for three benches of 6's is 951 days. The next best average, of 919 days, is for four more benches in this stack, charged at the same time. The best work of 54 retorts, set in 9's, is an average life of 582 days – not so good as the 6's, one reason being higher heats. [...] Average life, from table in notes, of 600 retorts of different make, is 384 days.<sup>89</sup>

By contrast, a water-gas set could last for up to five decades with proper care, and periodic replacement of their *checkered* (open-space void pattern) firebrick liners, as contained within their vertical right-cylindrical steel-shell enclosures; each *set* having three *shells*. This ease of use and maintenance made water-gas plants far more responsive to consumer demand, able to make more gas, on call (with a nominal half-hour heating preparation) when needed, rather than having to supply gas at a fairly consistent rate around the clock.

By contrast, the checker-brick linings of water-gas apparatus had to be replaced more frequently than the firebrick benches that housed coal gas retorts—on the order of once every six weeks—but the task was much less onerous.<sup>90</sup>

Many gasworks in Massachusetts and elsewhere operated combined-process plants, with both coal gas and water-gas units, the manufacture gas outputs from which were commonly blended prior to distribution. The inherent beauty of CWG as a secondary gasworks manufacturing process at a coal gas plant was that its primary feedstock (coke) was produced as a direct by-product of coal gas production at the same gasworks, along with the light oils of tar (“naphtha”) which were trapped and captured (of necessity to proper gas distribution) at *drips*, the gasyard *naphthalene* traps that kept this light oil from its constant threat of crystallization (as solid, white-colored matter akin to *moth balls*), which would quickly clog the town gas distribution system, not to mention the consumers’ gaslight burners.

Lastly, CWG generated a rather different set of residuals than coal gas; although the volume of *gas liquor* was generally greater per ton of feedstock due to the use of steam in the process, the coal or coke feedstock was reduced to a smaller volume of refractory clinker.

CWG systems produced tar, but largely from the carburetion stage, and as a direct result of the carburetion oil added to the gas stream. The quantity of tar produced depended on how completely the oil was cracked, which was a function of the temperature of the reaction and the type of oil used, for example, whether light ends or middle-distillate “gas oil,” which corresponded roughly to modern No. 2 oil, or the heavy fuel oils used in the 1920s and later.<sup>91</sup>

The reaction of the steam with the coke produced little or no tar residual, since the coke contained little of the hydrocarbon fractions that would form tar, but when the feedstock selected was the least-optimal bituminous coal (instead of coke or anthracite), the process would almost always produce valueless tar–water emulsions, entrapping unacceptable proportions of gas liquor effluent wastewater, in which the tar content was often highly emulsified.<sup>92</sup> Some of the challenges associated with tar–water emulsions are discussed in greater detail below. Tar products with a water content greater than the nominal 6% upper limit for salable tar to by-product distillers were generally unusable, and some emulsions were known to contain as much as 94% water by weight.

In theory, CWG also required less clarification and purification than coal gas (since coke did not lend itself to the production of ammonia or hydrogen sulfide to the extent that gas coal did), but this advantage was not always apparent in practice.

### 1.7.3 DISADVANTAGES OF CWG

While CWG was generally a reliable method of making good-quality gas, it did have several distinct disadvantages. The most significant of these was the dependence on ideal feedstocks that were less readily available than bituminous gas coal, namely coke, anthracite coal, and naphtha.

The quantities of oil used in CWG were significant—one 1905 source references the CWG unit of the Universal Gas Company of Chicago using 175 gallons of “crude petroleum” per ton of coke, for a yield of 15,000 cubic feet of gas and 10–12 gallons of tar per ton of coke.<sup>93</sup> A gas company could therefore find itself going through several tens of thousands of gallons of oil a month, at a time when oil was less readily available than in later years, and oil therefore represented a major expenditure. The cost of various types of oil therefore had a major impact on the cost of making CWG, even when less expensive gas oil was substituted for naphtha. The cost of carbureting oil remained a problem until the end of the gasworks era, and ultimately resulted in the use of cheap but otherwise less desirable grades of residual fuel oil or even crude oil instead of naphtha. Gas oil normally consisted of middle-range hydrocarbons with about 0.3% sulfur, while heavy oils could contain up to 1% sulfur.<sup>94</sup> As discussed in subsequent chapters, the use of these heavy oils contributed directly to the problem of tar–water emulsions which exacerbated the already conspicuous pollution and nuisance conditions associated with gasworks.

Although simpler than a bench of coal gas retorts in terms of the resources needed, the three-shell Lowe-type CWG set required considerable finesse to ensure optimal performance. The process described in the original Lowe patents was formidably complex and included 28 separate steps. Excessive or inadequate heats, the duration of the blow-and-run cycles, the temperature or moisture content of the steam, and a dozen other factors could all make or break the effectiveness of a CWG plant.

### 1.7.4 GROWTH OF CWG IN MASSACHUSETTS

Despite the seven-year (1883–1890) ban on CWG gas as a commercial illuminating gas (the only such ban ever experienced in America), Massachusetts did not lag behind the trend. In 1887, CWG accounted for something like 1% of the total gas sold in the Commonwealth; then allowed only as a fuel gas. Ten years later, however, CWG accounted for 64% of the total gas produced.<sup>95</sup> The total quantity of gas produced in Massachusetts also approximately doubled during the same time, from about 2,774,960,829 to 5,321,101,506 cubic feet.<sup>96</sup> It is reasonable to infer that the vast majority of this increase came from new water-gas systems. Significantly, the quantity of coal gas produced in the same period not only failed to increase, but actually decreased—the production of coal gas in 1897 was only about 66% of the amount produced in 1887, the result of a number of small coal gas systems switching to water-gas.<sup>97</sup>

Only two Massachusetts gas companies specialized in oil-enriched water-gas or CWG during the 1880s; one was the tiny Citizens’ Gas Light and Steam company in Lynn, while the other was the scandalous Bay State Gas Company, which brought its massive Calf Pasture plant in Dorchester online in 1888, as discussed in greater detail in [Chapter 5](#). The Calf Pasture Station was equipped with the Flannery Process, an oil-enriched water-gas variant promoted by Bay State’s works Superintendent, Joseph Flannery. This process was based on the earlier Tessie du Motay process, imported from France by its inventor in 1872, as the Oxy-Hydrogen Co., at Buffalo, New York ([Figure 1.22](#)).

Once it became clear that the 10% CO standard was on its way out—it was replaced in 1888 with a system of licenses for making water-gas, subject to the Board’s approval—several companies took the plunge with the new technology.<sup>98</sup> The Amesbury and Salisbury Gas Company, Fall River Gas Company, Miller’s River Gas Light Company in Athol, Spencer Gas Company, and Cottage City Gas Company on Martha’s Vineyard were all duly fined in 1889 for exceeding their licenses’ CO standards.<sup>99</sup> Once the carbon monoxide standard was abandoned altogether, however, the number

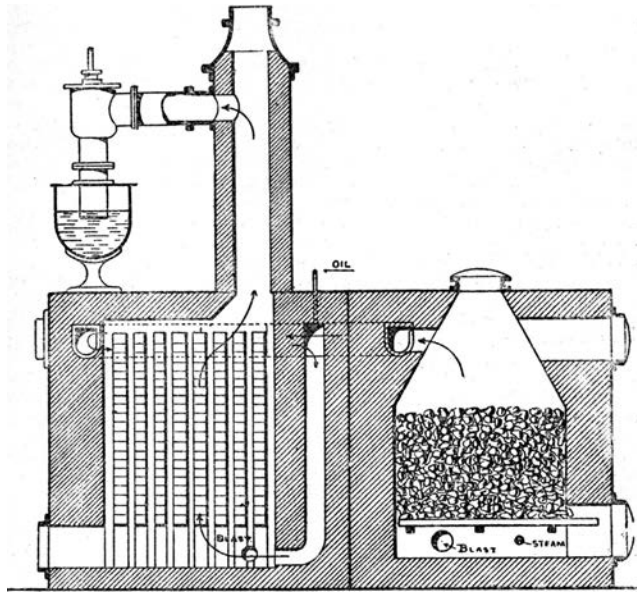


FIGURE 1.22 Schematic of a Flannery apparatus. (From *Progressive Age*, 1889).

of companies using water-gas grew from seven in 1889 to 18 in 1894, and both of the largest single gas-producing companies in the Commonwealth, Boston Gas and the Bay State Gas Company, depended primarily on CWG for their production.

CWG quickly eclipsed coal gas in many areas, and growth accelerated even more rapidly after 1892, when the Lowe patents, then held by the United Gas Improvement Company of Philadelphia, began to expire. By 1900, CWG accounted for something like 75% of the gas sold to the public in the United States.<sup>100</sup> By 1907, 35 companies statewide—approximately half of the total number of gas companies operating in Massachusetts—were producing either CWG alone or CWG blended with coal gas.<sup>101</sup>

By the early 1920s, CWG was effectively the default method of making gas in Massachusetts, and after 1918 the Board of Gas and Electric Light Commissioners no longer bothered to distinguish between coal gas and water-gas in reporting production quantities, since most of the gas in the state was produced either by combined process plants or by CWG alone.

## 1.8 OIL-ENRICHED WATER-GAS

The Lowe process was the most popular and widely used method of producing water-gas, but numerous rival American CWG technologies existed; some of these were genuinely different approaches to the issue, while others were near-imitators of the Lowe process. Lowe, however, held the patent rights to the term *Carbureted*, and his was the ultimate, economically workable process.

By the 1870s, gas engineering inventors were striving to extend the attractive nature of not only cracking superheater water into a carbon monoxide (CO)-rich fuel gas, but to somehow add to its makeup enough volatilized illuminants to produce a practical illuminating gas. From this worldwide industry came thousands of “water-gas” inventions and patented improvements, characterized by not one unified name, but that of the inventor, or some patent-protecting chemically related name (Table 1.7). The confusion that ensued suited only the inventors and their salesmen, and many poorly functional “patent” processes emerged, generally identified by their inventor’s name. This number included not a few outright frauds, and only a limited number of truly functional production processes of illuminating-type enhanced water-gas processes. Even so, one 1889

**TABLE 1.6**  
**Known Use of Oil-Enriched Water-Gas in Massachusetts**

Dates	Location and Name	Considerations
1887	Introduction of oil-enriched water-gas to Boston; UGI's Lowe process still thwarted from use at Boston	Bay State Gas Co., at its Calf Pasture Gasworks. Jerzmanowski "Baby" Apparatus, previously in use at NYC. Gas sold to Roxbury Gas Light Co., for admixture with coal gas, thus thwarting the Board of Gas Commissioners rule against CO in commercial gas. 1890: "Lowe (by Flannery)."
1888c–1891	UGI was making inroads in western Massachusetts with oil-enriched water-gas variations of Lowe process; in contravention to the 1880 legislative condemnation order	Pre-1890: "Lowe by Grainger" at Amesbury and Athol, along with coal gas; Bay State Gas Co. was employing Flannery; "Lowe by Grainger" at Charlestown GLC, Boston.
Pre-1889	South Boston Gas Co. introduces an undisclosed process of oil-enriched water-gas to its coal gas production	Done to increase daily production, but the customary relief holder was not added; customer dissatisfaction over the quality of the crudely admixed result led to order from Massachusetts Board of Gas and Electric Commissioners to desist from the practice. ( <i>AG-LJ</i> , April 8, 1889, p. 459)
1892	Wilkinson process, oil-enriched water-gas installed at Boston GLC, North Station and at Brookline Gas Co., Allston Gasworks.	Stop-gap measure as the plan was then to close the North End Gasworks in favor of production at Commercial Point Gasworks, Dorchester.
1894	Beauharnais oil-enriched water-gas debuts at New Bedford, Massachusetts	1894: "An echo of the famous gas hearing at New Bedford, Mass, which brought out the astonishing fact that gas made under the Beauharnais method was partly produced from 'potato extract and dried corn cobs,' is reported in the recent sale to private parties of the show plant that had been established by General Beauharnais and his associates on Taber's Wharf, New Bedford." ( <i>AG-LJ</i> , April 2, 1894, p. 485)

Source: Compiled by the authors from various sources.

article in the *American Gas Light Journal* enumerated two dozen processes in addition to the Lowe method.<sup>102</sup>

Author Hatheway, early in his research (1989c) was confronted with the widespread confusion, even in the historic literature, as represented by the indiscriminant use of the term *water-gas*, which correctly should be used only for the *blue gas*, that properly represents the nonilluminating fuel gas. In an effort to systematically identify the vast numbers of functional and fraudulent illuminating-types of water-gas, he has for the past 24 years applied the term *oil-enriched water-gas* as a means of separating *blue water-gas* processes, from the vast number of oil-enhanced water-gas process, and, more importantly, from the one master process, named by its inventor, T. S. C. Lowe, as *CWG*.

*Oil-enhanced water-gas* processes were notionally more demanding in terms of the quality of their Lowe-designated feedstocks—anthracite coal and coke—than coal gas processes, which typically used bituminous coal. Table 1.6 also is a reminder of those Massachusetts gas works at which the authors have found evidence of the former-presence of oil-enhanced water-gas production.

Most functional oil-enhanced water-gas processes were patented on the basis of whatever technicalities could be identified in order to circumvent the Lowe patents held first by T. S. C. Lowe and later by the UGI of Philadelphia, whose lawyers relentless pursued-and-sued for infringements. By 1894, the Lowe patents had expired and virtually every gas-machine supplier began to produce and

**TABLE 1.7**  
**Selected Massachusetts Nonresidential Facilities Known to Have Used Gas Machines<sup>175</sup>**

Facility Name	Municipality	Uses
Springfield Armory (Federal Government's sole small-arms manufactory at the time)	Springfield	Brazing, soldering, melting soft metals
American Optical Company	Southbridge	Brazing, soldering, melting soft metals
Overman Wheel Company	Chicopee	Presumably brazing for bicycle manufacture
Northfield Seminary	Northfield	Illumination and powering appliances
Mount Hermon Preparatory School	Gill	Illumination and powering appliances
Red Lion Inn	Stockbridge	Illumination, possibly appliances
Murdock High School	Winchendon	Illumination
Dover Stamping Company	Cambridge	Illumination, soldering
Nonotuck Silk Company	Northampton	Illumination
Hampshire Manufacturing Company	Huntington	Illumination
Chapin & Gould and Chester Paper Company	Huntington	Illumination
Worthy Paper Co.	Mittineague (West Springfield)	Illumination
Crane & Co.	Dalton	Illumination
Smith Paper Co.	Lee	Several mills
National Straw Hat Works H. O. Bernard	Westborough	Illumination
Amherst College	Amherst	Illumination, laboratory burners
Knowles Steam Pump Works	Warren	Illumination
Monson Academy	Monson	Illumination, appliances, laboratory burners
Lunt Silversmiths	Greenfield	Brazing and annealing
Page, Harden & Co Plate Glass Company	Lenox Furnace	Illumination and glassworking
Smith Paper Company Valley Mill	Lee	Illumination
Smith Paper Company Eagle Mill	Lee	Illumination
Smith Paper Company Columbia Mill	Lee	Illumination

*Source:* Compiled by Speight from Linebaugh (2011) and reviews of individual Sanborn maps by the authors.

marked “Lowe-Type” CWG sets, and the vast number of oil-enriched gas machines were quickly replaced as they wore out or were outstripped by production demands.

## 1.9 DIFFERENTIATION OF PETROLEUM OIL GAS FROM OIL-ENRICHED WATER-GAS

Many oil gas processes were devised in the immediate post-Civil War era to take advantage of the newly developing American petroleum sources, notably those discovered at Titusville in northwestern Pennsylvania in 1859 and the ensuing presence of oil refineries in that region. The rising prominence of the Standard Oil Company, established by itinerant petroleum oil and solvent salesman, John D. Rockefeller, helped facilitate the spread by ensuring petroleum distillates were available throughout the eastern seaboard, Midwest, and Deep South.

These methods generally coexisted with the earlier versions of oil-enriched water-gas and CWG. Hence, there are three evolutionary lines of gas-manufacturing processes other than coal gas during the 1873–1892 period.

These are as follows:

1. The “petroleum” variety of oil gas (1820–1873)
2. The CWG process, patented by T. S. C. Lowe in 1873–1875 and employed under license until 1892.
3. The 1873–1892 “oil-enriched water-gas” processes, generally developed to compete with Lowe, sometimes to the extent of infringing on the Lowe patents. Some of these processes are listed in [Table 1.6](#).

For the period of 1859–1900, the true 1859–1873 petroleum oil gas processes had the following general characteristics:

1. Based on the direct pyrolytic conversion of petroleum crude oil to create illuminating-quality gas.
2. Lack of coke, anthracite, or bituminous coal as a reactor bed to support flashing of steam to CO. This is the main point of distinction in comparison to carbureted water-gas oil oil-enriched water-gas.
3. Lack of a need to inject steam.
4. Lack of injection of a separate stream of oil of lighter gravity.
5. Where brick-lined iron “shells” were used rather than retorts, these processes probably used one shell instead of three (as contrasted with Lowe).
6. Since oil was continuously sprayed into the retort or shell, gas was continuously generated and there was no requirement for a “relief” gasholder to equalize pressure and flow rate as between a water-gas system’s blow-and-run cycles.
7. Associated with lampblack as the primary production residue.
8. A likely degree of shifting of process details, from the above, toward emulating Lowe, by morphing into an “oil-enriched water-gas” configuration, likely taking on a second, hyphenated name, and adding a reactor chamber to secure a mound of coke or coal, as the means of flashing the steam, along with a second shell, or cupola or other major fixture for admitting and managing steam. Oil gas processes could therefore evolve into a sort of hybrid oil gas/water-gas system over the years.

In 1892, sufficient of the Lowe CWG patents had expired for all gas-machine fabricators to produce “Lowe-Type” CWG sets, effectively beginning a general shut-down of the emulating “oil-enriched water-gas” competitors between 1892 and 1900.

### **1.9.1 GREENOUGH–JONES–ADDICKS FUEL GAS PATENT (1890)**

Business in the nineteenth century was frequently a cutthroat affair, but it occasionally produced strange flurries of unexpected cooperation. One of the strangest set of bedfellows the gas industry could likely have produced came together in the late 1880s to produce the Greenough–Jones–Addicks *Fuel Gas Patent* of 1890.<sup>103</sup> The principals involved in the patent for a blue water-gas process were strange bedfellows indeed: Malcolm Scollay Greenough, Chief Engineer of the Boston Gas Light Co. (dominated by the Greenough family and its’ interests); Edward Campbell Jones, the brilliant “practical” gas engineer and son of Edward Jones, Superintendent of the South Boston Gas Co.; and Walter R. Addicks, Chief Engineer of the Bay State Gas Co. and younger brother of its leader and President, J. Edward Addicks, the direct competitor of the Greenoughs, a corporate raider whose goal was to use the Bay State company as a means to a hostile takeover of the entire Boston gas industry.

The younger Jones was at San Francisco at the time. He had left his position as Assistant Superintendent of the South Boston Gas Company in 1887 to become Assistant Engineer of the San Francisco Gas Light Co., and was constructing engineer of its bold new North Beach Station.

In 1890, he had just been named its Chief Engineer. By 1915, Jones was president of the American Gas Institute and had become one of the most recognized Gas Engineers of America—a bold achievement for one who had not graduated college.

In the very same short period of time (1883–1891) in Boston, there were several major gas industry struggles going on:

1. Ongoing efforts of the UGI to promote CWG as (in actuality) the most economical method to produce gas for use either for illumination or for fuel
2. Resolution of the W. W. Greenough-inspired legislative condemnation of CWG as a gas poisonous to consumers, and the ban's revocation in 1890
3. Struggle (elder Addicks against elder Greenough) to take over the Boston gas market
4. Broad emergence of blue water-gas industrial fuel gas, as an alternative to coal-fired furnaces or steam boilers

Between the lines of the written record, it is now obvious that while the elder Greenough and the elder Addicks were battling for control of the Boston gas industry, the younger generation had become fixed on taking advantage of the opening of the fuel gas market, both for heating of all types, and for its greater employment as an industrial fuel gas.

The Greenough–Jones–Addicks Fuel Gas (GJA) Patent of 1890 set the stage for exploitation of the state of affairs in Boston. The patent described a two-shell device consisting of a producer-gas-like *generator* and a second, smaller shell acting as a *steam boiler*, in which the steam would flash into hydrogen and carbon monoxide, with a subsequent, much smaller “*closed-chamber tar trap or box*,” by which tar and other potential gas impurities are restrained from becoming associated with the actual production of fuel gas.

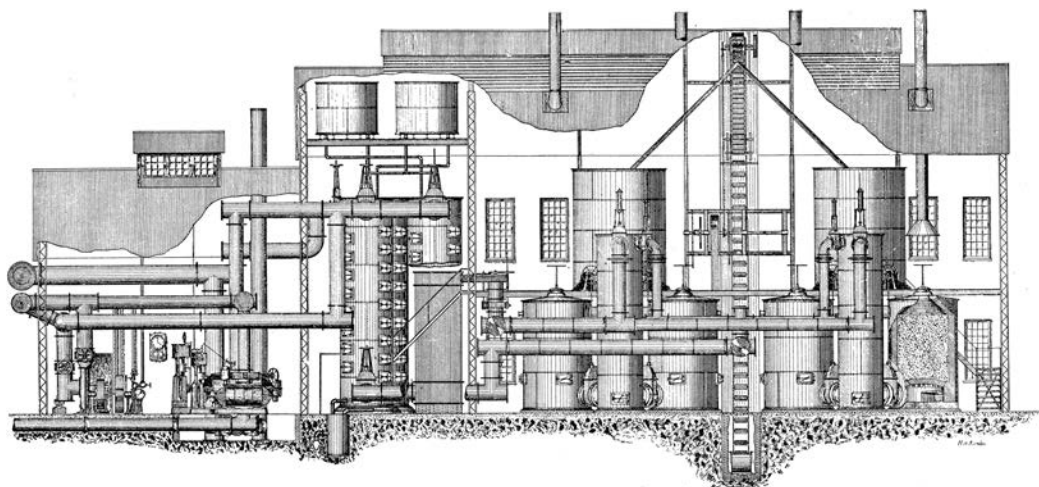
There is no known record of how and where the GJA-patented gas machines may have been fabricated and employed, but this invention of three seasoned gas engineers would have been far from speculative, and, in fact, should have become successful wherever there was a dual need for illumination gas in a fuel gas market.

### 1.9.2 LOOMIS PRODUCER FUEL GAS CWG AND BLUE GAS (1890)

The most commercially successful of Lowe's competitors among the oil-enriched water-gas processes was Burdett Loomis, Sr. a Chicago-based gas engineer and inventor who developed and patented gas production process subsequently referred to as the Loomis process. The Loomis method could generate CWG and blue (fuel) water-gas from alternative production settings of his single-shell and side stack “Loomis Producer” apparatus. Loomis had his first break of good fortune in the installation of a full-plant fuel gas system, including gasholders and a distribution system, for the enormous Henry Disston saw factory at Tacony District, Philadelphia (Figure 1.23).<sup>104</sup>

Buoyed by this success, Loomis formed the Mutual Light, Heat & Power Supply Co. (MLH&PSC) at Chicago, Illinois, a substantial company with an initial operating capital of \$1,000,000, and began vigorous independent marketing of *industrial gas producers*. Unlike Lowe's process, Loomis was less interested in the illumination potential of CWG and focused on *producer gas plants* dedicated to generating blue gas for industrial fuel. He subsequently started a branch of the same company in Hartford, Connecticut in 1890, and by about 1900, the MLH&PSC had evolved into the Loomis-Pettibone Co. of New York City.

By late 1890, Loomis was proclaiming that his fuel gas installations at a large paper mill in Turner's Falls and at the Waltham Watch Co. of Waltham, Massachusetts were available for inspection by prospective buyers.<sup>105</sup> These likely represent the earliest substantial Loomis plants to be installed in the state. The promise of cheap fuel gas was one of the straws that broke the back of the Greenough interests' control of the Boston gas supply, and contributed to J. Edward Addicks' take-over of the old Boston Gas Light Co., through stock manipulation, legislative pressure and the promise of cheap gas.



**FIGURE 1.23** Cross section of a Loomis water-gas system in use in Bridgeport, Connecticut. (From *Modern Machinery*, 1898.)

Loomis' success attracted attention, and in 1890 he was approached by Addicks himself. Addicks had previously been deeply involved in the consolidation of the Chicago gas industry and retained many ties there, through which he doubtless became aware of Loomis. Addicks and his backers retained Loomis' firm to install an undetermined number of Loomis Gas Producers at the old North Station works of the Boston Gas Company, which Addicks and his backers then owned. Addicks was at the time promising six miles of dedicated fuel gas distribution to be online by November 1, 1890. The authors presume that the first distribution would have been a line to the industries remaining in South Boston. It may be that Addicks' agreement with Loomis made redundant the GJA patent machines before they were brought into service. It is also unclear why Addicks may have chosen Loomis systems over the Flannery process developed by the superintendent of Addicks' own Calf Pasture works.

While Loomis' process was widely used for industrial fuel gas, it was less popular as a town gas process. One of the few such systems installed for illumination as well as fuel production was the Loomis plant in use at Cottage City on Martha's Vineyard, erected in 1909, to furnish illuminating gas. This system was equipped with checker brick and operated on "down" runs and blows.<sup>106</sup>

### 1.9.3 GRANGER OIL-ENRICHED WATER-GAS

The Granger process was perhaps the most obvious of the Lowe imitators; indeed, it could be considered a CWG process save only that Lowe had copyrighted the "CWG" name for his own process. The firm of A. O. Granger & Co. was founded in 1878 and for several years served as a contractor and millwright for Lowe plants. Granger subsequently patented a design that owed much to the Lowe process—barely different enough to avoid patent litigation—and launched the Granger Water-gas Company to design, build, and market the equipment. The Granger design was simple and reliable and some 70 plants adopted Granger equipment within about seven years, including one gas company in Chicago that commissioned a system with a massive 13-foot diameter generator.<sup>107</sup> By 1890, Amesbury and Salisbury Gas Light Company, the Charlestown Gas Light Company, the Lynn Gas Light Company, the Miller's River Company in Athol, and the Worcester Gas Light Company had brought Granger plants online, at which point there were more Granger plants in the state than any other type including Lowe, of whom the Fall River Gas Works Company was the only user.

The United Gas Improvement Company acquired the Granger Water-gas Company in 1885, a year after its purchase of the Lowe patents, and UGI viewed the Granger machine seemingly only

as a means of capturing a greater share of the potential market. Some of the Granger aspects were subsequently included in UGI versions of the Lowe equipment, but equipment was not marketed under the Granger name after about 1893. Some equipment supplied by UGI during the 1890s was therefore known as Lowe–Granger equipment.<sup>108</sup>

#### 1.9.4 JERZMANOWSKI OIL-ENRICHED WATER-GAS

One of the most prominent of the *de facto* Lowe competitors was the Jerzmanowski process, adopted by Boston Gas Light Company in 1893. Born in 1844 in the town of Kalisz in modern central Poland, Ezram (Erasmus) Jerzmanowski was a Pole who fled to France after the defeat of the January Uprising of 1863, a failed attempt to win Polish independence from Russian rule over that part of Poland. Relocating to Paris, Jerzmanowski was introduced to gasmaking technology while studying at the Paris Polytechnic Institute and then relocated to the United States in 1876, where he helped to introduce the French Tessie du Motay oil-enriched water-gas process to North America, mainly at New York City.

In 1876, Du Motay broke into the big market in his own right with the Municipal Gas Light Co. of New York City, and in 1882 also the Equitable Gas Light Co., also of New York; William Rockefeller was president of the latter company. Du Motay's process was often billed as "hydrogen gas."

Jerzmanowski patented several processes for producing gas. His best-known process, patented in 1895, was broadly similar to the Lowe process but specified anthracite as the intended feedstock, rather than coke, cycled between air and steam for the blow cycle and included a lime-filled scrubber that was intended to remove carbonic acid (CO) from the gas and to serve as a catalyst for decomposing hydrogen from hydrocarbons.<sup>109</sup> Hydrogen gas generators of the "Jerzmanowski type" were in use at the Brookline Gas Light Company's Allston plant (constructed circa 1894–1895).<sup>110</sup> After making a name and a considerable fortune in the New York City gas business, Jerzmanowski retired in 1896 and relocated to a large estate in Cracow, today now again in Poland, but then part of the Austro-Hungarian Empire, where he lived until his death in 1909.<sup>111</sup>

#### 1.9.5 WILKINSON OIL-ENRICHED WATER-GAS

Another offspring of the Tessie du Motay model, the Wilkinson process, saw limited use in Massachusetts. The sole user of note in Massachusetts was the Haverhill Gas Light Company, where it remained in use for something over two decades, including the duration of the lengthy litigation between city residents and the gas company over the cost and quality of gas.

The Wilkinson system consisted of four components: a generator, a scrubber, an "illuminator," and a retort. The generator was a fairly standard water-gas generator shell, and the latter two elements served essentially the same purpose as the carburetor and superheater in a Lowe set. In essence, the process generated water-gas, which was stored and which was then subsequently enriched with hydrocarbons by passing it through a masonry retort. The ultimate effect was similar to the Lowe process, but neither as refined nor as efficient, and the process equipment was much more cumbersome.<sup>112</sup>

#### 1.9.6 EXPIRATION (1894) OF LOWE PATENTS AND DECLINE OF THE OIL-ENRICHED WATER-GAS LOWE IMITATORS

By approximately 1894, the Lowe patents (held by UGI since 1884) had expired and nearly all of the CWG producers had embraced the Lowe process, many of them abandoning their specific patent-infringing or proprietary methods, and were producing outright copies of the Lowe gas sets (without, of course, the subsequent and still effective UGI-patented improvements.). The Board of Gas and Electric Light Commissioners' annual reports listed what process was used at water-gas plants, and by the early 1900s, these showed that the Lowe process had eclipsed virtually all the other water-gas processes in the utility industry.

The Board of Gas and Electric Light Commissioners recorded its own evaluation of the usefulness of water-gas in its *Annual Report* for 1889:

Numerous other reasons suggested by local conditions have induced companies to add to coal-gas works apparatus for making water-gas. It enables a company to easily meet a sudden demand for an unusual amount of gas. It can be made ready for gas-making at an hour's notice, then allowed to cool when the demand is over, and this course repeated indefinitely without injury, while coal-gas benches once treated in this manner would probably need rebuilding. An unexpected dark day may thus be readily provided for, and the considerable schedule, but are unexpectedly called for on stormy nights. In some places the increased consumption has made necessary some increase in the capacity of the works, which has been secured with less expense for extension by the introduction of water-gas apparatus, with a consequent saving in capital account. A brief period of extraordinary consumption in midwinter is sometimes provided for in this way. In many works where both kinds of gas are made, coke produced at the works is substituted for anthracite coal, furnishing a profitable use for surplus coke, and preventing a reduction of its price.<sup>113</sup>

One possible explanation for the opposition to water-gas was that the vested interests in Boston Gas and the other top-tier firms were well aware of what the new technology meant, but wanted to delay its introduction in order to prevent opposition companies from taking advantage of the new technology while the established firms were still integrating it into their own plants. Nonetheless, Boston Gas Light Company had a full-scale CWG system operational at its flagship North End works in Boston proper by 1893, within three years of the legislative overturning of the CWG ban that the authors believe was orchestrated by the Greenoughs.

## 1.10 LATER WATER-GAS AND BITUMINOUS COAL TECHNOLOGIES

Water-gas technologies continued to evolve during the remainder of the gasworks era, displaying an adaptability that demonstrates the soundness of the basic concept. Some of these innovations were refinements to produce higher quality gas or gas in greater quantity, but others were adaptations of necessity. The outstanding examples of the latter approach are the two entirely separate and unrelated Tenney systems, patented and promoted by affiliates of the C. H. Tenney organization, a utility holding corporation with interests across the East Coast, and of an unrelated Tenney gas entrepreneur, Charles I. Tenney of Newton, Iowa, whose organization blanketed much of the Midwest.

Along with virtually every other civilian user of coal, the gas industry faced an energy crisis that began with the nation's entry into the First World War in 1917. With supplies of coke and gas coal limited and prices rising, many water-gas users had to resort to using bituminous coal as a feedstock instead of the preferred coke or anthracite. Although Engineers and chemists such as Samuel Wyer of the U.S. Bureau of Mines had demonstrated that water-gas systems could accommodate a very wide range of materials as feedstocks, results were understandably less than satisfactory until the systems and operating processes had been adjusted to accommodate the new materials, which often meant making compromises that surrendered some of the more desirable qualities of water-gas, including the reduced amounts of tar, necessity for comprehensive purification systems, and relative ease of maintenance of the system.

Some water-gas and CWG systems were ultimately tailored from the start to run on these inferior feedstocks, notably the C. I. Tenney–Lowe and the separate C. H. Tenney-process CWG systems; the former appeared circa 1917, and the latter was first patented in 1925. These were tailored to use bituminous coal and “heavy” fuel oil (e.g., #4–#6 fuel oils), or light ends of coal tar—a marked contrast to the coke and naphtha or gas oil of the original Lowe designs. Although popular in the later decades of the gasworks era, thanks to their use of less expensive fuels, these methods were not without their faults, many of which lay with the “fixing” of the hydrocarbons into the gas, which was largely a function of heat, pressure, and the length of the carburetion process, or with

the duration of the condensing stage. If this was not properly done, the heavier hydrocarbons could drop out when gas was brought from the main pressure to the much lower service pressure, forming waxy deposits that would create difficulties.<sup>114</sup> The combination of steam and bituminous coal also contributed to the exasperating problem of tar–water emulsions, useless waste products that could not be used, sold or even given away.

Water-gas technology showed such promise for industry by the first decade of the twentieth century that the federal government took an interest in its development, seeing the furtherance of this technology as a means of reducing dependence on coal-fired steam boilers and the resulting endless smoke problems that plagued the nation’s cities. Beginning in 1904, the U.S. Geological Survey and the U.S. Bureau of Mines (established as a federal agency in 1910) commissioned a series of studies on the utility of water-gas systems at industrial facilities. Samuel Wyer, one of the researchers on these, noted on several occasions that given sufficiently wide tolerances in the heating value of the gas, water-gas systems could be used to produce gas from virtually anything containing carbon, and were not limited to coal or even petroleum.

Research into improvements to water-gas systems continued into the late 1940s, including studies for the use of previously unthinkable feedstocks such as coal tar pitch, but these research efforts appear to have run up against the limits of diminishing returns.<sup>115</sup> Further research into water-gas processes appears to have died off in the late 1940s as other fuel supplies became more readily available.

## 1.11 SMALL-SCALE GAS PROCESSES

At the other end of the spectrum from giant coking plants and major urban gasworks were a number of small-scale specialty processes. Gas equipment did not always scale up or down readily, and there was considerable demand for equipment that could produce gas easily and in small lots, either of high quality or for special needs.

### 1.11.1 PROPRIETARY GERMAN HIGH-BTU OIL GAS PROCESSES

On two occasions, pre-First World War German gas engineer inventors saw a universal need for high-Btu oil gas; both were highly successful and took control of the world market for the niche demand that they so adequately filled. Blau and Pintsch plants were not necessarily small facilities—the American Blau Gas Company plant on the eastern bank of the East River in Queens, New York, was quite a large plant—and can exhibit significant environmental contamination.

#### 1.11.1.1 Pintsch Gas

Pintsch gas, developed in 1851 by the German inventor Julius Pintsch, was derived from distilled by-product naphtha from manufactured gas plants.<sup>116</sup> It was used primarily for illuminating railroad passenger cars, replacing the tallow candles and oil lamps previously used for the purpose. The gas was typically produced at railway yards, using systems broadly similar to a commercial oil gas apparatus, but far more sophisticated. The gas was then pumped directly into tanks fitted to each car, where it was stored under relatively high pressure—14 atmospheres was considered high for the day—until needed. In this respect, Pintsch gas had a major advantage over coal gas, as while compression would reduce the illuminating power of coal gas by more than half, Pintsch gas would suffer only a nominal 12% reduction, enabling it to be compressed and stored until needed. Other uses for Pintsch gas included illuminating facilities such as lighthouses or navigation buoys, where the system could be activated and allowed to run off of a tank of compressed gas without maintenance for a period of weeks. The 1900 Middlesex County Atlas depicts a building labeled “gasworks” at the Boston and Maine Railroad yard in Cambridge, on the bank of the erstwhile Millers River, which was likely a Pintsch or similar plant (Figure 1.24).

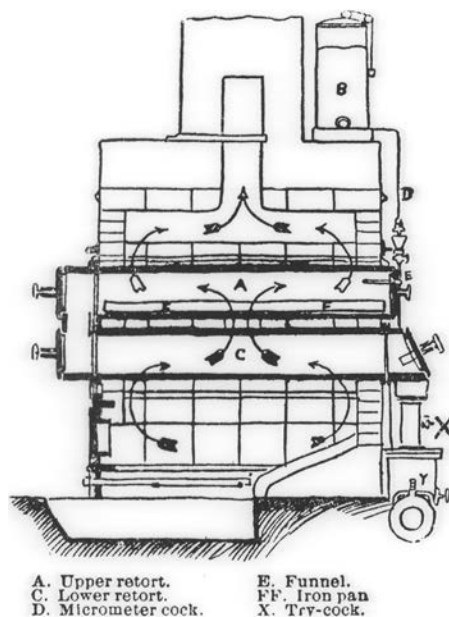


FIGURE 1.24 An example of a Pintsch apparatus. (From *Gas Engineering Record*, 1889.)

### 1.11.1.2 Blau Gas

Although “Blau” is the German word for the color “blue,” Blau gas should not be confused with “blue” water-gas. Rather, it takes its name from Dr. Hermann Blau, an organic chemist from Augsburg, Germany. It was essentially a highly refined form of Pintsch gas, highly compressed and stored in steel bottles, and in this form it was sold for industrial uses as well as for lighting and heating of residences. Unlike Pintsch gas, Blau gas could be compressed even into a liquid state, at  $\sim 100$  atmospheres.<sup>117</sup> The Blaugas Company opened in Augsburg in 1903 and expanded to the United States by 1913. One of the product’s signal advantages was that it contained no carbon monoxide. The gas was later used to fuel the Graf von Zeppelin dirigible engines, because it provided good fuel value for a weight far less than an equivalent supply of liquid fuel.

### 1.11.2 “SPIRIT” GAS (ALSO KNOWN AS GASOLENE GAS; AIR GAS)

As a more economical and modular alternative to producer systems, where gas was not otherwise available many large houses, factories, hotels, and institutions during the late nineteenth century resorted to “gas machines,” which produced “air gas” from gasolene or naphtha. There were numerous such devices developed by the 1860s, including the Maryland Portable Gas Generator (actually a small rosin gas system), the C. R. Woolworth & Company’s “Portable Gas Works,” and one early contender, Samuel Morey’s “American Water Burner” of 1817, which passed steam across a reservoir of heated turpentine.<sup>118</sup> By 1872, there were over 100 manufacturers of air gas systems in the United States.<sup>119</sup> The gas machine par excellence, however, was the Springfield Gas Machine, produced by Gilbert and Barker, Inc. in Springfield, Massachusetts. The Springfield machine developed a reputation as a safe, reliable “Cadillac” of gas machines, and they sold well. At one point there were nearly 300 *gasolene gas* spirit gas machines installed in Massachusetts alone, and the firm appears to have produced  $\sim 4,000$  units in a single 10-year period.<sup>120</sup> The definitive story of the Springfield Gas Machine, and an excellent summary of the uses of gas machines in general, is Donald W. Linebaugh’s 2011 monograph *The Springfield Gas Machine, Illuminating Industry and Leisure, 1860s–1920s*.

These systems generally functioned by passing compressed air through a carburetor charged with gasolene or naphtha, which in the 1870s and 1880s were relatively inexpensive by-products from the distillation of crude oil for kerosene, by means of a clockwork or water-driven pump, to produce a gas with a nominal hydrocarbon content of 15% by volume.<sup>121,122</sup> Linebaugh credits the customer testimonials that Gilbert & Barker included in their advertising at face value in discussing the system's ease of use and the quality of the gas, but in at least some instances consumers preferred the gas machine to municipal service even when the latter was available. The convenience was highly attractive—although the initial capital outlay was steep (approximately a year's wages for a laborer), once installed the machines needed little maintenance and had little upkeep cost other than the cost of gasolene, and in at least one instance, a gas machine remained in use at a boarding school from 1889 until 1953.<sup>123</sup>

Under heavy pressure from insurance underwriters worried about fires or explosions, gas machines gradually evolved to a generally common set of principles. Machines were typically “cold process,” with no retorts or heating of the feedstock, the gas machine itself was typically located in an underground vault away from the building it served, and after the 1870s the gasolene was typically stored in underground tanks. Initially constructed of iron, later generations of machines were usually built of copper or bronze, to avoid corrosion, and after the early 1900s galvanized steel was common.<sup>124</sup> In the process of developing the market for gas machines and their ancillary equipment, Gilbert & Barker also became one of the country's largest retailers of *gasolene*, catering to the users of their gas machines, to the tune of between 75,000 and 100,000 barrels of gasolene-grade feedstock per year by 1884, when a subsidiary of the Standard Oil trust acquired the firm.<sup>125</sup>

Gas machines varied in size from units designed to support 20 burners, suitable for a private home and generally available “off the shelf” from a manufacturing firm such as Gilbert & Barker or the Walworth Manufacturing Company, to large made-to-order systems capable of supplying gas to a thousand or more burners, which could provide gas for a mill or a school campus. Units rated to supply up to 500 burners were apparently sufficiently common that Gilbert & Barker carried them in their standard catalog.<sup>126</sup> Mount Holyoke College in South Hadley, Massachusetts, relied on what Linebaugh considered to be “the largest and most impressive Springfield system used at an educational institution” for at least some of its illumination needs from 1896 through possibly as late as 1929.<sup>127</sup> This system boasted some 2,000 burners in 13 buildings, including gas lights as well as Bunsen burners in the science laboratories, and even service for chafing dishes in the dining hall.<sup>128</sup>

Gas machines were not limited to illumination or to residential use. Some factories, such as the War Department's Springfield Armory in Springfield, Massachusetts, used gas machines for fuel gas as well as illumination, for processes where a convenient heat source was necessary but where matters of scale or low thermal demand meant full-scale producer system was not necessary, such as melting lead or precious metals, brazing and soldering, and the like. Linebaugh notes (Table 1.7) 37 mills located in Massachusetts (of a total of 95 mills, nationwide) were listed in various Gilbert & Barker catalogs as using the firm's gas machines, most of which were operating as textile or paper-making facilities.<sup>129</sup>

## 1.12 LATE NINETEENTH-CENTURY NONCARBURETED FUEL GAS

In the 1860s, British industry advanced the practical notion of placing nonilluminating, low-Btu (~150 Btu) fuel gasworks at the actual industrial factories at which such gas would be useful to heat various types of furnaces, particularly those used at temperatures and combustion volumes less than required for making iron and steel and for casting iron objects. This adaptation was introduced by the emigrant German engineer, Wilhelm Siemens, in 1863. By 1880, Siemens was marketing gas producers for British industry. An earlier German arrival, the industrial chemist Ludwig Mond (1839–1908), also became an important figure in the fuel gas field but his ventures into gas producers did not come about until he launched The Power Gas Corporation, Ltd. in 1901.

As it turned out, America did not take notice of Mond or the brothers Seimens, though the prominent gas machine fabricators and fitters, R. D. Wood, of Philadelphia, carried the entire line of Mond equipment after gas producers became an American industrial staple circa 1890. The Mond design was notable in that it could even run on cheap bituminous “slack,” or the residue of small fragments and dust left behind after the better parts of a load of coal was consumed.<sup>130</sup>

Seimens’ marketable gas producer was not readily taken up in America, but remained popular in the British empire, taking on such degrees of modern enhancements to have been assessed (1931) by the prominent American Gas Engineer, Dr. Jerome J. Morgan, as a combination of blue gas and producer gas, capable of mixing air and steam with gas made from noncoking, high-ash bituminous coal—inexpensive low-grade material not otherwise suitable for gasmaking—and could be set up to recover ammonia as a by-product cost offset.

The real father of practical producer gas was again T. S. C. Lowe, who from 1873–1875 refined the course of his patented CWG, and took up the notion that one of his CWG sets could also serve to cheaply produce large quantities of nonilluminating *blue gas*.

Thus began America’s developing awareness of cheap manufactured fuel gas. Lowe was tireless in his promotion of his patents, both for illumination and, as offered, as a means of generating industrial fuel gas. This promotion, of course, soon fell on the ears of the master promoters and fabricators of manufactured gas equipment, along with ownership and operation, the UGI, of Philadelphia, formed in 1882, on the advent of its acquiring Lowe’s patents. Lowe served briefly as UGI’s Chief Engineer and renewed promotion of the Lowe System, then was replaced by more formally educated gas engineers, and moved off to Pasadena, California circa 1884 to spread his gas gospel and gas ventures to the west coast, where his influence led to establishment of the new Pacific Coast oil gas process.

### 1.12.1 GREASED WIND (GREASED AIR)

The majority of the gas production technologies that saw use during the nineteenth century were the products of legitimate business ventures, but as was essentially inevitable for any breakthrough in technology in the nineteenth century, an endless series of scams grew up around the gas industry. This problem peaked in the 1890s, spurred on by the breakthroughs in water-gas technology. The general theme of these scams was a noisy bragging of a revolutionary process promising nearly unlimited high-quality gas for a cost as low as three cents per thousand cubic feet. These schemes were dismissed by legitimate gasmen as “greased wind” or “greased air.”<sup>131,132</sup> Some of these processes produced little more than a mixture of steam and oil vapor. One such entrepreneur, W. H. Harris, acquired considerable notoriety for setting up a series of fraudulent enterprises including the American Gas Company (not to be confused with an older namesake, a UGI covert subsidiary of 1882, based at Philadelphia), organized in Indiana. Harris’ patent process for producing gas was blatantly improbable in the eyes of reputable gasmen, although it attracted a seemingly endless stream of confidence men and the naïve, including one party who imported the process to Belfast in the United Kingdom.<sup>133</sup> When arrested in New York City on an outstanding warrant for fraud, Harris had a million dollars’ “worth” of the gas company’s bogus stock on his person.<sup>134</sup>

## 1.13 COMBINED-PROCESS GAS PLANTS

By the first decade of the twentieth century, approximately half of the gas companies operating in Massachusetts, including all of the largest suppliers, were producing and selling coal gas blended with CWG, and most of the gas being sold in Massachusetts was blended gas. It was not unusual for larger gasworks to have both coal gas and water-gas units, rather like a modern power plant may have separate units fired variously by coal, oil, or gas.<sup>135</sup>

The combined process plant was also able to enrich the gas much more economically, since the coal gas had a much higher candlepower value; simply blending coal gas with water-gas would enable the plant to economize on the amount of oil used to enrich the water-gas.

At least one combined-process plant, the Springfield Gas Light Company's facility, remained in use until the changeover to natural gas. This facility had both a coal gas unit using then-modern vertical retorts and a substantial water-gas plant.<sup>136</sup>

## 1.14 BY-PRODUCT COKE-OVEN GAS

While the means of producing gas discussed thus far were designed solely for the production of gas, industrial coke production in so-called by-product coke ovens could also yield significant amounts of gas. By-product coke ovens were broadly similar in concept to coal gas retorts, although they differed greatly in physical details. The focus of a coking plant, however, was the coke, especially high-grade "metallurgical coke," the primary consumers of which were steel mills, foundries, shipyards, and railroads. Coke also became a premium domestic heating and cooking fuel circa 1900, as many large cities began to pass smoke ordinances that discouraged the use of soft coal in residential stoves and furnaces. The gas and other products were in most cases considered to be by-products of coke-making in the same way that coke and tar were considered by-products of a coal gas plant. By-product coke ovens were originally developed in the Belgian steel industry but the first widespread use of by-product coke ovens was in Germany, where they became widely used after 1884.<sup>137</sup>

Prior to the First World War, most of the United States' coke-making capacity relied on primitive stone-masonry "beehive" ovens operated at coal mines, simple to build and cheap to operate, but which made no provision for recovering gas, oils or other materials. In stark contrast to Germany, where the meteoric rise of the steel industry meant that the primitive beehive coke ovens had been entirely supplanted by by-product plants by 1914, in the same year by-product plants accounted for a mere 30% of the United States' coke production.<sup>138</sup> The number of by-product plants subsequently increased rapidly, and by 1937 by-product plants provided 94% of the nation's coke, although rather surprisingly, beehive ovens remained in use until after 1950.<sup>139</sup> In 1950, there were 85 active by-product coking plants in the United States, 12 of which were owned directly by city gas companies chartered as public utilities and used essentially as manufactured gas plants, but not including other facilities that only sold gas to utilities.<sup>140</sup>

Since there were no viable coal deposits in Massachusetts, the earlier, crude coke ovens found by the tens of thousands in Pennsylvania and by the thousands in Ohio, West Virginia and in Alabama, never appeared in the Commonwealth. Most New England coke-oven facilities were *merchant plants* designed to produce coke, typically for metallurgical purposes, and produce gas as one of the captured *residuals*, thus creating all possible by-products.

### 1.14.1 TRANSPORT INFLUENCES ON BY-PRODUCT COKE OVENS

Modern—by the standards of the turn of the twentieth century—coke-oven facilities were also of necessity massive undertakings, in order to capitalize on economies of scale. Transportation requirements generally dictated that coking facilities had to be located close to the coalfields and to the steel production areas. Most of the nation's coking plants were therefore located in Pennsylvania or the Midwest, close to Pittsburgh, Detroit, and other steel-making centers, and also close enough to the coalfields of Pennsylvania and Illinois. Massachusetts had but one by-product coke-oven plant and it was fed with Nova Scotian coal transported by sea-going *colliers*, and its by-products evacuated by rail, with the sole exception of its main by-product, finished commercial gas, sent to Boston via pipeline.

### 1.14.2 NEW ENGLAND GAS AND COKE COMPANY, EVERETT

Massachusetts boasted only one coking plant of note, operated by the New England Gas and Coke Company and located in the Boston north suburb of Everett, near the confluence of the Mystic and

Island End rivers. Since Massachusetts had no native steel-making industry, it should be a surprise that it had a coking plant at all, but this plant was an immense facility for its day, with 400 coke ovens of a modified Otto Hoffman by-product type. When the Everett plant opened in 1899, it was the largest coking plant in the nation and single-handedly gave Massachusetts more of this type of coke ovens than the entire state of Pennsylvania, where coke-making and steel manufacture was a long-standing major industry.<sup>141</sup> Similar facilities were developed soon after in Connecticut, with the Connecticut Coke Company in New Haven (a Koppers subsidiary), and the Providence Gas Company in Rhode Island, the latter of which was a relatively small plant with 40 Koppers ovens each taking 11.6 tons per charge.<sup>142,143</sup> The size of the Everett plant compared favorably with the massive plants used by the steel industry; in 1922 the largest coking plant in the world with the Carnegie Steel Company's plant in Clairton, Pennsylvania had twelve batteries of 64 Koppers ovens each (Figure 1.25).

The plant was state of the art at the time of construction, and at one point was the largest and most modern by-product coking plant in the country. The plant was located on 288 acres of filled salt marsh, mostly in Everett but partly in Chelsea, which had been reinforced with about 35,000 wooden piles that supported a concrete cap. The stellar advantage of this location was that once a channel had been dredged, full-size seagoing colliers could dock directly at the plant's own 900-foot long wharf, without needing to transfer the coal to lighters or barges (Figure 1.26).<sup>144</sup>

The Otto Hoffman coke ovens were tall vertical rectangles, like a book stood on its spine, measuring 33 feet long, 6 feet high, and 1.5 feet in interior width, with each oven having a capacity of six tons of coal, and a cycle time of 24 to 36 hours, so that the plant could process 2,000–2,400 tons of coal daily. The coal used was a washed slack coal shipped in from Cape Breton Island in Canada. Longer runs produced very hard, higher-quality coke suitable for steelmaking or high-performance locomotive fuel at the expense of the reduced productivity per oven, while shorter runs produced a coke suitable for general fuel purposes.<sup>145</sup> The coke was shipped by road, rail, and ship to various commercial, industrial, and domestic markets. The initial 400 ovens were considered at the time to be “phase 1” of the plant, with an eventual, never-to-be-realized total of 1,200 ovens planned (Figure 1.27).

As with coal gas, the first half of the gas “make” at a coking plant was usually the best product, in terms of candlepower and fuel value. In the case of the Everett plant, the first half of each make was siphoned off, clarified, stored in a 5 million cubic feet gasholder, and pumped off through two 42-inch gas mains to be purified and blended into the Boston gas supply. The purification works were technically owned by New England Gas and Coke's sister company, the Massachusetts Pipe Line Gas Company. The inferior second half of each make was stored and used to fuel the coking plant ovens. The plant had two complete sets of gas treatment equipment, one for the “rich” gas sold to the Boston gas market, and one for the “poor” gas used to fuel the plant; this received less treatment, as it was not sold to the public, it did not have to meet the state's gas quality requirements.<sup>146</sup>

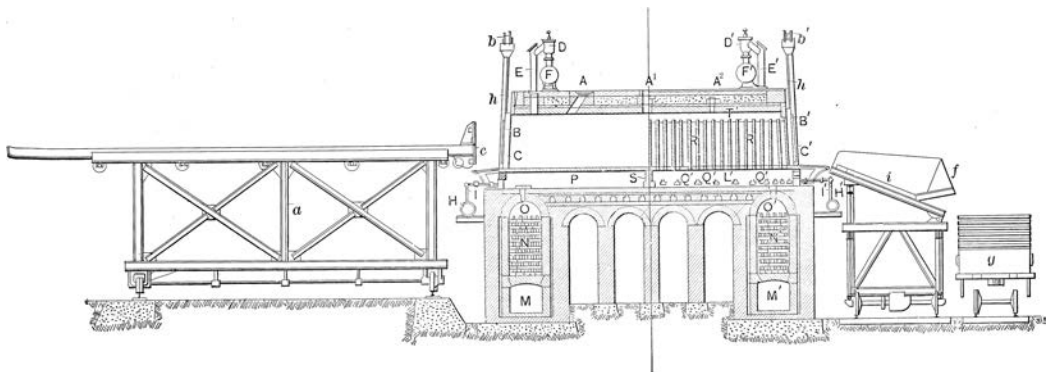


FIGURE 1.25 Crosssection of Otto-Hoffman coke-oven battery. (From Landis, 1899.)

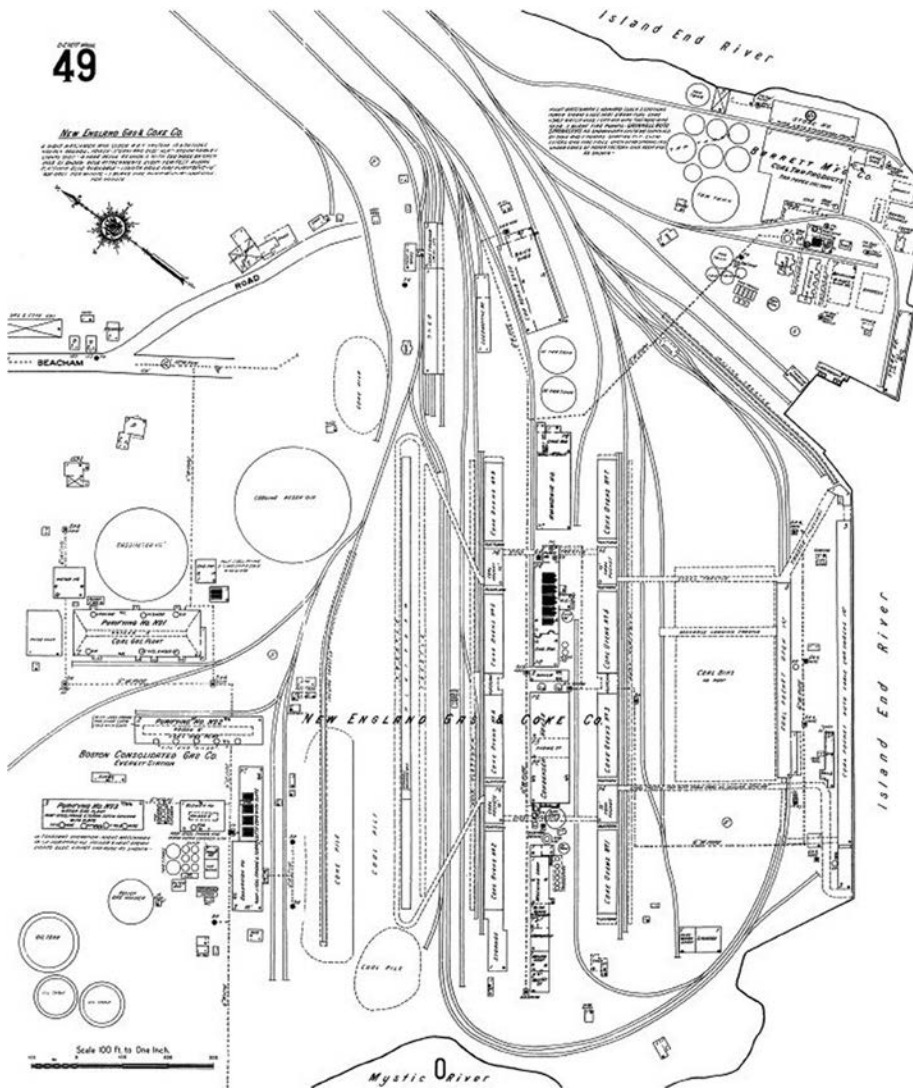


FIGURE 1.26 A 1910 layout of the New England Gas and Coke plant, After Sanborn.

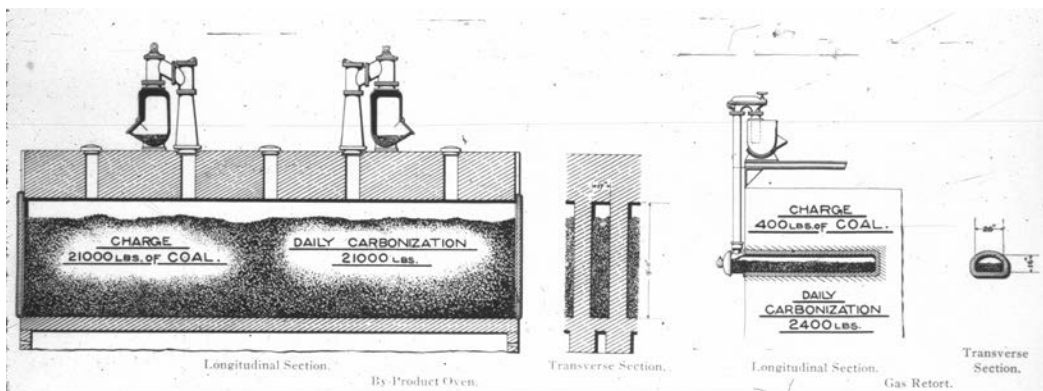


FIGURE 1.27 Comparison of a coke oven with a conventional coal gas retort. (Authors' collection).

Tar was collected in two massive tar wells and pumped to a pair of 19,000-gallon holding tanks, drawn off to the abutting coal tar distillation plant. The plant also generated large quantities of ammonium sulfate—touted as 30 tons of the material per day—which was shipped mostly by rail. The ammonia was recovered using several processes, including steam distillation to recover volatile ammonia, mixing with lime, redistillation for fixed ammonia salts, and finally washing with sulfuric acid to convert the ammonia to ammonium sulfate.<sup>147</sup>

In what appears to be a unique role for a coking plant, the Everett plant was established not simply to make coke, but played a crucial role in a much larger scheme, by which the entire spectrum of coal carbonization industries would thrive on the symbiotic use of residuals and by-products. By 1910, the end-use was “envisioned as endeavor to revive the iron industry of New England, if the government will give them certain concessions which will enable them to bring iron ore by boat to the site they have selected for a large smelter, where iron will be manufactured.”<sup>148</sup> The smelter never materialized, but a blast furnace for steelmaking was eventually constructed. Steel production did not commence until the 1920s, however, and even then was only on a limited scale.

As we discuss more in [Chapter 4](#), New England Gas and Coke was part of a family of corporations controlled by the Boston financier Henry Whitney, who also controlled the Dominion Coal Company of Canada, most of the American importation of Canadian Maritime Province coal, and a shipping line. Using Canadian coal that he sold to himself at a discount and shipped by sea at cost in his own freighters, Whitney and his backers established the Everett coking facility with far more than coke in mind.

Whitney’s syndicate also held controlling interests in several of the gas companies serving metropolitan Boston, during a tumultuous period that saw one of the longest and most severe gas wars in the industry’s history. The syndicate’s plan was to blend the abundant surplus gas from the coking works with gas from the other plants the organization controlled to provide a cheap and marketable supply of gas, thereby undercutting the competition. The facility’s nature as a coking plant also had a further advantage in this master plan—after a prolonged dispute and an opinion from the state Attorney General, the Massachusetts Board of Gas and Electric Light Commissioners grudgingly conceded in 1898 that New England Gas and Coke was not itself a public utility gas company, since it only sold gas to gas companies, and not to the public, and was therefore outside the Board’s jurisdiction.<sup>149</sup> The plan eventually collapsed due to the Whitney organization’s unstable finances, as part of the chain of events led to the 1904–1905 consolidation of the entire Boston gas industry under the new Boston Consolidated Gas Company.

By no coincidence whatsoever, after its 1904–1905 consolidation the Boston Consolidated Gas Company erected a massive new combined-process gasworks, directly adjacent to the Everett by-product coke oven plant. Gas from the two facilities was blended at the BCGC gasworks and distributed to the gas company’s customers. The merchant coking plant operated around the clock and its surplus gas supplied ~40% of the base-load gas supply for the Boston metropolitan area. In 1917 this came to roughly 2.9 billion cubic feet, with the balance of the gas supply coming from the most efficient of Boston Consolidated’s own works, to the tune of 4.15 billion cubic feet.<sup>150</sup> In 1917, the coking plant’s owners contracted with Boston Consolidated to supply the gas company each day with 5 million cubic feet of unpurified gas, with a minimum calorific value of 575 Btu, for the price of 29½ cents per thousand cubic feet. Significantly, the quality of the gas is denominated in Btu rather than candlepower, although this arrangement apparently antedated the formal replacement of the candlepower standard in Massachusetts with a calorific standard.<sup>151</sup>

The long-planned blast furnace was brought online in September 1926, being officially turned on (or “blown in”) by President Calvin Coolidge, who flipped a remote switch connected to a telegraph key in the White House. This was a fairly common ceremonial stunt during the early twentieth century; President Wilson had started the fashion by remotely detonating the final charges for the Panama Canal excavations in 1913. The plant had a nominal input capacity of about 500 tons of pig iron a day.<sup>152</sup>

The Massachusetts Gas Companies, a holding company, acquired both Boston Consolidated Gas Company and New England Gas and Coke shortly after 1905. New England Gas and Coke was,

however, kept nominally separate from Boston Consolidated, in order to keep it outside the Board of Commissioners' purview. In 1929, the Massachusetts Gas Companies was acquired by the Koppers Company, a major coal and coke producer based in Pittsburg, Pennsylvania, that had been formed in 1908 as a German overseas holding, which was then sold in 1914 to the Mellon interests. With the coming of the Great Depression, the Congress passed the 1935 *Public Utilities Holding Company Act* and Koppers was forced to spin off much of its gas, coke, and coal production into Eastern Gas & Fuel Associates of Philadelphia, which had been organized in 1929, and which remained nominally a subsidiary of Koppers until 1950.<sup>153</sup>

EG&FA was a classic example of corporate vertical integration in a limited market. Through its subsidiaries, the corporation owned assets at every stage of the coal market, from coal mines through railroads and shipping lines to end-users such as gas companies, steel mills, and simple coal vendors, with a profitable chain of Koppers-brand general stores in Appalachian mining towns.

Eastern Gas & Fuel Associates shut down the New England Gas and Coke coking and blast furnace plant in late 1959, with layoffs of about 800 men, in response to weakening sales of coal and coke as domestic fuels, a slowdown in the steel industry resulting from a major strike, and the dwindling market for gas from the coking works now that Boston Consolidated Gas Company was switching to natural gas. The coking and blast furnace units had been idled or in reduced production for several periods during the mid- and late 1950s, and with much of the company's remaining coal and coke production going overseas, there was little economic sense in maintaining the Everett plant when plants closer to coal country could keep up with demand.<sup>154</sup>

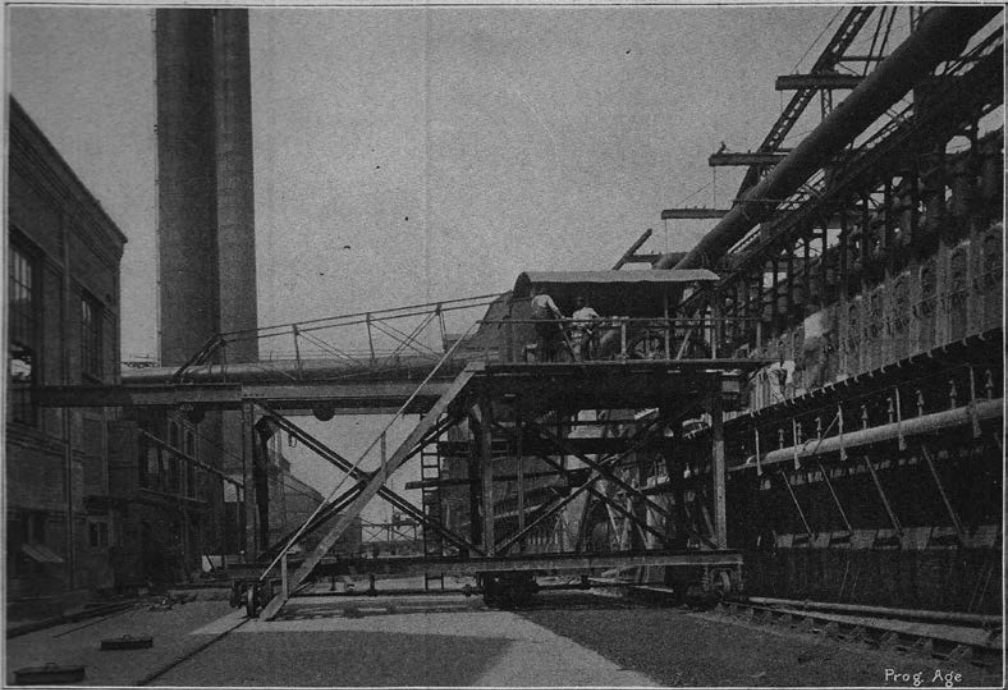
#### 1.14.2.1 General Nature of the Everett Coke-Oven Plant

Unlike gasworks, where the production machinery was installed in retort houses or generator buildings, a by-product coking plant was essentially a single immense open-air machine with no pretensions of being a building. The heart of a full-scale coking facility consisted of rows upon rows (each termed a *battery*) of ovens laid out in the open, squat utilitarian structures, typically charged by a one-operator traveling trolley (a *larry*), attended by a laborer on foot; all operating on top of the oven battery. Hoffman-type ovens were vertical arrangements; the laborer opened the charging ports located in the deck running along the tops of the ovens (typically three per oven) and dropped the coal in, as opposed to the crews of stokers who operated at the faces of the coal gas benches in a retort house. This convenient gravity-feed feature likely inspired the development of vertical and sloping retorts for gasworks. One other signal difference between a coal gas retort and a coke oven was that while the retort charges at gasworks were denominated in hundreds of pounds roasted for four to eight hours, those of the much larger coke ovens were typically denominated in tons and were roasted for 24 hours (Figures 1.27, 1.28, and 1.29).

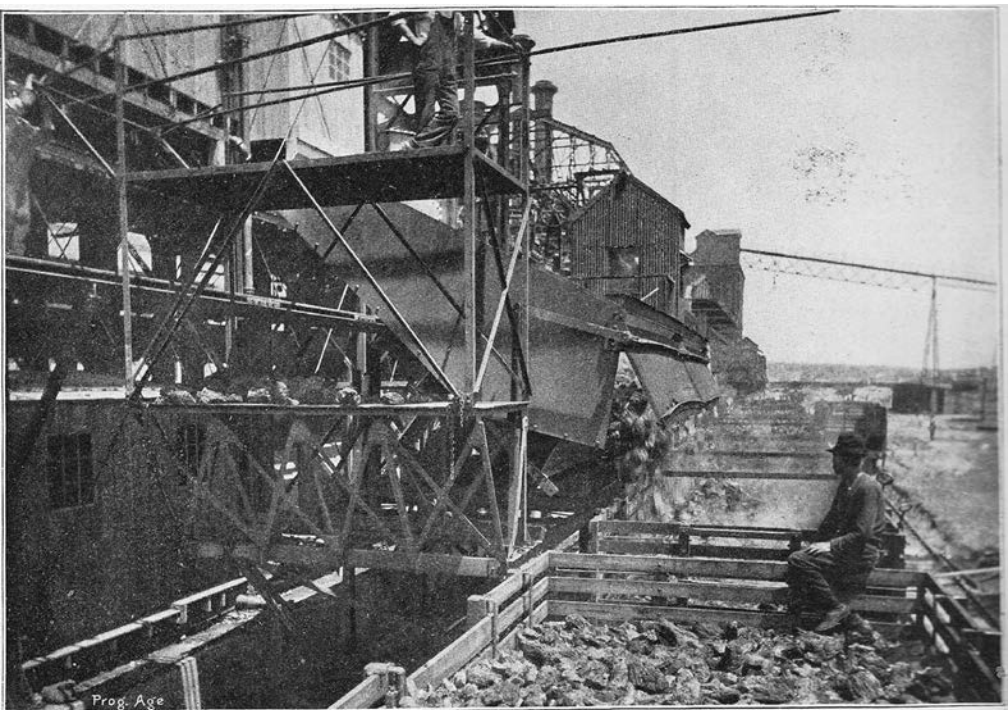
By the early 1900s, there were three primary types of by-product coke ovens being marked in America; the Otto–Hoffman (or simply “Otto”) system, the Semet-Solvay type, and the Koppers type. Of these, only the Otto and Koppers types are known to have been used in Massachusetts on an industrial scale, both at the Everett plant. All three types bore some common features—they were long, narrow “slot” ovens (17–19 inches wide), varying from three to nine feet in height, and up to 35 feet in length. Ovens were heated by shared gas-fueled under-furnaces, the hot exhausts of which were circulated through flues built into the oven walls.<sup>155</sup> These ovens were usually constructed in 50-oven *batteries* with shared heating and gas recovery systems.

Samuel Wyer described the Otto–Hoffman oven thus:<sup>156</sup>

The Otto–Hoffman oven in the American form is shown in sectional perspective in Fig. 83. The coking chamber itself consists of a long, narrow retort of firebrick construction, a number of such retorts, usually 50, being placed side by side to form a battery. The dimensions of this retort are 33 ft. long, 61 ft. high, and from 17 in. to 22 in. in width, containing 6 to 7 net tons of coal at a charge. The walls of the retort are built with vertical internal flues, heated by gas. The ends of the retorts are closed by iron doors, lined with firebrick, fitting closely to the brickwork and luted with clay. These are raised



**FIGURE 1.28** This photograph shows the Hanna Coke plant in Detroit, with a battery of Koppers-type coke ovens to the left and a “larry” or mechanical charger at center. (From Schneiwind, 1899.)



**FIGURE 1.29** An 1899 image showing the dumping of a charge of coke. (From Schneiwind, 1899.)

and lowered by a winch or by an electrical lifting device. The coal is charged into the ovens from three larries moved by hand along tracks, laid on the oven top or, in the later plants, by a single electrically operated larry as shown in the illustration.

The single larry has spouts which deliver the coal from corresponding openings in the oven top to the oven chamber below. The coke is pushed out of the oven by the electrically operated pusher and is received and quenched on a wharf, from which it is loaded by hand into railroad cars on a depressed track alongside. The heating of the oven is done by gas, returned from the condensing house through lines running along each side of the battery, there being a burner at each end of each oven. Only one burner is used at a time. The air for combustion is taken in at the end of the battery, where the gas and air reversing valves are located, and is led through the underground passages, shown in the figure, to the flues beneath the regenerative chambers. These extend the whole length of the oven battery and are filled with checker-brick.

The air rising through this checkerwork is heated to a high degree, passing then through uptake connections to the space beneath the floor of the oven chambers, and through lateral ports to the combustion chamber, where it meets the gas from the burner. The burning gases rise through the vertical flues of half the wall, pass along the horizontal connecting flue above, and down the remaining vertical flues to the horizontal flues below, thence passing to the regenerator, where their sensible heat is absorbed by the checkerwork. From there they are led to the lower regenerator flue, past the reversing valve to the draft stack. On the reversal of the air and gas, the gas burner on the other end of the oven comes into use, the air passing up through the heated regenerator on that side, and to the gas chamber and combustion chamber, the heated gases passing in a reverse direction through the wall flues downward through the regenerator and so to the stack. The period of reversal is 30 minutes.

Subsequent alterations to the plant included the addition of a battery of Wilputte ovens (Battery A) in the early 1920s, an on-site by-product recovery plant and a blast furnace in 1926, a later enlargement of the by-product plant, and a dedicated producer gas plant. The original Hoffman ovens remained in at least partial use until 1935, when the remaining units were replaced with three batteries of more efficient Koppers ovens in batteries B, C and D. An ammonium thiocyanate recovery system was installed in 1930. Battery C was replaced in 1949.<sup>157</sup>

The sprawling coke plant complex shared a stubby, once-marshy peninsula with several other eventual EGFA subsidiaries—the Boston Consolidated Everett plant, the Mystic Iron Works Blast Furnace, and the enormous coal wharf of the Mystic Steamship Division, which operated a fleet of colliers. The overall Eastern Gas & Fuel Associates Everett complex—coking plant, gasworks, coal wharf and all—had 34 miles of railroad track and its own fleet of locomotives for shifting loads of coal and coke, tanks of tar or other by-products. A by-product recovery plant operated by the New England Manufacturing Company, a subsidiary of New England Gas and Coke, was added during the First World War.

Something of the scale of this plant can be understood from a June 1946 notation in the Eastern Gas & Fuel Associates' company magazine, *Associate*, which credited the plant with a production capacity of a million tons of coke per year, and employed about 850 people, down from a wartime peak of over 1,000 (Figure 1.30).<sup>158</sup>

By 1949, the coking plant generated 12,500,000 gallons of tar per year.<sup>159</sup> In order to take full advantage of the vast quantities of tar produced by the coking plant, the always aggressive Barrett Manufacturing Company's subsidiary, the National Coal and Tar Company, constructed an adjacent by-product tar distillation and chemical manufacturing plant northeast of the coking plant that opened in 1910. The coking plant closed and was demolished in the early 1960s, together with the adjacent tar-processing plant and Boston Consolidated's Everett gasworks.

The plant received some unwanted attention in the summer of 1949, when the Massachusetts Attorney General's Office began to consider proceedings against EGFA and several other local industries, alleging that these facilities had created a public nuisance through pollution of the Island End River, the Mystic River, and Boston Harbor. EGFA subsequently hired Metcalf & Eddy, a respected local engineering company with extensive experience in wastewater and sanitary engineering, to conduct an engineering review of the site.<sup>160</sup>



**FIGURE 1.30** New England Gas and Coke in the late 1940s. (From *EGFA Associate*, May–June 1946).

Metcalf & Eddy reported in March 1950 that seven of seventeen drain outlets serving the Everett complex were at times discharging tars, oils, or scum into the rivers, and that “large quantities of tar were entering the ground through leaking pipes and broken manholes” and that “oils and tar were present particularly in the benzol plant and byproducts plant yards.” One of the drains reportedly discharged directly onto along the river. Metcalf & Eddy reportedly recommended the installation of wastewater controls, repair of damaged pipes, rebuilding of coke ovens, and monitoring of discharges, and Eastern’s successors represented during litigation that these measures were implemented. In addition, the coal tar processing facility (then leased to Koppers) installed an oil water separator and coke filters to treat wastewater discharges.<sup>161</sup> The Attorney General did not proceed with enforcement action.

### 1.14.3 COKE-OVEN GAS AND BY-PRODUCTS

By-product coke-oven gas was generally a poor-quality gas, lacking virtually any illuminants and of only modest fuel value, and required significant enriching or blending with another source of gas in order to produce a gas that would meet the prevailing regulatory requirements for gas sold to the public.

Coke-oven gas was, however, less expensive to produce than coal gas, in large part because of the economies of scale allowed by the coking process. Much of the coke-oven gas was used to fuel the ovens themselves, but surpluses could be had if the plant was designed to produce them, and where no use was available, were sometimes allowed to run to waste. Coke ovens also produced the usual tar and ammonia by-products, and in quantities sufficient that the federal government took notice of the need for efficient beneficial use of coke-oven residuals as a matter of national interest.<sup>162</sup>

### 1.15 1930s HIGH-BTU WATER-GAS AND SECOND-GENERATION OIL GAS

Water-gas and CWG generally dominated the national gas industry between 1890 and the 1930s. By the 1930s, some gas companies had begun to introduce high-Btu water-gas, either to blend with natural gas where it was available, or in response to consumer demand. These plants generally did not appear in Massachusetts until after the end of the Second World War and in the interim of just a few years before the planned introduction of natural gas via pipeline, where they were used as auxiliary capacity in case of demand outstripping the supply of natural gas (so-called *peak shaving* plants), or to facilitate the transition from manufactured gas to natural

gas, the latter of which had a much higher Btu value (between 800 and 1,200 Btu per cubic foot) than did coal gas or ordinary CWG. By introducing high-Btu gas to parts of its distribution on a rolling basis before natural gas became available, the gas company could phase the conversion in over a longer period, avoiding a massive logistical scramble for literally “overnight” exchange of gas burners in stoves, ovens, boiler furnaces, and other uses of fuel gas. Oil gas was introduced to the Northeast slightly earlier, in the 1930s, after a long history on the west coast; this was in most cases primarily a cost-saving measure to replace worn-out coal gas retort benches or older water-gas generator sets.

High-Btu water-gas was produced by a number of processes, one of which was the Tornquist Heat Balance Process. This method introduced some of the carbureting oil in the superheater shell of a modified water-gas set, which along with other modifications produced a gas up to 1,090 Btu, nearly twice the usual value for previously supplied CWG.<sup>163</sup>

There is somewhat of a gray area between high-Btu water-gas and second-generation oil gas, because a three-shell water-gas system could easily be converted to an oil gas generator (such as had been accomplished on the West Coast by L. P. Lowe, in the years after 1887). The crux of the distinction is that in oil gas, the need to heat a mass of coke or coal was no longer required as a heat reactor; the same first (of three) shell space being filled with checker-brick, and the atomized oil sprayed directly into the superheater, where it was cracked by superheated steam.

Some dedicated oil gas processes also existed during the 1920s and 1930s, including the Dayton process installed at the Plymouth Gas Light Company in 1922, where it supplemented an existing coal gas system.<sup>164</sup>

The use of oil gas was partly motivated by the decrease in petroleum prices relative to those for coke or anthracite, while still yielding better results than bituminous coal, and also partly because the elimination of a solid coke or coal feedstock greatly reduced the labor costs of manually handling the feedstock, and then removing its ash and clinker.<sup>165</sup>

## 1.16 ACETYLENE AS AN ILLUMINATION AND HEATING GAS

Acetylene gas appeared in the Massachusetts gas industry in the last years of the twentieth century, chiefly as a means of providing gas to small rural communities where no other source of illuminating or heating gas was available. We inject this subject here, late in the progression of Massachusetts manufactured gas process, for the simple reason that, for the most part, these gas plant sites do not represent modern environmental or public health threats. On the other hand, acetylene gas plants generally bore commercial names that are indistinguishable from those of major urban gasworks. Only when one unravels the local history, and takes into consideration the limited temporal operation (after 1890 and prior to 1920), it is realized that the particular gasworks is seen to serve a “one horse town” or an institution or private estate, and that the gas plant was not only rural and of small annual production, but delivered a high-priced form of illuminating and cooking gas, aside from its innocuous nature.

### 1.16.1 GENERAL RURAL NATURE OF ACETYLENE GAS PLANTS

These firms were as a rule very small, with minimal capital, as a rule not producing more than half a million cubic feet of gas per year and sales to at most a few hundred customers, and were often operated as unincorporated partnerships or sole proprietorships rather than as formal corporations. Acetylene gas apparatus could also be found at many large manufacturing facilities, where it was used to provide welding gas.

The gasmaking process was elementary; granular calcium carbide was introduced into a reactor vessel filled partway with water. The resulting chemical reaction produced acetylene gas ( $C_2H_2$ ), which could then be regulator-valved directly into the distribution system without further processing or purification. The gas could attain extremely high candlepower values (up to 200 cp/cubic foot)



**FIGURE 1.31** Acetylene gasmaking apparatus, preserved at Herndon, Virginia. (Authors' photograph).

and similarly high calorific values. Roughly 3.5 pounds of carbide could produce a thousand feet of gas, but the gas was so expensive, ranging from \$12 to \$20 per thousand cubic feet, that it was commonly sold in Massachusetts by the hundred cubic feet.

Acetylene gas was a relatively innocuous process in terms of persistent pollutants; the chief waste product of the process was a slurry or sludge consisting mostly of calcium hydroxide (innocuous “lime”). The authors predict most plant area dumping to represent these lime masses of perhaps up to few tens of cubic yards per location, and to be located rather close to the recorded or suspected acetylene gaslight plant sites (Figure 1.31).

### 1.16.2 ACETYLENE GAS PLANTS OF RURAL MASSACHUSETTS

Acetylene gas companies were most common in the northern half of the Connecticut River valley, with plants in South Hadley, South Deerfield, Northfield, Bernardston, Sunderland, Hadley, and Hatfield, and on the Buzzard's Bay coast and Cape Cod, with plants at South Dartmouth, Marion, Chatham, Cotuit, and Hyannis.

The chief advantages of acetylene gas were the small size and low cost of the plant necessary and the simplicity of the process, which could be managed by persons not trained as gas engineers and staffed with minimal part-time manpower. The Vineyard Lighting Company on Martha's Vineyard switched from CWG to acetylene gas in 1916 as an economy measure; this firm was the only regulated gas company to switch from conventional gas to acetylene gas and, in hindsight, this move was to prove spectacularly ill timed.

The main drawback of the acetylene process was the relatively high cost of its carbide feedstock, produced by a power-intensive electrochemical process that was not feasible on an industrial scale until the Niagara Falls hydropower system became operational in the 1890s and provided plentiful and cheap electricity to the Buffalo region. This feedstock cost led to a correspondingly high cost of gas, not easily borne in the generally rural communities in which acetylene companies operated. The process was also more likely to be outright dangerous than other gasmaking methods, in part because pure acetylene gas is odorless and thus provides no warning of leaks; nearly a quarter of the acetylene plants built in Massachusetts exploded disastrously at some point in time.<sup>166</sup> Most of

these were not rebuilt, a testament to the limited capital of the companies and the tenuous nature of their commercial markets.

The number of acetylene companies in Massachusetts peaked at 16 in 1911 and declined precipitously after 1914, due in large part to the outbreak of war in Europe prompting sudden and drastic rises in the cost of calcium carbide, which was essential for many contemporary steelmaking and metal-fabricating processes. The entry of the United States into the war in 1917 put the final nail in the industry's coffin, as the War Industries Board promptly sequestered most of the nation's carbide production for the war effort. The last acetylene company in Massachusetts, located in the small town of Princeton, northwest of Worcester, went out of business in 1922.

### 1.17 LATE PERIOD HIGH-BTU REFINERY GAS REFORMING (1929–1955)

Like coking, petroleum refining processes generated *residual* gases that could be converted (*reformed*) at the larger-capacity individual gas plants and set to use as *by-product* fuel gases; it was a bygone conclusion that gaslighting would continue to diminish. Beginning around 1930 with refineries in northwestern Pennsylvania and also centered on the Delaware River around Marcus Hook, New Jersey, several petroleum companies began to provide attractively priced residual gases, at about the time that pressurized tank-car delivery by rail became feasible.

Petroleum refinery residuals were delivered to major urban gasworks and were reformed generally in modified CWG sets. On average, the modified CWG sets were up to 50 years in age; having economically attractive lives far beyond less-than-a-decade outlook for the coal gas benches that housed the nominal two-year longevity of their own ceramic retorts.

#### 1.17.1 BUTANE/PROPANE-AIR GAS (1929–1955)

Apart from the gas reforming option well suited to large, urban gasworks, the refineries also offered separated butane and propane residual gases, and such could be delivered directly to the rail sidings of virtually any small gasworks. Not only could these gases be employed in mid-to-large urban gasworks as an additive to boost Btu values, but also the gases could be mixed with ambient air at a pittance of installation cost; on average about \$2,500. Long sausage-shaped horizontal propane tanks became common sights at many gasworks during the 1930s and 1940s; the Boston Consolidated Gas Company added a propane-air standby plant in 1946–1947, with four batteries of seven 74-foot long tanks each. A company newsletter proudly proclaimed that each seven-tank battery was capable of supplying the entire output of the Boston Consolidated company for three and a half days of average output.<sup>167</sup>

#### 1.17.2 SECOND-GENERATION OIL GAS

Beginning in the early 1930s, many gasworks in the Northeast were converted to use oil instead of coal as a gas feedstock. These processes often followed the general lead of L. P. Lowe's "Pacific Coast" process, popularized in California, Washington State, and Oregon, where oil was more readily accessible than in the East. At its simplest, this new version of oil gas involved roasting high-sulfur California crude oil in two refractory checker-bricked right-circular *shells*, at four to six feet in diameter and 14–19.5 feet high. The general consensus amongst Eastern gas engineers was that the process's ability to digest California crude oil, which was otherwise undesirable due to its high sulfur content, had demonstrated the general usefulness of this modern technology of the time.

Something of a similar effect could be accomplished on a miserly budget by simply bypassing the generator shell of a Lowe system and spraying oil directly into the second stage together with superheated steam.

### 1.17.3 HIGH-BTU SUBSTITUTE NATURAL GAS REFORMING (1947–1955)

This last phase of oil gas production was born of the triple desperation of postwar service expansion amid the suburban building boom, postwar coal strikes, and the impending arrival of insufficient supplies of natural gas, additionally burdened with reasonable risks of interruptions to the natural gas supply. Hesitant to invest large funds in new and innovative reforming equipment, the gas companies generally met the challenge with service modifications of existing CWG generators, along with various new process generators being strongly marketed at the time.

As one example, although a rather unusually late one, a “synthetic natural gas” plant operated in Freetown, Massachusetts from 1972 until the early 1980s. The facility stored petroleum naphtha in a pair of 19-million gallon aboveground storage tanks and processed the naphtha into a gas with similar chemical and thermal properties as natural gas, with which it was blended.<sup>168</sup> While its operational life was brief, the facility was significant enough to be mentioned in a Department of Energy regulatory analysis and environmental impact report for alternatives for coping with natural gas shortages, along with a Boston Gas’ Everett propane plant, and several other synthetic natural gas plants.<sup>169</sup>

### 1.18 LATE-PERIOD INNOVATIVE GAS TECHNOLOGIES

By the late 1920s, the situation in America regarding the gasmaking feedstock supply situation was generally unsettling, and by the early 1940s the situation was positively grim. Gas companies faced tremendous economic pressures and generally had limited resources to invest in new and replacement plant public clamored for more and cheaper gas, there was a general gas industry consensus that reliable long-term natural gas supplies were theoretically possible but would require immense capital outlays to bring to New England, and organized trade union strikes by coal workers were on the rise. There was a general climate of realization that innovative gas-manufacturing technologies would have to be developed in order to bring about an increasing supply of what generally became known as *high-Btu substitute natural gas*. In this manner, if and when reliable pipeline natural gas supplies would be available in Massachusetts, the Commonwealth’s gas industry would already have high-Btu (1,025 Btu) gas in place.

### 1.19 KEY FINDINGS

The manufactured gas industry employed many gasmaking processes during its over 150-year history. A detailed understanding of these processes is essential to a thorough understanding of gasworks in particular and the manufactured gas industry as a whole. The type of gas-manufacturing process was the central defining feature of a gasworks during the period of that process’s use, and dictated much of a given site’s environmental legacy.

Of all of the important variables defining today’s public health threat of derelict gasworks, the one outstanding identifying characteristic remains that of the type of manufactured gas plant, defined by its dominant gas-manufacturing process. The requirements of operation of each of the different major gas process sets out a ready pattern for the general character of each of today’s remediation sites.

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