COAL & EMPIRE

The Birth of Energy Security in Industrial America

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were detailed to command or operate the private vessels. They were mostly lieutenants and passed midshipmen, though many would end their careers after the Civil War as captains, commodores, and admirals—Robert W. Shufeldt, Fabius Stanly, and Charles Stuart Boggs, for example, in addition to Porter. But their years of service aboard the several mail steam lines was comparatively brief. By the end of the 1850s, all federal subsidies for mail steamers had expired. Some officers and engineers returned to naval duty, while others left the service altogether. When the Civil War came, many would join either Union or Confederate fleets; other officers would command the mail steamers themselves, detailed in the emergency for war duty as they had been initially designed.[89]

Given the collapse of the Collins Line (two of its massive ships were lost at sea) and expiration of the contracts for the other lines in the late 1850s, it might appear that even without the Civil War, this policy experiment in federal steam communication subsidies had run its course. Yet even up to the eve of the war in 1861, memorials for new mail steam lines and modified routes continued to arrive in Congress, congressional committees that dealt with the post office and post roads continued to favorably report bills endorsing new subsidies, and both national politicians and the commercial public continued to debate new proposals.[90] If anything, growing sectionalism made it increasingly difficult to undertake these projects not because they were undesired but because it could not be ensured that their advantages would be distributed evenly.

After the Civil War, the political economy of international communication would again change. Countries would rely more heavily on new submerged telegraph lines, and international postal conventions would eliminate the threats of discriminatory actions by the nation whose ships carried the mail. These normalizations and modernizations of international communications would make the American mail subsidies less important than they had seemed in the 1840s and 1850s, though some subsidies were in fact reinstituted, like those to the Pacific Mail for mail carriage to Japan and China. But the antebellum steamers had another consequence. They brought the subject of coal before Washington in a way it had never been brought before. If Congress sought to connect the United States to the rest of the world by steam, it had to think about how to sustain that infrastructure. Where could coal come from? Who would provide it? How would it go from its source in urban eastern markets to potentially distant sites of consumption? In the later nineteenth century, some Americans claimed that the increased use of steam power demanded that the United States secure coaling stations overseas. Americans of the antebellum period came to other conclusions and experimented with a range of ways to support the fuel needs of steam vessels. What united the various approaches was a consistent concern with the idea of economy.

CHAPTER TWO

ENGINEERING ECONOMY

The ocean pales where'er I sweep,
  To hear my strength rejoice,
And the monsters of the briny deep
  Cower, trembling at my voice.
I carry the wealth and the lord of earth,
  The thoughts of his godlike mind;
The wind lags after my flying forth,
  The lightning is left behind.

George W. Cutter, "The Song of Steam"

As Americans in the Pacific and Caribbean quickly discovered, the challenges of limited fuel resources quickly shattered the fantasy that steam power would annihilate time and space. This tension between imaginable networks of communication and transportation and the practical limitations that confronted them persisted throughout the nineteenth century. Daniel Webster could declare of steam power in 1828 that "no visible limit yet appears, beyond which its progress is seen to be impossible," but even then, limits were, in fact, plainly visible. It was one thing to imagine a transpacific steamship service, to petition Congress, to draw up a business prospectus; it was quite another to ensure the availability of abundant quantities of coal—of precise varieties of coal—all at reasonable prices halfway around the world. It was more challenging still to commit the national defense to machines never before tried by war. All these challenges demanded careful attention to anything that might facilitate powering ships by steam power. Nineteenth-century Americans had a word for managing this attention to progress amid scarcity of time, money, and resources: "economy."[1]

Economy did not mean efficiency. The two words, similar in connotation by the turn of the twentieth century, once expressed two very different concepts. In the nineteenth century, as Timothy Mitchell notes, economy "referred to a process, not a thing."[2] Economy evoked proper management, responsible government, and a frugality—but not parsimony—with money or resources. Economy could describe the regulation of the household, as in the phrase "domestic economy," or the polity, as in "political economy." Economy was a moral value, an obligation to family and country. "The man who is economical," wrote Lydia Maria Child in her bestselling guide to home management, "is laying up for himself the permanent power of being useful and generous." As Child suggested, this economical man was inherently forward looking, husbanding resources in the present to ensure sufficiency in the future.[3] A responsible public official steered the ship of state in a similar way.

In contrast, in the early nineteenth century, "efficiency" was much closer in meaning to the related word "efficacy." Both words expressed an ability to cause some desired consequence. The words so closely shared a meaning that Webster's 1841 dictionary defined them nearly synonymously: efficiency was "the act of producing effects," "effectual agency," and the "power of producing the effect intended." Efficacy was the "power to produce effects" and "production of the effect intended."[4] This sense of efficiency had roots that stretched back to antiquity and the notion of "efficient causes," what Aristotle defined as "the source of the first beginning of change or rest."[5] Within the sciences, efficiency likewise expressed a notion of effective causality. Davies Gilbert, serving in 1827 as president of the Royal Society, defined "efficiency" as a physical quantity: what was done to a machine to cause it to operate. How the machine reacted in response he labeled "duty." An operator expended efficiency on a machine and in return, a machine performed duty.[6] Five years later, this definition was adopted by the prolific polymath William Whewell, who employed it as a now-forgotten means for explicating the science of mechanics.[7]

In the middle of the nineteenth century, "efficiency" was just beginning to take on its modern connotations. Among engineers, the word evolved from meaning an action administered on a machine (as employed by Gilbert and Whewell) to a property of that machine—a number measuring the actual performance of a machine against its ideal performance. This usage was developed most significantly by W. J. M. Rankine, a Scottish engineer and central figure in the development of thermodynamics. In 1858, Rankine, building on several years of earlier investigations, defined a machine's efficiency as "a fraction expressing the ratio of the useful work to the whole work performed." For Rankine, efficiency expressed how much work a machine could perform "in producing the effect for which the machine is designed"—pumping water, driving a paddle wheel—divided by all the work the machine performed, useful work as well as work lost to friction, heat dissipation, or other impediments. By this measure, a "perfect" machine was one that wasted no work, whose total work was entirely "useful," making the efficiency fraction simply one, or "unity." As a corollary, this definition implied the responsibility of the machine-building engineer, which was "to bring their efficiency as near to unity as possible."[8] Gradually, this usage slipped from engineering into wider circulation. By 1911, Frederick Winslow Taylor could use efficiency in its fully modern sense, describing a worker's "highest state of efficiency" as "when he is turning out his largest daily output."[9]

In the 1840s and 1850s, the pursuit of economy expressed a more expansive concept than efficiency in either its earlier or later usages. Thinking about efficiency meant thinking about machines, either what powered them or how they operated. Thinking about economy connected those machines to wider networks of fuel and broader methods of operation. The economy of fuel implied attention not merely to prudent means but desired ends. "It is not the *saving* only of fuel which merits attention," instructed the Scottish engineer Robertson Buchanan in his 1815 *Treatise on the Economy of Fuel*, "but its *safe*, *easy*, and *healthful* application to the various purposes of life."[10] Economy meant ideas, judgment, and attention to the complex relationships that linked people to the world around them. If for Rankine, the engineer's responsibility was building steam engines that operated closer to a calculable ideal, for the French engineer Sadi Carnot, achieving "the considerations of convenience and economy" with steam engines required the cultivation of "the man called to direct"—the wise engineer trained to evaluate the factors of expense, materials, design, constraints of space, and safety of operation in particular ways for particular purposes.[11]

One could pursue economy in any realm, and economy affected everything. Discussing the increasing adoption of anthracite coal as a domestic and manufacturing fuel, the American chemist Walter R. Johnson noted that "the consequences of such changes, if judiciously made, will doubtless be the diminution of expense, the saving of labor, the gaining of comfort, and the economizing of space and time."[12] Economy could also frame the perception of limits. For Columbia College professor James Renwick, transoceanic steam navigation was both possible and useful, but "in point of economy," it could "never compete with sails" and would likely only be used for passenger travel or naval purposes.[13] In these terms, achieving economy of fuel encompassed all aspects of what historians would later call a socio-technical system.[14]

As the construction of naval and mail steamers increased during the antebellum period, the economy of fuel became a subject for the national government. These projects introduced new demands on resources, budgets, and bureaucratic organization. They raised new questions about the role and responsibility of government in providing material means for achieving policy ends. Along the way, the adoption of steam power led the federal government to rely on new forms of technical expertise. This technical expertise addressed fuel economy in primarily three forms: first, through chemical and physical investigations into different varieties of fuel and their combustion; second, through engineering experimentation and ship design; third, though geological and diplomatic expeditions to investigate fuel supplies in distant lands. This chapter explores the first two, and the following chapter considers the third. In all areas, the pursuit of technical knowledge both influenced political actions and was, in turn, influenced by them.

The Calculus of Combustion

Economy of fuel began with adequate supplies. As mail steamer commanders and line proprietors quickly discovered, ensuring sufficient coal presented one of the fundamental challenges to establishing global, or even simply coastal, communications networks. The problem was not that the United States lacked mineral deposits—in the eighteenth century, Americans had become aware of tremendous strata of coal near the Appalachians and further west. Enterprising operators in Virginia had begun commercial mining in the coalfields surrounding Richmond in the 1740s and in the western, mountainous portion of the state during the first two decades of the nineteenth century. Jefferson mentioned both in *Notes on the State of Virginia*, repeating the widespread belief in the vastness of western deposits—it was thought "that the whole tract between the Laurel mountain, Missisipi [*sic*], and Ohio, yields coal." In neighboring Pennsylvania, accounts of the "Pittsburgh seam" date back at least to the French and Indian War, and local coal consumption began there no later than the 1780s.[15]

In the decades that followed, political campaigns for internal improvements and economic development blossomed, as did a desire to harness the capacity of the state. Between 1823 and 1850, twenty-two states commissioned surveys to better understand regional geological structures. Most importantly for state legislatures, these surveys sought to locate, identify, and map commercially valuable minerals, coal notably among them. North Carolina's pioneering state survey, begun in 1823 under Denison Olmsted, was the first to characterize the state's Deep River coal formation. Larger and more sophisticated surveys followed, especially in Virginia and Pennsylvania (both initially undertaken in 1836), the former under William Barton Rogers and the latter by his brother Henry Darwin Rogers. Both of the Rogers brothers devoted considerable efforts to describing the coalfields of their respective states (what William called "our great western coal region" and what Henry described as "the enormous series of coal measures"), while geologists in Maryland, Ohio, Indiana, and elsewhere mapped extensive coalfields in those states as well. In the minds of scientists, legislators, and aspiring industrialists, there was little doubt that the United States possessed enormous deposits of coal.[16]

Still, even late into the 1830s, there was reason to doubt that American steamships could ever compete with British ones on account of the inferior quality of coal for steaming purposes. When a London newspaper in 1829 criticized the prospects of American steam navigation because of the limited extent of American coal and its suitability for steaming purposes, U.S. newspapers reprinting

the article swiftly pointed out the vast extent of the country's coalfields. No paper, however, could respond to the charges of poor quality—no one in fact knew whether the quality of the coal was good or bad—and on that subject they remained conspicuously silent.[17] This question of quality haunted plans for ocean steam navigation. When the British *Sirius* and *Great Western* raced across the Atlantic in April 1838 in the first transatlantic steamship competition, the smaller *Sirius* arrived in New York nearly depleted of fuel. The larger and more carefully outfitted *Great Western* still had nearly a third of its coal remaining (203 of 660 tons), seemingly easing the fears of those who had fretted over the ability of any steamship to carry enough fuel to make it across the ocean. Returning home, however, remained a problem, for there was still no adequate American variety of steaming coal to fuel the vessels. Nearly two months after the ships had successfully reached New York, editors at the *Albion* worried that the expense of shipping British coal to America would still doom transatlantic steam navigation, calling the absence of American coal suited for steaming "the only difficulty in the way of this enterprise."[18]

One way to address this difficulty was to locate a superior variety of American coal. The *New York Herald* mocked those who threw up their hands and declared "that nature has interposed an effectual barrier to prevent the United States from competing with Great Britain in steam navigation, owing the scarcity and inferior quality of our bituminous coals." True, American bituminous coals consumed valuable space aboard ships, fouled decks, and were known to release distinctive plumes of billowing smoke, thus revealing the presence of American warships as much as seventy miles away, but according to the *Herald*, skeptics had not considered the introduction of vast quantities of American anthracite. Still, simply pointing to anthracite was an expression of hope, not a solution.[19]

Even as American mining companies, geologists, and chemists uncovered new varieties of domestic coals, the difficulty of identifying the ideal steaming fuel persisted through the Civil War. Engineers understood that different industrial processes called for different kinds of coal, the precise chemical compositions of which favored different uses. Weighing these compositions against price and availability, steam engine operators selected bituminous coal or anthracite or sometimes hardwood or pine. "Each of these has its peculiar manner of burning," instructed a popular engineering manual, "and hence the furnaces or fire-places in which they are used must differ in form and arrangement."[20] This peculiarity meant that between the 1820s and 1850s, research into steaming fuels required careful attention to specific varieties of fuel from specific places. Unlike wheat or hogs, high-precision fuel woods and coals were not easily commodified across different states, fields, or strata. Wood from apple trees, American chestnuts, or Jersey pines all burned in particular ways that rooted them to particular geographies, just as coal from the Lehigh Valley would forever burn differently from specimens mined along the Schuylkill or in faraway Newcastle. Coal for copper smelting could not contain large quantities of sulfur or iron. Cannel coal suited steam engines but not iron making. Broad Mountain white-ash anthracite coal of the Lehigh Valley was ideal for making iron but Buck Mountain coal, also of the valley, was better for steam generation. Especially for steel making or transatlantic steaming, the choice of coal varieties was critically important, and investigating the properties of fuels revealed the inextricable connection between nature, politics, and the market.[21]

At first, American investigators looked to Europe, where experiments on the economy of different fuels had begun in the late eighteenth century. In Paris, the French Ministry of Finance had asked Antoine Lavoisier in 1779 to examine various domestic fuels and determine their heating capacities when their price in the marketplace was taken into account. Turning to Paris's most common fuels, Lavoisier selected a local coal, coke, charcoal, beech, and oak. Despite his coal samples exhibiting roughly double the heating effects of wood, Lavoisier found that the taxes, fees, and transportation costs levied on coal made that fuel more expensive per unit of heat it provided, a fact of political economy that the chemist considered absurd in a kingdom of forests "chers et rares" and where the more abundant fuel, found in accessible riverside mines, was made more expensive by the state.[22]

In Munich, Benjamin Thompson undertook more elaborate experiments almost twenty years later. As part of his ongoing investigations into the practical applications of heat, the American-born Thompson (ennobled Count Rumford in Bavaria in 1792) considered understanding the properties of fuels and combustion essential for social betterment. "The great waste of fuel in all countries must be apparent to the most cursory observer," he noted in an essay of 1797. Focused on lessening this waste, especially in the furnaces of the poor, Thompson concocted novel mixtures of fuel that generated greater heat, devised innovative fireplace and kitchen designs to better conserve wood and coal, and manipulated the conditions of combustion in boilers to achieve maximal effect. Thompson also investigated the combustion of different fuels. In one experiment, he employed a specially designed calorimeter to determine the heat produced by burning different varieties of wood (elm, oak, ash—twelve species in all) in a variety of preparations. In another, he determined how much combustible charcoal he could produce from various species. As did Lavoisier, Thompson focused on practical improvements.[23]

Lavoisier's and Thompson's research influenced investigations on the other side of the Atlantic. In the United States, the Philadelphian Marcus Bull followed their research by analyzing the combustion of forty-six species of American trees in a series of experiments in the 1820s. Like Thompson, Bull justified his research by pointing to its social utility, noting the lengthy American winter, particularly for those too impoverished to ensure an adequate supply of fuel. His work constituted a contribution to what he called "an improvement in the domestic economy of society." Bull's results showed that eleven kinds of oak each burned differently, as did cedar, chestnut, poplar, and swamp whortleberry. Bull also discovered that various woods and coals of equal weights produced roughly similar quantities of heat, a warning to those consumers who purchased fuels by standard volume measures such as a cord. Due to the wide variance in density of different woods and coals, equal volumes of different fuels could produce a considerable range of heat.[24]

Lavoisier, Rumford, and Bull pursued their fuel studies as applications of science for social betterment. The proliferation of railroads made consideration of the fuel question vital to the success of highly capitalized corporations while simultaneously stimulating research into the problem for steamers. Even into the late 1840s, coal use on American railroads remained rare, unlike in England, where locomotives burned coke (a coal product). At first, American railroads followed the English example, but then they quickly adopted cheap and abundant pinewood. There were exceptions, however. "Strange to say we commenced with anthracite and at a time when people hardly thought it was stuff that would burn at all in anything," wrote Benjamin Henry Latrobe II of the Baltimore and Ohio in 1845. Fifteen years earlier, the railroad had begun using special anthracite-burning engines designed by New York's Peter Cooper, an experiment adopted by few other lines. But while the B&O continued consuming anthracite in these older engines, its experiments on different fuels arranged by Latrobe in the late 1830s revealed that burning Maryland's Cumberland coal—a bituminous variety—both saved money and more effectively evaporated water. In subsequent years, all of the B&O's new engines used wood or a mixture of wood and Cumberland coal.[25]

Latrobe's observations about the perceived obstacles to burning anthracite stemmed from how it combusted. In the most commonly used engines, anthracite ignited slowly; when finally burning, it generated so much heat that it ruined boilers. Furthermore, its ash fused into damaging clinker, and hard chunks blown out with the steam damaged copper engine components, leaving railroad mechanics struggling to prevent leaks from the joints of the boiler's iron tubes. The challenges posed by anthracite notwithstanding, wood had its own problems, ranging from its bulkiness to its relative weakness in generating fire to the frequency with which its sparks, ejected from the smokestack, tended to ignite the farms and forests through which locomotives rolled.[26]

Still, anthracite's abundance in Pennsylvania encouraged railroads there to continue experimenting with it. Some small, coal-carrying roads running from the anthracite fields of eastern Pennsylvania were able to make use of the locally abundant fuel by employing specially designed boilers (as had stationary steam engines and some river and sound steamers), but the much larger Reading Railroad struggled to do so. The anthracite engines of smaller roads had to perform less strenuous work than their giant neighbor, and engineers for the Reading discovered that small-road operations simply could not scale up. To accommodate its existing infrastructure, the Reading tried manufacturing patent fuels from anthracite coal dust, but it knew a better solution would somehow employ the coal directly.[27] During the late 1840s and early 1850s, the Reading pursued a series of investigations into anthracite fuel, adopting specially designed coal-burning engines and carefully analyzing their behavior.[28] These investigations yielded positive results in a short period of time, success that was aided by reductions in coal prices due to increased national production. In 1846, the Reading burned 66,000 cords of firewood to haul 1,188,258 tons of anthracite coal to market. That wood cost the railroad over $200,000, compared with barely $1,000 for the sporadic use of anthracite as a fuel, making the line's fuel budget the largest single expense—over 30 percent—of its Transportation Department.[29] After experiments and engine innovations, within a decade, wood use declined by nearly two-thirds, to a mere 23,274 cords, while consumption of anthracite fuel rose to over $100,000 for more than 50,000 tons of coal. Over the following decades, this transformation took place in various forms on lines across the United States, and by the 1880s, some 90 percent of American railroads burned coal.[30]

Despite many similarities between railroads and steamships, there was never any prospect of transoceanic lines consuming wood, as steamers needed the more energy-dense fuel to travel for weeks without stopping. Successful ocean steamers meant coal. For ocean steam navigation, there were three qualities in particular that the coal needed to possess. As articulated by Maryland chemist James Higgins, steam coal required "quickness of combustion, continuance of combustion, and steady combustion." Unfortunately, as late as the mid-1850s, neither chemists nor engineers knew of a variety of coal that exhibited all three attributes simultaneously. Most bituminous coals possessed considerable quantities of bitumen, the sticky, flammable substance that accelerated ignition but burned so quickly that fires required continual refueling. Anthracite coals contained little or no bitumen, slowing their ignition but lengthening their combustion once alight. This characteristic of chemical composition had real consequences. As steamship firemen often discovered, unless they burned anthracite in specially designed engines, shoveling additional anthracite into a firebox "deadened" fires, lowering fire temperatures and rates of combustion until the new batch of coal could fully ignite and leading to uneven engine performance.[31]

Higgins represented the scientific boosters of state surveys and highlighted the connections—real and rhetorical—between science, economic promotion, and security. He argued that western Maryland's Cumberland coals possessed the perfect amount of bitumen—just enough to ignite quickly but too little to consume a fire quickly. At stake was national defense. "The policy of the world at present is for steam navigation," wrote Higgins, "not only for commercial, but also for warlike purposes." War steamers in particular needed coals that could reliably enable the ship to engage with—or escape from—a potential adversary. "A minute's delay may prove disastrous," he concluded, while "the increased revolution of the paddlewheels for a few times will frequently insure success." This exhortation was steam engineering booster boilerplate; Higgins had a product to push. "Our national flag may float gloriously over the sea," he continued, "or be stricken from the mast, as the ship which bears it is well or ill supplied with fuel, and these ships should always use the Cumberland coal."[32] These arguments, by a state-supported scientist advocating the economic interests of his state, were part of a larger effort in Maryland to leverage naval coal consumption to capture growing foreign markets for steamship fuel. This effort had begun in 1842, when the navy commissioned Walter R. Johnson, a professor of chemistry and physics at the University of Pennsylvania, to analyze American coals to identify the ideal naval steaming fuel. It was a project designed to utilize the needs of national defense to launch research that might yield a broader social and economic benefit.

Johnson was an institutionalist in search of an institution, a scientist seeking to apply the insights of science not merely for public betterment but state-sponsored public betterment. In 1838, he had sketched a plan to use James Smithson's unexpected bequest to the country to create a great American scientific body for research for the national welfare. That same year he advised Congress on the prospects of establishing a national foundry in Washington to forge naval cannon (a project dependent on the nearby coal mines in western Maryland). In 1843, Johnson joined a navy commission to investigate the causes of explosions in steam boilers. In 1845 he investigated the public water supply for Boston. His most significant technical contributions, however, came from a series of experiments on the comparative qualities of different kinds of coal, a subject he long believed had never received the attention its importance in the industrializing world deserved. In contrast to textiles or metals, "the material which furnishes *motive power*," he lamented in 1850, "is either wholly overlooked, or soon forgotten."[33]

Given the fuel needs of the navy and prospective commercial steamers, as well as those of growing industrial and commercial interests, Johnson believed that coal was a problem for the federal government. "The Government of the United States," he wrote, "though not possessing this direct interest of proprietorship in mines, has still such a stake in the value of their resources, and the prosperity of citizens more immediately concerned in making them available, that the least which could reasonably be expected of it, is, to aid in some measure in ascertaining their true value." To this end, Johnson's research program followed the kind of public-private partnership that characterized a great deal of governance in mid-nineteenth-century America. Johnson had approached the navy in June 1841, offering his scientific services, and the department accepted. In early 1842, the navy issued a call to American coal mine owners and coal dealers to supply the chemist with samples for comparative analysis, an analysis that not only would aid the navy in evaluating different fuels but also promised to help coal companies themselves learn to what purposes their products were ideally suited. Soon, coal samples reached Johnson from mines in Pennsylvania, Maryland, Virginia, Indiana, and Nova Scotia, while an international dealer in New York supplied a range of British specimens. Johnson, essentially a contracted scientist, performed his research in the facilities of the Washington Navy Yard. Receiving the final report, navy secretary John Y. Mason indicated the value of Johnson's experiments beyond their contribution to naval service by referencing "the large and growing interests which the United States possess in their vast coal mines, scarcely yet developed, and the numerous national and domestic uses to which the article of coal is applied."[34]

Johnson's research reinforced the notion that with coal, geography mattered. After testing samples from the range of coalfields, Johnson ranked them by ten characteristics. For ocean steaming, the most important was "evaporative power under equal bulks," or the weight of steam produced by a cubic foot of coal. Stark differences separated economical coals from uneconomical ones; the most powerful produced nearly 5¾ times as much steam per volume as simple pinewood, while the worst coal produced only 3½ times as much. This difference could mean making it across the Atlantic or not. To the delight of Maryland's coal industry, the outstanding sample by this measure was a bituminous coal specimen from Cumberland, "taken from a vein 9 feet some inches in thickness, on the eastern slope of Dan's mountain, about 40 feet below the surface of the earth, on a stream known by the name of Clary's run, two miles south of the national road."[35] Johnson's results suggested the value of similar coals mined nearby, which could improve the economic prospects of the coal region. Another Cumberland coal sample rounded out his top five, along with, unsurprisingly, three anthracite coals from eastern Pennsylvania.[36] "For Maryland this ministerial step has a considerable amount of interest," noted the *Baltimore Sun*, adding that "we think we may venture to predict an immense advantage to her, to be derived through one of her staples, but very partially developed as yet, as the result of Professor Johnson's experiments."[37]

Johnson's report had immediate consequences for both producers and consumers of coal. Following its publication, the navy began issuing proposals for contracts to supply Cumberland coal to its new ocean steamers, including the *Mississippi*, *Susquehanna*, and *Saranac*. At least one coal producer published a promotional brochure based on Johnson's results, advertising the consistently high performance of its product. Consumers of coal similarly saw the value of his research. After Johnson exhausted his research funds, over sixty prominent citizens of Massachusetts, including numerous railroad and manufacturing executives, petitioned Congress in 1850 to renew its support of the investigations, citing newly uncovered coalfields, the proliferation of railroads and steamships, and burgeoning industry, all of which had contributed to a doubling of American coal consumption in just seven years.[38]

Operators of Pennsylvania's anthracite mines, however, refused to cede what might become a lucrative market to their southern neighbor. They railed against interpreting Johnson's report as evidence for the superiority of Cumberland coal over anthracite for steaming, dismissing Maryland coal as having merely performed "an inappreciable shade above the Anthracite—a mere shade, amounting to exactly nothing in practice."[39] The frustration of anthracite operators reflected the fact that they did not see themselves as engaged in mere domestic competition with Cumberland. While the quantity of coal used for steam navigation represented only a small fraction of total American coal consumption, capturing a major steamship contract—or even better, a naval one—was the first necessary step toward entering a burgeoning global marketplace—a marketplace rapidly becoming a British domain.[40] Between 1830 and 1845, British coal exports came to dominate international markets. Their exports to Prussia increased by 1214 percent; to the East Indies and Ceylon by 2025 percent; to Denmark by 1800 percent; and to the United States by 287 percent. By the mid-1840s, Britain exported nearly 650,000 tons of coal annually to France alone.[41]

American coal producers had good reason to worry. By the end of the 1840s, they watched as the Royal Navy tried to cement Britain's growing global dominance of coal export markets with the development of a research program into the steaming qualities of various domestic and foreign coals far larger than Walter Johnson's American program. The British experiments, conducted for the Royal Navy by Sir Henry de la Beche and Lyon Playfair at the Museum of Practical Geology, again highlighted the geographic particularity of fuel quality. Geographic origins mattered. De la Beche and Playfair tested Myndd Newydd and Pentrefelin coals from Wales, Dalkeith Jewel and Grangemouth coals from Scotland; Slievardagh coal from Ireland, coal from Borneo, Formosa, Patagonia, and Vancouver, and six kinds of manufactured patent fuels—133 varieties of fuel in all.[42] The experimenters performed chemical analysis on each of these coals, surveyed their mechanical structure, and analyzed their behavior in actual steam engines under various conditions, what de la Beche and Playfair described as research of "rather a practical than a scientific character."[43] Like other chemists before them, the pair observed that ideal naval fuels should possess a range of characteristics: they should ignite quickly, boil large quantities of water into steam, generate no position-betraying smoke, hold together without crumbling and yet be dense enough to stow compactly aboard ship, and be chemically free from sulfur and not prone to spontaneous combustion. And like their competitors across the Atlantic, the researchers found that no single coal exhibited all of these characteristics. Anthracite, for example, packed a lot of energy but ignited slowly. It held together without pulverizing in storage, but since it did not fuse together while burning, it risked tumbling inside the furnace with the inevitable pitches of the ship. It was smokeless, but its intense heat rapidly oxidized the iron of grate bars and boilers.[44] Still, four years of research provided a guide for both purchasers in the Royal Navy as well as coal dealers working in both domestic and international markets. While other researchers in Britain, like the natural philosopher William Thompson and the engineer W. J. M. Rankine, pursued a more theoretical and fundamental understanding of the nature of energy, de la Beche and Playfair attended to the materials at hand to support Britain's global commercial and naval predominance.[45]

Americans abroad were among the consumers of British coal exports. Both U.S. naval vessels and merchant ships depended on it when cruising on faraway stations. In the Mediterranean, American consuls supplied British coal to American ships, as they did for the steamer *Mississippi* during its cruise there in 1849. Yet some officers, along with domestic coal merchants, worried about a false economy. They questioned whether the fees, duties, and costs of transportation—not to mention the presumed greater efficiency of American coals established by Walter Johnson—really made American coals more costly. And even if the costs of American and English coals were simply equal, wondered navy captain Charles W. Morgan upon taking charge of the Mediterranean squadron in 1849, would it not make sense to support American industry? American coal burned cleaner, he argued in a brief for sending Cumberland coal overseas, and "the Government would be giving large and valuable orders to our own citizens which would otherwise be supplied by foreigners."[46] Anthracite merchants in Pennsylvania thought the same about their coal, imagining that if they could claim even a small portion of this global coal trade, they would earn fabulous profits. All they needed was a little help from the government.

Philadelphia anthracite merchants believed they could break into the global market with their high-grade coals by appealing to the need for national defense. Some time around 1845, they nominated Benjamin H. Springer, himself a coal dealer and former president of the Coal Mining Association of Schuylkill County's board of trade, to visit Washington and lobby the navy to adopt their higher grade, more expensive anthracite fuels. If the lobbying succeeded, coal mines would see profits and commission dealers would receive income, but neither of those would matter as much as the fact that American naval vessels overseas would be advertising the products of American coal country to foreign navies and steamship lines. The merchants sought to turn the navy into a floating promotion of their wares. "The trade urged me, as I was acquainted in Washington," recalled Springer years later, "to get the appointment with a view to that more than anything else."[47]

In Washington, Springer argued that naval operations were too important and coal characteristics too inscrutable to the inexperienced to rely on the old practice of simply purchasing from the lowest bidder. This method, which had been the navy's modus operandi since the first naval steamer *Fulton* had been built in 1815, had been used to obtain all manner of naval materiel. Coal, Springer argued, was different. "The properties of coal are so various that a person who is not thoroughly acquainted with it may purchase a bad article and endanger the ship and all on board," he explained. "The received opinion of persons not acquainted with the subject is that all coals are alike; but there is as much difference between different coals as there is between the best hickory and the worst pine wood." After the failure of his initial efforts, Springer returned to Washington during every session of Congress through 1850. Millard Fillmore's navy secretary, William A. Graham, advised him that if Congress would only grant the department more flexibility on coal purchases, Graham would appoint a special agent to manage the business. Speaking for the measure in the Senate, Pennsylvania senator James Cooper, himself a resident of his state's anthracite country, supported the plan by discrediting the bituminous competition, claiming "it is impossible to purchase the coal and wood without getting the worst article in the market, and very often at higher prices than it would be necessary to pay for good articles." Cooper surely exaggerated, but his remarks suggested the ways the anthracite interests sought to expand their market at the expense of bituminous coal dealers, especially coal dealers from Cumberland. Springer finally succeeded in September 1850, when Congress granted the secretary the "power to discriminate and purchase" whatever fuel best suited the public service.[48]

The new law allowed the secretary of the navy to appoint two agents, one for anthracite coal in Philadelphia and another for bituminous in Baltimore. After having lobbied for the creation of the post for over half a decade, Benjamin Springer secured the anthracite agency for himself. Almost immediately, Pennsylvania's Senator Cooper began pushing the value of using anthracite. At Cooper's prodding, Springer dispatched questionnaires to leading engine manufacturers and figures in the coal industry, the responses to which confirmed Springer's belief that anthracite offered a superior fuel for ocean steamers and government use. He began trying to persuade the navy to abandon its preference for bituminous steaming coal—which had been department policy since Walter Johnson's research program in the early 1840s—and adopt anthracite instead. Already, several naval steamers had begun experimenting with it.[49] Believing that the Pennsylvania fuel possessed both economic as well as technical advantages over bituminous, Springer asked the secretary to allow a comparative test to be conducted, ceteris paribus, a plan that was approved and overseen by the navy's engineer-in-chief, Charles B. Stuart, at the Brooklyn Navy Yard. Though Springer represented the proposed evaluation of the two fuels in the dispassionate language of scientific objectivity ("the trial can be made by the same men," he had explained, "and under the same boilers; and it is fair to infer that a full and impartial result will be attained"), the political and economic consequences of the investigation were clear in Maryland. Maryland coal dealers had viewed the creation of the two anthracite and bituminous agencies in 1851 as validating the value of their state's product and as a defeat for Pennsylvania forces bent on snatching the lucrative naval contracts from Cumberland bituminous. When news of the navy's new experiments became widely known just a year later, Maryland's general assembly hastily instructed its congressional delegation to discover what could possibly have happened to cause the navy to reconsider its reliance on Cumberland coal.[50]

Charles Stuart's steaming tests pitted Cumberland against Pennsylvania anthracite coals. Walter Johnson had found Cumberland a superior steam generator for its density; this time, Stuart found no such thing. Stuart attributed his results, "not in accordance with theories heretofore received," to Johnson's experimental design, different from any conditions a steamer actually encountered at sea. Johnson had only tested small quantities of coal (usually less than half a ton per trial and never close to even a single ton), burned coal at less than half the rate of actual steamers, and used a boiler unlike any in use aboard ships.[51] In contrast, Stuart had ton upon ton of both coals for his experiments, and even in a pumping engine designed for bituminous coal, he found that anthracite coal enjoyed what he called an "economical superiority" about two-thirds greater than bituminous. This result meant that a ship could steam two-thirds farther on the same weight of fuel. Anthracite had the additional virtues of greater density (so captains could store even more coal aboard ship) and of burning without smoke. After the success of the navy yard tests, Stuart recommended the adoption of anthracite fuel aboard all naval vessels with iron boilers. After one of those ships, the steamer *Fulton* (the third to carry that name), had burned anthracite for several days, her engineer exclaimed that her "engine worked as well as any I ever saw, but the boilers exceeded my calculations." Little soot, constant steam pressure, no need to force a draft—he predicted the ship "will do *more* service at *less expense*, than any steamer government will have in five years."[52]

In the 1840s and 1850s, combustion experiments helped define the character of various coals for commercial and naval purposes. But it was not the only way Americans considered making sense of the new challenges of steam power. Another possibility was that instead of merely arbitrating between commercial mines, the government could itself purchase coal lands for future naval purposes. This was the approach favored by Charles Miner, a former Pennsylvanian representative, editor, and promoter who had helped first open the great anthracite fields of the state's Wyoming Valley during the War of 1812. Four decades later, Miner came to regret the capitalist frenzy in anthracite country he had helped unleash. "The Anthracite Coal Lands are being absorbed by wealth and monopolized by speculators," he grumbled in 1852. Though he confessed that he "sometimes thought it was almost to be wished that the use of Anthracite, so limited in Quantity, so invaluable for naval purposes, should be excluded from common use, wherever a substitute could be found," Miner knew that such a proposal was impossible. Instead, he urged the navy to secure its own thousand or fifteen hundred acres of anthracite land in Wyoming Valley. With this reserve, he explained, the security of the nation could never be threatened by "monopoly purchasers" or be forced to "submit to their terms." Of course, Miner touted anthracite coal as a better fuel than bituminous, but the significance of his proposal was its integration of antimonopoly sentiment with the specter of a failure in war preparedness. While nothing came of the proposal in the 1850s, the establishment of naval fuel reserves would be pursued for both coal and oil lands after the turn of the twentieth century.[53]

Unlike Miner, most anthracite operators in Pennsylvania were content merely to siphon the trade from Maryland. Through the 1850s, they continued boosting their product. This pressure had little immediate effect, and until the end of the decade, the navy retained both its bituminous and anthracite agents and continued to purchase coal from both Maryland and Pennsylvania. Still, Pennsylvania anthracite producers did not stop lobbying the department or sending samples for analysis—chief engineer Benjamin Isherwood conducted one influential comparative analysis in 1859—and during the Civil War, the rapidly growing Union navy would overwhelmingly consume anthracite in its steamers.[54]

Even before the war, however, Isherwood was as interested in designing engines to suit available coal as he was in analyzing coal to suit available engines. In this interest he was not alone. Since the invention of the steam engine itself, inventors had tinkered with it to improve economy and often pursued alternatives to steam that would hopefully replace it. In the 1840s and 1850s, some of these inventors turned to the federal government at precisely the moment when the navy and mail service were becoming dependent on coal. The question was, who would design the new engines?[55]

Political Engineering

Choices about engine design were political choices. In 1859, a special House committee, chaired by a rising Republican from Ohio, John Sherman, investigated a series of charges against the Navy Department alleging corruption, graft, and gross incompetence. Among the claims: that the navy had allowed Daniel B. Martin, one of its own chief engineers with patent interests in a particular boiler design, to sit on a board selecting engine manufacturers for five new steam sloops recently authorized by Congress. When the board only approved contractors incorporating Martin's design—at a higher cost than competing proposals—critics cried foul. As Sherman's committee discovered, however, when it came to proving corruption, plausible inference was not the same as dispositive evidence.[56]

As they investigated, the members of the Sherman's committee received considerable technical educations. They considered the relative merits of horizontal and vertical tubular boilers, the strength of propeller shafts, and the effects of excessive propeller revolutions. They reviewed the operations of high and low pressure engines, the advantages of varying cylinder diameters and lengths of stroke, and the limits to the structural integrity of the longitudinal bulkhead. Determining whether Martin's judgment was shaped by financial gain or engineering expertise would require members of Congress to think like engineers. How did they evaluate the merits of competing experimental designs? How did the government balance its interests in security with cost and administrative capacity and without showing favoritism to politically connected contractors? Answering these questions took the committee deep into the weeds of steam engineering and technical design.[57]

At the heart of the investigation was a basic question that would be revived over a century later by historians of technology: did artifacts have politics? Did design choices instantiate particular relationships and empower certain groups, like the nascent brotherhood of professional naval engineers who jealously guarded their claims to expertise? Did they weaken others, like the independent inventors who believed they could not have their own innovations fairly examined? Moreover, were the designs of government steam engines the result of abstract engineering principles or the temptations of power, political connections, and greed? How would Congress, itself bitterly divided in the 1850s along partisan lines, ultimately adjudicate these complex, technical questions? Congress faced the particular questions of Martin's boiler after two decades of government experience pursuing fuel economy in the engines of naval and mail steamers. At first, the Navy Department alone had handled this subject, but inventors and patent holders increasingly turned to Congress to press their innovations. Though these appeals for congressional support only occasionally resulted in legislation, they kept the issue of engineering fuel economy before legislators, who generally debated more over the proper means of attaining economy than the desirability of the ends.[58]

The role of Congress in naval ship construction has usually been understood to have involved appropriations for new shipbuilding programs, the designs of which remained the obligation of the navy itself.[59] But throughout the 1850s, members of Congress received proposals for a range of technical innovations in naval steam engines, nearly all of which promised reductions in fuel consumption. Both chambers of Congress devoted time in committees and floor debates to wrangling over the merits of novel condensers or boilers and considering even more radical proposals for propulsion innovations and the question of whether Congress should legislate their adoption. Some proposals resulted in appropriations or other legislation; others merely led members of Congress to debate the relationship between technological innovation and government action. Taken as a whole, these episodes reveal the ways fossil-fueled steam technology looked in the 1850s rather than in hindsight decades later. Unlike subsequent historians and naval analysts, engineers and politicians of the 1850s did not see the absence of American coaling stations around the world as the limiting constraint on embracing steam power. Instead, they looked to a range of technical innovations to exploit the advantages of new machines within the constraints of national policy. In the antebellum period, Americans preferred to seek technical innovations, not foreign coaling stations. Which technical innovations would work was a different matter, however. The English engineer Josiah Parkes claimed that in studying the problems of fuel consumption and engine performance "any person endowed with common powers of observation and experimental tact" was "as capable of discovering the position of an engine, in the scale of economy, as if he were gifted with the genius of a Newton."[60] But in practice, engineering could not be so easily cleaved from politics.

The inventors who approached Congress arrived at the importance of engineering for fuel economy by a variety of paths. In the mid-1840s, Thomas Ewbank found inspiration at a New York fish market. Delayed there while shuttling to Harlem, Ewbank began drawing what he called "these natural propellers" arrayed before him—the tails of porgee, salmon, cod, mackerel, and flounder. Later, he would add sketches of the curves and angles of porpoises and seals, the webbed feet of cormorants and geese, the legs of frogs and wings of bats. According to Ewbank, nature held lessons for contemporary engineers. "In the tails and fins of fishes," he wrote, "in wings of birds and insects, and especially in the palmipeds, she has nowhere sanctioned a rectangular propeller."[61] According to Ewbank, as with all steam innovations to save fuel, the objective was doing more with less. Redesigning paddle wheels according to the lessons of nature would shave twelve to twenty-four hours from a transoceanic voyage "without any increase of power."[62]

Ewbank, then serving as commissioner of patents, was not solely motivated by the forms he found in the fish market but also by the transformation in international communication he witnessed from his homes in New York and Washington. "Engineers and naval constructors, animated with the ambition of Olympian competitors, are preparing for a series of Atlantic chariot races," he declared in one essay.[63] In another, he exclaimed that "oceanic steamers are too essential links to the system of cheap and free postage—domestic and international,—to be allowed to pursue undisturbed their present average passages."[64] For Ewbank, the pursuit of speed through improved design benefited the nation and demanded government attention. Ewbank lobbied Congress to appropriate $10,000 for additional experiments, pointing to the navy's ability to leverage its size and technical sophistication to promote mechanical innovation for both public and private purposes. In this pursuit he was joined by navy officials. "Private individuals cannot well make the experiments but the Government interest in Steam Navigation is already sufficiently large to warrant the resolution of these problems," wrote Charles B. Stuart.[65] Like many similar appeals, Ewbank's was rejected by the Senate's Committee on Naval Affairs, but not before William Seward declared on the floor of the Senate that people of the future would look back on the inefficient paddle wheels of his present day and "wonder at their gross unmechanical action."[66] Even if Congress failed to appropriate funds for further study, it began regularly debating the importance of economizing mechanical designs for public benefit.

A greater challenge for achieving fuel economy came from the innovation that made Ewbank's research on paddle wheels increasingly outmoded—the introduction of screw propellers. The navy's *Princeton*, designed by John Ericsson and launched in 1843, featured this new propulsion system, and more propeller ships followed over the coming decade. But by the early 1850s, engineers found that the thrust these propellers produced also generated enormous friction and taxed ship engines. Screw ships had to steam slower than their paddle-wheeled counterparts. Engineers variously applied discs, collars, and grooved rings in futile attempts to reduce friction and conserve fuel. An invention by George Parry, a peculiarly shaped circular casing of rollers, finally appeared to solve the problem. Parry noted the foremost advantage he offered for rotating screw propellers—"securing additional Speed, efficiency, and safety combined with a great saving in *Fuel* and *Oil*." A navy board examined the device in 1855, finding it reduced coal consumption by 35 percent and shaved twenty minutes from a three-and-a-half-hour voyage. When navy chief engineer J. W. King sought to test Parry's thrust bearing aboard the *Wabash*, he found it so superior to the ordinary one (which rapidly overheated) that he abandoned the test and simply continued using Parry's device. At least fifteen firms and engineers from around Philadelphia and New York similarly reported superior results aboard their ships. Meanwhile, the expanding scope of American commercial interests added to its prospective value. "In China, the East Indies, or any part of the Pacific Ocean, or Coast of Brazil where Coal costs $20 per ton," wrote Parry, "this would effect a saving of $58.20 per day." Parry estimated that a naval frigate steaming there would save over $20,000 in a typical three-year cruise, not to mention avoid the reduced physical work of coaling, decrease the space needed for stowing fuel, and eliminate time lost in potentially hazardous ports of call.[67]

Stephen Mallory, chairman of the Senate's Committee on Naval Affairs, was so impressed with the device that he felt he could only express his committee's thoughts "by presenting to the inspection of each member of the Senate a working model of the 'Anti-friction Box'" along with an account of its myriad advantages to the navy. This rolling mechanism offered a better way to relieve the massive friction of new screw propellers, explained Mallory, producing "greater speed, with *saving in fuel*, together with a diminished consumption of *oil* used in lubricating the thrust-bearing." Mallory, however, advised against Congress mandating that the navy adopt the contrivance, but only because he was sure that if all the testimony Parry offered proved accurate, the navy would surely do so on its own. A year later, he added that government support should come from naval adoption rather than an outright purchase of the patent, principally because government patent rights could preclude the device's use in the general economy.[68]

Congress proved more forthcoming with support for a particular invention when the request for action came from within the navy itself. In 1850, Congress funded the navy to experiment with variously designed steam condensers. For years, ships attempting ocean voyages generated steam by boiling salt water, the saline residues of which fouled boilers. Condensers purified water, keeping engines running smoothly and with an accompanying savings in coal. Following the congressional appropriation, a naval scientific commission examined twenty-nine condenser designs and found four excellent, but each in different ways. Faced with mixed conclusions, the navy secretary, William Graham, proposed brokering an agreement between the patent-holding parties, thus allowing the navy to combine the most desirable features of each condenser into a single device. This negotiation need not have involved Congress, but following the release of the navy commission's equivocal report, subsequent, more conclusive experiments found that overwhelmingly just one condenser, invented by Joseph Pirsson, alone fully satisfied government needs. Of its value, according to one engineer who adopted it, "no better evidence is required than the fact that a much greater volume of steam can be produced by the same amount of fuel than when salt water is used." According to an account in the *New York Herald*, the device could shave two full days off the transatlantic route between New York and Liverpool. Uncertain of how to proceed without incurring criticism from competing patent holders, the secretary turned to Congress. As an amendment to the annual naval appropriations bill, Graham asked Congress to require that the navy adopt Pirsson's condenser alone.[69]

As senators debated this appropriation bill in August 1852, they faced questions of how to deal with technological change. Should Congress specify the details of engine designs? Did the navy secretary not already possess sufficient authority to chose between competing designs? Did the Senate have the expertise needed for such judgments? Party affiliation and ideology was hardly a sure guide. Some, like Lewis Cass (a Democrat) and John Davis (a Whig), objected that designs and inventions properly remained a matter for the navy. Supporters of having Congress mandate the adoption of Pirsson's condenser appealed to the urgent need to save fuel and money. New Jersey Senator Robert Stockton, a Democrat and himself a retired commodore and advocate of the naval adoption of new steam technology, presented the endorsements of nearly twenty engineers, engine builders, steamship line proprietors, and naval officers, along with the unified voice of the Senate's Naval Affairs Committee, all favoring requiring Pirsson's patent for naval use. After recounting the condenser's merits, Stockton exclaimed that "nothing remains for me to do but to make a long, scientific discussion on the subject of marine engines, and the use of coal, to show the absolute necessity that something should be done to reduce the expense of your steam navy," an expense Stockton estimated could be lowered by the use of Pirsson's condenser by as much as $200,000 a year.[70] In the end, Stockton's arguments carried the day, and with Pirsson's name removed (on principle) from the amendment, the Senate voted to empower the navy secretary to adopt "any steam-condenser which may be found best calculated for the purpose"—a criterion met by Pirsson's condenser and in language sufficiently prescriptive to allow the navy secretary to chose Pirsson's design over competing ones.[71]

Pirsson's condenser, which promised to save the government coal, was just one innovation amid a flurry of experimentation in both Britain and the United States to improve the economy of steam engines. But coal and steam power had hardly begun to transform oceanic transportation when mechanics and entrepreneurs began experimenting with alternatives. In 1849, in a project championed by Missouri senator Thomas Hart Benton, Congress appropriated $20,000 to Charles Grafton Page, a patent examiner and chemistry professor at Washington's Columbian College, to pursue experiments on "electromagnetic power as a mechanical agent for the purposes of navigation and locomotion." Though it quickly became apparent that the expense of a viable electromagnetic engine would be far greater than that of existing steam engines, Page hoped the public would evaluate his work not merely by the relative costs of zinc and coal but by what the *National Intelligencer* reported as "the cost of human life, the sacrifice of millions of property, and risk of many millions more"—the entire existing sociotechnical system for producing coal and sustaining the infrastructure for steam power.[72]

American scientists and engineers enthusiastically greeted Page's initial exhibitions of his engine. His engine attracted particular attention at an 1850 demonstration in New Haven attended by many of the leading figures of American science. Joseph Henry, America's expert on electricity and magnetism, proclaimed his interest, while another member of the so-called American Lazzaroni, Benjamin Pierce, "felt astonishment and great delight." The elder statesman of American science, Benjamin Silliman, was impressed by how far Page's research had progressed in so short a time. Two men who had spent years examining coal and steam, Walter R. Johnson and William Barton Rogers, both discussed the new engine's cost relative to steam, with Johnson concluding that he anticipated that the two sources of power would find complementary uses. "Where there were serious objections to the use of steam power," he was reported as saying, "this power would come in very well."[73]

Interest in an electromagnetic engine next reached Washington. Benton, the leading spokesman of the West in Congress, saw the project as both a boon to his state of Missouri, as it could provide a way to efficiently excavate untapped deposits of zinc, and his section as a whole, as it could power locomotives across the wide expanse of western North America on the way to increased trade with the Far East. But Benton was particularly interested in the nautical uses to which the engine might be put. Though Page designed his engine to power an experimental locomotive, Benton provided an exhaustive list of reasons that favored the electromagnetic engine over the steam engine at sea. The navy of the future, explained Benton, would find it "saving room in the vessel, the engine and battery requiring but little space, and the fuel very compact compared to coal—doing away with chimneys, smoke-stacks, and their cumbrous fixtures—instantaneous communicability of the full power, so important in changing course and avoiding collision—capacity to run a blockade, making no noise and showing no light, except at pleasure—simplicity in the construction of vessels—diminution of insurance from absence of danger from explosions and conflagrations, and less danger from collisions."[74] The electromagnetic engine would eliminate the constraints imposed by coal and conventional steam engines and herald a new dawn of safety, savings, and security.

Still, Page's efforts to construct an experimental electromagnetic locomotive succumbed to technical obstacles, and he depleted his political and financial resources. His most efficient battery, a design adopted from a cell built by the British chemist William Grove, required zinc but also copious quantities of platinum. The battery itself proved exceedingly fragile and difficult to operate. With little to show for his efforts, his initial appropriation quickly ran out. When Benton pushed his Senate colleagues for a second round of funding, twice as large as the first, they balked, and Page instead futilely tried supporting his work on his own. Lacking adequate resources, assistants, and technical expertise, Page saw his trial locomotive barely travel a few miles before its batteries quickly fell apart.[75]

No challenge to the limits of fuel economy, however, elicited as much anticipation and subsequent sense of failure as John Ericsson's hot air or "caloric" engine. Before the development of thermodynamics in the 1850s, Ericsson's caloric engine represented one of many attempts to devise a source of motive power superior to steam in cost, convenience, and economy of fuel. Unlike Page's electromagnetic engine, these many and varied attempts relied on the same basic principles of steam engines—using a fluid to propel an oscillating piston—but they substituted various agents for steam. Since the late eighteenth century, mechanics had experimented with engines propelled by substances as varied as alcohol, ether, mercury, and carbonic acid. The U.S. Navy investigated a carbon bisulphide engine in the late 1850s, a design that would periodically resurface for decades afterward. Ericsson, however, focused on pistons powered solely by atmospheric air, a substance universally (and freely) available. Employing air meant no need for frequent replenishment with fresh water, a challenge at sea or in arid terrain. Most importantly, Ericsson promised a vehicle that would consume a mere fraction of the coal as a comparable steam engine, just enough to put the caloric engine in motion and keep it moving as it slowly lost heat.[76]

Ericsson's efforts to champion caloric engines spanned two decades. After leaving his native Sweden for London in 1826 to pursue a career in engineering, he spent six years crafting various machines to improve the fuel economy of steam engines through new designs or added apparatuses. None proved satisfactory. By 1833, convinced that heat—"caloric"—was a physical quantity that could produce effects without changing itself, Ericsson constructed his first caloric engine. This five horsepower model included the key elements, what he called "regenerators," that Ericsson would employ in later versions, including his largest experiment aboard the ship bearing his name in 1853. Regenerators recaptured the caloric of heated air that had already been used to raise a piston, held it, and then imparted it to a fresh blast of air to raise the piston still more times. To begin the cycle, the engine called only for a small quantity of coal, the substance whose relative scarcity and expense lay behind the project. Ericsson insisted his engine was not quite perpetual motion—some heat would indeed be lost and need occasionally to be replenished—but the design promised fantastic savings of fuel. Ericsson's nineteenth-century biographer characterized the inventor's ambition as "to remove farther into the future the inevitable period when the world's coal supply will be exhausted."[77]

After several more years in England, in 1839, Ericsson sailed for America. For the next dozen years, he labored on a range of projects, including an ill-fated navy propeller steamer, the *Princeton*, but he also continued his research on caloric engines.[78] In the decade after 1840, he constructed eight new prototypes of progressively larger size and expense. In 1851, Ericsson built a ninth model: it cost $17,000 more than all his previous engines combined and was capable of running for three or more hours without refueling. Its complex network of heat-retaining wire mesh effectively recycled waste heat but could not yet produce enough power to compete economically with steam. By late 1851, Ericsson was ready to seek investors for a full-sized prototype, to run aboard a specially designed ship. Financially underwritten by some $500,000 from New York merchants and bankers and constructed at a breakneck pace, the *Ericsson* launched in New York harbor in September 1852, beginning its trial voyage on January 11, 1853.[79] Ericsson's creation was nothing if not original. Examining the ship before its launch, the navy's former engineer in chief Charles Haswell pronounced it "the strangest ship out of the port."[80]

For expectant observers, the *Ericsson* evoked more than simple wonder at its design, for it was a machine whose operation blurred the line between the living and the inert. It was "the breathing ship," according to a party of early passengers, "an immense breathing monster," and a vessel "with lungs, respiratory organs, and every visible sign of vitality." The New York press nearly universally fawned over it. The *Tribune* trumpeted that "the age of Steam is closed; the age of Caloric opens." The *Express* emphasized the engine's ultimate advantages: "Economy in fuel, economy in space, economy in manual labor, and economy in the expense of machinery." Turning to the great reduction of dangerous engine-room jobs to as few as a fifth of what steam required, the paper added that "there is what perhaps ought to be valued more than all the rest, economy in human life." The *Times* proclaimed that "no mechanical event since the time of Fulton has promised so well for the interest of mankind." As for the unprecedented mobility the engine offered, the paper noted that "the vessel will be able to carry her coals for the longest trips out and back, even should the voyage be extended beyond the customary route of our packet steamers." In contrast, "steamships can carry a supply sufficient only for a single trip." The only sour note came from *Scientific American* editor Orson Munn, who had snuck aboard uninvited. Munn leveled his criticism more at his credulous colleagues in the press than the inventor, calling Ericsson "more modest in lauding the merits of his invention, than the few un-scientific croakers who blunderingly call the invention a new motive power."[81]

Despite Munn's grousing, when Ericsson took the ship to sea for a voyage to Washington, the vessel was a roaring success. It kept good time in bad weather along the coast, and navy commander Joshua Sands, along for the voyage, expressed his surprise at the coolness of the ship's fire rooms and the ability of a single tender to keep the ship supplied with coal. As word of the voyage reached New Orleans, the *Times-Picayune* opined that once Ericsson engines would be seen on the continent's inland waterways, the labor needed to operate steamboats would fall by as much as 80 percent and the cost of fuel would drop even more. "New Orleans will then be better able to compete with the East and North than she now is," the paper wrote, "for freights will fall enormously, and boats will increase enormously, and the river will thus be enabled to compete to some advantage with railroads."[82] The ship similarly captured the imaginations of politicians eager to apply the innovation to the same challenges steam vessels faced in the realm of international trade and in shoring up sectional economies. At a banquet in February, just as the *Ericsson* was making its way from New York to Washington, Alexander Stephens of Georgia—later the Confederate vice president—toasted his hosts and a gathering of political dignitaries with a request to remember the need for mail steam packets for the south. "Steamers," he exclaimed, "no, not steamers, for they were behind the times—but an Ericsson motor or two."[83]

Once anchored in Alexandria, Virginia, Ericsson and his ship were met by a delegation headed by President Fillmore and his successor, who had just arrived, Franklin Pierce. Accompanying them was a party of over a hundred—the sitting cabinet, the heads of naval bureaus, four commodores, distinguished younger officers like Charles Wilkes and Matthew Maury, and three members of the House Committee on Naval Affairs. Mail steamer champion Thomas Butler King was there, as was editor and power broker Francis P. Blair, former speaker of the house Robert Winthrop, the visiting William Thackeray, and literary light (and former diplomat) Washington Irving. "The Ericsson appeared to justify all that had been said in her praise," Irving wrote his sister, "and promises to produce a great change in navigation." Irving may have watched as the two presidents, Ericsson, the secretary of state, Edward Everett, and the navy secretary, John P. Kennedy (who had organized the demonstration) illustrated the engine's power by sitting atop one of her pistons as it rhythmically "breathed" up and down. The enthusiastic Kennedy anticipated contracting with Ericsson to build a caloric frigate for the government, a recommendation he passed along to the House Committee on Naval Affairs.[84]

The committee's chairman, a pro-navy Democrat from Tennessee named Frederick Stanton, embraced the proposal. His committee endorsed it, too, but it soon met a roadblock of parliamentary dysfunction. That year, partisan deadlock in the House had ground the normal mechanisms of the legislative process to a halt. Stanton found himself stymied in his attempts to persuade the full chamber to even consider a bill recommended by his committee to appropriate

$2.5 million toward building eight new vessels that used either steam power or Ericsson's new hot air engine. Abandoning his efforts to force the House to consider the full bill, Stanton tried to raise the proposal again in late February, the day after the public demonstration in Alexandria. With the thirty-second Congress just days from ending, Stanton attempted to secure an amendment to the regular naval appropriation. This proposal called for six ships, at least two frigates of which would be built by Ericsson with his novel power system. Ericsson, Stanton assured his colleagues, promised "that they will acquire a speed of ten miles an hour, and burn only eight tons of coal per day" and guaranteed a plan whose technical innovations, whether through steam or hot air, "will secure economy in the expenditures of the Navy Department." Still, though the proposal had garnered considerable support, opponents engaged in still more parliamentary maneuvers, with the chair ultimately ruling that an amendment for new construction was out of order, as it did not appropriate funds for any already existing authorization, and declaring that the naval appropriation must be limited only to the repair of existing vessels. Stanton protested in exasperation that there was no law authorizing the repair of vessels either and demanded the matter be appealed to the rest of the chamber. After several minutes of canvassing, Stanton lost by a single vote, sixty-one to sixty.[85]

This legislative defeat began the end of the caloric engine's seemingly inevitable triumph over steam. Congress never funded the ships. Ericsson, meanwhile, returned to New York to improve the design and increase the power of the engines. As part of this work, he continued planning the construction of caloric ships for the navy. On April 27, 1854, on a trial run off Sandy Hook, Ericsson reported reaching a record eleven miles an hour without even pushing the engine to its fullest, consuming coal at close to the promised rate of eight tons per day. But despite an otherwise calm day, a sudden tornado struck the ship, dunking its starboard side and causing a rush of seawater to flood into her portholes. Minutes later, the ship was entirely underwater. A distraught Ericsson conceded that even after raising the ship, repairing her caloric engine would be too costly, so he consented to replacing it with more conventional steam power.[86]

Whether caloric engines ever really offered an alternative to steam remains a complicated question. The engines occupied too much space aboard the *Ericsson* to leave room for other essential features like cargo or armaments. At the size required, the machinery also reached higher temperatures than most nineteenth-century materials could handle for long periods of time. Still, smaller caloric engines became popular in the years that followed 1854. The inventor's biographer notes that Ericsson sold a thousand engines in two years and as many as three thousand over the years that followed. They found employment powering small yachts, pumping water, and driving sewing machines. One promotional manual of 1860—itself printed by a press powered by a caloric engine—prominently advertised that the engine consumed only a third the coal as a comparable steam engine, and numerous testimonials affirmed the value of its simple operation and savings of fuel. By this time, however, Ericsson had abandoned his efforts to persuade the government to adopt his invention. His promise to the government of economy through a radical engineering innovation remained unfulfilled.[87]

Which brings us back to the Sherman committee of 1859. Just as an assessment of the value of Ericsson's caloric engine remained elusive, so too an authoritative technical resolution to the best design of steamship boilers remained out of reach. Here, partisan politics clouded definitive conclusions. Three of its five members, two Democrats and one Know-Nothing, voted essentially to acknowledge mismanagement and errors of judgment in the Navy Department but absolved anyone with authority of any actual responsibility. According to the majority, the Brooklyn Navy Yard indeed exhibited "glaring abuses" but they had grown slowly over so long a period of time, no one administration could be held accountable. The anthracite coal agent, they concluded, had become a worthless sinecure, but no one in the navy was at fault and, in any event, the navy always got the best coal at a reasonable price anyway. There was no evidence of corruption in the awarding of engine contracts, only the zeal of the secretary to maintain "the good of the public and the interests of the service." On the other hand, Sherman and his fellow Republican David Ritchie came to different conclusions, blaming navy secretary Isaac Toucey directly for appointing a coal agent with no knowledge of the business, for abuses of patronage in the navy yards, for supposedly granting contracts based on party membership, and especially for allowing navy engineer Daniel Martin to sit on boards of engineers when he held patent interests in the matters under consideration, a failure for which they demanded congressional censure. Congress took no action during the remainder of the thirty-fifth Congress, which ended a week after the reports were released, but a year later, Sherman forced the issue again and won passage of five resolutions, each condemning the management of Isaac Toucey's navy.[88]

Was Martin's patented vertical boiler design inferior to unpatented horizontal boilers? This question is only answerable in specific contexts. Every part of an antebellum steamship was an evolving element of what were perhaps the most sophisticated technological systems of their day. Particular innovations like Martin's boiler were superior when the boiler was boiling salt water, as it allowed the easy removal of saline incrustations that accreted inside boilers, but not when it was boiling fresh water, which was becoming increasingly common in the late 1850s with the use of surface condensers.[89]

Twenty years later, the navy engineer Benjamin Isherwood would note that Martin's vertical boilers consumed coal more economically than horizontal alternatives of the same dimensions, suggesting that their commercial rejection by engine builders in both the United States and Britain was a result of manufacturers' incentive structure, not the inferiority of the design. Marine engineering firms, Isherwood noted, typically built their engines for fixed fees to produce ships of stated horsepower or speed. Martin's vertical boilers were more expensive to build and weighed more than other designs. Yet they consumed coal more efficiently and could thus be more economical for consumers in the long run. Since the manufacturers never paid for coal, they rarely paid attention to this cost.[90]

The problem also reflected fundamentally different ways of conceiving of the process of engineering itself. Edward Dickerson, a New York patent lawyer and partner in the engineering firm Sickels and Dickerson (and informal consultant to navy secretary Isaac Toucey), explained the philosophy of steam engine design through what he called the "two theories upon which engines are built," exemplified by the country saw mill and the precision marine engine. "The one is to make the simplest possible form of a machine," he explained, "without regard to its efficiency. The other is to make a machine that will develop the highest possible power from the steam, and then to make that as simple as it can be made without detriment to its efficiency." With an abundance of fuel, the country steam engine could afford to be inefficient. The steamship at sea could not. But what the navy lacked in fuel it compensated for with labor, for it could afford to dedicate a crew to maintaining the marine engines to a degree not possible in the old country saw mill. That, at least, was the theory, and Dickerson was among those engineers who believed the navy had so far failed to see the difference, the consequence of which was wasteful engines, weak ships, and a considerable waste of precious coal. "Heretofore we have been making for the man-of-war the same engine which was adapted to the country saw mill, to get the engine into as few pieces as possible and then to attain as much efficiency as possible with that simplicity. In other words," he explained, "we have been making the engine for the engineer, instead of making the engineer for the engine."[91]

During and after the Civil War, Dickerson would engage in a public and acrimonious fight with engineer in chief Benjamin Isherwood. Historians have not remembered Dickerson kindly, in large part for his aggressive attacks on the integrity of Isherwood and the naval administration. He has also been criticized for a series of failed projects like the engines for the navy's *Pensacola* that went over budget and under specifications using engine designs of baffling complexity. Isherwood, in contrast, has been characterized as an engineering visionary, having undertaken influential experiments on coal and steam engines, not to mention having successfully designed numerous vessels. Yet Dickerson's testimony to the Sherman committee reveals a great deal about his philosophy, which was no less innovative than Isherwood's, even if the two men could not understand or value each other. Dickerson conceded the complexity of his designs but justified them in the name of efficiency—a term he repeatedly employed in its modern connotation with reference to measurable characteristics of steam engines—and claimed that in the long term, experience would make it possible to simplify them. It was an approach to engineering that for all of Dickerson's failures would become increasingly common in the decades that followed.[92]

Until then, the pursuit of economy remained the prevailing American approach to addressing the new challenges created by steam power. Between combustion experiments and new engineering innovations (or attempted innovations), Americans tried to alleviate the constraints imposed by coal. Rather than rethink their expectations of ocean travel, Americans sought economy, hoping to reap all the advantages in speed and power that steam offered while somehow retaining the freedom to travel long distances at low costs more characteristic of sailing vessels.

Still, through the 1850s, even with improvements in engine and boiler economy and a greater understanding among engineers of the properties of different varieties of coal, American steamers struggled when operating far from domestic ports. "At foreign stations we have to buy coal from merchants and other persons who have shipped it there for sale," explained John Lenthall, chief of the Bureau of Construction, Equipment, and Repairs, the governmental department that was responsible for coal purchases, "and we must buy such as the market affords. We can have no assurance that we can obtain the best coal." Lenthall believed that the superiority of Pennsylvania anthracite demanded that the navy continue shipping it to foreign stations.[93] Others saw a different future, hoping to develop coal resources in distant lands themselves.

CHAPTER THREE

THE ECONOMY OF TIME AND SPACE

> By our recent acquisitions on the Pacific, Asia has suddenly become our neighbor, with a placid, intervening ocean, inviting our steamships upon the track of a commerce greater than that of all Europe combined."
>
> Robert J. Walker, *Report of the Secretary of the Treasury*, December 9, 1848

After returning in September 1845 from circumnavigating the globe, Captain John Percival of the USS *Constitution* did what many frustrated public servants before him had done: he asked Congress to be paid. The trouble was a question of law. While preparing for sea in early 1844, Percival had asked President Tyler if he might employ a naturalist for his coming voyage to the East Indies. Tyler agreed, as did the acting secretary of the navy, Lewis Warrington. But Warrington cautioned that there was no provision in naval statutes to raise the number of officers serving the ship without congressional approval. The captain, however, believed he found a clever solution. Percival's choice for the post, John Chandler, was also a clergyman. Percival could thus appoint him to serve as the ship's chaplain—at the ample annual salary of $1,200—while assigning him additional scientific pursuits once at sea.

Though Percival refrained from disclosing this appointment until leaving the United States, it is unlikely that either the auditor at the Treasury Department or members of Congress would have much cared had Chandler not fallen ill en route to Rio and, once there, been discharged from the ship. Finding himself once again in need of a naturalist, Percival hired a native Pennsylvanian residing in Brazil, a Dr. J. C. Reinhardt. Reinhardt was fortunately skilled as a natural historian but, unlike the man he replaced, not as a minister of the gospel. Percival appointed him naturalist anyway (at the lower pay of a passed midshipman), then set sail for the Far East. Upon returning to Boston a year later, the captain found that the Treasury had rejected his claims for reimbursement for the pay of both men, thus leading to his appeal to Congress.[1]

Part of Percival's troubles in paying his naturalists derived from the ambiguous purposes of the cruise itself. The Tyler administration had presented it not as a scientific voyage, like Charles Wilkes's recent United States South Seas Exploring Expedition around the Pacific, but instead as a trade mission. His task