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Title: "Building a Landscape of Energy Abundance: Anthracite Canals and the Transformation of the Eastern Mid-Atlantic, 1820-1860"

Abstract

The construction of a network of coal-carrying canals transformed the society, economy, and environment of the eastern mid-Atlantic between 1820 and 1860. By making it possible to transport anthracite coal cheaply, reliably, and in great quantities, the canal network enabled the region's residents to consume massive amounts of fossil fuel energy for the first time. By using this coal in homes, iron forges, steam engines, and factories, people in the mid-Atlantic initiated a transition from living in an organic to a mineral economy. This shift in the relationships between land and energy would lead to the emergence of an energy-intensive, urban, and industrial society. This article integrates environmental history, history of technology, and business history 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.

"Building a Landscape of Energy Abundance: Anthracite Canals and the Transformation of the Eastern Mid-Atlantic, 1820-1860"

Between 1820 and 1860, anthracite canals transformed the eastern mid-Atlantic region. By allowing fossil fuel energy to be transported cheaply, reliably, and in great quantities, this canal network wrought structural changes in the relationships between land and energy that had shaped the region's early history. At the beginning of this period, all energy was derived from the land, either in the form of firewood, falling water, or food that fueled humans and animals. This limited the number of people who could live in a fixed area and provided constraints on where manufacturing enterprises could be located and their overall output. With the opening of the Lehigh Canal in 1820 and a network of similar canals soon afterwards, these limits to growth were lifted. Flush with abundant fossil fuel energy, residents of the eastern mid-Atlantic discovered new possibilities for urban growth, increases in manufacturing output, and dense concentrations of industry in a single location. Anthracite and canals did not simply lead to increases in fossil fuel consumption; they generated new patterns of social, economic, and environmental development.

The story of anthracite coal has been told many times.[1] In this essay, I shine fresh light on this important topic in two ways. The first is by emphasizing the transportation of coal. The vast majority of energy studies focus on production. While these studies have offered many benefits, they have underestimated the importance of transportation networks for triggering

[1] 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, no. 2 (1972), 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).

changes in how people got and used energy. In particular, I argue that the single most important factor shaping the emergence of a fossil fuel intensive society during this period was the development of energy transportation infrastructure.[2] Second, I demonstrate how anthracite coal flows initiated a widespread shift from an organic to a mineral economy in the eastern mid-Atlantic. The emergence of a mineral economy had wide-ranging consequences for the region, ultimately giving rise to an urban and industrialized society.

Geography is central to my analysis. This is a regional study of an area I am describing as the eastern mid-Atlantic. Essentially, this region includes the eastern half of Pennsylvania, eastern/southern New York, New Jersey, and northern Maryland. Three parts of the region get most of the focus in this essay. The first is the anthracite regions. Practically all of the eastern mid-Atlantic's fossil fuel reserves are located in a small area in mountainous northeast Pennsylvania (see map on page 15).[3] The second focus is on Philadelphia and New York, the key cities in the region. Because many of the changes were most apparent in Philadelphia, I often use the Quaker City to illustrate new patterns that emerged. The third part of the region is the canal network, which linked the anthracite regions to the seaboard cities thereby creating a new energy landscape. For those living within the borders of this energy landscape, anthracite coal transformed where they lived, how they worked, and the material basis of their society.

Technologies are not determinative, but they do exert a powerful shaping influence on the decisions societies make. The anthracite canal network did not force people to use fossil fuels nor did it guarantee that they would. However, by making coal cheap and widely available, the

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[2] 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).

[3] The anthracite regions are typically divided into the Southern, Northern, and Middle fields (the Middle field is often further divided into the Eastern and Western fields). The Schuylkill Region consists of the Southern field plus the Western Middle field. The Lehigh Region consists of the East end of the Southern field plus the Eastern Middle field. The Wyoming Valley region consists of the Northern field.

canals made fossil fuel energy extremely attractive. Once people saw the benefits of using fossil fuel, it set into motion a pattern that would be repeated throughout American history: large technological investments in infrastructure to transport fossil fuels created exponential increases in energy consumption at sites geographically separated from its production. In today's world, we are so accustomed to having energy available at any time and place that we forget this is not a natural or inevitable feature of the world we live in. Seeing the shifts that took place in antebellum America when canals broke the barriers between geography and energy use can give us a useful perspective on our contemporary energy practices.

Section 1: Organic and Mineral Economies

Between 1820 and 1860, residents of the eastern mid-Atlantic transitioned from living in an organic economy to a mineral economy. These concepts—organic and mineral economy—provide a useful way of understanding how the introduction of anthracite coal shaped social possibilities including how and where people lived and worked.[4] This section describes the differences between these systems, focusing on the role of fossil fuel energy in changing the relationships between land, energy, and society characteristic of an organic economy.

The defining feature of an organic economy is that land is the source of all products and resources. Humans can use the land in one of three primary ways: arable (raising crops), pasture (feeding animals), or forest (growing combustible materials).[5] All of the necessities and luxuries of human existence must be derived from one of these land uses. For example, most human

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[4] In this section I draw heavily on: E. A. Wrigley, *Continuity, Chance and Change: The Character of the Industrial Revolution in England*, (Cambridge: Cambridge University Press, 1988). The concept of a solar-agrarian regime, introduced by Rolf-Peter Sieferle, is complementary, and expresses similar ideas using different terminology: Rolf Peter Sieferle, *The Subterranean Forest: Energy Systems and the Industrial Revolution*, (Cambridge: White Horse Press, 2001).

[5] Fisheries provide an additional source of food and products. Sieferle suggests we think of fisheries as "virtual area": Sieferle, *The Subterranean Forest: Energy Systems and the Industrial Revolution*, 95.

societies have considered at least four things necessary for survival: food, clothing, lodging, and firing (heating and cooking). In an organic economy, food comes from arable (crops), pasture (meat), or forest (hunting and gathering) land. Clothing comes from arable (textiles), pasture (wool or leather), or forest (hides) land. Lodging (wood for housing material, firewood to operate kilns to make bricks, or wood supports for a stone house) and firing materials (wood for burning in stoves and ovens) come from forestland. The same relationship between land and goods occurs for non-essential or luxury products. Goods like iron and glass require significant amounts of forestland for charcoal or firewood. Regardless of the type of product, some amount of land is necessary for its supply.

This relationship between land and resources means that the carrying capacity of the land produces finite limits to growth. Increasing the amount of goods generated by society requires the cultivation of more land area or its more efficient utilization (the latter process being particularly difficult in an organic economy). For example, once one has optimized land yields, having more meat means devoting more land to pasture. In a sparsely populated society, this is not a problem. However, in a densely populated world, the pasture land must replace land being used for other purposes (a negative feedback loop). More meat means less of something else, and society must accept trade-offs. In essence, this is a Malthusian world.[6] The dependence on the carrying capacity of the land in an organic economy produces negative feedback loops and a zero-sum game of trade-offs.

[6] 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, no. Supplement: Population and Resources in Western Intellectual Traditions (1988).

Applied to energy, the relationship between land and resources of an organic economy has two important implications. First, the overall supply of energy is limited by land availability (either forestland for firewood or pasture and arable land to support humans and work animals). Energy can also be supplied by wind and water in an organic economy, but only in certain places and certain amounts. There is little that humans can do to increase its supply. Second, energy is local. Transporting energy in an organic economy is difficult and expensive. Sieferle notes that wood could only be economically transported overland 6-7 hours in any direction in nineteenth century Europe, and that its price doubled every 2-4 km it traveled.[7] River transportation was cheaper, but required both the trees and the site of consumption to be near navigable waterways. Water power was limited to a short distance from the banks of falling streams while wind power could not be transported at all.

The results of these conditions were that an energy-rich area, due to falling streams and productive farmland, might be located next to an energy-poor region with little chance for the two to share the resources. Therefore, in an organic economy, people moved to sites of energy abundance, rather than the opposite. Energy-intensive enterprises, such as ironworks, can only be located in rural regions where there are no competing demands for the land. An organic economy necessitates decentralized living and production patterns.

A mineral economy emerges when a society alters its relationships between land and resources. The key shift is fossil fuels which reduce the constraints on the land, thereby removing previous limits to growth. The negative feedbacks of an organic economy are replaced by positive feedback cycles that allow exponential growth and shifts in how and where people and industries are located.

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[7] Sieferle, *The Subterranean Forest: Energy Systems and the Industrial Revolution*, 59.

If we return to the four requirements of food, clothing, lodging, and firing, we can see how coal and fossil fuels replace the use of land to provide these necessities. For firing, coal provides a direct substitution for firewood in heating and cooking purposes. It makes more lodging possible when fossil fuel energy is used to make bricks or other building materials such as concrete. A mineral economy also enables the expanded production of luxury goods such as iron, other metals, and distilled spirits. When thermal energy is converted into mechanical energy, it creates new possibilities for transportation, production, and location of industries. Dense concentrations of people can live in centralized cities and be fed by fertilized fields that send food via mechanized transport to homes heated by fossil fuels.

These new uses of energy replace the negative feedback cycles of the organic economy with the synergistic growth patterns characteristic of the mineral economy. The Malthusian world is changed into a world where continued industrial growth is possible. Coal does not cause industrialization single-handedly, but it is an essential precursor for the process by altering the structural relationships between land and resources that made such growth impossible in an organic economy. There are, of course, limits to growth in a mineral economy based primarily on the exhaustibility of non-renewable resources like fossil fuels. However, these limits have not been faced yet so we have not learned what the effects of the end of cheap energy will be on global economic patterns.

Let us now return to the world of Philadelphia in the early nineteenth century and see how the introduction of anthracite coal was part of an early switch from an organic to a mineral economy for the eastern mid-Atlantic.

Section 2: Coal Canals and the Creation of a New Energy Landscape

In the beginning of the nineteenth century, Philadelphia and its hinterlands operated as an organic economy. Most of the city's business involved trade along the eastern seaboard and throughout the Atlantic world, where wind power on the open water enabled long-distance shipping. Manufacturing was a small component of the city's overall activity, largely concentrated on falls along the Schuylkill River. The city's heating and cooking fuel came mostly from firewood that was either cut near the city or floated down the Schuylkill and Delaware rivers at times of high water. Even though people had known there were large deposits of anthracite coal in Northeast Pennsylvania for several decades, the difficulty and expense of transportation precluded the development of an active trade. Simply put, the anthracite coal regions were not part of Philadelphia's hinterland.

In 1820, this began to change. Eastern Pennsylvanians developed a network of canals that linked Philadelphia and other eastern seaboard cities to the anthracite regions in Northeast Pennsylvania. The canals enabled coal to be shipped cheaply and in huge amounts, thereby creating an energy landscape of intensive energy flows for the eastern mid-Atlantic. This transformation of the built environment played a crucial role in enabling the emergence of a mineral economy. This section analyzes these developments by looking at the use of coal before 1820, the construction of the anthracite canal network, and the coal trade that developed over these routes.

Coal Before 1820

While Philadelphia's energy base before 1820 was characteristic of an organic economy, the city had been importing small amounts of coal for several decades before 1820, mostly from

Virginia, Britain, and Nova Scotia.[8] The primary users of the coal were manufacturers such as blacksmiths, nail smiths, brick kilns, distilleries, and the water works. However, the scale of the trade was modest. In 1784, Philadelphia imported around 500 tons of coal, just over 1,000 tons by the early 1790s, and around 3,000 tons per year by the 1810s.[9]

Over the first two decades of the nineteenth century, there were several attempts to introduce anthracite coal to Philadelphia. The existence of "stone coal" as anthracite was often called, had been known for a long time—as early as the 1770s its use was common in Wilkes-Barre and the Wyoming Valley. In 1792 a group of prominent Philadelphians formed the Lehigh Coal Mine Company to operate anthracite mines in the Lehigh Valley, but the company failed. Other entrepreneurs including George Shoemaker—a Colonel, early mine operator, and hotel operator—brought shipments of a few tons to Philadelphia in the early 1810s but had difficulty selling the coal because anthracite's high carbon content made it more difficult to light than bituminous.[10] When the British fleet cut off Philadelphia's coal imports during the War of 1812, Jacob Cist, a merchant and amateur scientist, had some success selling a few hundred tons of anthracite in Philadelphia. However, when the war ended and bituminous shipments resumed, his business dried up.[11] While none of these efforts was a commercial success, they did lay the groundwork for the later growth of the anthracite trade by introducing users to anthracite and overcoming some of the technical challenges involved in lighting it.

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[8] Much of the coal that arrived from Britain was only imported because it served as ballast on for ships crossing the Atlantic.

[9] 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, 24-5.

[10] The difference between anthracite and bituminous coal is that anthracite has a much higher percentage of carbon. This means that its heat content is much higher, but that it is also much harder to light. In order to get an anthracite fire going, it was often necessary to redesign furnaces and change kindling practices.

[11] Powell, *Philadelphia's First Fuel Crisis: Jacob Cist and the Developing Market for Pennsylvania Anthracite*.

In all these cases, the critical problem was the transportation of coal. Overland transportation was difficult and expensive. To move a wagon load of coal (about a ton and a half) from the Wyoming Valley to Philadelphia cost about $20 at the turn of the century, and a trip could only be justified if the wagon returned full of goods.[12] A common British metric was to assume that the price of coal would double every ten miles it was transported overland.[13] Transportation over water sources was much cheaper, but neither the Schuylkill or Lehigh rivers offered reliable navigation. Both rivers had significant stretches of rapids and shallow waters, and could only be navigated during "freshets" or periods of high water during the spring and fall.[14] The realities of transportation costs meant that under normal circumstances it was cheaper to ship coal 3,000 miles from Britain than 80-100 miles from the anthracite regions.[15] The prohibitive transportation costs meant that the anthracite regions remained effectively beyond Philadelphia's hinterland.

The Development of the Anthracite Coal Network

When anthracite promoters began addressing the challenge of transportation infrastructure in the late 1810s, they created the possibilities for a new energy landscape. The two most significant developments for the region's fossil fuel consumption were the improvements of the Lehigh and Schuylkill rivers. Philadelphians had hoped to develop these rivers since the eighteenth century in order to promote trade in agricultural and manufactured goods. William Penn had envisioned a canal connecting the Susquehanna and Schuylkill rivers

[12] Ibid., 99.
[13] Wrigley, *Continuity, Chance and Change: The Character of the Industrial Revolution in England*, 56.
[14] At these times of high water, local rivermen would guide arks (temporary wood barges) down the rivers loaded with products, sell the wood of the arks for lumber, and walk back upstream. Small amounts of coal could be shipped this way, but trade was significantly limited by the short shipping season and limited number of skilled rivermen.
[15] George Rogers Taylor, *The Transportation Revolution, 1815-1860*, (New York: Rinehart, 1951), 132-3.

and there was an effort led by David Rittenhouse and Robert Morris in 1791 to implement this plan.[16] There were at least seven acts of the Pennsylvania legislature authorizing the improvement of the Lehigh River before 1820.[17] However, due mostly to insufficient funds, none of these efforts improved either river sufficiently to allow regular trade.

The first successful effort to improve one of Pennsylvania's major rivers began in 1817 when Josiah White spearheaded work on the Lehigh River. White was a practical man who had gained experience with both river improvement and anthracite coal while operating an iron rolling mill at Philadelphia's Schuylkill Falls (about four miles north of the present Fairmount dam). At this location he built a dam across the Schuylkill 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 claimed that the bill gave White and his partners the privilege of ruining themselves.[18] White found others similarly skeptical. His former business partner even refused to lend him a horse to survey the Lehigh, and he and Hazard struggled to acquire capital. Eventually, they managed to raise $50,000 to support their efforts which allowed their enterprise to take root.

It was quite a surprise to many in Philadelphia, therefore, when the first shipments of coal began to float down the Lehigh River in 1820. White and his workers achieved this early

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[16] Ronald Filippelli, "The Schuylkill Navigation Company and Its Role in the Development of the Anthracite Coal Trade and Schuylkill County, 1815-1845" (M.A. Thesis, Penn State University, 1966), 3.

[17] 1771, 1791, 1794, 1798, 1810, 1814, and 1816 were the years of the various acts: 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.

[18] Ibid., 37-8.

success by creating a series of "bear-lock" gates across the Lehigh River.[19] These hydro-static gates allowed a stretch of high water to build up behind the dams. When it was released, a group of ark-boats (rafts of wood about 15 feet by 20 feet and capable of carrying about 70 tons of coal) could travel through the dam along the wave of high water until reaching the next dam, where the water would collect once again. Once the coal reached Easton, it was floated down the Delaware River to Philadelphia.[20] At Philadelphia, the coal was sold, and the arks were broken up to be 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 another load of coal.[21] 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 along the whole length of the river.[22]

In contrast to White's minimalist plan for the Lehigh River, the Schuylkill Navigation Company had much more ambitious plans. This company had been formed in 1815 with a capitalization of $500,000 to build a canal that would allow ascending and descending navigation along the Schuylkill River. The company was heavily supported by farmers along the river, who hoped that the improved navigation would give them easier access to Philadelphia's international grain trade and also lower the cost of goods shipped up the river.[23] The coal trade was an afterthought at first. In fact, as late as 1818, the company's directors hoped that the emerging

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[19] The term "bear-lock" apparently was the response workers liked to give to curious passersby who asked what they were building.

[20] 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.

[21] Josiah White, *Josiah White's History, Given by Himself*, (Philadelphia: Press of G.H. Buchanan Company, 1909), 58-9.

[22] Once the trade had been established, White replaced the bear-lock system with a full canal beginning in the late 1820s.

[23] 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. Chester Lloyd Jones, *The Economic History of the Anthracite-Tidewater Canals*, (Philadelphia: University of Pennsylvania Press, 1908), 126.

coal market might provide 10,000 tons of business per year.[24] By the time the work on the canal was finally finished in 1825 (ten years after construction began and after expenditures of $2.2 million), however, it was clear that coal would be the main article of trade.[25] The great majority of the boats traveling between Pottsville and Philadelphia would end up carrying coal, not crops.

Collectively, the Schuylkill and Lehigh canals constituted an important change to eastern Pennsylvania's built environment. Huge quantities of anthracite coal began to flow from the anthracite regions to Philadelphia and other seaboard cities enabling new patterns of energy consumption characteristic of a mineral economy. As can be seen from the table below, once people began to see the benefits of using coal, their appetite for mineral fuel grew at an exponential rate.

Table 1: Lehigh and Schuylkill Coal Shipments[26]

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

** denotes shipments from Schuylkill Canal plus Reading Railroad

The Wider Coal Distribution System

The Lehigh and Schuylkill canals were the pioneering developments that initiated a new landscape of energy flows between northeast Pennsylvania and the growing cities along the

[24] Ibid., 129.

[25] Practically every canal constructed over this time period took more time and money than expected. This makes the accomplishment of White along the Lehigh River that much more impressive.

[26] Data from: Jones, *The Economic History of the Anthracite-Tidewater Canals*, Miners' Journal, *Coal Statistical Register for 1870*, (Pottsville, PA: Miners' Journal Office, 1870).

eastern seaboard. Soon after their development, several other canals, and later railroads, were built to further extend this network. Collectively, these structures constituted a new built environment for the region that facilitated the emergence of the mineral economy.

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 60-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 New York harbor. 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 Lehigh Valley Railroad starting in 1838 and 1855, respectively. The Delaware, Lackawanna, and Western served the northern Wyoming field starting in 1853.[27]

The millions of dollars spent on infrastructure to move coal attest to the critical nature transportation played in the development of a fossil-fuel intensive society. Anthracite was the

[27] Jules Irwin Bogen, *The Anthracite Railroads; a Study in American Railroad Enterprise*, (New York: The Ronald Press Company, 1927).

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 transporting companies. From an economic perspective, the investments in the transportation of coal far outweighed the costs of mining it. For example, by 1834, over $9,750,000 was invested in transportation infrastructure (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).[28] Mining coal was comparatively easy; getting it to market was much harder and more expensive.[29] 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."[30]

Most importantly, these canals and railroads made it possible for millions of people along the eastern seaboard to obtain coal cheaply, reliably, and in ever-increasing quantities. As seen in Table 1 above, the total shipments of coal increased from thousands to hundreds of thousands to millions of tons of coal per year. At the same time, the price of coal began to drop significantly. Prices of imported bituminous coal in the 1810s were consistently between $8 and $10 per ton.[31] 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 had decreased to $4.50 by 1850.[32] Anthracite canals had created a new energy landscape—the built environment of the eastern mid-Atlantic region was now designed for fossil fuel consumption.

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[28] "Report of the Committee of the Senate of Pennsylvania Upon the Subject of the Coal Trade," (Harrisburg: Henry Welsh, 1834), 31.

[29] The difficulty of transporting anthracite coal can be contrasted with the British example. Although the development of canals and other waterway improvements facilitated the British coal trade, much of the coal was located near waterways, making it easier for this trade to be initiated.

[30] Dublin and Licht, *The Face of Decline: The Pennsylvania Anthracite Region in the Twentieth Century*, 12.

[31] Powell notes that Virginia coal was 30 cents per bushel (there were 28 bushels to a long ton, for a cost of $8.40) before the War of 1812 when short supplies pushed the price to $1 per bushel. Powell, *Philadelphia's First Fuel Crisis: Jacob Cist and the Developing Market for Pennsylvania Anthracite*, 24.

[32] R. C. Taylor, *Statistics of Coal*, (Philadelphia: J. W. Moore, 1855), 405. Prices were typically $1 per ton higher in New York City and $2 per ton higher in Boston.

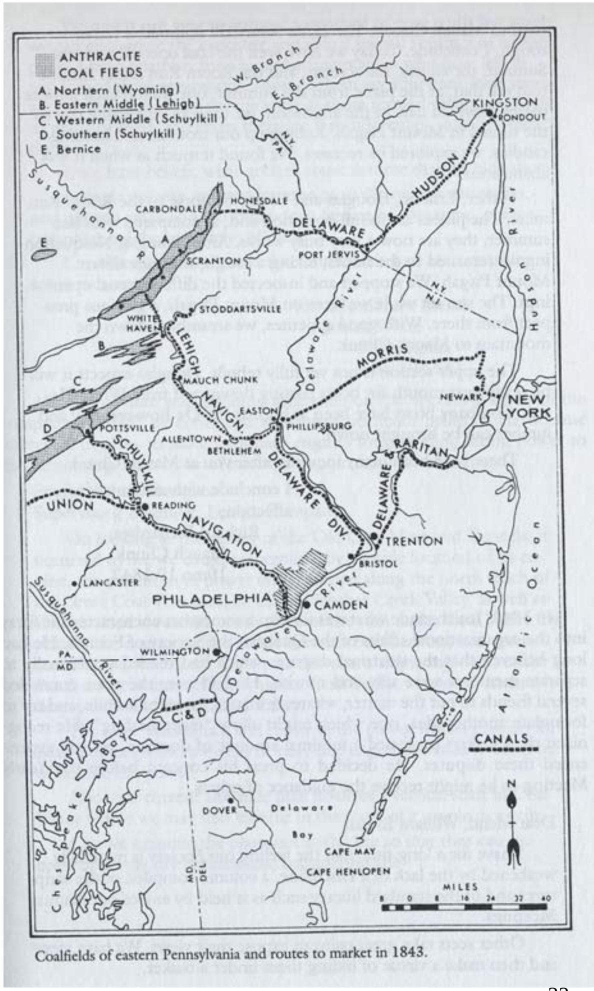

Figure 1: Map Showing Anthracite Canals[33]

Section 3: Consuming Coal, Creating a Mineral Economy

The investments in canals and railroads were necessary preconditions for the widespread use of anthracite coal in Philadelphia and along the eastern seaboard. However, the availability of coal did not dictate whether or how it would be used. Converting to any new fuel requires changes in technology, equipment, and social practices. As a result, the adoption of anthracite was not natural or inevitable. It was actively shaped by the region's boosters, including the

[33] Norris Hansell, *Josiah White: Quaker Entrepreneur*, (Easton, PA: Canal History and Technology Press, 1992), 131.

transportation companies, coal merchants, scientific societies, and philanthropic organizations.[34] These parties agreed with the British geologist William Buckland who stated "the presence of Coal is, in an especial degree, the foundation of increasing population, riches and power, and of improvement in almost every art which administers to the necessities and comforts of mankind."[35] By demonstrating the benefits of fossil fuel use, the region's boosters encountered little opposition.[36]

As eastern mid-Atlantic residents began using anthracite, they slowly 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 as an industrial fuel, 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.[37] 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 most importantly, constant growth without facing the limits of an organic economy.

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[34] Binder, *Coal Age Empire: Pennsylvania Coal and Its Utilization to 1860*, Sean P. Adams, "Warming the Poor and Growing Consumers: Fuel Philanthropy in the Early Republic's Urban North," *Journal of American History* 95, no. 1 (2008).

[35] As cited in C. G. Childs, *The Coal and Iron Trade, Embracing Statistics of Pennsylvania*, (Philadelphia: C. G. Childs, 1847), 9.

[36] While it is impossible to determine what the "average" Pennsylvanian thought of the developing coal trade, extensive reading in the literature finds remarkably little opposition to the coal trade. While increases in prices or perceived abuses by large corporations transporting coal drew negative attention, these attacks were directed at those parts of the trade that were thought to be unfair. In my readings through primary sources and periodicals, the value to the state and society of developing a coal trade was hardly ever questioned.

[37] The canals, and later railroads, were frequently upgraded to increase their capacity. For example, the Lehigh Canal was expanded in 1827-29, 1837, and 1841. The Schuylkill Canal was expanded in 1840 and 1846. These expansions allowed the companies to increase the boat capacity from around 50 tons to nearly 200 tons. Jones, *The Economic History of the Anthracite-Tidewater Canals*.

This section examines the consumption patterns of anthracite during the antebellum period in homes, iron manufacture, steam engines, and factories, studying how these practices came about, how much coal was involved, and how these new patterns initiated a shift to a mineral economy.

Home Heating

The most common use of anthracite coal was for heating homes. By the turn of the nineteenth century, eastern seaboard cities including Philadelphia, New York, and Boston were struggling to keep their burgeoning populations warm. Firewood had to be imported over longer distances at increasing prices. Several contemporary writers believed the dwindling firewood supply would soon present a limit to these cities' growth.[38] The availability of anthracite ensured that the limited carrying capacity of forestland would not constrain urban expansion.

The increasing price of wood and growing urban population made home heating a logical market for coal merchants. In Philadelphia, a poor family required at least 2.5 cords of wood to heat a small apartment while wealthy families often used more than 20 cords a winter.[39] On average, a typical household consumed around six to eight cords of wood for the year, as some wood was needed for cooking during the summer months as well.[40] As the average home in Philadelphia housed about six people, this meant that each resident consumed about a cord of wood each year.[41]

[38] "Exposition," *Miners' Journal*, April 2 1831.
[39] 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," *Hazard's Register*, August 20 1831, "Anthracite Coal, Versus Wood," *Hazard's Register*, November 15 1834, Adams, "Warming the Poor and Growing Consumers: Fuel Philanthropy in the Early Republic's Urban North."
[40] "Coal and Wood," *Hazard's Register*, October 10 1829, "The Economy of Heat," *Hazard's Register*, February 23 1833.
[41] According to the 1860 Census, the average number of persons per dwelling was 5.98 in 1850 and 5.64 in 1860.

However, the difficulty of burning anthracite was a significant hindrance to its adoption. Consumers had to invest in a specially designed stove or grate and alter their heating and cooking practices. Because burning anthracite in a stove meant abandoning the pleasant flame of an open hearth, many objected on aesthetic grounds. Anthracite boosters adopted several strategies to counter these difficulties. Scientists performed experiments demonstrating the superior heating qualities of anthracite.[42] The Fuel Savings Society, a philanthropic organization, contracted with the Steinhaur & Kisterbock company to build stoves costing only $5.50, making it cheaper for consumers to switch over.[43] Josiah White had his wife keep an anthracite fire burning in their Philadelphia home and allowed guests to see how it worked.[44]

By the end of the 1820s, their efforts were starting to succeed. No homes in Philadelphia were heated with anthracite before 1820, but by 1830 the consumption level was around 20,000 tons used in home heating, enough coal to heat roughly 10% of the population.[45] New York City was sufficiently dependent on anthracite that a shortage of supply in the winter of 1831 caused widespread alarm.[46] As people became more experienced using anthracite, purchased stoves, and saw that prices of coal continued to drop (both absolutely and in relation to firewood) the adoption rate increased 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

[42] 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).
[43] "Fuel Savings Society."
[44] Knies, *Coal on the Lehigh, 1790-1827: Beginnings and Growth of the Anthracite Industry in Carbon County, Pennsylvania*, 52.
[45] 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% 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%: "Report of the Committee of the Senate of Pennsylvania Upon the Subject of the Coal Trade," 43.
[46] Binder, *Coal Age Empire: Pennsylvania Coal and Its Utilization to 1860*, 17.

their home heating needs. 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.[47] New York City's 813,669 people most likely had a similar adoption rate. With a population of 565,529 in 1860, citizens of Philadelphia were likely burning between 500,000 and 600,000 tons of anthracite per year to keep warm with another 750,000 tons consumed in New York City.[48]

Anthracite burned in home heating facilitated a shift to the mineral economy by making it much easier for eastern seaboard cities to support large populations. Simply put, it would have been extremely expensive and difficult to heat this population with wood, and this constraint may have negatively impacted the growth of Philadelphia and other cities. For example, Philadelphia's 565,000 people in 1860 would have required about 850,000 cords of wood just to support their living needs. A measure of the sustainable yield of timberland under nineteenth century forestry practices is one cord of wood for every 2/3 of an acre.[49] Therefore, Philadelphia would have required a dedicated wood hinterland of 567,000 acres (~885 square miles or roughly 1/50th of Pennsylvania) to support the heating and cooking needs of its population.

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 that was near transportation facilities would have been more highly sought after as farmland. More likely,

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[47] 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.
[48] Even more anthracite was likely being consumed for home heating in New York City, where the adoption rate was lower but the population was greater.
[49] Under good conditions in the nineteenth century, an acre of land could produce 30 cords of wood if clearcut, and would take 20 years to re-grow. 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.

Philadelphians would have relied on the vast timber resources of Maine and North Carolina to fill the gap. However, the additional requirements 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 expansive since most American buildings were made out of wood at the time.[50] Therefore, being able to preserve trees for lumber versus firewood increased the supply of lumber and kept prices down. 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 zero-sum 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.[51] As a cheap heating fuel, anthracite removed a significant constraint to the growth of nineteenth century cities.

Iron Manufacture

The application of anthracite to iron production became one of the most important and revolutionary uses of coal during this period. It 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 not only had to provide heat, it needed to provide structural support in the furnace and remove 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, several efforts were undertaken to help solve the problems. The

[50] In 1839, 84% of the 54,000 newly constructed houses were made out of wood. Ibid., 147.
[51] 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.

Franklin Institute promoted gold medal prizes 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.[52] 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 who had recently discovered processes for making iron with anthracite.[53] Once anthracite was introduced as a fuel for iron production, the industry quickly took on the exponential growth of a mineral economy. While charcoal iron production would continue to increase in absolute terms during the middle decades of the nineteenth century, its relative share diminished rapidly as anthracite coal became the main smelting fuel. While no iron was forged with anthracite before 1840, within 7 years there were already more than 40 forges producing 151,331 tons of iron.[54] The explosive growth continued over the next decades, with total anthracite iron production exceeding charcoal iron in 1855. As shown in Table 2, the relative increase of anthracite iron production in a very short period of time was dramatic, with the decline coming from the share of iron produced by charcoal.

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[52] Thomas Childs Cochran, *Frontiers of Change: Early Industrialism in America*, (New York: Oxford University Press, 1981), 93.

[53] 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: Pennsylvania Coal and Its Utilization to 1860*, 65.

[54] 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), 52-3. The same year there were 219,674 tons produced from nearly 300 charcoal forges, or an average of around 730 tons per furnace. Childs, *The Coal and Iron Trade, Embracing Statistics of Pennsylvania*, 23.

Table 2: U.S. Iron Production (Tons) By Fuel Source, 1847-1864[55]

Year	Anthracite	% of total	Bituminous and coke	% of total	Charcoal	% 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

The iron industry consumed massive quantities of coal. Two tons of coal were needed for every ton of iron forged with anthracite. An additional quarter ton of coal per ton of iron was needed to power a steam engine if there was not water power to operate the furnace bellows. In addition, much of the iron was further processed into products such as rails, nails, and plates. These operations required additional heat—two tons of coal to roll or puddle iron and as many as eight tons of coal to forge steel.[56] At least half as much anthracite, therefore, was used after the initial iron was produced. For example, in 1847, a year for which good data exist, there was a total production of 151,331 tons of pig iron, and the entire industry was said to consume 483,000 tons of anthracite.[57] 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%. Assuming a similar ratio between production of pig iron and total anthracite consumption, more than a million tons of anthracite were used a year for iron production by the mid-1850s, and the number was nearly two and a half million by the end of the Civil War.

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[55] Bartholomew, Metz, and Bartholomew, *The Anthracite Iron Industry of the Lehigh Valley*, 52-3, 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 Press, 1960), 66, *Proceedings of the American Iron and Steel Association at Philadelphia, Nov. 20, 1873*, (Philadelphia: Chandler, 1873), 51. 1864 data from 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.

[56] Philadelphia Convention of Iron Masters, *Documents Relating to the Manufacture of Iron in Pennsylvania*, (Philadelphia: 1850), 96.

[57] Childs, *The Coal and Iron Trade, Embracing Statistics of Pennsylvania*, 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.

Table 4: Estimates of Anthracite Consumed in Iron Production, 1847-1864

Year	Pig iron made with anthracite	Coal used for pig iron production	Coal used in secondary iron processing (60%)	Anthracite used in iron industry (estimate)	All Anthracite Shipments	% of total
1847	151,331	305,000	180,000	485,000	2,882,309	17%
1854	339,435	680,000	410,000	1,090,000	5,831,834	19%
1855	381,866	760,000	455,000	1,215,000	6,486,097	19%
1856	443,113	885,000	530,000	1,415,000	6,751,542	21%
1857	390,385	780,000	470,000	1,250,000	6,431,378	19%
1858	361,430	720,000	430,000	1,150,000	6,524,838	18%
1859	471,745	940,000	565,000	1,505,000	7,517,516	20%
1860	519,211	1,040,000	625,000	1,665,000	8,143,938	20%
1864	684,519	1,370,000	820,000	2,190,000	9,998,046	22%

This coal consumption provides a clear example of the escape from limits provided by the mineral economy. Sieferle demonstrates that British iron production in 1820 had already exceeded the capacity of its total landmass if charcoal had been the fuel.[58] A similar dynamic began to appear in Pennsylvania during this period. A charcoal furnace in the early nineteenth century producing 300 tons of iron required a tree plantation of 9,000 acres for sustainable operations.[59] 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 output would have been 982,500 tons of iron. By 1860, forges in Pennsylvania produced 519,211 tons of pig iron with anthracite in addition to 278,331 tons with charcoal.[60] By 1869 the iron production of Pennsylvania from all sources exceeded the carrying capacity of the land. National iron production that year was approximately 1.9 million tons, about 1.25 million tons of

[58] Sieferle, *The Subterranean Forest: Energy Systems and the Industrial Revolution*, 103.
[59] Bartholomew, Metz, and Bartholomew, *The Anthracite Iron Industry of the Lehigh Valley*, 6. Most iron plantations did not operate sustainably during this period. The typical practice was to clear-cut the surrounding forest until one ran out of trees, and then move the furnace to a new site.
[60] This was approximately 80% of the nation's total output of anthracite iron and 50% of the charcoal iron was being produced in Pennsylvania. Daddow and 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*.

which were produced in Pennsylvania. Most of this (~800,000 tons) was anthracite iron.[61] The anthracite iron industry of the eastern mid-Atlantic clearly operated according to the dictates of a mineral economy.

It is also significant that 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 anthracite iron industry was that it had a new geographic logic. Charcoal forges required lots of land for fuel, thereby encouraging the development of a rural and decentralized industry. Its products were expensive because of the high transport costs from these rural locations. By contrast, the energy flows made possible by the anthracite canals 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. In addition, the canals provided cheap transportation for the finished iron, giving a cost advantage to anthracite iron. 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, there were 30 furnaces in the Lehigh Valley that used nearly 500,000 tons of coal to produce more than 200,000 tons of iron in an area about 730 square miles.[62] 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

[61] Anthracite iron production was 971,150, about 80% of which was produced in Pennsylvania. In addition, there were 392,150 tons made with charcoal and 553,341 with coke and bituminous. At least half of this production came from Pennsylvania. Ibid.

[62] Total production in the Lehigh Valley in 1864 was 214,093 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].

increased as well, with gains in grain, corn, oats, and dairying during the 1840s and 1850s.[63] Moreover, its coal output skyrocketed as well, as indicated in Table 1. The ability to increase multiple areas of economic activity at the same time without needing to decide between alternatives was a clear indication that canals were enabling many 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 where steam engines were used to transform the heat potential of coal into mechanical energy. By doing so, steam engines encouraged the shift to a mineral economy by separating sites of industrial activity from sites of energy production and allowed new flows of people and goods to emerge. This section looks at the impacts of steam engines used in manufacturing, coal mining, steam vessels, and railroads.

Because of the easy availability of coal, Philadelphians quickly adopted steam engines. There were between 60 and 80 steam engines in Philadelphia burning anthracite in 1831, while more were operating in New York City and on steamboats.[64] 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.[65] There is 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

[63] Anthony Brzyski, "The Lehigh Canal and Its Economic Impact on the Region through Which It Passed, 1818-1873" (Ph.D. Dissertation, New York University, 1957), 711-22.
[64] "Anthracite Coal Trade of the United States," *Hazard's Register*, July 16 1831.
[65] Secretary of the Treasury, "Report on Steam Engines," (Washington, DC: Thomas Allen, Printer, 1838), 156-67, 379.

capacity of 49,674 hp.[66] At first, the total coal consumption of these steam engines was modest. In 1838, the consumption was likely around 26,000 tons.[67] By 1870, the demand of steam engines had increase dramatically, to about 275,000 tons of coal per year.[68] The use of steam engines in manufacturing contributed to two of the shifts of the mineral economy. 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. Stationary steam engines separated the links between land and energy sources that had structured the locations of manufacturing enterprises in the organic economy. In an organic economy, mills and manufacturing establishments were concentrated along streams with falling water and places where abundant forest could provide heat. The creation of the giant textile mills at Lowell, Massachusetts is the quintessential example of this logic.[69] These locations usually provided cheap energy, but had the disadvantages of being distant from markets, workers, and suppliers. By providing a flexible form of power, steam engines gave energy-intensive enterprise the option to locate a plant in an urban location where workers, suppliers, and markets were nearby. Several industries, particularly textiles and metal-workers in the case of Philadelphia, took advantage of these opportunities and concentrated in cities. Similar to the ways that canals allowed the concentration of iron forges along their banks, steam engines allowed a dense concentration of

[66] Philadelphia Committee on United States Census 1870, *Manufactures of the City of Philadelphia. Census of 1870*, (Philadelphia: King & Baird, 1872), 27.
[67] 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 horsepower 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, no. 2 (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.
[68] 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 12 hours a day, 6 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, "The Regional Diffusion and Adoption of the Steam Engine in American Manufacturing," 295.
[69] The concentration of textile mills along falling water in the Carolina Piedmont followed a similar logic.

manufacturing enterprises in urban locations. Instead of moving manufacturing establishments to sites of energy, entrepreneurs moved factories to cities. In other words, the Philadelphia model replaced the Lowell model as the primary pattern of American industrial development.

Steam engines were also widely used in coal mining. As demand grew, miners had to dig further below the surface, which meant that water had to be pumped out and the coal had to be raised several hundred feet to the surface.[70] With coal directly available at the site of consumption, steam engines provided an effective solution. The growth of steam engines used in mining is documented most clearly in the Schuylkill region. The first steam engine was purchased by the North American Coal Company in 1833. By 1840, there were twelve engines in mining operations. A decade later, there were 165 steam engines in mining operations in the Schuylkill region and 320 used in all regions by the end of the Civil War.[71] Since the fuel supply was so cheap to the mining companies (they were fed with pulverized coal that couldn't be sold in markets) the steam engines were likely far less efficient than those in Philadelphia.[72] Extrapolating the data from steam engines in Schuylkill County to the rest of the industry, it is likely that around 150,000 tons of coal were burnt in 1850 and 725,000 by the end of the Civil War.[73] In other words, with the use of steam engines, the consumption of anthracite became an important part of its production.

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[70] During the first years of anthracite mining, most miners were able to mine coal seams near the surface, thereby avoiding expensive capital investment in power equipment.

[71] 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, 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*, 726.

[72] To illustrate this, a report on the North American Coal Company's 15 horsepower steam engine in 1834 noted that it burned 2 tons of coal operating five hours a day. This implies that the engine was consuming fuel at the astounding rate of 53 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*, Aug 30 1834.

[73] 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

Steam engines were also used in transportation, particularly for steamboats. 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, observers reported that the pine lands of New Jersey were being rapidly deforested for use in steam vessels and charcoal production.[74] The extensive use of anthracite coal in steam vessels really began at the beginning of the 1840s. There were only six steam vessels burning anthracite in the New York City area in 1831, but by 1845, the practice was well established. Philadelphians operated 35 steam boats consuming 45,000 tons of anthracite that year and boats in the New York harbor consumed an estimated 100,000 tons.[75] By the 1850s, over half the steamships in the US coastal trade burned anthracite, consuming around 250,000 tons annually.[76] Most of these boats were based in Philadelphia and New York.[77]

The other great transportation revolution of the antebellum era was the railroad. Anthracite boosters had great hopes for the use of anthracite in railroad locomotives, but this market would not develop as they hoped. This was a surprising result since one of the first

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% 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, 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*.

[74] "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: Pennsylvania Coal and Its Utilization to 1860*, 91.

[75] *Thirteenth Annual Report, Made by the Board of Trade, to the Coal Mining Association of Schuylkill County,* (Pottsville: Benjamin Bannan, 1845), 8-9.

[76] *LeBow's Review*, as cited in Binder, *Coal Age Empire: Pennsylvania Coal and Its Utilization to 1860*, 104-5.

[77] Western steamboats, particularly those on the Mississippi River, continued to burn wood for much of the nineteenth century due to the abundance of trees along the route.

American locomotives, the "Tom Thumb" of the Baltimore & Ohio Railroad in 1832, burned anthracite.[78] 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 or decrease the power output when the train was starting, stopping, or going up slopes. The higher maintenance costs associated with burning anthracite encouraged the B&O and other railroads to use other fuel sources (mostly wood). As late as 1850, many of the technical problems of burning anthracite in locomotives remained unsolved.[79] Even the Reading Railroad, the largest transporter of anthracite, largely burnt wood until the 1850s. In 1847, only 5% of their engines used anthracite, whereas 85% did by 1854 (consuming 50,000 tons per year).[80] Thus, the total market for anthracite coal in railroads never approached the demand from other sectors.

The use of coal in steam vessels enabled new patterns of transportation. Waterways were the main transportation conduits in the organic economy with wind and currents providing the main energy. Before the introduction of steam vessels, there were already large numbers of boats plying the coastal waters of the Atlantic seaboard and the interior rivers. In this sense, steam vessels simply enhanced existing patterns. However, steam vessels could do two things sailing ships could not. First, they could travel efficiently upriver against a current, thereby enabling new trade patterns to emerge. Previously, bulk agricultural goods were floated down in barges while only high-value goods such as mail, manufactured products, and passengers could justify the expenses of upstream shipment. Steam vessels made it possible for more reciprocal trade relations to emerge. Second, steam vessels were much less dependent on the weather. A

[78] Binder, *Coal Age Empire: Pennsylvania Coal and Its Utilization to 1860*, 111.
[79] "Coke and Anthracite for Locomotives," *Miners' Journal*, May 25 1850.
[80] G. A. Nicolls, "Anthracite Coal in Locomotives," *Miners' Journal*, Jan 27 1855.

steam vessel would not need to wait in port until a favorable wind, thereby making regularly scheduled services available.

Factory

The final category of anthracite consumption came from its use in heat-intensive enterprises. While the previous section described anthracite steam engines used to provide 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 a form of 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.[81]

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.

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, enough anthracite was being used to

[81] "Anthracite Coal," *Hazard's Register*, Dec 24 1831.

make a notable difference in the paths of Philadelphia's economic development. Diane Lindstrom noted that whereas abundant water power in New England encouraged the growth of textile mills focused on spinning and weaving, Philadelphia manufactures took a leading role in heat-intensive operations, including bleaching, dyeing, paper making, glass making, distilling, and metal-working.[82] As with steam engines, the use of coal in urban factories helped create a new geographical pattern of production and consumption centered in cities.

These collective social effects of burning anthracite in homes, factories, iron forges, and steam engines produced far-reaching changes to 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 places to live in and establish businesses that were independent of the natural characteristics of the surrounding 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 in coal, 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 exponential growth of population and manufacturing output that could be sustained over time by eliminating many of the natural limits that were characteristic of an organic economy. Mid-Atlantic residents had taken their first big steps towards a new relationship with land and resources characteristic of a mineral economy.

[82] Diane Lindstrom, *Economic Development in the Philadelphia Region, 1810-1850*, (New York: Columbia University Press, 1978), 48, footnote 101.

Section 4: Regional Differentiation

The previous sections demonstrated how the anthracite canal network created a new energy landscape and that residents of the eastern mid-Atlantic used coal in ways that shifted the society towards a mineral economy. However, it is important to realize that this new landscape was not a level playing field. Not everyone experienced the same shifts. Instead, the location of the canal network determined who had access to cheap energy, thereby structuring where it was used and what the regional effects were. This section examines how people lived in relation to the canal network—at the terminus in Philadelphia or New York, at the beginning in the anthracite regions, along the route, or not connected at all—influenced their experience of the emerging mineral economy. The most significant changes were felt in cities at the ends of canals followed 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 networks in Philadelphia and New York. These cities consumed the greatest amounts of coal in the widest array of uses and most quickly adopted the characteristics of a mineral economy.[83] Of the four major uses of anthracite coal described earlier in this chapter, all except iron production was most pronounced in seaboard cities. By 1860, the large majority of Philadelphians and New Yorkers were burning anthracite in their homes, and the cities' heat-intensive businesses relied on coal. Most of the steamboats burning anthracite were headquartered in Philadelphia and New York where they altered the trade possibilities for these cities. In addition, while Philadelphia was not a center of iron production, there was a significant industry processing iron into finished products. Overall, Philadelphia and New York had clearly

[83] 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.

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. There were sweeping social changes for residents of 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. However, I want to separate those social changes that were typical of other mining regions from those changes that were part of the emerging mineral economy. From this perspective, there were fewer shifts that took place in the anthracite region itself. In fact, much of the activity in the anthracite regions was characteristic of the organic economy. The main tools were pickaxes, wheelbarrows, wagons, donkeys, and canals. It is interesting to note that although the anthracite regions were supplying the raw material that would make the mineral economy possible, the production of coal occurred largely in the context of the organic economy.

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 experience some aspects of the mineral economy. As the industry matured and the coal above the water level had been mined, the expansion of the industry was dependent upon solving the problems of draining deep shafts and raising the coal hundreds of feet. Because of the amount of power involved, traditional power sources such as animals could not address this problem on a grand scale.[84] Steam engines, which were originally developed for this capacity in Britain, provided an effective solution. With the large-scale introduction of steam engines for mining, and later for railroads, anthracite mining took on the patterns of the mineral economy.

[84] Land was once again a limiting constraint. Draught animals required significant land area for grazing and for raising other food stock. This limited the possible number of animals that could be supported in the coal regions.

The regions along the paths of the canals experienced less change than either the coal regions or the cities. Between 1820 and 1840 only around 5 to 10% of the coal shipped along the Schuylkill and Lehigh canals was consumed along their length.[85] Even comparatively large towns along the paths, such as Reading, only had 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 to people in these towns. It was only with the introduction of the anthracite iron industry beginning in 1840 that the towns along the path become integrated into the mineral economy. As discussed previously, the production of iron with anthracite coal was characteristic of a mineral economy. For people living in towns such as Reading, Phoenixville, Bethlehem, and Allentown, the development of the anthracite iron industry ushered in a significant change to their local economies. The iron industry itself generated significant amounts of wealth for several decades 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 everywhere except the great iron works. As a result, the impacts of the mineral economy on ironworkers was profound, but much less so for the rest of the communities.

In the rest of the eastern mid-Atlantic region, there was very little experience of the mineral economy. The predominantly rural population experienced very little change in their daily lives. Their patterns were still governed by the organic economy, although the limits were hardly apparent and rarely mattered in a region where forests were still abundant. 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

[85] 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*.

near such streams and along waterways that would facilitate transportation to distant markets. 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.

Thus, the experience of these changes was significantly influenced by where people lived in relation to the paths of the anthracite canals. It is also important to note that these geographic shifts were not neutral. The distribution of costs and benefits accompanying these shifts favored those living in cities versus those living in the anthracite regions economically, environmentally, and physically.

Economically, the development of the anthracite industry benefited cities the most. In Diane Lindstrom's analysis of the relationships between Philadelphia and its hinterland, she notes that while all regions may have benefited from the development of an integrated economy, the urban core experienced the greatest gains. She demonstrates that Philadelphia had the fastest rates of population growth, the highest rates of return on investment, and captured the benefits of the transportation savings, which were usually passed on to consumers instead of producers.[86] 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 (coal) and towns along the paths of the canals (iron) on a single product 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 a scarred landscape in many locations. In addition, it produced large quantities of coal dust that settled on houses and fields and tainted drinking water supplies. And while most anthracite was burnt in urban locations, its high carbon content

[86] Lindstrom, *Economic Development in the Philadelphia Region, 1810-1850*, chapter 6.

mitigated the effects of smoke pollution. Anthracite smoke was far cleaner than bituminous smoke due to the lack of impurities in the coal. 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 suffocation through 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.[87] Workers in cities also experienced physical risks accompanying the rise of industrialization and steam engines, but 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.

Conclusion

The new energy landscape of anthracite coal not only initiated a shift into a mineral economy, it also laid the first stages for the region's dependence on fossil fuel energy. 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. At the dawn of the Civil War, the eastern mid-Atlantic had already begun to depend on ever-increasing supplies of fossil fuel energy. Without coal's continued availability, 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

[87] Anthony Wallace, "The Perception of Risk in Nineteenth Century Anthracite Mining Operations," *Proceedings of the American Philosophical Society* 127, no. 2 (1983): 99.

industries and people from urban centers. The free choices that people experienced about whether to adopt a new energy source in the 1820s and 1830s were no longer so free by 1860.

Two analytical concepts can help us make sense of this transition. In history of technology, Thomas Hughes introduced the concept of momentum to describe an important characteristic of technological systems.[88] 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 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. In environmental history, Donald Worster has introduced the idea of an infrastructure trap.[89] 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.

Fossil fuel consumption gained the momentum characteristic of an infrastructure trap in the eastern mid-Atlantic during this time. Technologically, 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 coal for heating and power purposes. 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 higher heating value of anthracite versus

[88] Thomas Parke Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*, (Baltimore: Johns Hopkins University Press, 1983).
[89] Donald Worster, *Under Western Skies: Nature and History in the American West*, (New York; Oxford: Oxford University Press, 1992), chapter 4.

firewood and its lower 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 was 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.

This path-dependent pattern of ever-increasing fossil fuel consumption in the mid-Atlantic continued throughout the rest of the nineteenth century with impacts that extended far beyond its borders. At a national level, the outcome of the Civil War was influenced by the geography of energy consumption. The fact that the eastern mid-Atlantic was contained almost exclusively in the North put the South at a significant economic and manufacturing disadvantage. Despite some coal flows into Maryland and modest coastal exports of anthracite to Charleston and New Orleans, the South operated as an organic economy.[90] The North benefited greatly from its ability to out-produce the South, particularly in metals. Moreover, the victory of the North gave legitimacy to the developmental model of the eastern mid-Atlantic. It encouraged other regions to develop policies, infrastructure, and practices that would allow them to access fossil fuel energy in the hopes that they would catch up to the eastern mid-Atlantic.

From a global perspective, one of the major transformations of the second half of the nineteenth century was the rise of America as an industrial power capable of challenging the traditional European powers. This economic development grew out of the antebellum experiences of the eastern mid-Atlantic. Simply put, America's exponential industrial growth

[90] This was not because the South lacked coal, but because suitable transportation infrastructure was not developed. For a comparative account showing the different policy choices regarding coal canals in Pennsylvania and Virginia, see: Sean P. Adams, *Old Dominion, Industrial Commonwealth: Coal, Politics, and Economy in Antebellum America*, (Baltimore: Johns Hopkins University Press, 2004).

would not have been possible within the negative feedback loops of an organic economy. Coal provided the energy base for this transition. As other regions followed the lead of the eastern mid-Atlantic, the geographical expansion of the mineral economy enabled the United States to become a global industrial power, thereby rearranging international relationships.

It is well known that Philadelphia played an important role in establishing long-standing patterns of the American governance by hosting the signers of the Declaration of Independence and Constitutional Convention during the 18th century. No less than that, the city's active role in stimulating the development of the anthracite canal network was critical in establishing long-standing patterns of American fossil-fuel dependence. By pioneering the development of coal transportation infrastructure, Philadelphia initiated a pattern of fossil fuel adoption that would be replicated throughout the nation and the world up through the present day.

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