CHRISTOPHER F. JONES

a landscape of energy abundance: ANTHRACITE

COAL CANALS AND THE ROOTS OF AMERICAN FOSSIL FUEL DEPENDENCE, 1820–1860

ABSTRACT

Between 1820 and 1860, the construction of a network of coal-carrying canals transformed the society, economy, and environment of the eastern mid-Atlantic. Artificial waterways created a new built environment for the region, an energy landscape in which anthracite coal could be transported cheaply, reliably, and in ever-increasing quantities. Flush with fossil fuel energy for the first time, mid-Atlantic residents experimented with new uses of coal in homes, iron forges, steam engines, and factories. Their efforts exceeded practically all expectations. Over the course of four decades, shipments of anthracite coal increased exponentially, helping turn a rural and commercial economy into an urban and industrial one. This article examines the development of coal canals in the antebellum period to provide new insights into how and why Americans came to adopt fossil fuels, when and where this happened, and the social consequences of these developments.

IN THE FIRST DECADES of the nineteenth century, Philadelphians had little use for anthracite coal.[1] It was expensive, difficult to light, and considered more trouble than it was worth. When William Turnbull sold a few tons of anthracite to the city's waterworks in 1806, the coal was tossed into the streets to be used as gravel because it would not ignite.[2] In 1820, the delivery

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of a few hundred tons of anthracite from the Lehigh Valley "completely stocked the market" and was only sold "with difficulty."[3] Philadelphia's homeowners, merchants, and artisans met the large majority of their energy needs with firewood, falling water, and muscle power. Like most other Americans at the time, Philadelphians neither used nor needed large amounts of fossil fuel energy.

By the dawn of the Civil War, Philadelphians' energy habits were radically different. Wood, water, and muscles were no longer sufficient to warm the city's residents, power its factories, and transport its goods. In 1860, Philadelphians had come to depend on cheap and abundant inputs of anthracite coal. The city's coal consumption had grown exponentially over a forty-year period, from mere hundreds of tons to more than a million tons annually.[4] Without the constant injection of fossil fuel energy, the city's population and economy would have been severely disrupted. Anthracite coal had become a necessary part of everyday life.

These changes in Philadelphia illustrate a transformation in energy practices throughout the eastern mid-Atlantic during the antebellum period. Between 1820 and 1860, anthracite coal from northeast Pennsylvania flowed in great quantities to cities along the paths of the Schuylkill, Lehigh, Susquehanna, and Hudson rivers, especially Philadelphia and New York. Anthracite coal became cheap and abundant for many, but not all. Mid-Atlantic urban residents consumed the lion's share of anthracite while substantial quantities were also shipped to New England cities including Boston and Providence. Very little anthracite coal was shipped south of Baltimore, west of Pennsylvania, or north of Boston.

In this essay, I am centrally concerned with two questions. How and why did this energy transition happen when and where it did? In brief, I argue that the construction of new transport infrastructure—coal canals—played a crucial and underappreciated role in stimulating the growth of fossil fuel consumption in the eastern mid-Atlantic. And second, what were the social consequences of these developments? The use of anthracite coal pioneered a shift in the relationships between land, energy, and society that transformed the region's opportunities for economic, industrial, and urban growth. To use E. A. Wrigley's framework, it initiated a shift from an organic to a mineral economy.[5]

The development of an anthracite canal network has been well documented by scholars.[6] But its role in understanding the dynamics of energy transitions has not been given corresponding attention. Three aspects of my approach are designed to shine fresh light on this important topic.

First, while the vast majority of energy studies focus on production, I emphasize the movement of anthracite coal and the importance of transport networks in stimulating energy transitions.[7] William Cronon demonstrated in his path-breaking study of Chicago that analyzing the movement of goods provides new insights into the relationships between transport infrastructure, environmental change, and regional development.[8] Similarly, I argue that the transformation of energy practices in the eastern mid-Atlantic was predicated on a drastic alteration of the region's built environment. Before the building of canals, the long-distance shipment of anthracite coal was expensive, difficult, and limited. With canals, coal could be shipped cheaply, reliably, and in ever-increasing quantities. Canals created a new built environment that facilitated the emergence of a fossil fuel intensive society.

Second, I stress the regional nature of energy transitions. Most works on energy analyze trends on a state or national level. Such aggregation can be misleading because it masks significant differences both within and between regions. Anthracite coal use became common in the eastern mid-Atlantic, but not in other regions such as the South and the western parts of Pennsylvania and New York. Even within the eastern mid-Atlantic there were significant regional differences; cities served by canals or on the seaboard gained easy access to anthracite while communities located more than a few miles from a navigable waterway were largely excluded. A regional perspective, therefore, provides a more nuanced view of where energy transitions occur and who is included.

Third, I interpret the social consequences of new energy practices using E. A. Wrigley's framework of a shift from an organic to a mineral economy. Wrigley provides a useful way of understanding how, when, and why anthracite coal changed the structural possibilities for processes such as urbanization and industrialization in antebellum America, and what these changes mean in the larger picture.[9] When we examine the relationships between land, energy, and society, the concept of organic and mineral economies helps us see the deep interconnections between fossil fuel energy and the ways we live. I review these concepts in the next section for readers who are not familiar with them.

This essay is part of a broader project analyzing the role of transport infrastructure in shaping social energy practices.[10] One of the peculiar features of the modern world is that cheap, abundant, and reliable energy is available in so many places. Although it is easy to take this state of affairs for granted, it is neither natural nor inevitable. Current global energy practices are possible only because of massive alterations to the built environment. By investing huge sums of capital, material, and labor into pipes, rails, and wires, we have created a world in which geographic space is largely rendered irrelevant to energy consumption. As a result, coal from Wyoming is burnt to create electricity in Louisiana, oil from the Middle East fuels cars in California, and Russian natural gas powers many cities and factories in Europe. In America, this curious pattern began with the construction of anthracite canals in the eastern mid-Atlantic. Returning to this history can give us a useful perspective on our contemporary energy practices.

ORGANIC AND MINERAL ECONOMIES

IN AN ORGANIC ECONOMY, all energy is derived from the direct capture of solar energy.[11] Plants use photosynthesis to grow, and the sun's energy drives rain and wind patterns that create falling water for mills or wind for sail boats. Humans get most of their energy from the land by eating plants, feeding them to animals, or burning them.[12] The direct links between energy and the land have a number of important implications. First, energy use is limited by the carrying capacity of the land. Once all the available land is being used at or near its capacity, there is no way to increase the overall energy supply. In a sparsely populated society, this is unproblematic. However, in a densely populated world, humans must make choices between various land uses. For example, to increase the amount of firewood means that land previously used to grow crops or pasture animals must be abandoned. Society must give up one thing to gain more of another: there are negative feedback loops between land, humans, and energy.

Second, organic energy sources are difficult and expensive to transport because of their low energy density. Shipping goods overland without fossil fuel energy is extremely expensive, and can only be justified for high-value products. Bulky organic energy sources like firewood rarely warrant the expense: in nineteenth-century Europe, firewood could be economically transported overland for six or seven hours in any direction, and its price doubled every two to four kilometers it was carried.[13] The low weight-value ratio of crops impeded their transport as well, which is why American farmers settling new regions often transformed corn into whiskey and pigs. When water transport was available, it allowed people to transport bulk goods much farther. However, water transport was largely limited by nature's distribution of rivers, lakes, and seas.[14] The power from wind and falling water could not be transported at all: the energy from a water wheel could only be used at the river bank and wind was only useful in those places where it blew regularly.

Because land is needed for most energy production and the expense of transporting organic materials, energy use tends to be local in an organic economy. The characteristics of the immediate landscape—the soil quality, availability of falling water, presence or absence of navigable waterways—determine whether an area is energy-abundant or -scarce. This influences how and where people live and work. Most communities have to be largely self-sufficient in terms of energy: energy-intensive enterprises need to be established near abundant forests or falling streams or in rural areas with few competing demands for energy. Agricultural communities tend to form at sites where there is enough water power available for mills, and commercial societies congregate where river currents and ocean breezes facilitate transport. Cities are energy-poor sites because there is little available land and multiple demands for energy. In an organic economy, population densities are low and communities settle at sites of energy abundance. In essence, an organic economy is a Malthusian world of negative linkages between land, population, and production.[15]

A mineral economy emerges when a society begins to use fossil fuels intensively. Hydrocarbons are also the product of solar energy—they are formed from the remains of plants and animals decaying in an oxygen-poor environment over millions of years. However, humans have very different relationships with coal, peat, oil, and natural gas than with organic energy sources. Fossil fuels represent massive stocks of energy available for immediate use rather than the direct capture of solar energy flows. Hydrocarbons break the link between energy supply and the land's carrying capacity. And the high energy density of fossil fuel deposits justifies investing in infrastructure to transport energy long distances, thereby separating sites of energy production and consumption.[16] Energy use is no longer necessarily local or limited.

Most important, a mineral economy enables new patterns of social organization. As long as abundant fossil fuel stocks are available, the constraints and zero-sum trade-offs of an organic economy are replaced by the possibility of continual growth. When coal is substituted for firewood, production and distribution can be expanded enormously. No longer do populations need to live near sites of energy: a mineral economy makes possible dense concentrations of people and industries because energy is shipped long distances to homes and factories heated and powered by fossil fuels.

The concept of organic and mineral economies draws our attention to the deep interconnections between energy use and the types of economic and living arrangements that are possible. Before proceeding, let me clarify my use of these ideas. First, these are analytical concepts, not actor categories. Anthracite boosters were not trying to create a mineral economy; this result is only apparent in hindsight. Second, these are ideal types. The development of a mineral economy does not mean the organic economy disappears, and just because a society uses some fossil fuel energy does not mean it necessarily takes on all characteristics of a mineral economy. With these distinctions in mind, let us return to Philadelphia in the early nineteenth century to see how anthracite canals helped initiate the transition from an organic to a mineral economy in the eastern mid-Atlantic.

CANALS AND THE ANTHRACITE COAL TRADE

AT THE BEGINNING of the nineteenth century, many Philadelphians knew that there were extensive deposits of anthracite coal in northeastern Pennsylvania. Farmers near Wilkes-Barre in the Wyoming Valley had been using anthracite in homes and forges since the Revolutionary War, and outcroppings of coal had been identified in the Schuylkill and Lehigh valleys as well.[17] Moreover, several parties believed the exploitation of these reserves would be beneficial for Pennsylvania. Drawing parallels to the interconnections between coal and economic growth in Britain, several boosters attempted to rally support for the anthracite trade.

However, early anthracite boosters were frustrated by two factors: geography and limited demand. Geographically, coal was located far from centers of population and capital. The anthracite regions, as the coal-bearing lands of northeastern Pennsylvania soon became known, were in a rural and remote area only loosely connected to the eastern seaboard. Transporting goods over the rough roads and unreliable rivers was difficult, time-intensive, and expensive. Simply put, the anthracite regions were not part of Philadelphia's trade hinterland. Moreover, anthracite boosters knew there was minimal demand for their product. Philadelphia homeowners and craftsmen had little reason to abandon organic energy sources and foreign imports of bituminous coal for anthracite, known to be costly, infrequently delivered, and difficult to light. Under these circumstances, the growth of the anthracite industry would have to be driven by supply, not demand.

Canals provided a solution to both of these challenges. They overcame the geographic barriers separating the anthracite regions from population centers on the eastern seaboard and they initiated a supply-side energy transition. Built in anticipation of increased demand for coal, canals created a situation of energy abundance by delivering anthracite in ever-increasing quantities at ever-decreasing prices. This abundance, in turn, encouraged anthracite boosters to develop new uses for coal that led to the emergence of a mineral economy.

COAL IN PHILADELPHIA BEFORE 1820

BEFORE 1820, COAL PROVIDED only a tiny fraction of Philadelphia's energy needs, and very little of this coal came from northeast Pennsylvania. Homeowners used firewood for heat while artisans relied on falling water, firewood, and human or animal muscles for power. While some craftsmen such as blacksmiths, nail smiths, brick makers, and distillers used small amounts of bituminous coal imported from Virginia, Britain, and Nova Scotia, the scale of the trade was modest.[18] Philadelphia imported around five hundred tons of coal in 1784, just over a thousand tons by the early 1790s, and around three thousand tons per year in the 1810s.[19]

Anthracite and bituminous are varieties of coal distinguished by their relative composition of carbon. Anthracite coal is mostly carbon (usually more than 85 percent), giving it a hard, shiny appearance that led many to call it "stone coal." Anthracite is relatively rare; most of the world's coal reserves are bituminous, semibituminous, or lignite, in order of decreasing percentage of carbon. Bituminous coal typically has less carbon (roughly 50 to 85 percent) and more volatile gases.[20] Because of the lack of volatile gases, anthracite is more difficult to ignite. This was a significant obstacle to its early adoption because consumers found it challenging to use. But because it contains more carbon, anthracite burns hotter and cleaner than bituminous. As a result, anthracite has advantages over bituminous for certain applications such as home heating and forging iron.

In the early nineteenth century, several parties attempted to create a market for anthracite coal in Philadelphia.[21] These anthracite boosters were a heterogeneous group of merchants, industrialists, scientists, politicians, and citizens with varied motivations including personal profit, a desire to see Philadelphia and Pennsylvania surpass their regional neighbors, and the use of anthracite coal as a national industrial fuel that could strengthen the independence of the young republic.[22] Despite their differences, the boosters were united in seeing anthracite as a way to improve their world. Coal, they knew from observing Great Britain, was closely linked with economic development and global power. Thomas Cooper, a professor of chemistry, expressed this viewpoint succinctly: "In this country every suggestion that brings forward the importance of coal to the public view is of moment: we know little of its value in Pennsylvania as yet. All, all the superior wealth, power and energy of Great Britain, is founded on her coal mining."[23] If Pennsylvanians could develop an anthracite trade, many believed it would lead to personal, regional, and national economic growth.

Anthracite boosters did more than give speeches. In 1792 a group of prominent Philadelphians formed the Lehigh Coal Mine Company and bought several thousand acres of coal lands in the Lehigh Valley, although the company never delivered much to market. Other entrepreneurs including George Shoemaker—a colonel, early mine operator, and hotelier—shipped a few tons of coal from the Schuylkill Valley to Philadelphia in the early 1810s but had difficulty selling the coal. When the British fleet cut off Philadelphia's coal imports during the War of 1812, Jacob Cist, a merchant and amateur scientist, sold a few hundred tons of anthracite; however, when the war ended and bituminous shipments resumed, his business dried up.[24]

None of these efforts succeeded in addressing the twin challenges of geography and demand. Moving coal on land was difficult and expensive. A common metric from the British coal industry held that the price of coal doubled every ten miles that it was shipped overland. Transporting a wagonload of coal (about a ton and a half) from the Wyoming Valley to Philadelphia cost about twenty dollars at the turn of the century, and a trip could only be justified if the wagon returned full of goods. By comparison, Virginia coal brought by water was selling for about eight dollars a ton around 1810 in Philadelphia. Though water transport was much cheaper, neither the Schuylkill or Lehigh rivers offered reliable navigation. Both rivers had significant stretches of rapids and shallow waters and could be safely navigated only during periods of high water during the spring and fall. The high transport costs meant that under normal circumstances it was cheaper to ship coal three thousand miles from Britain than eighty to a hundred miles from the anthracite regions.[25] Moreover, because anthracite was expensive and supplied irregularly, consumers had little incentive to turn away from firewood or imported bituminous for their energy needs.

IMPROVING THE LEHIGH AND SCHUYLKILL RIVERS

When boosters turned their attention to the improvement of the Lehigh and Schuylkill rivers in the late 1810s, they transformed the fate of the anthracite coal trade. By focusing on canals, anthracite boosters were responding to the failures of earlier efforts as well as tapping into broader efforts to develop internal improvements. In the early years of the republic, many people saw roads, turnpikes, and canals (known at the time as internal improvements) as a way to create a strong and integrated nation out of a collection of individual states.[26] They believed that improved transport infrastructure would facilitate trade and communication, thereby binding people together. For example, the commissioners for the Erie Canal claimed: "[Canals] constitute improvements peculiarly fit for a republic. They contribute equally to the safety and opulence of the people, and the reputation and resources of the government. They are equally desirable in reference to the employments of peace, and the operations of war. In whatever light they are viewed, they seem to combine the substantial glories of the most splendid and permanent utility."[27] Robert Fulton, the steamboat pioneer, put the matter more directly: "what stronger bonds of union can be invented than those which enable each individual to transport the produce of his industry 1,200 miles for 60 cents the hundred weight? Here then is a certain method of securing the union of the states, and of rendering it as lasting as the continent we inhabit."[28] Internal improvements were not just a commercial activity for early boosters; they were nation-building.

Anthracite boosters were quick to adopt this line of thinking. Josiah White, pioneer of the Lehigh Canal, made the links between coal and canals explicit: "It is a general belief that the extraordinary personal industry of the English people is the cause of the wealth of that empire. I ask, what would the value of all their labor be, in all their commercial articles, without their canals? The steam engines spread all over England are said to perform many times over the labor of the entire population of that country. The coal for those engines comes on their canals.... Canals are the foundation of their wealth. Canals give industry its essence—the collecting of raw materials and the sending of the products of the factory to market."[29]

Boosters knew that the Lehigh and Schuylkill rivers reached into regions with anthracite coal, but the flow of these rivers was too variable to support regular trade. By creating dams, channels, and locks, canal builders hoped to reconfigure the rivers to serve the needs of human commerce. However, recommending canal construction was easier than actually building one. Canals are complex technological systems requiring large amounts of capital, labor, and expertise. They require removing rocks and impediments, damming falls, constructing locks, building reservoirs, and developing a towpath along the canal length. The magnitude of these obstacles explains why several attempts of Philadelphians to improve the Schuylkill and Lehigh rivers before 1815 had failed.[30]

This pattern began to change in 1817 when Josiah White spearheaded an effort to improve the Lehigh River. White was a practical man who had gained experience with river improvement while operating an iron rolling mill at Philadelphia's Schuylkill Falls. He built a dam across the river for water power and was one of the Philadelphia merchants who bought anthracite coal from Cist during the War of 1812. After his factories burned down in 1815, he and his partner Erskine Hazard turned their attention to developing the anthracite trade. In 1817, the men obtained a charter from the Pennsylvania legislature to improve the Lehigh River. One dubious legislator reportedly commented that the bill gave White and his partners the privilege of ruining themselves.[31] White found others similarly skeptical: his former business partner even refused to lend him a horse to survey the Lehigh. The partners struggled to acquire capital but eventually managed to raise $50,000 in 1818, allowing White and a team of workers to begin work.

By 1820, the company had improved the river sufficiently to begin shipping coal to Philadelphia.[32] The improvement, however, was not in the form of a conventional canal. White and his workers achieved this early success by creating a series of "bear-lock" gates across the Lehigh River.[33] These hydrostatic gates allowed a stretch of high water to build up behind them. When the water was released, a group of ark-boats (rafts of wood about fifteen feet by twenty feet and capable of carrying about seventy tons of coal) could travel through the gate along the wave of high water until reaching the next gate, where the water would collect once again. Once the coal reached Easton, it was floated down the Delaware River to Philadelphia.[34] At Philadelphia, the coal was sold, and the arks were broken up and sold as lumber. The boatmen kept the iron nails and walked or rode carriages back to the Lehigh Valley to build new arks and transport more coal.[35] By creating a system of one-way navigation, White was able to improve the river enough to ship coal and develop a reliable market before taking on the additional cost of building a two-way canal in the late 1820s to replace the "bear-lock" system.

Whereas the development of the Lehigh River was undertaken explicitly with the goal of bringing coal from the Lehigh Valley to Philadelphia, plans for the improvement of the Schuylkill River began with the agricultural trade. In 1815, the Schuylkill Navigation Company was incorporated and quickly raised five hundred thousand dollars to build a canal. Much of the capital came from farmers along the river, who hoped that improved navigation would give them easier access to Philadelphia's international grain trade and also lower the cost of manufactured goods shipped up the river. The coal trade was an afterthought at first: in 1817, the company's directors thought ten thousand tons of coal shipments per year was an optimistic estimate.[36] However, by the time the work on the canal was finally finished in 1825 (after ten years and more than $2 million in costs) it was clear that coal would be the main article of trade. While some agricultural and manufactured goods were shipped on the canal, most of the boats carried coal. In 1835, over 300,000 tons of coal were shipped down the Schuylkill River, more than thirty times the supply the company had considered optimistic less than two decades before.[37] The Schuylkill River had been converted to a coal highway.

These projects to transform the Lehigh and Schuylkill rivers were among the largest and most expensive undertakings of the time. Hundreds of laborers worked in the riverbeds to remove large rocks, erect canal banks, and blast away slate ledges. The Schuylkill Canal cost so much money to complete that it would have gone into bankruptcy if Stephen Girard, the richest American at the time, had not granted large sums of money to the enterprise.[38] Josiah White claimed that the hundreds of workers improving the Lehigh River in 1820 were the largest work force in Pennsylvania's wilderness to date.[39] The completion of these canals was only possible because residents of the eastern mid-Atlantic poured a significant fraction of their labor, savings, and expertise into these projects.

The Schuylkill and Lehigh river improvements created a new energy landscape in the eastern mid-Atlantic. For the first time in the region's history, coal could be shipped cheaply, abundantly, and reliably. In 1830, the typical cost of shipping goods along canals was about a tenth of the cost of wagon transport.[40] In 1834, it cost about $2.25 to ship a ton of coal from the Schuylkill Valley to Philadelphia.[41] In addition, the price became lower as more coal was delivered. As the Schuylkill canal was expanded to allow boats that could carry 180 tons each in the 1840s, the price of coal deliveries dropped to $1 per ton.[42]

Canals also made coal transport reliable. Although goods had been shipped on the Lehigh and Schuylkill rivers before the canals were built, deliveries could only take place when the water level was neither too low nor too high. As a result, the quantity of goods that could be transported was limited by the small number of navigable days. In addition, one could not guarantee when a shipment would take place. Goods were delivered according to the vagaries of rainfall, not by the human calendar. By regularizing the flow of the river, canals allowed reliable coal shipments for at least eight months a year (canals typically froze beginning in mid-December and were re-opened in March or April). For example, Josiah White proudly estimated that the Lehigh Canal could deliver more than ten thousand tons of coal per day, eight months a year, or more than two and a half million tons a year.[43]

In a short time, the potential of canals to ship coal cheaply and reliably became a reality. From 1820 to 1860, the delivery of coal from the anthracite regions to the eastern seaboard increased dramatically, soon exceeding millions of tons a year and far outstripping population growth (Table 1). At the same time that shipments increased, prices decreased. Imported bituminous coal in the 1810s typically cost $8 to $10 per ton.[44] Before the opening of the canal networks, anthracite cost as much as $20 per ton in Philadelphia. By 1830, the price of Lehigh coal in Philadelphia was $6.50 per ton and $4.50 by 1850.[45]

The collective effect of these improvements on the Lehigh and Schuylkill rivers was a revolution in Philadelphia's coal marketplace. Anthracite canals had created a built environment in which ever-increasing shipments of fossil fuel energy were possible, and—due to the synergistic relationships between supply and price—desirable. The energy landscape of the eastern mid-Atlantic region was now designed for intensive fossil fuel consumption.

Table 1: Lehigh and Schuylkill River Coal Shipments.

Year	Schuylkill River Coal Shipments (tons)	Lehigh River Coal Shipments (tons)	Total Coal Shipments (tons)	Percent Increase in Coal Shipments	Philadelphia Population (city and county)
1820		365	365		137,097
1825	6,500	28,393	34,893	9500%	
1830	89,984	43,000	132,984	381%	188,797
1835	339,508	131,250	470,758	354%	
1840	452,291	225,585	677,876	144%	258,037
1845	1,083,824**	429,492	1,513,316	223%	
1850	1,717,007**	723,099	2,440,106	161%	408,792
1855	3,318,555**	1,276,367	4,594,922	188%	
1860	3,234,834**	1,091,032	4,325,866	−6%	565,529

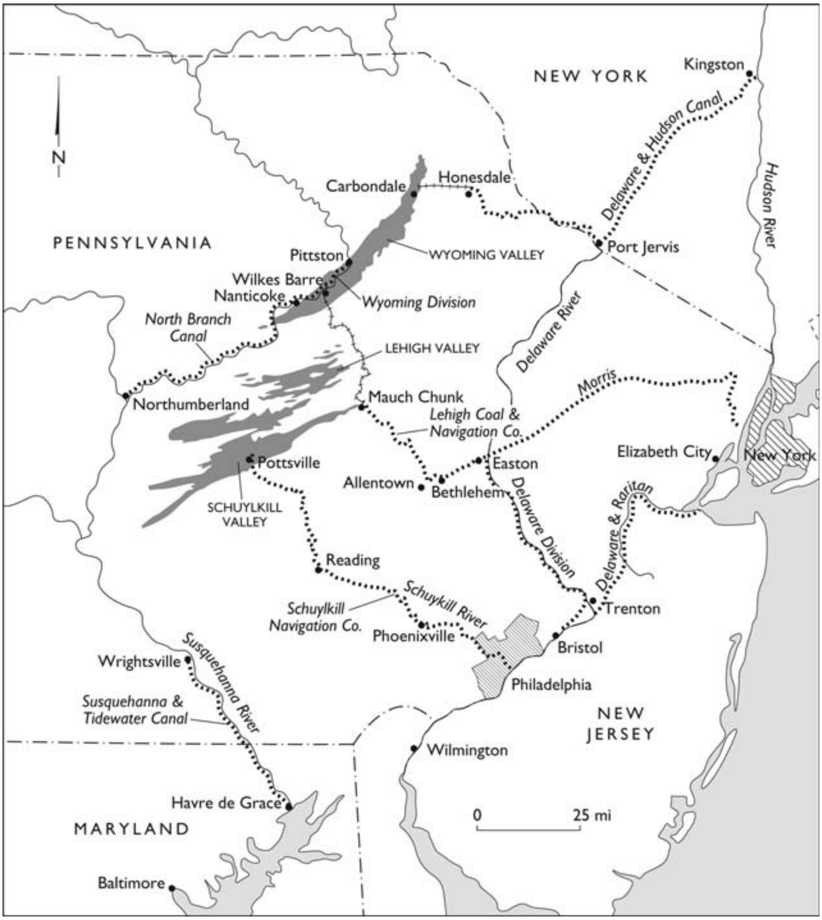
** denotes shipments from Schuylkill Canal plus Reading Railroad
Sources: Chester Lloyd Jones, *The Economic History of the Anthracite-Tidewater Canals* (Philadelphia: University of Pennsylvania Press, 1908); Miners' Journal, *Coal Statistical Register for 1870* (Pottsville, PA: Miners' Journal Office, 1870). Population data from John Andriot, *Population Abstract of the United States* (McLean, VA: Andriot Associates, 1980).

THE WIDER COAL DISTRIBUTION SYSTEM

THE LEHIGH AND SCHUYLKILL CANALS were the pioneering developments that initiated a new landscape of energy flows between the anthracite regions and Philadelphia. Soon after their completion, several other canals, and later railroads, were constructed to further extend this network. Five more canals were built to transport anthracite. The most important was the Delaware & Hudson canal, opened in 1829, which connected New York City to the northern end of the anthracite fields via a sixty-mile canal linking the Delaware River with the Hudson River. In Pennsylvania, the Delaware Division Canal improved the Delaware River between Easton and Bristol, allowing large coal boats to reach Philadelphia when water levels were low. Improvements along the Susquehanna River as part of the State of Pennsylvania canal network connected the anthracite regions with Harrisburg and Baltimore. Finally, two canals crossed New Jersey, allowing anthracite to reach the harbor of New York City. The Delaware & Raritan canal crossed the middle part of the state beginning in the late 1830s and was used to transport large quantities of coal from Philadelphia to New York City. The Morris Canal was opened in the 1840s and stretched over the mountainous northern part of the state from Easton to Jersey City.

Beginning in earnest in 1840, railroads began to transport coal as well, often engaging in bitter competitions with the canal routes. The first major player was the Reading Railroad, which fought the Schuylkill Navigation Company for thirty years beginning in 1840 until the latter's capitulation in 1870. The Lehigh Canal faced competition from the Beaver Meadow Railroad and

Map 1. Anthracite Canal Network, circa 1845.



Map design by Bill Nelson, for the author.

Lehigh Valley Railroad starting in 1838 and 1855, respectively. The Delaware, Lackawanna, and Western Railroad served the northern Wyoming field starting in 1853.[46]

The millions of dollars spent on infrastructure to move coal attest to the critical nature transport played in the development of the anthracite coal trade. Anthracite was the major item of trade on all these canals and railroads, meaning that their economic success was tied to the fate of the coal trade. Just as important, the coal trade owed its success to the activities of the transport companies. From an economic perspective, investments in the transport of coal far outweighed the costs of mining it. For example, by 1834, over

$9,750,000 was invested in canals and railroads in the anthracite regions, while only $1,270,280 was invested in collieries (and much of this capital was spent on boats and wagons).[47] As Thomas Dublin and Walter Licht note: "[t]he movers and shakers of the trade would be the transporters and merchandisers of coal, not the operators of mines."[48]

COAL AND THE MINERAL ECONOMY

CANALS PROVIDED AN EFFECTIVE SOLUTION to the challenge of anthracite's geography, but boosters still faced an unenthusiastic market. While anthracite had become cheaper and more abundant in Philadelphia, people did not know how to use it. Over the 1820s and 1830s, canal operators, factory technicians, scientists, politicians, and civic organizations worked to find new applications for anthracite and overcome barriers to its use. Their efforts were particularly successful in the domains of home heating, iron manufacture, steam engines, and manufacturing.

The canals played an important role in creating new demands for coal. By providing a cheap and abundant supply of coal, they encouraged a wide range of actors to find applications for anthracite. With supply assured, potential users of anthracite including factory owners, steamboat operators, and stove manufacturers now had the incentive to invest in technologies for its consumption. At the same time, canals created a set of powerful financial motivations for their owners and operators to pursue new applications for anthracite since increased shipments led to increased profits. The directors and employees of canal companies were among the most active boosters seeking to find new applications for anthracite.

As eastern mid-Atlantic residents began using anthracite, they initiated a transition to the mineral economy. The key feature was a synergistic feedback loop that developed between coal supply and demand. At first, anthracite boosters had to convince users to adopt the new supplies made available by the canals. As people began using anthracite to heat homes, forge iron, power steam engines, and manufacture goods, they created a powerful ongoing demand for more coal. Supply drove demand, demand drove supply, and at the center of the system, the canal network grew steadily to ensure that anthracite was always available.[49] By 1860, the region had taken important steps into a mineral economy, characterized by new relationships with energy, new population centers, new types of manufacture, new geographies of industrial activity, and constant growth without facing the limits of an organic economy.

HOME HEATING

HOME HEATING BECAME the most common use for anthracite coal. In the early nineteenth century, the price of firewood was increasing in eastern seaboard cities as nearby forests were depleted. As urban populations grew, some contemporary writers warned that the dwindling firewood supply would limit these cities' growth. This potential constraint, plus the large number of potential consumers, encouraged anthracite boosters to develop the domestic heating market.[50]

However, the difficulty of burning anthracite hindered its adoption. One could not simply add anthracite to a fire and expect it to ignite. A fifteen-page tutorial from an 1827 servants' guide indicates the many steps involved in burning anthracite, including buying coal, breaking it, starting a fire, and keeping it going: "Very few servants at first understand the method of kindling and continuing a fire of Lehigh coal, many will never learn, and many more from erroneous instructions, whilst they think they understand it, make but a bungling piece of work of it.... [I]t must be granted that a knowledge of how to make a Lehigh coal fire, when it is becoming so common in this country, is quite an acquisition." The recommendations included breaking the coal into the right size pieces ("about as large as your fist, if your hand is rather a small one"), using the right kindling ("charcoal, unless dry hickory be preferred"), keeping the fire going ("judicious use of the poker is essential to the well-being of an anthracite fire"), as well as an analysis of the relative merits of anthracite ("I place *cleanliness* at the top of its virtues,–cleanliness as to smoke, dust, and smell").[51]

In addition to learning to manage anthracite fire, consumers had to invest in a specially designed stove or grate that altered the flow of air and allowed pieces of ash to fall away from the coal. Anthracite boosters adopted several strategies to help consumers overcome these challenges. Manufacturers began to develop new models of stoves, many of which were designed to burn anthracite coal. Between 1815 and 1839, 329 patents were issued for stove designs–3.6 percent of the Patent Office's awards.[52] Scientists performed experiments demonstrating the superior heating qualities of anthracite.[53] The Fuel Savings Society, a philanthropic organization, commissioned a company to build stoves costing only $5.50, enabling poorer consumers to switch to coal.[54] Josiah White had his wife keep an anthracite fire burning in their Philadelphia home so that potential clients could see how it worked.[55]

By the end of the 1820s, the boosters' efforts were starting to succeed. Before 1820, no homes in Philadelphia were heated with anthracite, but by 1830 homeowners were consuming around twenty thousand tons, enough coal to heat roughly 10 percent of the population.[56] New York City was sufficiently dependent on anthracite that a shortage of supply in the winter of 1831 caused widespread alarm.[57] By 1850, 90 percent of homes in northern states had stoves.[58] As people became more experienced using anthracite, purchased stoves, and saw that prices of coal continued to drop, the adoption of coal accelerated, and demand began to encourage supply. By the outbreak of the Civil War, Philadelphia and other eastern seaboard cities were using anthracite almost exclusively for their home heating needs.[59] With a population of 565,529 in 1860, citizens of Philadelphia were likely burning over half a million tons of anthracite per year to keep warm with roughly another 750,000 tons consumed in New York City (population 813,669).

Anthracite burned in home heating facilitated a shift to the mineral economy by making it easier for eastern seaboard cities to support large populations. It would have been extremely expensive and difficult to heat this population with wood, and this constraint might have negatively impacted the growth of Philadelphia and other cities. For example, Philadelphians in 1860 would have required about 850,000 cords of wood for their heating and cooking needs.[60] Under nineteenth-century forestry practices, one could expect a sustainable yield of one and a half cords of wood per year from an acre under good conditions.[61] Therefore, to support the heating and cooking needs of its population, Philadelphia would have required a dedicated wood hinterland of 567,000 acres—about 885 square miles or roughly 2 percent of the state's landmass.

Even though it was within the technical capabilities of the time to meet these heating needs with firewood, it would have been difficult and required trade-offs. Philadelphians could have chosen to create a large wood reserve for the city, although any land near transport facilities would have been more highly sought after as farmland. More likely, they would have relied on the vast timber resources of Maine and North Carolina to fill the gap. However, the additional demands on these forests, not only of Philadelphia, but also New York, Boston, and other eastern seaboard cities, would have significantly raised the cost of firewood and increased the rate of exhaustion. It would have also driven up the price of lumber, thereby making housing more expensive, since most American buildings were made out of wood at the time.[62] In other words, while Philadelphia could have supported its population in 1860 with firewood instead of anthracite, this would have required more land and the trade-offs that were characteristic of an organic economy. In addition, these changes would have become more acute as Philadelphia's population grew to 675,000 in 1870, 875,000 in 1880, and over a million by 1890.[63] As a cheap heating fuel, anthracite removed a constraint to the growth of nineteenth-century cities.

IRON MANUFACTURE

THE APPLICTION OF ANTHRACITE to iron production became one of the most important and revolutionary uses of coal during this period. Although American ironmasters had been using charcoal for several decades to forge iron, the use of anthracite initiated a new chapter for the industry. Iron forged with anthracite shattered previous limits to growth and occurred in a geographical arrangement that was impossible in the context of an organic economy.

However, forging iron with anthracite was easier said than done. Iron manufacture is a complex chemical and engineering process with many variables. The fuel has to serve several functions including supplying heat, providing structural support in the stack, and removing impurities from the ore. As with home heating, supply drove demand at first. Because Philadelphia's boosters saw the potential for an anthracite iron market, they made several efforts to solve these problems. The Franklin Institute promoted gold medals (its highest prize) to anyone who could forge iron with anthracite; a group of wealthy men including Nicholas Biddle offered a $5,000 reward to anyone who could keep an anthracite forge in operation for three months; and the State of Pennsylvania granted favorable corporate charter privileges to companies forging iron with anthracite.[64] Transport companies also worked to develop this market. The operators of the Lehigh Canal offered free water power and cheap transport rates to anthracite iron companies. Moreover, Josiah White sent his nephew to Wales to learn methods of forging iron with anthracite and established a subsidiary company that became one of the first to produce anthracite iron in the Lehigh Valley.[65] Despite these incentives, it still took years of experimentation until the technical problems were solved and a mid-Atlantic anthracite iron industry could develop.

By 1840, several people began to have success, largely drawing on the expertise of Welsh ironmasters.[66] Once anthracite was introduced as a fuel for iron production, the industry grew dramatically. Within seven years there were already more than forty forges producing 151,331 tons of iron.[67] The explosive growth continued over the next decades, with total anthracite iron production exceeding the amounts forged with charcoal by 1855 (Table 2).

The rapid growth in the anthracite iron industry demanded massive quantities of coal. Two tons of coal were needed for every ton of iron produced. If water power was not available, an additional quarter ton of coal per ton of iron was needed to power a steam engine to operate the furnace bellows. In addition, much of the iron was further processed into products such as rails, nails, and plates, requiring additional heat: two tons of coal to roll or puddle iron and as many as eight tons of coal to forge steel.[68] I estimate that approximately an additional 65 percent of the amount of coal used for pig iron production was consumed in secondary processing.[69] More than a million tons of anthracite were being used a year for iron production by the mid-1850s, and by the end of the Civil War, consumption exceeded 2 million tons (Table 3).

This coal consumption exemplifies how the mineral economy escaped the limits of the organic economy. Charcoal production required lots of land. In 1820, Britain produced so much iron that had charcoal been the fuel, the entire landmass of the British Isles would have been necessary to grow the requisite number of trees.[70] A similar dynamic began to appear in Pennsylvania during this period. A charcoal-fueled furnace in the early nineteenth century producing six hundred tons of iron required a tree plantation of 9,000 acres for sustainable operations.[71] Pennsylvania's area is 46,055 square miles, or 29,475,200 acres. If the entire landmass of the state had been dedicated to timber for iron production, the maximum sustainable output would have been less than two million tons. In 1860, forges in

Table 2: U.S. Iron Production (Tons) By Fuel Source, 1847–1864.

Year	Anthracite (Tons)	% of Total	Bituminous and Coke (Tons)	% of Total	Charcoal (Tons)	% of Total
1847	151,331	38.9	17,800	4.6	219,674	56.5
1854	339,435	46.1	54,485	7.4	342,298	46.5
1855	381,866	48.7	52,390	8.0	339,922	43.3
1856	443,113	50.2	69,554	7.9	370,470	41.9
1857	390,385	48.9	77,451	9.7	330,321	41.4
1858	361,430	51.3	58,351	8.3	285,313	40.5
1859	471,745	56.1	84,841	10.1	284,041	33.8
1860	519,211	56.5	122,228	13.3	278,331	30.3
1864	684,519	59.5	210,108	18.3	255,486	22.2

Sources: Craig L. Bartholomew, Lance E. Metz, and Ann M. Bartholomew, *The Anthracite Iron Industry of the Lehigh Valley* (Easton, PA: Center for Canal History and Technology, 1988), 52-53; Sam H. Schurr and Bruce Carlton Netschert, *Energy in the American Economy, 1850-1975: An Economic Study of Its History and Prospects* (Baltimore: Johns Hopkins University Press, 1960), 66; *Proceedings of the American Iron and Steel Association at Philadelphia, Nov. 20, 1873*, (Philadelphia: Chandler, 1873), 51; Samuel Harries Daddow and Benjamin Bannan, *Coal, Iron, and Oil, or, the Practical American Miner: A Plain and Popular Work on Our Mines and Mineral Resources, and a Text-Book or Guide to Their Economical Development* (Pottsville, PA: Benjamin Bannan, 1866), 698.

Pennsylvania produced 519,211 tons of iron with anthracite in addition to 278,331 tons with charcoal.[72] By 1886, anthracite iron production was greater than two million tons, with the vast majority produced in Pennsylvania. In addition, the Pennsylvania iron industry produced large amounts of iron using charcoal and bituminous coal as well.[73] The anthracite iron industry of the eastern mid-Atlantic operated according to the dictates of a mineral economy.

Of course, the anthracite iron industry did not require the landmass of the entire state. It did not even require the landmass of the districts it was located in. A second critical shift of the mineral economy was that it operated according to a new geographic logic. Charcoal forges required lots of land for fuel, thereby encouraging the development of a rural and decentralized industry. By contrast, the energy flows made possible by the canal network allowed the anthracite iron industry to be densely concentrated along their banks. Because anthracite iron forges did not require land to grow fuel, several forges could be located in close proximity. If the anthracite canals were the backbone of the new energy landscape, it is not surprising that iron forges, the society's most energy-intensive industry, attached themselves like ribs.

The Lehigh Valley gives a clear example of the new geography of the mineral economy. In 1864, in an area of only about 730 square miles, there were thirty furnaces that used nearly half a million tons of coal to produce more than 200,000 tons of iron.[74] This density of production was impossible in an organic economy. Moreover, there were no Malthusian trade-offs. While the Lehigh Valley anthracite iron industry developed, its agricultural output

Table 3: Estimates of Anthracite Consumed in Iron Production, 1847–1864.

Year	Anthracite iron production (Tons)	Coal used for pig iron production (Tons, estimate)	Coal used in secondary iron processing (65%) (Tons, estimate)	Anthracite used in iron industry (Tons, estimate)	All anthracite shipments (Tons)	Percentage of total anthracite shipments used in iron industry
1847	151,331	305,000	200,000	505,00	2,284,659	22%
1849	109,166	220,000	145,000	365,000	3,027,708	12%
1854	339,435	680,000	440,000	1,120,000	5,086,391	22%
1855	381,866	760,000	495,000	1,255,000	5,876,872	21%
1856	443,113	885,000	575,000	1,460,000	6,607,517	23%
1857	390,385	780,000	505,000	1,285,000	6,896,351	19%
1858	361,430	720,000	470,000	1,190,000	6,644,941	18%
1859	471,745	940,000	610,000	1,550,000	6,802,967	23%
1860	519,211	1,040,000	675,000	1,715,000	7,808,255	22%
1864	684,519	1,370,000	890,000	2,260,000	9,566,006	24%

Sources: Anthracite iron production numbers are from Table 2. Coal used for pig iron production is estimated by multiplying anthracite iron production by two. Given that this does not include any coal for firing steam engines, this number is a conservative estimate. Coal used in secondary iron processing is calculated by multiplying coal use in pig iron production by 65 percent, as described in endnote 69. Anthracite used in iron industry is the addition of the previous two columns. All data for anthracite shipments are from Miners' Journal, *Coal Statistical Register for 1870*.

increased, with gains in grain, corn, oats, and dairying during the 1840s and 1850s.[75] Moreover, its coal output skyrocketed as well, as indicated in Table 1. The ability to increase multiple areas of economic activity without needing to decide between alternatives was a clear indication that canals were enabling certain parts of the eastern mid-Atlantic to escape the bonds of the organic economy.

STEAM ENGINES

THE DEVELOPMENT OF THE STEAM ENGINE has widely been recognized as one of the crucial drivers of industrialization. This was particularly true in Philadelphia, which became a center of American steam engine use due in large part to abundant supplies of cheap anthracite coal. Steam engines used in manufacturing, coal mining, steamboats, and railroads encouraged the shift to a mineral economy by separating sites of industrial activity from sites of energy production and allowing new flows of people and goods to emerge.

Before the first steam engine using anthracite was built in 1825, there were only a few steam engines in Philadelphia were powered by wood and bituminous. The real acceleration in steam engine use came once canals began to deliver anthracite to Philadelphia. In 1831, there were between sixty and eighty steam engines in Philadelphia burning anthracite.[76] By 1838, Philadelphia County led the nation in the use of steam engines and their various applications. Of the 1,860 stationary steam engines in the nation, 178 were in Philadelphia and another 41 were in surrounding counties, likely consuming around 26,000 tons of anthracite.[77] There are no reliable data on steam engines from 1850 and 1860, but by 1870, it was reported that there were 1,877 establishments using steam power in Philadelphia with a total capacity of 49,674 horsepower consuming around 275,000 tons of coal per year.[78]

The use of steam engines in manufacturing contributed to the mineral economy in two ways. The first was the exponential increase in energy consumption, shown by the large increase in steam engines and coal demand. The second shift was geographic. Steam engines separated the links between land and energy sources that had structured the locations of manufacturing enterprises in an organic economy. In an organic economy, mills and manufacturing establishments were concentrated along falling water and near abundant forests. The creation of the giant textile mills at Lowell, Massachusetts, is the quintessential example of this logic.[79] Such a location could provide cheap energy, but had the disadvantages of being distant from markets, workers, and suppliers. Moreover, the inventor Oliver Evans noted that organic energy sources had other limitations: "Water-falls are not at our command in all places, and are liable to be obstructed by frost, drought, and many other accidents. Wind is inconstant and unsteady: animal power, expensive, tedious in the operation, and unprofitable, as well as subject to innumerable accidents. On neither of these can we rely with certainty. But steam at once presents us with a faithful servant, at command in all places, in all seasons; whose power is unlimited."[80]

By providing a flexible and steady form of power, steam engines gave energy-intensive enterprises the option to locate in urban locations where workers, suppliers, and markets were nearby. Several industries, particularly in textiles and metals, took advantage of these opportunities and concentrated in Philadelphia, similar to the ways that canals encouraged the aggregation of iron forges along their banks. Instead of moving factories, workers, and supplies to sites of energy, entrepreneurs moved factories to cities. The Philadelphia model began to replace the Lowell model as the primary pattern of American industrial development.[81]

Steam engines were also widely used in coal mining. As demand for anthracite grew, miners had to dig further below the surface, which meant that water had to be pumped from the mines. Steam engines were an effective and obvious solution (this same problem inspired Thomas Newcomen to develop the steam engine in 1712). The growth of steam engines used in mining is documented most clearly in the Schuylkill Valley. The first steam engine was purchased by the North American Coal Company in 1833. By 1840, there were twelve engines in mining operations and a decade later, there were 165 in the Schuylkill Valley. In 1865, 320 steam engines were being used in the Schuylkill Valley and nearly 800 throughout the anthracite regions.[82] Since the fuel supply was so cheap to the mining companies (the engines were fed with pulverized coal that could not be sold in markets) the steam engines were likely far less efficient than those in Philadelphia.[83] Extrapolating the data from the Schuylkill Valley to the rest of the industry, I estimate that around 150,000 tons of coal were consumed in colliery steam engines in 1850 and 725,000 tons by 1865.[84] With the use of steam engines for mining, the consumption of anthracite became an important part of its production.

Steam engines were also used in transport, particularly for boats. Early steam vessels were powered by burning wood, which was initially abundant along the paths of the boats (mostly the Delaware and Hudson rivers, and the Atlantic coast for Philadelphia and New York's fleets) until the boats consumed much of the available supply. As early as 1829, the pine lands of New Jersey were being rapidly deforested for use in steam vessels and charcoal production.[85] The extensive use of anthracite coal in steam vessels began in the 1840s, driven in large part by the efforts of the companies operating the Lehigh and Delaware & Hudson canals.[86] There were only six steam vessels burning anthracite in the New York City area in 1831, but by 1845, the practice was well established: in that year, Philadelphians operated thirty-five steam boats consuming 45,000 tons of anthracite that year and boats in the New York harbor consumed an estimated 100,000 tons.[87] By the 1850s, over half the steamships in the U.S. coastal trade burned anthracite, consuming around a quarter million tons annually.[88]

The other great transport revolution of the antebellum era was the railroad. Anthracite boosters had high hopes for the use of stone coal in locomotives, but this market did not meet expectations. This was a surprising result since one of the first American locomotives, the 1832 "Tom Thumb" of the Baltimore & Ohio Railroad, burned anthracite.[89] However, when used in locomotive engines, the intense heat of anthracite melted grates, impeded combustion, and destroyed boilers. In addition, it was harder to control the flame of an anthracite fire to increase the power output when the train was starting or going up slopes or to decrease it when stopping. The higher maintenance costs associated with burning anthracite encouraged railroads to rely on wood or bituminous coal. As late as 1850, many of the technical problems of burning anthracite in locomotives remained unsolved.[90] Even the Reading Railroad, the largest transporter of anthracite, largely burned wood until the 1850s: in 1847, only 5 percent of their engines used anthracite.[91] Thus, the total market for anthracite coal in railroads never approached the demand from other sectors.

FACTORY

THE FINAL MAJOR CATEGORY of anthracite consumption came from its use in heat-intensive enterprises. In addition to driving steam engines to furnish mechanical power in mills and manufactories, anthracite also provided direct heat for a wide variety of businesses that had previously relied on wood, charcoal, and imported bituminous coal. Bakers, brewers, distillers, brick-makers, sugar refiners, tanners, bleachers, salt-makers, metal-workers, and more all required significant amounts of heat to produce a finished product. In fact, very few business enterprises did not require heat, if only to warm the working environment during the winter. Even hat makers began adopting anthracite to heat the pots of water necessary for shaping materials.[92]

For enterprises simply needing heat, substituting anthracite for wood or imported bituminous coal was a relatively straightforward process. There were a few kinks to be worked out, such as reconfiguring stoves to burn anthracite, modifying boilers to withstand the heat of an anthracite fire, and separating the gas emissions from edible goods to ensure they did not taste of sulfur or soot. However, in comparison with the efforts required to apply anthracite to steam engines or iron manufacture, these challenges were minor. As anthracite was the cheapest heating fuel available by the 1830s, it is likely that most mill owners in Philadelphia converted to coal for their heating needs.[93]

The decentralized nature of these businesses and the lack of statistics make it impossible to estimate the total use of coal in this category. However, it is clear that enough anthracite was being used to make a significant difference in Philadelphia's economic development. Whereas abundant water power in New England encouraged the growth of textile mills focused on spinning and weaving, Philadelphia manufacturers took a leading role in heat-intensive operations, including bleaching, dyeing, paper making, glass making, distilling, and metal-working.[94] As with steam engines, the use of coal in urban factories helped create a new geographical pattern of production centered in cities.

These collective effects of burning anthracite in homes, iron forges, steam engines, and factories produced far-reaching changes in the society and economy of Philadelphia. This is best encapsulated by studying what was possible at the end of the period compared to the beginning. First, people could choose to live in and establish businesses in places without regard to the carrying capacity of the land. This led to the concentrations of people and industries in cities. Second, industrial growth could occur without requiring trade-offs in land use. For example, the Lehigh Valley could attain a thriving trade not only in coal, but also in iron and agricultural goods. People could do more without having to do with less of something else. Third, and related to the above points, the use of anthracite coal paved the way for an exponential growth of population and manufacturing output by eliminating many of the natural limits that were characteristic of an organic economy. Mid-Atlantic residents had taken their first big steps toward a new relationship with land and resources characteristic of a mineral economy.

REGIONAL DIFFERENTIATION

THE INTENSIFIED USE of fossil fuel energy in the eastern mid-Atlantic was in marked contrast to developments in other regions. The emergence of the mineral economy was largely a phenomenon of the mid-Atlantic. In 1860, organic energy sources provided most of the energy needed by Americans outside the mid-Atlantic.[95] Even in New England, where large quantities of anthracite were imported to cities such as Providence and Boston, falling water continued to power most of the region's factories.[96] There were intraregional differences as well: not everyone in the mid-Atlantic experienced the same shifts. These differences were largely a product of the geographies of the canal network, which structured who had access to cheap energy. The most significant changes were felt in cities at the ends of canals, and secondarily by people in the coal regions and those along the paths of the canals. The lives of those in the countryside were hardly affected by these changes.

The shift from an organic to a mineral economy was most pronounced at the termini of the canal networks in Philadelphia and New York. These cities consumed the greatest amounts of coal in the widest array of uses.[97] Of the four major uses of anthracite coal, all except iron production were most pronounced in seaboard cities. By 1860, the large majority of Philadelphians and New Yorkers were burning anthracite in their homes, the cities' heat-intensive businesses relied on coal, and most of the steamboats burning anthracite were based in Philadelphia and New York. While neither city was a center of iron production, each supported many factories processing pig iron into finished goods.

Philadelphia and New York had clearly developed new relationships with land, energy, and limits that were no longer characteristic of an organic economy. The story in the anthracite regions was somewhat different. To be sure, social changes had affected towns such as Pottsville, Mauch Chunk, and Honesdale due to the rise of the coal industry, the rapid influx of population, and the booms and busts associated with mining districts.[98] However, while these social changes resulted from the emergence of the anthracite industry, they were not necessarily linked to its consumption. In fact, much of the activity in the anthracite regions was characteristic of the organic economy. Even while the anthracite regions were supplying the raw material that would make the mineral economy possible, the main tools were pickaxes, wheelbarrows, wagons, donkeys, and canals: the power came mostly from human and animal muscles. It was only with the extensive use of steam engines for coal mining during the later period of this study that the anthracite regions began to operate as a mineral economy.

The regions along the paths of the canals experienced change, but less than either the coal regions or the cities. Between 1820 and 1840 only around 5 to 10 percent of the coal shipped along the Schuylkill and Lehigh Canals was consumed along their length.[99] Even comparatively large towns along the canals, such as Reading, had only 8,410 people in 1840. Wood was still relatively abundant for heating and manufacturing purposes, and the limits of the organic economy were hardly constraining at these sites. It was the introduction of the anthracite iron industry beginning in 1840 that began to integrate the towns along the paths of the canals—Reading, Phoenixville, Bethlehem, and Allentown—into the mineral economy. For several decades, the iron industry generated significant amounts of wealth in these towns and encouraged the growth of subsidiary industries. However, because there was relatively little consumption of coal separate from the iron industry, the rhythms and patterns of the organic economy persisted in most places outside the great iron works.

In the rest of the eastern mid-Atlantic region, the predominantly rural population experienced very little change in their daily lives. Due to low population densities, their energy needs were satisfied by the abundant supply of organic sources. The charcoal iron industry continued to increase its output in rural Pennsylvania, taking advantage of the uncut forests. There were enough streams to support mills for farming communities, who congregated near their banks. On the whole, rural residents of the mid-Atlantic remained in the organic economy and would not be integrated into a mineral economy for several decades.

The canal network also shaped the distribution of costs and benefits accompanying these changes. The development of the mineral economy favored those living in cities and disadvantaged those living elsewhere economically, environmentally, and physically. Economically, the development of the anthracite industry benefited cities disproportionately. Diane Lindstrom notes that while all regions may have benefited from the development of an integrated economy, the urban core gained the most. She demonstrates that Philadelphia experienced the fastest rates of population growth, had the highest rates of return on investment, and captured the benefits of the transport savings, which were usually passed on to consumers instead of producers.[100] In addition, the varied uses of coal in cities gave rise to a diversified urban economy that was better able to withstand peaks and valleys in business cycles. The dependence of the anthracite regions on coal and towns along the paths of the canals on iron left them subject to significant recessions when the coal and iron markets experienced difficulty, a regular occurrence throughout the nineteenth century.

People in the anthracite regions bore most of the environmental harms of the anthracite industry. The extraction of coal led to scarred landscapes of abandoned mines, deforested hills, and slag heaps. Mining produced large quantities of coal dust that settled on houses and fields and tainted drinking water supplies.[101] Over time, the anthracite regions became a sacrifice zone—an area whose environment was abandoned to serve the needs of distant consumers. Urban consumers faced some pollution from anthracite smoke, but the high carbon content mitigated these effects. Anthracite smoke was far cleaner than bituminous smoke due to its lower levels of impurities. Therefore, the urban air quality of eastern seaboard cities such as Philadelphia and New York, while never ideal, was far better than urban locations dependent on bituminous coal like Pittsburgh, Chicago, and St. Louis.

Finally, coal mining in the antebellum era was an extremely dangerous occupation. Miners faced a range of physical threats including poor ventilation, the collapse of mine shafts or tunnel supports, dynamite explosions, and fires. Anthony Wallace calculated that anthracite miners had less than an even chance of surviving fourteen years of employment without a fatal or crippling accident.[102] While workers in cities also experienced physical risks from the mechanization of the factory, it was not to the extent that injury permeated coal mining. Therefore, those living in the anthracite regions experienced a disproportionate share of the costs of the anthracite industry while recouping fewer of the benefits than those living in cities.[103]

DEPENDENCE

THE STEPS THAT mid-Atlantic residents took into the mineral economy during the antebellum era would not be their last; there were lasting consequences to these choices. At first, people experienced the new availability of anthracite coal as an open choice. By the end of the period, this was no longer the case. As of 1860, the eastern mid-Atlantic had already begun to depend on ever-increasing supplies of fossil fuel energy. Without the continued availability of coal, eastern seaboard cities would have faced great difficulties heating their populations, the iron industry would have collapsed, and there would have been an exodus of industries and people from urban centers. The free choices that people experienced in the 1820s and 1830s about whether to adopt a new energy source were no longer so free by 1860. People depended on coal to maintain their way of life.

Two analytical concepts can help us make sense of this transition to dependence. The historian of technology Thomas Hughes has articulated the concept of momentum.[104] At the beginning of their development, technological systems are open to significant modification by social actors. Over time, however, this flexibility is diminished as the system becomes more entrenched. This momentum is partly technological—the capital investments in a system make it increasingly expensive to make any changes—and partly social—operators of the system establish stable rules and procedures and users become accustomed to a particular way of doing things. Environmental historian Donald Worster has developed the idea of an infrastructure trap.[105] Once a society commits a certain amount of resources to solving a problem in a particular way, those choices become a straitjacket, making it difficult to think about or address problems in any other way.

During the antebellum period, fossil fuel consumption gained the momentum characteristic of an infrastructure trap. Mid-Atlantic residents altered their built environment in ways that depended on the continued availability of anthracite. They constructed dense concentrations of homes and factories in cities that would require more heat and power than could be supplied by organic energy sources. Capitalists who invested in iron forges along the banks of the canals or operated steam vessels along the eastern seaboard could only generate a return to investors if coal was available. Moreover, as people gained familiarity with burning coal, they became accustomed to its use and benefits. The high heating value of anthracite and its low cost meant that homes could be kept warmer in winter, factory production costs were lower, and land was freed up for other purposes. For most people, life with coal became better than life without it. Gradually, thousands of individual decisions by people and industrialists about where to live, how to heat their homes, and where to locate factories created a new built environment and set of cultural expectations in the mid-Atlantic that depended on ever-increasing supplies of coal. The mid-Atlantic was effectively trapped in a coal economy.

The legacies of the path-dependent pattern of ever-increasing fossil fuel consumption pioneered in the mid-Atlantic are still with us today. Despite the known dangers of climate change and the inevitability that we will one day run out of cheap and abundant fossil fuel energy, Americans have been able to make very few meaningful changes. Stepping into the mineral economy has so far proved easier than stepping out of it.

CONCLUSION

THERE WERE DEEP INTERCONNECTIONS between canals, anthracite coal, and the development of a mineral economy in the eastern mid-Atlantic. By transforming the geography of the region and initiating a supply-driven energy transition, canals played a crucial role in the development of America's first fossil fuel intensive region. Of course, canals did not act autonomously. Boosters, industrialists, consumers, scientists, and government officials shaped whether and when canals would be built, how they would be operated, and the ways people used anthracite. But focusing on transport infrastructure allows us to ask questions that we might not through an exclusive focus on energy production or consumption. In particular, it encourages us to look at issues of interest to enviro-tech scholars including time, use, and space.

One of the most salient characteristics of infrastructure systems is that they last a long time. David Edgerton has been correct to admonish historians of technology for their failure to grapple sufficiently with the full life-cycle of technological systems.[106] There has been an implicit assumption that the early stages are the most important and that the social consequences of technological systems emerge from the decisions of inventors and early adopters. This is not necessarily the case. The canals built along the Schuylkill and Lehigh rivers did not have the same social effects in the 1820s as they did in the 1840s or 1860s. The mineral economy did not emerge immediately in the aftermath of the first anthracite shipments. Instead, we can only retrace the shifting and uneven development of a fossil-fuel intensive society by examining change over a several-decade period. Canals, as technologies with particularly long life cycles, are particularly appropriate for this type of analysis.

Second, analyzing transport infrastructure encourages us to study technological systems in action. As I have shown throughout the essay, canals did not transform the energy practices of the nation through the simple act of their construction. The key process was a synergistic feedback loop that emerged between canals, canal managers, anthracite boosters, and users: canals helped make anthracite available in new places, boosters developed new applications for coal, users gradually increased their demand, and the canal network was steadily expanded to ensure that supply remained abundant. Looking at energy flows draws our attention to the dynamic interplay between technology and society; we get a richer picture of social change when we focus on technologies in use.

Finally, thinking about transport infrastructure draws our attention to the spatial dynamics of energy practices. Canals made new forms of energy available, but only to specific people and places. Residents of the mid-Atlantic reaped a disproportionate share of the benefits of anthracite coal. Within the region itself, the large eastern seaboard cities such as Philadelphia and New York gained the most from new energy supplies. However, the canal network did not serve large swaths of the eastern mid-Atlantic. Paying attention to transport infrastructure is a way to see the unequal geographic distributions of energy's costs and benefits.

Transport infrastructure is not only a topic for the past. Making a transition to renewable energy sources is one of the most pressing public policy questions of our day. However, one of the greatest constraints to the development of wind and solar power, particularly in America, is the lack of transmission wires to move electricity from those places where the wind blows hardest and the sun shines brightest to population centers. The story of anthracite coal canals suggests that we should pay as much attention to the transport of renewable energy as we do to its production. Furthermore, we should realize that the relative cheapness of fossil fuel energy is a product of years of investment in infrastructure systems: coal, oil, and natural gas are so cheap in large part because we have built canals, railroads, and pipelines to transport them long distances. If we were to invest in similar infrastructure for renewable energy systems, we might create a world in which sun and wind become much more cost-effective.

Will a transition to renewable energy sources, either taken proactively to minimize climate change or reactively once we have used up our cheap fossil fuels, constitute a return to an organic economy? Yes and no. We will once again need to derive our energy from the direct capture of the sun's energy. Our total energy supply will be limited based on our ability to tap into these flows. On the other hand, transforming wind and solar power into electricity offers the potential for the long-distance transport of organic energy sources. Therefore, a post-mineral economy will likely be a hybrid of these systems, creating new linkages between people, land, and energy. We can ask several questions about such a world. Will we continue the trend of establishing population and manufacturing centers far removed from sites of energy supply, or will future historians see it as a peculiar feature of our hydrocarbon age? Will we continue to live in a world where energy is cheap and abundant regardless of location? Or will this also be seen as an aberration from world historical patterns? Our choices about whether, how, when, and where to build energy transport infrastructure will go a long way toward determining the answers to these questions.

***Christopher Jones** is a postdoctoral fellow at the Harvard University Center for the Environment. His research studies the intersections of energy, technology, and the environment. He is currently working on a book manuscript studying the history of coal canals, oil pipelines, and electricity transmission wires in the American mid-Atlantic between 1820 and 1930.*

NOTES

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1. Anthracite refers to coal that contains a particularly high percentage of carbon—usually more than 85 percent. Anthracite coal is relatively rare—most of the

world's coal reserves are classified as bituminous, semi-bituminous, or lignite, each of which contains a decreasing percentage of carbon.

2. Michael Knies, *Coal on the Lehigh, 1790-1827: Beginnings and Growth of the Anthracite Industry in Carbon County, Pennsylvania* (Easton, PA: Canal History and Technology Press, 2001), 13-14.
3. *History of the Lehigh Coal and Navigation Company, Published by Order of the Board of Managers* (Philadelphia: William S. Young, 1840), 11.
4. More than a million tons of coal were shipped to Philadelphia each year after 1845, but much of this was transshipped to other ports. In 1860, Philadelphians likely consumed 1,134,00 tons of coal in addition to the amounts that were sent elsewhere. Richard G. Healey, *The Pennsylvania Anthracite Coal Industry, 1860-1902: Economic Cycles, Business Decision-Making and Regional Dynamics* (Scranton: University of Scranton Press, 2007), 71.
5. E. A. Wrigley, *Continuity, Chance and Change: The Character of the Industrial Revolution in England* (Cambridge: Cambridge University Press, 1988).
6. The literature on anthracite coal is vast. Among the most important works are: Alfred Dupont Chandler, "Anthracite Coal and the Beginnings of the Industrial Revolution in the United States," *Business History Review* 46 (1972): 141-81; Donald L. Miller and Richard E. Sharpless, *The Kingdom of Coal: Work, Enterprise, and Ethnic Communities in the Mine Fields* (Philadelphia: University of Pennsylvania Press, 1985); Thomas Dublin and Walter Licht, *The Face of Decline: The Pennsylvania Anthracite Region in the Twentieth Century* (Ithaca, N.Y.: Cornell University Press, 2005); Clifton K. Yearley, *Enterprise and Anthracite: Economics and Democracy in Schuylkill County, 1820-1875* (Baltimore: Johns Hopkins Press, 1961); Frederick Moore Binder, *Coal Age Empire: Pennsylvania Coal and Its Utilization to 1860* (Harrisburg: Commonwealth of Pennsylvania, Pennsylvania Historical and Museum Commission, 1974).
7. Works addressing the transport of anthracite coal include: Chester Lloyd Jones, *The Economic History of the Anthracite-Tidewater Canals* (Philadelphia: University of Pennsylvania Press, 1908); Anthony Brzyski, "The Lehigh Canal and Its Economic Impact on the Region through Which It Passed, 1818-1873" (PhD Dissertation, New York University, 1957); Knies, *Coal on the Lehigh;* Ronald Filippelli, "The Schuylkill Navigation Company and Its Role in the Development of the Anthracite Coal Trade and Schuylkill County, 1815-1845" (MA Thesis, Penn State University, 1966).
8. William Cronon's analysis of commodity flows shaping the development of Chicago and the Great West is an important inspiration for my work: William Cronon, *Nature's Metropolis: Chicago and the Great West* (New York: W. W. Norton, 1991).
9. The most thorough treatment of this topic is Wrigley, *Continuity, Chance and Change.* Other scholars have described systems similar to the organic economy using the language of a solar-agrarian regime (Sieferle), somatic energy regime (McNeill), or biological old regime (Marks): Robert Marks, *The Origins of the Modern World: A Global and Ecological Narrative* (Lanham, MD: Rowman & Littlefield, 2002); John McNeill, *Something New Under the Sun: An Environmental History of the Twentieth Century World* (New York: Norton, 2000); Rolf Peter Sieferle, *The Subterranean Forest: Energy Systems and the Industrial Revolution* (Cambridge: White Horse Press, 2001). Other scholars using organic and mineral economies include: Thomas G. Andrews, *Killing for Coal: America's Deadliest Labor War* (Cambridge: Harvard University Press, 2008); Richard Wilkinson, "The English Industrial Revolution," in *The Ends of the Earth*, ed. Donald Worster

(Cambridge: Cambridge University Press, 1988); John Landers, *The Field and the Forge: Population, Production, and Power in the Pre-Industrial West* (Oxford; New York: Oxford University Press, 2003); Paul Warde, "Fear of Wood Shortage and the Reality of the Woodland in Europe, c. 1450–1850," *History Workshop Journal* 62 (2006); and Vaclav Smil, *Energy in World History* (Boulder: Westview Press, 1994).

10. My dissertation extends this analysis to the operations of oil pipelines and electricity transmission wires in the mid-Atlantic: Christopher F. Jones, "Energy Landscapes: Coal Canals, Oil Pipelines, and Electricity Transmission Wires in the Mid-Atlantic, 1820-1930" (PhD Dissertation, University of Pennsylvania, 2009).
11. My description of organic and mineral economies is drawn heavily from Wrigley, *Continuity, Chance and Change*, and Sieferle, *The Subterranean Forest.*
12. In 1600, for example, Paul Warde estimates that wind and water power represented at most 1.5 percent of the total energy supply used by humans in England and Wales. Over 75 percent of the energy came from human muscles, animals, and firewood. Much of the remaining energy came from the isolated burning of coal in brewing and salt manufacturing. Paul Warde, *Energy Consumption in England and Wales, 1560-2000* (Rome: Consiglio Nazionale delle Ricerche (CNR), Istituto di Studi sulle Societa del Mediterraneo (ISSM), 2007), 60, 69.
13. Sieferle, *The Subterranean Forest*, 59.
14. Even canals, which were made by humans, not nature, usually followed the path of existing waterways.
15. Wrigley argues that Thomas Malthus's principle of population was a description of an organic economy. Malthus observed that an exponentially increasing population occupying a fixed quantity of land would lead to a diminishing quality of life because the limited number of goods would be split between more and more people. In essence, the pie was not going to get much bigger, but it would have to be divided into many more (and therefore much smaller and less satisfying) pieces. Adam Smith and David Ricardo largely agreed with Malthus in this regard: E. A. Wrigley, "The Limits to Growth: Malthus and the Classical Economists," *Population and Development Review* 14, Supplement: Population and Resources in Western Intellectual Traditions (1988).
16. The energy density of fossil fuels makes the development of transport infrastructure economically viable. Organic energy sources tend to be decentralized and lack the density necessary to justify extensive alterations of the built environment for their transport. Firewood is spread out over large forests in a relatively thin layer that would be less than four inches thick if distributed evenly. By contrast, coal seams are often found in deposits several feet thick with as many as 30 to 120 layers on top of one another. This means that the energy yield from a single place is at least 300 times (and often several thousand times) greater with coal than firewood. As a result, there is much greater incentive for capital investment in transport infrastructure with fossil fuels because the costs can be recouped through the high volume of traffic. Sieferle, *The Subterranean Forest*, 22.
17. Dublin and Licht, *The Face of Decline*, 11.
18. Most of the coal arriving from Britain could be sold cheaply because it was used as ballast by ships crossing the Atlantic. Coal from Virginia came from mines along the James River just north of Jamestown. As Sean Adams demonstrates, the slow development of the Virginia coalfields had much to do with the lack of investment in transport infrastructure in that state. Sean P. Adams, *Old Dominion, Industrial*

Commonwealth: Coal, Politics, and Economy in Antebellum America (Baltimore: Johns Hopkins University Press, 2004).

19. Philadelphia's population during these years was 28,522 in 1790, 41,220 in 1800, and 53,722 in 1810 according to the Census. Coal import numbers from: Howard Benjamin Powell, *Philadelphia's First Fuel Crisis: Jacob Cist and the Developing Market for Pennsylvania Anthracite* (University Park: Pennsylvania State University Press, 1978), 9, 24-25.
20. Carbon percentage numbers from Adams, *Old Dominion, Industrial Commonwealth*, 15.
21. These parties drew on knowledge of how to use anthracite coal developed in the anthracite regions. As early as the 1770s, several craftsmen and farmers in Wilkes-Barre and the Wyoming Valley were using anthracite in a variety of applications. Dublin and Licht, *The Face of Decline*, 11.
22. In general, anthracite boosters favored policies supporting the economic growth of the manufacturing sector advocated by figures such as Alexander Hamilton and Tench Coxe in contrast to a Jeffersonian notion of a nation of rural independent farmers. Many anthracite boosters saw the various motivations as complementary. Josiah White, future developer of the Lehigh Canal, articulated both civic responsibility and personal profit as motivators for developing a project on the Schuylkill River in 1810: "If I succeeded, it would lead to a similar improvement in the interior of Pennsylvania which would be of great public good. While the water power & the Falls would make it a profitable investment to me & fully as well as to invest my capital elsewhere." Josiah White, *Josiah White's History, Given by Himself* (Philadelphia: Press of G.H. Buchanan Company, 1909), 12-13.
23. Thomas Cooper, "Statement on Coal" from early nineteenth century, as cited in Powell, *Philadelphia's First Fuel Crisis*, 1.
24. Ibid.
25. Wrigley, *Continuity, Chance and Change*, 56. Powell, *Philadelphia's First Fuel Crisis*, 24, 99. George Rogers Taylor, *The Transportation Revolution, 1815-1860* (New York: Rinehart, 1951), 132-33.
26. For example, several Philadelphians founded The Society for Promoting the Improvement of Roads and Inland Navigation in the State of Pennsylvania in 1789. In 1808, Albert Gallatin, the Secretary of the Treasury, presented an analysis of existing transport systems in the United States and advocated further developments. In 1824, Philadelphians established The Pennsylvania Society for the Promotion of Internal Improvement in the Commonwealth. United States. Department of the Treasury, *Report of the Secretary of the Treasury, on the Subject of Public Roads and Canals* (Philadelphia: William Duane, 1808).
27. *Memorial of the Commissioners of the State of New York, in Behalf of Said State; Praying the Aid of the General Government in Opening a Communication between the Navigable Waters of Hudson River and the Lakes*, (Washington, DC: Printed by William A. Davis, 1816), 8.
28. United States. Department of the Treasury, *Report on Roads and Canals*, 123.
29. Josiah White, "English Industry" *The Democratic Press*, March 20, 1821, as cited in Norris Hansell, *Josiah White: Quaker Entrepreneur* (Easton, PA: Canal History and Technology Press, 1992), 56.
30. Philadelphians had hoped to develop the Schuylkill and Lehigh rivers since the eighteenth century in order to promote trade throughout the state. William Penn had envisioned a canal connecting the Susquehanna and Schuylkill rivers and David Rittenhouse and Robert Morris led a failed attempt in 1791 to implement

this plan. The Pennsylvania legislature passed at least seven acts authorizing the improvement of the Lehigh River before 1820, but none of these efforts succeeded (the years of these acts were 1771, 1791, 1784, 1798, 1810, 1814, and 1816). Filippelli, "Schuylkill Navigation Company", 3. Knies, *Coal on the Lehigh, 1790-1827*, 13.

31. Knies, *Coal on the Lehigh, 1790-1827*, 37-8.
32. This success was remarkable because almost all canals built during the antebellum era cost far more money and took far more time than expected.
33. The term "bear-lock" apparently was the response workers liked to give to curious passersby who asked what they were building, an early form of trade secrecy.
34. The Delaware River was navigable most of the year, although it was later improved with a canal to allow heavier coal boats to travel to Philadelphia.
35. White, *Josiah White's History*, 58-59.
36. The capital structure of the company made shares available to farmers, even if they had moderate incomes. Each share cost $50 and a person could subscribe with a down payment of only $5. Jones, *Economic History Anthracite Canals*, 126, 29.
37. In the same year, less than 140,000 tons of other goods were shipped down the river and fewer than 60,000 tons of goods were shipped upriver. Ibid., 149-54.
38. Stephen Girard purchased large blocks of stock and also financed a mortgage so that a section of the canal between Reading and Hamburg could be completed. Miller and Sharpless, *The Kingdom of Coal*, 34.
39. Richard Richardson, *Memoir of Josiah White. Showing His Connection with the Introduction and Use of Anthracite Coal and Iron, and the Construction of Some of the Canals and Railroads of Pennsylvania, Etc* (Philadelphia: J.B. Lippincott & Co., 1873), 59.
40. Goods shipped on canals cost on average 1.5 to 3.3 cents per ton/mile around 1830, versus 17.4 to 18.8 cents overland. As coal was shipped in bulk, its costs were usually on the lower end of the spectrum. Diane Lindstrom, *Economic Development in the Philadelphia Region, 1810-1850* (New York: Columbia University Press, 1978), 113.
41. "Report of the Committee of the Senate of Pennsylvania Upon the Subject of the Coal Trade," (Harrisburg: Henry Welsh, 1834), 81.
42. R. C. Taylor, *Statistics of Coal* (Philadelphia: J. W. Moore, 1855), 396.
43. Lehigh Coal and Navigation Company, *Report of the Engineers of the Lehigh Coal & Navigation Company, Who Were Appointed, on the Nineteenth Instant, a Committee on the Subject of an Expose of the Property of the Company* (Philadelphia: S. W. Conrad, 1826), 5.
44. Powell, *Philadelphia's First Fuel Crisis*, 24.
45. Taylor, *Statistics of Coal*, 405. Prices were typically $1 per ton higher in New York City and $2 per ton higher in Boston due to coastal shipping costs.
46. Jules Irwin Bogen, *The Anthracite Railroads; a Study in American Railroad Enterprise* (New York: The Ronald Press Company, 1927).
47. "Report of the Committee of the Senate of Pennsylvania Upon the Subject of the Coal Trade," 31.
48. Dublin and Licht, *The Face of Decline*, 12.
49. The canals, and later railroads, were frequently upgraded to increase their capacity. For example, the Lehigh Canal was expanded in 1827-1829, 1837, and 1841. The Schuylkill Canal was expanded in 1840 and 1846. These expansions allowed the companies to increase the boat capacity from around fifty tons to nearly two hundred tons. Jones, *Economic History Anthracite Canals*.
50. "Exposition," *Miners' Journal*, April 2, 1831.

51. Robert Roberts, *The House Servant's Directory: Or a Monitor for Private Families ...* (Boston: Munroe and Francis, 1827), 159-73. Italics in original text.
52. Priscilla J. Brewer, *From Fireplace to Cookstove: Technology and the Domestic Ideal in America* (Syracuse, NY: Syracuse University Press, 2000), 64.
53. Marcus Bull, *Experiments to Determine the Comparative Value of the Principal Varieties of Fuel Used in the United States, and Also in Europe and on the Ordinary Apparatus Used for Their Combustion* (Philadelphia: Judah Dobson, 1827). Marcus Bull was a scientist who was also an officer of the North American Coal Company.
54. "Fuel Savings Society," *Hazard's Register*, August 20, 1831.
55. Knies, *Coal on the Lehigh, 1790-1827*, 52.
56. In 1830, the total sales of coal in Philadelphia amounted to $308,400 according to a report by the Pennsylvania Senate. As anthracite was retailing at an average of $6.50 per ton this year, there were approximately 47,500 tons of coal in the marketplace. Assuming about 20 percent of this to be imported bituminous coal, that leaves about 40,000 tons of anthracite. Contemporaries observed that at least as much anthracite was being used in industry as in homes, which gives an estimate of about 20,000 tons of coal used in home heating. The population of Philadelphia City and County in 1830 was 188,797. Since one ton of coal could last a person for the winter, this gives an adoption rate of roughly 10 percent: "Report of the Committee of the Senate of Pennsylvania Upon the Subject of the Coal Trade," 43.
57. Binder, *Coal Age Empire*, 17.
58. Brewer, *From Fireplace to Cookstove*, 98.
59. A Boston physician reported in 1868 that 99 out of 100 homes in that city were heated by anthracite, and it is fair to assume that a similar ratio held in Philadelphia by 1860, given that anthracite was both cheaper and more easily available in Philadelphia. George Derby, *An Inquiry into the Influence Upon Health of Anthracite Coal When Used as Fuel for Warming Dwelling-Houses* (Boston: A. Williams and Co., 1868), 6.
60. A typical household of six people required about eight cords of wood for heating and cooking purposes. A cord of wood was a stacked pile of wood four feet wide, eight feet long, and four feet high. For estimates of fuel consumption see "Fuel Savings Society"; "Anthracite Coal, Versus Wood," *Hazard's Register*, November 15, 1834; Sean P. Adams, "Warming the Poor and Growing Consumers: Fuel Philanthropy in the Early Republic's Urban North," *Journal of American History* 95 (2008): 69-94.
61. Under good conditions in the nineteenth century, an acre of land could produce thirty cords of wood if clear-cut, and would take twenty years to regrow. With poor soil or indifferent forestry practices, the yield would likely be lower. Thus, an estimate of 1.5 cords of wood per acre, or two-thirds an acre for one cord of wood is a reasonable, if optimistic, estimate. Michael Williams, *Americans and Their Forests: A Historical Geography* (Cambridge: Cambridge University Press, 1989), 106.
62. In 1839, 84 percent of the 54,000 newly constructed houses were made out of wood. Ibid., 147.
63. New York City grew even faster during this period, with 942,292 people in 1870, 1,206,299 in 1880, and 1,515,301 in 1890.
64. Thomas Childs Cochran, *Frontiers of Change: Early Industrialism in America* (New York: Oxford University Press, 1981), 93.

65. Craig L. Bartholomew, Lance E. Metz, and Ann M. Bartholomew, *The Anthracite Iron Industry of the Lehigh Valley* (Easton, PA: Center for Canal History and Technology, 1988), 21-27.
66. The winner of Biddle's $5,000 prize was a man named William Lyman who hired Benjamin Perry from the Pentyweyn Iron Works in South Wales to run his forge. In addition, the Lehigh Crane Iron Company began operations under the leadership of David Thomas, who had worked under George Crane in Wales. Binder, *Coal Age Empire*, 65.
67. Bartholomew, Metz, and Bartholomew, *The Anthracite Iron Industry of the Lehigh Valley*, 52-53. The same year there were 219,674 tons produced from nearly 300 charcoal forges, or an average of around 730 tons per furnace. C. G. Childs, *The Coal and Iron Trade, Embracing Statistics of Pennsylvania* (Philadelphia: C. G. Childs, 1847), 23.
68. Philadelphia Convention of Iron Masters, *Documents Relating to the Manufacture of Iron in Pennsylvania* (Philadelphia: 1850), 96.
69. Three points of data give credibility to the estimate of 65 percent. First, in 1847, there was a total production of 151,331 tons of pig iron, and the entire industry was reported to have consumed 483,000 tons of anthracite. If roughly 300,000 tons were used to produce the pig iron, that leaves about 180,000 tons used in secondary processing, or an additional 60 percent. Second, in 1855, total pig iron production was 381,866 tons. Assuming that about half of this was made in the Lehigh and Schuylkill valleys (190,000 tons) this would have required 380,000 tons of coal. Based on analysis of canal shipments, the regions consumed about 639,825 tons of coal in iron production, leaving a balance of 259,825 tons, or 68 percent more. Finally, in 1860, total pig iron production was 519,211 tons, with an estimated 260,000 produced in the Schuylkill and Lehigh regions. About 885,000 tons of coal were consumed in the region, which leaves a balance of about 365,000 tons of coal used in secondary iron operations or a ratio of 70 percent more than in pig iron production. Bartholomew, Metz, and Bartholomew, *Anthracite Iron Industry*, 52-53; *Proceedings of the American Iron and Steel Association at Philadelphia, Nov. 20, 1873*, 51; Daddow and Bannan, *Coal, Iron, and Oil*, 698; "Henry Clay in Philadelphia," *Miners' Journal*, August 10, 1850. Childs, *The Coal and Iron Trade*, 24. Note: all antebellum statistical data must be read critically. The records are incomplete and often involved some amount of guesswork. The data presented in this paper has been gathered from several sources to provide as accurate an overall picture as possible.
70. Sieferle, *The Subterranean Forest*, 103.
71. Bartholomew, Metz, and Bartholomew, *Anthracite Iron Industry*, 6. Most iron plantations did not operate sustainably during this period. It was common to clear-cut the surrounding forest until one ran out of trees, and then move the furnace to a new site.
72. This was approximately 80 percent of the nation's total output of anthracite iron and 50 percent of the charcoal iron was being produced in Pennsylvania. Daddow and Bannan, *Coal, Iron, and Oil*.
73. Anthracite iron production in 1886 was 2,099,597 tons, with 459,557 tons of charcoal iron, and 3,806,174 tons of iron forged with bituminous and coke (Bartholomew, Metz, and Bartholomew, *The Anthracite Iron Industry of the Lehigh* Valley, 53).
74. Total production in the Lehigh Valley in 1864 was 214,093 tons of pig iron using 486,105 tons of anthracite. Ibid., 698. Area information from Lehigh Valley

Convention and Visitor's Bureau Home Page: http://www.lehighvalleypa.org/ [accessed September 18, 2008].

75. Brzyski, "The Lehigh Canal and Its Economic Impact", 711-22.
76. "Anthracite Coal Trade of the United States," *Hazard's Register*, July 16, 1831.
77. Secretary of the Treasury, *Report on Steam Engines* (Washington, DC: Thomas Allen, Printer, 1838), 156-67, 379. The total horsepower rating of these engines was 1860: Secretary of the Treasury, *Report on Steam Engines*, 156-67, 379. Atack et al. estimate the fuel efficiency of steam engines in the 1830s as 7.5 pounds of coal per horse-power hour. Jeremy Atack, Fred Bateman, and Thomas Weiss, "The Regional Diffusion and Adoption of the Steam Engine in American Manufacturing," *Journal of Economic History* 40 (1980): 295. Assuming the engines were operated 12 hours a day 6 days a week, the total consumption is estimated to be 25,863 tons.
78. Philadelphia Committee on United States Census 1870, *Manufactures of the City of Philadelphia. Census of 1870* (Philadelphia: King & Baird, 1872), 27. By the 1890s, Atack, Bateman, and Weiss argue fuel consumption of steam engines had declined to two pounds per horsepower-hour. In 1870, it was likely around 3 pounds. If the engines operated twelve hours a day, six days a week, the fuel consumption would be 278,969 tons (6 x 12 x 52 x (3/2000) x 49,674). Atack, Bateman, and Weiss, "Regional Diffusion of Steam Engines," 295.
79. The concentration of textile mills along falling water in the Carolina Piedmont followed a similar logic.
80. Oliver Evans, *The Abortion of the Young Steam Engineer's Guide* (Philadelphia: Printed by Fry and Kammerer, 1805).
81. The historical geographer D. W. Meinig notes that despite the persistent popular mythology of the small New England mill town tucked into nature, by the mid-nineteenth century "the dominant patterns of industrializing … America would come to resemble … Pennsylvania much more than the model mill towns of New England." D. W. Meinig, *The Shaping of America: A Geographical Perspective on 500 Years of History*, 4 vols. (New Haven: Yale University Press, 1986), vol. 2, Continental America, 1800-67, 397.
82. 1840 data from *Eighth Annual Report Made by the Board of Trade to the Coal Mining Association of Schuylkill County*, (Pottsville, PA: Benjamin Bannan, 1840). 1850 data from "Steam Engines in This Region," *Miners' Journal*, January 5, 1850, 4. 1865 data from Daddow and Bannan, *Coal, Iron, and Oil*, 726.
83. To illustrate this, a report on the North American Coal Company's fifteen horsepower steam engine in 1834 noted that it burned two tons of coal operating five hours a day. This implies that the engine was consuming fuel at the astounding rate of fifty-three pounds per horsepower-hour. Given that this was one of the first engines in mining operations, I assume that the efficiency improved over time. "Anthracite for Steam Engines," *Hazard's Register*, August 30, 1834.
84. In 1850, the 165 steam engines in the Schuylkill region had a total horsepower of 4,753. Assuming the engines were operated 16 hours a day, 6 days a week and had an efficiency rating of 8 pounds of coal per hour, the total consumption in the Schuylkill region would be about 95,000 tons (94,908 = [4,992 hours multiplied by 4,753 horsepower equals 23,726,976 horsepower hours multiplied by 8/2000]). Other anthracite regions produced 48 percent of the total output this year, although the other regions were mined by larger organizations needing fewer steam engines. Assuming that there were a third fewer steam engines per total production, this implies an additional coal consumption of about 60,000 tons for a total of 155,000 tons (58,754 = 95,000 multiplied by 48/52 multiplied by .67). In 1865, the

data is more straightforward. There were 792 steam engines in the entire industry rated at 41,453 horsepower. With estimated consumption of 7 pounds of coal per horsepower-hour, this suggests total consumption of 725,000 tons (724,267 = 4,992 hours multiplied by 41,453 horsepower multiplied by 7/2000). "Steam Engines in This Region."; Daddow and Bannan, *Coal, Iron, and Oil.*

85. "Pine Lands of New Jersey," *Hazard's Register*, July 25, 1829. In 1828, it was reported that the NYC fleet of steamers consumed 200,000 cords of pine per year and that Philadelphia's fleet used an additional 150,000 cords: Binder, *Coal Age Empire*, 91.
86. In 1831, the Lehigh Coal & Navigation Company was operating a steam vessel, *The Pennsylvania*, to haul coal barges up and down the Delaware River. During the 1830s, the Delaware & Hudson company gave free anthracite to companies experimenting with anthracite boilers, absorbed the costs of converting fireboxes and grates in New York City ferries, and supported efforts by entrepreneurs to develop marine boilers that would be fueled by anthracite. Binder, *Coal Age Empire: Pennsylvania Coal and Its Utilization to 1860*, 90-93.
87. *Thirteenth Annual Report, Made by the Board of Trade, to the Coal Mining Association of Schuylkill County*, (Pottsville: Benjamin Bannan, 1845), 8-9.
88. *LeBow's Review*, as cited in Binder, *Coal Age Empire: Pennsylvania Coal and Its Utilization to 1860*, 104-05.
89. Ibid., 111.
90. "Coke and Anthracite for Locomotives," *Miners' Journal*, May 25, 1850.
91. By 1854, the Reading had successfully converted 85 percent of their engines to use anthracite for fuel. G. A. Nicolls, "Anthracite Coal in Locomotives," *Miners' Journal*, January 27, 1855.
92. "Anthracite Coal," *Hazard's Register*, December 24, 1831.
93. Firewood consistently sold at prices that were higher than anthracite coal per heating value. In 1815, Jacob Cist noted that the average winter price of cordwood in Philadelphia was $7.00 per cord. In 1835, the Fuel Savings Society was selling wood at a discount cost of $4.40 per cord, which was considered half of the market price, to Philadelphia's poor (Sean P. Adams, "Warming the Poor and Growing Consumers," 80-81). Moreover, we can get a better sense of the change in average price if we track the markets for coal and lumber. If we assume that firewood prices followed the general trajectory of the lumber market, then we get clear evidence that coal steadily became more cost-competitive than firewood. Between 1820 and 1860, the indexed price of coal fell dramatically, from an index price of 100 to 42, a nearly 60 percent fall. Lumber markets, by contrast, fell only 10 percent during the same time period. White pine went from an index price of 91 to 81 and wooden staves for barrels went from 120 to 109. As the price of anthracite in 1820 ($8.20 per ton) was set to be competitive with other heating materials, over the course of the antebellum period coal gained a steady comparative advantage as its relative price to consumers fell much faster than wood (Anne Bezanson, Robert Davis Gray, and Miriam Hussey, *Wholesale Prices in Philadelphia, 1784-1861* [Philadelphia: University of Pennsylvania Press, 1936], 2:37, 167, 212).
94. Lindstrom, *Economic Development in the Philadelphia Region, 1810-1850*, 48, footnote 101.
95. Nationally, more than five times as much firewood was used in comparison with coal in 1860 (2,641 trillion BTUs from fuel wood versus 516 trillion BTUs from coal, the majority (279) of which came from anthracite). Schurr and Netschert, *Energy in the American Economy, 1850-1975: An Economic Study of Its History and Prospects*, 495-96.

96. In 1870, waterpower provided 75 percent of New England's power supply versus 25 percent for steam. David E. Nye, *Consuming Power: A Social History of American Energies* (Cambridge: MIT Press, 1998), 82.
97. Other seaboard cities including Boston, Baltimore, Providence, and New Haven also experienced some of the changes characteristic of a mineral economy during this period when coal was shipped along the Atlantic seaboard from Philadelphia and New York.
98. Miller and Sharpless, *The Kingdom of Coal: Work, Enterprise, and Ethnic Communities in the Mine Fields*, 46-50; Yearley, *Enterprise and Anthracite: Economics and Democracy in Schuylkill County, 1820-1875*, 31.
99. Lehigh data from Annual Reports of the Lehigh Coal & Navigation Company and Jones, *The Economic History of the Anthracite-Tidewater Canals*, 112. Schuylkill data from Miners' Journal, *Coal Statistical Register for 1870*.
100. Lindstrom, *Economic Development in the Philadelphia Region, 1810-1850*, ch. 6.
101. Miller and Sharpless, *The Kingdom of Coal: Work, Enterprise, and Ethnic Communities in the Mine Fields*, xxi.
102. Anthony Wallace, "The Perception of Risk in Nineteenth Century Anthracite Mining Operations," *Proceedings of the American Philosophical Society* 127 (1983): 99.
103. There were further distinctions between the distribution of benefits within cities and within the anthracite regions, which I do not have sufficient space to address in depth here. Clearly, the benefits of bringing coal to the surface benefited factory owners to a greater extent than workers, and mine owners profited more than miners. However, other judgments are more mixed. Fuel made up a greater percentage of the family budget for working families as opposed to the wealthy, so the relative cheapness of anthracite may have benefited laborers more than those with greater financial resources. Even though mining was dangerous work, it was attractive enough as a profession to draw tens of thousands of workers looking for a better life. Whether anthracite made their lives better or worse is not a question with a single answer.
104. Thomas Parke Hughes, *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore: Johns Hopkins University Press, 1983).
105. Donald Worster, *Under Western Skies: Nature and History in the American West* (New York; Oxford: Oxford University Press, 1992), ch. 4.
106. David Edgerton, *The Shock of the Old: Technology and Global History since 1900* (Oxford: Oxford University Press, 2007).