The Schola

A Quarterly Journal
Humanities and Social Sciences
Young Scholars Worldwide

3

III

Volume 3 | Issue III | September 2019

ISSN 2508-7835

The Schola | Volume 3 | Issue III | September 2019

Editor: Eva M Shin
Publisher: Veritaum
Editorial contact: editorial@theschola.org
Cover design: Leo Solluna

This issue was typeset on a MacBook Air, using Microsoft Publisher.

For further information on *The Schola*, visit our website: www.theschola.org.

CONTENTS

Volume 3 | Issue III | September 2019

The Schola | Volume 3 | Issue III | September 2019

History

How Coal and Coal Technology Made Britain the World's First Global Superpower

Caroline Schlossel '20
The Spence School
New York, USA

Abstract

Three characteristics define a global superpower – economic might, military power, and the projection of values that others are willing to embrace. Without the first two (hard power), the third (soft power) is generally inconsequential. Using this framework, only two nations have attained superpower status – the United Kingdom and the United States. But what drives hard power? This paper will argue that the economic and military capabilities necessary to reach superpower status require access to abundant energy reserves and the technological abilities to transform these natural resources into mechanical energy; more broadly, the advancement of human civilization is inextricably tied to access to and development of, ever-increasing powerful energy sources.

Introduction

By 1900, Britain's empire comprised 12 million square miles of land (24 percent of the world) on which lived 440 million people (25 percent of the world's population); in just the prior three decades Britain added an astonishing 4.25 million square miles of land mass and 66 million people.[1] The Queen of England was the Empress of India,[2] and Britain exercised unprecedented global influence. As the beneficiary of

[1] Paul Kennedy, *The Rise and Fall of the Great Powers* (New York: Vintage Books, 1989), 224-26.
[2] Ibid., 226.

immense coal[3] reserves, Britain was fortunate to have been at the intersection (and in many ways pioneered) of the energy movement from the Agricultural Age (human/animal energy) to the Fossil Fuel Age, with a large population and societal and legal structure that facilitated the advancement of coal technology and commerce. This post-Agricultural Age energy-dynamic drove unprecedented industrial-based economic growth, and facilitated the development of a powerful military whose speed and command structure helped manage the world's largest-ever hegemony; Britain had become the world's first superpower.[4]

Energy history demonstrates a strong correlation between a society's advancement, its increasing use of more powerful and dense energy resources, and the technological ability to efficiently convert them

[3] Coal, along with oil and natural gas, is a fossil fuel (high carbon-content natural fuels formed in the geological past from remains of living organisms, including plants and animals). There are four types of coal, each possessing varying degrees of heat and carbon content: (1) lignite - the lowest quality, has the lowest heat and carbon content, and when burned emits the most pollution (due to sulfur content; note that coal does not only produce carbon dioxide, a greenhouse gas, when burned, but the sulfur in coal also creates pollution, and is a cause acid rain) of all coals; (2) sub-bituminous - the second most powerful in terms of heat and carbon content (lignite and sub-bituminous are "soft" coals and often referred to as "thermal" coal used for generating heat but do not possess the requisite chemical components for iron making (i.e. "metallurgy") that are found in "metallurgical" coal; (3) bituminous - a hard coal and superior to soft coal in terms of heat and carbon content, can be used for heat generation but its carbon content make it ideal for metallurgy; and (4) anthracite - has the highest heat and carbon content by a substantial margin, but is extremely rare, and not a material part of global coal consumption. (Roy L. Nersesian, *Energy Economics, Markets, History and Policy* (New York: Routledge, 2016), 155-56).

[4] A Superpower "has the capacity to project dominating power and influence anywhere in the world." (Lyman Miller, "China an Emerging Superpower?" *Stanford Journal of International Relations* (Winter 2005). https://web.stanford.edu/group/sjir/6.1.03_miller.html.) Such power requires preeminent economic and military strength ("hard power"), as well as political and cultural influence. (Ibid.) Cultural influence, often referred to as "soft power," reflects how a nation's political value system (i.e. democracy and freedom), foreign policy, language, and typical culture is received and, in some cases, adopted abroad. (Joseph Nye. Jr., *Soft Power, The Means to Success in World Politics* (New York: Public Affairs, 2004), 5-14.) Nye notes that soft power can be defined as "getting others to want the outcomes you want" through co-opting rather than coercing, and "rests on the ability to shape the preferences of others." (Ibid., 5.) Naturally, a nation's values can only be influential if such nation lives up to them, and where "they are seen as legitimate and having moral authority." (Ibid., 6). Economic and military power form the pillars of superpower-status, and the two are often intertwined; military power in isolation is not possible without a strong industrial base and tax revenue, and "military power is usually needed to acquire and protect wealth." (Kennedy, *The Rise and Fall of Great Powers*, xvi.)

into "heat, light, and motion."[5] Self-sufficiency in natural resources, including food, is also important to increasing national power as reliance on others reduces influence.[6] Energy resources are arguably more important than agriculture, as they are required for industrial production and waging modern warfare.[7] During the Agricultural Age, natural resources played a subordinate role in ascertaining power; but, as warfare became dependent on industrialization, control of raw materials (coal and iron) became critical.[8] The development of heavy industries became indispensable once warfare depended increasingly on larger, faster ships, and advanced weaponry.[9]

Based on these criteria, only two nations have reached undisputed superpower status – Britain (nineteenth century) and America (twentieth century); their pathways were analogous. Britain was propelled into superpower status based primarily on coal reserves and the development of coal technology that facilitated access to low-cost, powerful energy to drive industrialization and military strength. The US replaced Britain with a similar energy-dynamic – even larger coal reserves, but more critically on dense oil reserves, and its ability to develop oil technologies, including the internal combustion engine and refining techniques. These drove economic and military capabilities to even higher levels.

Britain – The First Fossil Fuel Energy Power

Before the Coal Age, food facilitated limited mechanical energy through muscle movement, and biomass (wood) provided warmth, facilitated protein intake (cooked meat), and made possible basic iron smelting for tools and weapons, requirements for material economic expansion were lacking.[10] Growth was limited by energy supply

---

[5] Vaclav Smil, *Energy and Civilization: A History* (Cambridge: MIT Press, 2017), 1. Energy density is "the amount of energy per unit of mass of a resource." (Ibid., 9.)
[6] Hans J. Morgenthau, *Politics Among Nations, The Struggle for Power and Peace* (New York: Alfred A. Knopf, 1963), 113; Michael Beckley, *Unrivaled, Why America Will Remain the World's Sole Superpower* (Ithaca: Cornell University Press, 2018), 7, 56-58. Negative changes in agricultural output in the Near East and North Africa during the Agricultural Age relegated these geographies from power centers to third-rate powers. (Morgenthau, *Politics Among Nations, The Struggle for Power and Peace*, 114.)
[7] Morgenthau, *Politics Among Nations, The Struggle for Power and Peace*, 114.
[8] Ibid., 115-17.
[9] Ibid.
[10] E. A. Wrigley, "Energy and the Industrial Revolution," *Philosophical Transactions: Mathematical, Physical and Engineering Sciences*, 371, no. 1986 (March 13, 2013), 2. https://www.jstor.org/stable/23364180.

constraints.[11] Classical economists of the pre-Industrial Age, including Adam Smith, argued that expansion must be limited due to land restraints and growth suitable for agriculture; agricultural raw materials and products were not just food for population growth and animals that supplied wool, leather, and protein, but included wood for heat and charcoal for metallurgy.[12] Despite increasing efficiencies, limits on productivity led to decreasing returns on labor and capital; economic growth in "organic" economies hit asymptotic ceilings.[13]

The emerging coal revolution did not rely upon photosynthesis and land to drive economic production; timber shortages and costs no longer created asymptotic restraints. Britain, with its new energy capabilities, and the societal foundation to facilitate innovation, would soon dominate global economic growth and productivity.[14] Access to "cheap" energy transformed Britain into an accelerating "mineral economy."[15] As the world entered the Fossil Fuel Age, a new dynamic of "natural resource crescents"[16] would define economic growth, living standards, and superpower status starting around 1700.

While the Magna Carta (1215) codified natural rights, the Glorious Revolution (1688) established private property rights, a foundational component of the Industrial Revolution[17] facilitating free enterprise. Britain was unknowingly prepared for the soon-to-arrive coal-

---

[11] Ibid. Agricultural practices eventually faced limits on efficiencies and yields. photosynthesis captures only 0.1 to 0.4 percent of the solar energy that reaches Earth, and fertile land is finite. (ibid.)
[12] Ibid., 2-3.
[13] Ibid., 3.
[14] Tombs, *The English and Their History* (New York: Vantage Books, 2016), 377; Niall Ferguson, *Empire, The Rise and Demise of the British World Order and the Lessons for Global Power* (London: Basic Books), 215-21.
[15] Tombs, *The English and Their History*, 382.
[16] During the Agricultural Age, those global regions most naturally conducive to agricultural production are referred to as "fertile crescents." They were characterized by similar climates, soil quality, biodiversity, and elevation changes. These agricultural "crescents" encompassed geographical zones 2,500 miles north and south of the equator between 30 degrees and 40 degrees latitude. Even today, China and one-half of the US, which fall into this region north of the equator, are the world's largest wheat producers. Domestication of animals that facilitated agricultural production (i.e. animal energy used for plowing and transporting products) also happened much more frequently within fertile crescents. (Manfred Weissenbacher, *Sources of Power, How Energy Forges Human History*, Vol. One, *Before Oil: The Ages of Foraging, Agriculture, and Coal* (Santa Barbara: Praeger, 2009), 150-51.) "Natural resource crescents," with large coal, oil, and natural gas deposits, developed hundreds of millions of years ago in even narrower regions than fertile crescents.
[17] Robert C. Allen, *The British Industrial Revolution in Global Perspective* (Cambridge: Cambridge University Press, 2009), 5.

driven economic opportunities.[18] Coal did not simply appear as the Agricultural Age ended in 1750. Romans used it for jewelry,[19] heating, and blacksmith furnaces while occupying Britain.[20] For millennia, wood was the dominant energy source for heating and metallurgy[21] because coal was easily accessible at or near the surface;[22] it was in short supply, smelly, dirty, and was believed unhealthy.[23] As wood demand accelerated,[24] forest excavation continued for firewood, construction materials, and agricultural production.[25] The bubonic plague, starting in the mid-1300s A.D.,[26] ended wood's surge for 150 to 200 years as Britain's population was cut in half, driving down energy demand. Wood supplies had an opportunity to replenish.[27]

When the plague ended by the mid-1500s, Britain's population again increased along with economic activity, leading to new timber shortages and rising prices. Two specific factors drove this dynamic beyond agricultural demand – Britain's wool industry expanded rapidly, encouraging landowners to remove trees for sheep pastures, and growing iron demand facilitated increasing charcoal demand.[28] Charcoal is almost pure carbon[29] with far higher energy density than wood,[30] and responsible for nearly all metallurgy until the Coal Age.[31]

---

[18] Niall Ferguson, *Empire, The Rise and Demise of the British World Order and the Lessons for Global Power* (London: Basic Books), 206-08. The foundation of soft power that Britain possessed was their highly confident belief that they were special people whose pioneering political, economic, and cultural framework should be spread.
[19] Barbara Freese, *Coal, A Human History* (New York: Basic Books, 2016), 15.
[20] Ibid. 15-16.
[21] Ibid., 25. At this time, wood was being used and was being utilized by blacksmiths and beer brewers. (Ibid.)
[22] Ibid., 21.
[23] Ibid., 24. It is believed that when Queen Eleanor was visiting Nottingham, the major British coal-producing town, in 1257, she left because she could not bear the smell of coal-produced smoke, and was afraid for her health. (Ibid.) The environmental movement may have started in 1285 when Britain established commissions to address coal smoke. (Ibid., 25.)
[24] Ibid., 26.
[25] Ibid.
[26] Ibid., 26-27. It is believed the bubonic plague (a bacterium that is spread by infected fleas) originated in Asia and had already ravaged populations in Asia, India, and the Middle East before it arrived in Europe (Sicily) by boat in 1347 A.D. (Ibid.)
[27] Ibid., 27.
[28] Weissenbacher, *Sources of Power,* Vol. One, 157-61, 192. At this time, wood was the primary raw material for many uses, including heating, shipbuilding, glassmaking, homebuilding, and furniture. (Ibid; Freese, *Coal, A Human History*, 31.)
[29] Thomas J. Straka, "Charcoal as a Fuel in the Ironmaking and Smelting Industries," *Advances in Historical Studies* (March 21, 2017), 58. In contrast, wood is composed of only 50 percent carbon. (Ibid.) To make charcoal, wood is piled into stacks, and covered by leaves, straw, and earth to keep air out, but some holes are cut to facilitate minimal ventilation; a fire is then started within the pile, not to burn the wood, but to

Basic iron production requires heat of 700 degrees Celsius.[32] While wood burns at 600 degrees, charcoal reaches 900.[33] In addition, carbon is the primary chemical required to make iron.[34] Charcoal satisfies these two requirements more efficiently than wood.[35] As populations grew and economic activity increased, iron demand accelerated; wood supplies could not meet demand; timber costs accelerated and[36] coal filled the void.[37]

Coal's higher carbon content facilitates superior iron production.[38] As when wood is heated to make charcoal, coal is heated to make "coke."[39] The replacement of wood (charcoal) with coal (coke) is considered one of history's greatest inventions,[40] By the mid-1700s, British technological advances increased coke's power equivalent to 7,000 times higher than charcoal's power.[41] Metallurgical coke facilitated two critical transformations – reducing reliance on wood and allowing for substantially larger furnace capacity. This means higher absolute

---

heat the wood at very high temperatures. The heat changes the composition of the wood by removing impurities. (Ibid., 57.) While modern societies moved to the more powerful and energy dense coal fossil fuel starting in the mid-1700s, charcoal remains a critical fuel source in many developing economies, along with basic wood. There are significant carbon emissions in charcoal's initial production process, as well as when burned, just like fossil fuels. (Ibid.)

[30] Weissenbacher, *Sources of Power*, Vol. One, 84.

[31] Ibid.

[32] Ibid.

[33] Ibid.

[34] Ibid.

[35] Ibid., 84-86. Unfortunately, charcoal production is inefficient; only 20 percent of wood weight is recovered as charcoal. (Ibid., 86.)

[36] Ibid., 193.

[37] While coal emits 29 percent more carbon dioxide than oil, and 68 percent more than natural gas, for the same amount of energy expended, coal and wood emit approximately the same amount of carbon dioxide even though coal is far more powerful and dense than wood. (Nersesian, *Energy Economics, Markets, History and Policy*, 77-78, 328.)

[38] Vaclav Smil, *Energy: A Beginner's Guide*, 2nd ed. (London: Oneworld Publications, 2017), 20, 105-06.

[39] Weissenbacher, *Sources of Power*, Vol. One, 194-95.

[40] While there is evidence China was involved in some level of rudimentary "coking" in the fourth century A.D., the advanced processes were invented in Britain in the early eighteenth century. (Smil, *Energy and Civilization*, 234.) The invention of coking is often credited to Englishman Abraham Darby in 1709. (Ibid.)

[41] Vaclav Smil, *Power Density: A Key to Understanding Energy Sources and Uses* (Cambridge: MIT Press, 2016), 4.

production capacity and increased productivity,[42] eliminating Britain's reliance on iron imports when domestic wood supplies fell;[43] national power and global influence accelerated.[44]

Compared to "fertile crescents," the Coal Age formed in narrower geographic regions possessing substantial coal deposits and charcoal-driven metallurgical technology.[45] Despite its smoke and smell, coal was two to five times less expensive than wood and far more powerful; it soon became welcome in British homes. By the 1620s, coal was widely used by the rich and poor,[46] reigniting environmental concerns. Queen Elizabeth in 1578 had been "greatly grieved and annoyed with the taste and smoke of [coal]," and in 1661 one of the first books (called *Fumifugium*) addressing coal environmental issues was published.[47] Yet, even though most citizens believed coal smoke might eventually kill them, they were more concerned with immediate death from cold weather.[48] By 1620, coal surpassed wood as the primary source of British heat generation.[49]

Industries increasingly recognized coal's compelling alternative - lower costs and higher output.[50] But heat energy independent of mechanical energy[51] could not drive exponential growth.[52] The only known mechanical energy had been provided by human and animal

---

[42] Smil, *Energy and Civilization*, 234. To move to coal from wood also reduced the iron industry's reliance on building furnaces near forests, which limited productive capacity. (Ibid.)
[43] Smil, *Power Density*, 4.
[44] Morgenthau, *Politics Among Nations, The Struggle for Power and Peace*, 115.
[45] Weissenbacher, *Sources of Power*, Vol. One, 235.
[46] Freese, *Coal, A Human History*, 33., 41-42. Staying warm generally trumped air quality; the invention of the chimney, allowing smoke to be directed out of the home, helped facilitate coal's acceptance. (Ibid.)
[47] Ibid., 34-35. The author was a Britain named John Evelyn. Evelyn blamed coal for London's grey sky, incessant coughing, and resident spitting; he also noted how visitors that became sick in London would feel fine after leaving. (Ibid., 37-38)
[48] Ibid., 41.
[49] Smil, *Energy and Civilization,* 233. In 1950, coal was still the preeminent energy source at 91 percent; overall, coal dominated Britain's energy use (more than 75 percent) for nearly 250 years, far longer than any nation in history. In comparison, in 1850, wood remained the dominant energy source in France at 75 percent. In America, whose coal reserves were far larger than Britain's, coal constituted only 20 percent of energy use by 1860 as advanced coal technology and industry was not yet highly developed. (Ibid.)
[50] Wrigley, "Energy and the English Industrial Revolution," 8. Glass was one industry segment that saw a substantial increase in output as glass making requires substantial heat energy. (Ibid.)
[51] Mechanical energy is the energy of an object due to its motion, or to its position. Mechanical energy involving motion is also referred to as kinetic energy.
[52] Wrigley, "Energy and the English Industrial Revolution," 8.

muscle energy, and to a much lesser extent, wind (windmills, sailboats) and water (watermills); by 1700, while coal comprised nearly 50 percent of all energy consumption, none was used to generate mechanical energy.[53]

Coal Mine Flooding – The Catalyst to the World's First Superpower

One significant problem related to producing coal, already the dominant British energy in the early 1700s, set in motion Britain's hegemonic acceleration.[54] Coal mining is dangerous.[55] Miners risk death from breathing poisonous gases, collapsing mines, explosions, and drowning.[56] Various water threats are particularly burdensome - underground streams, rainwater accumulation, and mines below water tables.[57] As demand increased, easily accessible coal was exhausted. Deeper mines created problems, especially flooding,[58] which were addressed primarily using human and animal energy, including drainage tunnels and chain-linked buckets.[59] Mines near streams removed water through waterwheel-generated mechanical energy.[60] As increased demand drove production deeper, costs increased. By 1700, Britain was producing approximately five times more coal than the rest of the world combined, but drainage problems limited further growth.[61]

Fortunately, Britain possessed two critical attributes to lead the Coal Age – an established scientific research community[62] in the Royal Society,[63] and deep-rooted iron-manufacturing capabilities formed through charcoal expertise. Coal became a primary topic of interest.[64] While some investigations looked at whether coal was "alive" and miners

---

[53] Ibid., 6-8.
[54] Freese, *Coal, A Human History*, 42.
[55] Ibid., 10-11. Charles Dickens wrote about the plight of miners. (Ibid.)
[56] Ibid., 47-52. Poisonous gases include carbon dioxide, carbon monoxide, and methane. (Ibid.)
[57] Ibid., 52.
[58] Ibid., 52-53.
[59] Ibid., 54-55.
[60] Ibid., 55.
[61] Ibid., 56. The deepest mines increased to 100 meters from 50 meters just decades before, and by 1765 they surpassed 200 meters (Weissenbacher, *Sources of Power*, Vol. One, 198.); muscle and water wheel energy (alcos called hydro energy) became increasingly ineffective as mines became deeper. (Ibid., 199)
[62] Allen, *The British Industrial Revolution in Global Perspective*, 6-8.
[63] Freese, *Coal, A Human History*, 56-57. Some of history's greatest scientists were Society-members, including Isaac Newton. (Ibid., 57)
[64] Ibid.

encountered demons, the predominant focus became flooding and water-pumping technology solutions.[65]

Initial work included how atmospheric weight fills vacuums, believing air pressure against a vacuum could be harnessed.[66] An early success in the late-1600s by Society member Denis Papin involved a small device with a piston inside a brass cylinder; condensed steam was forced into the cylinder, moving the piston. While the piston was not large enough for industrial purposes, steam technology was born; steam engines are based on the expansion and condensation of water vapor (heated water) to move pistons.[67] Small-town inventor Thomas Newcomen is credited with creating industrial-level large-piston capacity.[68] Newcomen's steam engine was first used in 1712 to pump water from a British mine.[69] His device, called a "fire engine," was managed by a "fireman," charged with maintaining the fire (with coal). One engine performed the work of 50 horses and costs were low with free coal available at the site.[70] Newcomen's device spread widely after 1750,[71] and by the 1760s, hundreds were employed throughout Britain to pump water.[72] This device became the first new engine since the windmill 800 years earlier.[73] But, its large size required enormous coal supplies; while engines located at the coal mine had unlimited amounts of "free" coal, further technological advancement was required for widespread industrial use.[74]

James Watt (born 1736), a Scottish mathematical instruments student, realized that Newcomen's machine wasted heat; he discovered that by installing a separate condenser, the cylinder could remain hot continuously, ready for the next steam injection. Watt lacked the metallurgical skills to manufacture critical components to advance his invention[75] but fortunately found a partner in English business owner Matthew Boulton, who had already built a successful business

---

[65] Ibid., 57-58.
[66] Ibid., 58.
[67] Ibid.
[68] Ibid., 58-59. Unfortunately for the Society, Newcomen was not a Society member. (Ibid.)
[69] Ibid., 59. In this device, the piston propelled an overhead beam which moved the rod of a vacuum pump. (Ibid.)
[70] Ibid., 59-60.
[71] Smil, *Energy and Civilization*, 237.
[72] Freese, *Coal, A Human History*, 60.
[73] Smil, *Energy and Civilization*, 235.
[74] Freese, *Coal, A Human History*, 60-61.
[75] Ibid., 62-63.

manufacturing buckles and clocks.[76] Watt moved to Boulton's Birmingham factory in 1773[77] and they produced a working cylinder within three years – one successfully tested in a coal mine, another in an iron foundry.[78] This new engine generated four times more power from a similar amount of coal than Newcomen's.[79] Boulton & Watt spearheaded a revolution.[80] A measure of the change in total energy consumption in Britain over 200 years provides a stunning example of Britain's economic growth based on coal utilization and this new coal technology; following the period in which coal supplanted wood in the 1600s, and the steam engine began driving coal mining and industry from the 1700s through the mid-1800s, energy consumption increased 15-fold.[81]

Coal became increasingly important to iron production. Coal-driven steam engines provided continuous power generation, replacing now outmoded water wheels to blast air into fires to maintain sufficient temperatures for iron production. And because charcoal was crushed under iron's weight in large furnaces,[82] foundry sizes were limited. Coal technology and coal solved both problems; steam engines provided strong, continuous power to maintain the requisite furnace temperature, and coke's superior strength supported significantly larger foundries,[83] accelerating metallurgical production. The major weakness of an organic economy, limited timber reserves, disappeared. Britain's coal reserves and coal technologies facilitated the nation's industrial growth at home, and its ability to build superior global military capabilities.[84]

---

[76] Ibid., 63. Boulton had actually corresponded with Benjamin Franklin on engine design, and heard of Watt's steam engine work in Scotland before forming a partnership. (Ibid.)
[77] Ibid., 63-64.
[78] Ibid., 64.
[79] Ibid.
[80] While most credit for coal technology (specifically the steam engine) has been rightfully bestowed on the British, the decades-long process leading to this achievement involved the importing of various technological and engineering ideas from continental Europe; then, once Britain developed the working steam engine, this new technology was eventually exported back to the continent. Also, by the 1790s, technology publications started to become more widely available, facilitating increasing knowledge sharing, and steam-operated printing presses allowed for mass productions for newspapers and other written information. (Weissenbacher, *Sources of Power*, Vol. One, 240, 268.)
[81] Smil, *Energy and Civilization*, 236. The creation of the steam engine in the mid-1700s demonstrates the true acceleration in energy utilization as British coal production increased from approximately four million tons in 1750 to approximately 275 million by 1900. (Ibid., 272-73.)
[82] Freese, *Coal, A Human History*, 66.
[83] Ibid.
[84] Ibid.

Economic Impact of Coal and Coal Technology

Steam power increased the demand for coal, iron, and manufactured goods. Between 1700 and 1830, Britain's coal industry expanded tenfold, further doubling by 1834.[85] Between 1850 and 1859, coal represented 92 percent of all consumed energy, while wood dropped to 0.1 percent.[86] With increasingly efficient coal extraction from steam technology, coal's cost continually decreased through the 1800s.[87] With low-cost coal available for home heating, industrial production (coking and steam-induced mechanical energy), and transportation (shipping, rail), coal utilization and productivity accelerated, far surpassing other nations. Between 1850 and 1854, the three largest continental European coal producers, Belgium, France, and Germany, had combined annual coal output of 16.6 million tons, while Britain produced 58 million; on a per person metric, the disparity was more conspicuous Britain leading 2.87 to 0.24.[88] This disparity extended to coal-produced goods and raw material consumption used in steam-driven factories; during this period, Britain produced annually three million tons of iron compared to 1.1 million by the other three combined, and Britain consumed annually 319,000 tons of cotton for textile production compared to 104,000 for the others.[89]

While total production ostensibly provides a true measure of economic power, coal technology had extraordinary impacts on productivity, arguably a more critical indicator of economic strength.[90] By 1820, steam-driven spinning machines produced 200 times more output than a hand worker.[91] Increased productivity lowered production costs and product prices, increasing global product demand, and demand for machinery. More compelling, this same year, Britain's steam engines possessed four million horsepower, equivalent to the work product of 40 million men.[92] Between the mid-1700s and mid-1800s, textile productivity rose by factors of 300 to 400, accelerating Britain's global economic share of manufacturing; this was only possible with coal.[93] In 1880, Britain's per capita level of industrialization was a staggering 87

---

85 Ibid., 67.
86 Wrigley, "Energy and the English Industrial Revolution," 6.
87 Gregory Clark and David Jacks, "Coal and the Industrial Revolution," *European Review of Economic History*, 11, no. 1 (April 2007), 42. https://www.jstor.org/stable/41378456.
88 Wrigley, "Energy and the English Industrial Revolution," 9.
89 Ibid.
90 Kennedy, *The Rise and Fall of the Great Powers*, 145-46.
91 Ibid., 145.
92 Ibid.
93 Ibid., 148.

(based on a scale equal to 100 for Britain in 1900) compared to Europe at 24, the US at 38, Japan at nine, and China at four.[94] A little more than a century earlier, these numbers were similar; in 1750, Britain was 10, China eight, Japan seven, and the US four.[95]

Britain's relative manufacturing strength was stunning. In 1830, Britain's share of world manufacturing was already 10 percent, and by 1860 that number doubled to 20 percent; at this time, with only two percent of the world's population, Britain produced 53 percent of global iron and 50 percent of its coal and consumed 50 percent of global cotton used for textile production through steam-generated spinning wheels.[96] Commercially, Britain was responsible for 20 percent of global commerce and 40 percent of trade in manufactured goods.[97] While British coal technology would find its way to continental Europe and America, Britain had a 50-year head start; in 1830, Britain produced approximately 80 percent of the world's coal (although America had larger coal reserves) and by 1834 it produced more iron than the rest of the world combined.[98] Around 1900, Britain controlled 20 to 25 percent of world trade, 30 to 40 percent of world shipping, 38 percent of world trade in manufactured goods, and nearly 50 percent of foreign investment, the greatest relative dominance in history.[99]

Britain's dominating global economic performance in the 1800s is correlated to its accelerating per capita energy consumption.[100] In 1860, its coal consumption was five times greater than the US and Germany, six times greater than France, and 155 times greater than Russia.[101] In 1870, Britain consumed 100 tons of coal (or 800 million calories of

---

[94] Ibid., 149.
[95] Ibid. By 1900, Third World productivity was only one-fiftieth of Britain's.
[96] Ibid., 151.
[97] Ibid.
[98] Freese, *Coal, A Human History*, 69.
[99] Tombs, *The English and Their History*, 558. As Britain's productivity increased, exports of manufactured goods increased, steadily raising the nation's surplus of capital and gold, which continued to be re-invested overseas to continually expand the scale and scope of the hegemony, protected by the Royal Navy; while land for agricultural energy was no longer the desire of rising powers as they were during the Agricultural Age, controlling foreign markets for which to export manufactured goods became the driver. (Weissenbacher, *Sources of Power,* Vol. One, 301-04.) In many of the British controlled regions, British exports or installed British manufacturing on foreign soil negatively impacted whatever level of local manufacturing base that existed and accordingly the British economic and political machine was not always welcome; as a result, many regions had to be controlled militarily as well as politically by the growing superpower. (Ibid., 302)
[100] Wrigley, "Energy and the English Industrial Revolution," 5-6.
[101] Kennedy, *The Rise and Fall of the Great Powers*, 151.

energy), equating to feeding 850 million adult males when Britain's population was 31 million.[102] Similar data for Italy demonstrates how energy consumption distinguished Britain economically; Italy's coal consumption in 1850 was seven percent of all energy,[103] similar to Britain's 300 years earlier,[104] while biomass comprised more than 50 percent of Italy's energy consumption, and human and animal muscle constituted 41 percent.[105] Italy, not blessed with meaningful coal reserves, remained far below Britain's pace of industrialization well into the 20th century; in 1910, Italy produced only 3,000 tons of coal while Britain produced 270,000 tons, and with a low energy-intensity economic foundation, Italy specialized in labor-intensive industries.[106] Britain's annual consumption of coal per person increased more than 40 times between the late-1500s to the mid-1800s.[107]

A 2007/2008 United Nations study supports the strong correlation between energy consumption and economic power.[108] The U.N.'s Human Development Index (HDI) measures living standards (income per capita), life expectancy, and education,[109] and expresses energy consumption in terms of barrels of oil equivalent; on these metrics, the correlation between energy consumption and HDI is exceedingly high.[110] Three-quarters of a barrel of oil per person per year is necessary for providing a nation's basic needs.[111] These consumption

---

[102] Ibid., 147.
[103] Silvano Bartoletto, "Patterns of Energy Transitions: The Long-Term Role of Energy in the Economic Growth of Europe." In *Past and Present Energy Societies; How Energy Connects Politics, Technologies and Cultures*, ed. Nina Mollers and Karin Zachmann (London: Transcript Verlag, 2012), 311. https://www.jstor.org/stable/j.ctv1wxt7r.13.
[104] Wrigley, "Energy and the English Industrial Revolution," 5.
[105] Bartoletto, "Patterns of Energy Transitions," 311.
[106] Ibid. By 1870, three nations, Britain, Germany, and the United States produced over 80 percent of the world's coal, with Britain producing most among these three. (Walter S. Tower, "The Coal Question," *Foreign Affairs* 2, no. 1 (Sept 15, 1923), 102.)
[107] Wrigley, "Energy and the English Industrial Revolution," 5-6.
[108] Manfred Weissenbacher, *Sources of Power, How Energy Forges Human History*, Vol. Two, *The Oil Age and Beyond* (Santa Barbara: Praeger, 2009), 806. Compounding the problem of the poorest nations has been a population explosion as the wealthiest nations have not exported wealth or energy technology to these nations, but have exported pharmaceuticals that increased child mortality and overall life spans; at the same time, developing nation have been unsuccessful in reducing birth rates compared to developed nations. (Ibid., 805-06.)
[109] United Nations, *United Nations Human Development Report 2007/2008, The Human Development Report*, 225.
http://hdr.undp.org/sites/default/files/reports/268/hdr_20072008_en_complete.pdf.
[110] Weissenbacher, *Sources of Power,* Vol. Two, 807.
[111] Ibid, 806.

levels were found in Britain in 1800 and China in 1950.[112] Most critically, the U.N. found that societies that demonstrated significant industrial advances and quality of life consumed 10 times this amount, equal to seven barrels of oil per person per year.[113] These levels were reached in Britain in 1880, Japan in 1930, and China in 1980.[114] The highest levels of affluence require 15 barrels which France reached in the 1970s.[115] Today, the US, the wealthiest nation in history, consumes 59 barrels per person while the world average is 13.

Coal and coal technology also drove advancements in land transportation in Britain and within its colonies, enhancing economic growth and global influence. In particular, the development of the rail system, which reduced reliance on poor dirt roads and inefficient canals, was driven by coal and coal technology; growing demand for coal increasingly required more efficient methods to transport coal from mines to factories and shipyards (for export). A definable pattern continued to develop: coal disclosed a problem (flooding, transportation), facilitated a solution (steam engine, rail), and that solution drove economic growth and military power.[116]

Military Impact of Coal and Coal Technology

Coal and coal technology facilitated significant advancement in Britain's military power and communication speed, a critical component of military preparedness, arguably the most important factor in winning

---

112 Ibid.
113 Ibid.
114 Ibid.
115 Ibid.
116 Freese, *Coal, A Human History*, 85-86. George Stephenson, the son of a British coal "fireman," was blessed with mechanical and inventive skills. After teaching himself to read so he could learn about Watt's engine, by twenty he held one of the highest paying jobs at a coal mine operating equipment; after a 12-hour shift, he made clocks and other items to generate additional income. He was later placed in charge of more efficient methods to use steam engines to move coal on tracks; until then coal was moved by animal energy. While Englishman Richard Trevithick created a high-pressure steam engine (Watt's was low pressure) that was necessary for the enormous power required to drive locomotives, Stephenson created the first railway in 1825, 26 miles in length between Darlington and Stockton; thousands of British citizens watched as a 34-car train carrying coal and hundreds of passengers. (Ibid., 91) The railway became a symbol of Industrial Revolution acceleration and the power of technological progress; by 1845 Britain had 2,200 miles of track and by 1852, 6,600 miles. (Ibid., 95) Also, a coal-powered railway steam engine accomplished more than hundreds of packhorses, with considerably more speed. (Kennedy, *The Rise and Fall of the Great Powers*, 145.)

wars and exerting influence.[117] In the 1600s, more ships were used to transport coal in Britain than all other goods combined, and with an expanding commercial coal fleet, Britain developed an advanced port system and maritime skills; this proved useful in facilitating Britain's international business expansion and global naval capabilities.[118] Britain did not always possess significant maritime power; in 1588, Britain relied on armed commercial sailboats to defeat the Spanish Armada.[119] In the early 1600s, coal ships, larger in size and crews compared to fishing vessels, were used for naval training; they were relied upon, and often forced, to participate in military activities.[120] As coal commerce grew in importance, naval vessels escorted coal ships, protecting their path from northern Britain to the industrial south.[121]

Steam engines, iron, and naval power were evident with the construction of HMS *Warrior* (1860); driven by steam generated from British coal and armored with five inches of iron created from British coke, she was the world's most powerful battleship.[122] *Warrior* was one of 240 vessels with a combined crew of 40,000 that comprised the world's largest and most powerful navy by significant margins; Britain controlled one-third of the world's merchant tonnage,[123] and by the late 1800s was launching one-third of the world's warships and 60 percent of its merchant tonnage.[124] By 1900, the Royal Navy was equal in power to the next two largest navies combined and possessed an unequaled global network of navy bases.[125] No nation in history possessed such domination of the oceans.[126] In modern history, only highly industrialized nations can wage war on a large scale, and behind every naval vessel rests a large industrial plant, and the fuel to power military weaponry.[127] Nations with the largest coal reserves and leading coal technology possessed superior power and influence.[128]

---

117 Morgenthau, *Politics Among Nations, The Struggle for Power and Peace,* 118-19. Morgenthau also argued that the quality of a military force (personnel) is critical for national power, and not just the quality and size of the weaponry. (Ibid., 120-21.)
118 Freese, *Coal, A Human History*, Ibid., 85-86.
119 Ibid.
120 Ibid.
121 Ibid.
122 Ferguson, *Empire, The Rise and Demise of the British World Order and the Lessons for Global Power*, 138.
123 Ibid., 138-39.
124 Kennedy, *The Rise and Fall of the Great Powers*, 229.
125 Ibid., 226.
126 Ferguson, *Empire, The Rise and Demise of the British World Order and the Lessons for Global Power*, 139.
127 Walter H. Voskuil, "Coal and Political Power in Europe." *Economic Geography* 18, no. 3 (July 1942), 247. https://www.jstor.org/stable/141125
128 Ibid., 248.

Steam-powered ships provided superior coordination through improved communications. Steam reduced the four to six-week Atlantic crossing to only ten days by 1880.[129] Not only was time reduced, but steam allowed for larger vessels with increased weapons capacity.[130] With communications' speeds increasing, reaction times decreased, allowing military and commercial activities to operate at substantially higher levels of preparedness.[131]

Advanced steam engine technology provided distinct military advantages through industrial machine-tool applications; metallurgical coal was used to produce increasingly higher-quality iron-based new weapons classes. The breechloader, an improvement of the muzzle-loading gun, significantly increased the rate of boat gunfire, and Gatling guns and Maxims started a "firepower" revolution.[132] Increasingly efficient and smaller steam engines were placed on smaller gunboats that could advance inland from open waters, providing increased mobility; during the Opium War of 1841 and 1842, British naval forces easily defeated inland Chinese forces with machine guns and heavy weapons.[133] The firepower superiority gap was a direct function of steam technology and iron-making advancements. The ability to fight effectively from distances has always been a superior military advantage, and weapons built from coal technologies facilitated this advantage.[134]

The First Superpower

Economic and military power are inextricably linked; only highly industrialized nations with access to low-cost energy can exert substantial influence or wage war on a large scale.[135] Coal and coal technology were critical to industrial, economic, and military power. It accelerated

---

[129] Ferguson, *Empire, The Rise and Demise of the British World Order and the Lessons for Global Power*, 140.
[130] Ibid.
[131] Ibid., 145.
[132] Kennedy, *The Rise and Fall of the Great Powers*, 150.
[133] Ibid.
[134] Weissenbacher, *Sources of Power,* Vol. One, xv. Interestingly, due to Britain's increasing economic productive capacity and advanced metallurgical industry which lowered cost structures, they were able to construct and manage the world's most powerful, technologically-advanced navy and overall military at relatively low costs as a percentage of GDP. Ferguson, *Empire*, *The Rise and Demise of the British World Order and the Lessons for Global Power*, 204; Kennedy, *The Rise and Fall of the Great Powers*, 152-53. Part of Britain's success in keeping military expenditures low was also their selectivity in which conflicts to enter, focusing increasingly on facilitating their global influence through political strategies. (Kennedy, *The Rise and Fall of the Great Powers*, 153.)
[135] Voskuil, "Coal and Political Power in Europe," 247.

economic productivity, the foundation of wealth. It drove iron production, necessary to construct steam engines for industry, transportation, and the military equipment used to maintain open trade lanes and manage an empire. And finally, coal-related industries were independently large British employers. The wealth from these industries provided capital for foreign investment, further expanding global economic influence. While Britain had developed influential international banking and insurance businesses before steam technology, wealth from industrialization further strengthened these financial industries, critical for not only funding British expansion but for providing capital to foreign nations to purchase British products. In the early twentieth century, "nations which possess[ed]...coal and iron rule[d] the world"[136] since coal was the primary source of mechanical energy driving industrial and military power.[137]

Britain's accelerating economic and military power also facilitated its political and cultural influence, the third pillar of superpower status. Through economic and military might, Britain exerted influence on coastal traders, shippers, railway builders, and mining companies, and also facilitated explorers and Christian missionaries.[138] Britain's soft power is represented by roads, railways, buildings, and democracy.[139] While Britain had already achieved a level of global influence during the early decades of the coal revolution with deft naval abilities, diplomacy, and banking and insurance expansion, coal's continuing facilitation of greater economic and military strength transformed Britain into a superpower by the end of the century.[140]

Conclusion

Analyzing history through the lens of energy and energy technology demonstrates how Britain's coal reserves and capabilities to develop coal technologies, leading to the steam engine and chemical

[136] Tower, "The Coal Question," 114.
[137] Ibid., 100,
[138] Kennedy, *The Rise and Fall of the Great Powers*, 149.
[139] Ibid., 150.
[140] Ibid., 151. British economist William Jevons articulated the self-confidence of the nation as it reached superpower-status in 1865: "The plains of North America and Russia are our corn fields; Chicago and Odessa our granaries; Canada and the Baltic are our timber forests; Australasia contains our sheep farms, and in Argentina and on the western prairies of North America are our herds of oxen; Peru sends her silver, and the gold of South Africa and Australia flows to London; the Hindus and the Chinese grow tea for us, and our coffee, sugar, and spice plantations are in all the Indies. Spain and France are our vineyards and the Mediterranean our fruit garden; and our cotton grounds, which for long have occupied the Southern United States, are now being extended everywhere in the warm regions of the earth." (Ibid., 151-52.)

coking processes for advanced metallurgy, drove its rise to superpower. Coal transformed an organic, asymptotic, economy into a dynamic, mineral economy generating extraordinary economic growth and productivity. It facilitated military advancements, including larger, iron-based naval vessels and advanced weaponry; steam technology also increased military speed, facilitating improved communications and preparedness, critical military elements. Fortunately, Britain also possessed a strong foundation developed over prior centuries that arguably allowed it to fully realize the benefits of coal; specifically, Britain possessed codified legal freedoms, private property rights, and coal-based industrial infrastructure constructed with the biomass-related energy source called charcoal. Without this foundation, Britain may not have capitalized on its resources to excel economically and militarily. Before the Coal Age, Britain also possessed the foundation for global political and cultural influence, the third pillar of superpower status. Britain believed it should spread its democratic systems, freedoms, religion, and literature globally. A superpower must have political and cultural influence over other nations – an ability to have others view your institutions and values as something for which to aspire, so preferences can be shaped and attained without resorting to coercion. Without superior economic and military power, political and cultural influence remains unrealized.

A strikingly similar energy development pattern based on oil provides an equally compelling roadmap for the rise of the next superpower – America – and Britain's relative decline. The US possessed larger coal reserves than Britain which commenced initial economic and military acceleration, but more critically, the US possessed substantial reserves of denser and more powerful crude oil while Britain had minimal onshore reserves.[141] Following Britain's pattern of developing technologies to facilitate the utilization of a new energy source, the US developed critical oil-based technologies, including the internal combustion engine and refining techniques (analogous to the coal-driven steam engine and coking techniques for metallurgy); this drove US economic output, productivity, and military power to unprecedented levels. Automobile mass markets and powered flight were just two of many American transformative changes resulting from oil and oil technologies. The internal combustion engine and liquid fuel sources, driven by refining technology, also drove extraordinary advancements in

[141] Britain would not begin exploiting its offshore oil reserves in the North Sea until the second half of the twentieth century and currently ranks only 18th in global production while the US is the largest producer. (British Petroleum, *BP Statistical Review of World Energy Sources*, 14.) Nearly all British oil production remains offshore in the North Sea.

weaponry well beyond coal's capabilities. Specifically, this new engine technology facilitated the creation of the air force and tank development, all while improving naval ship technologies, including ship speed, and overall weapons advancement.[142] Britain continued to rely on coal, and became reliant on oil imports, reducing national power and global influence. Britain would not develop offshore oil reserves (far more expensive than onshore oil extraction) until the second half of the twentieth century and has never been a major oil producer. The US also replaced Britain to become the world's dominant energy consumer by significant margins, including on a per capita basis, a critical component of economic strength and living standards. Like Britain, the US also developed substantial political and cultural influence, as its value systems, derived from British institutions and based on freedoms and democracy, were mostly revered internationally, and its cultural influence, including universities, movies, and business, has for the most part been globally respected and accepted, facilitating even greater influence.

Nuclear power remains the most dense and powerful energy source and is primarily used for generating electricity.[143] Nuclear power is also clean, producing no greenhouse gases, but broad acceptance is likely to be challenged based primarily on radiation fears. The global focus is turning toward solar and wind energy, but they face significant challenges; they are clean and unlimited, but highly diffuse relative to fossil fuels, and not currently economic.[144] They do not fit history's path of advancing civilization by turning toward increasingly dense and powerful energy sources. Perhaps a nation that develops technologies facilitating the increased density of solar, wind, or other energy source will become the next superpower.

[142] Weissenbacher, *Sources, of Power*, Vol. Two, 382-99.
[143] Smil, *Power Density*, 254-55.
[144] Ibid.

Bibliography

Allen, Robert C. *The British Industrial Revolution Perspective*. Cambridge: Cambridge University Press, 2009.

Bartoletto, Silvana. "Patterns of Energy Transitions, The Long-Term Role of Energy in the Economic Growth of Europe." In *Past and Present Energy Societies; How Energy Connects Politics, Technologies, and Cultures*, edited by Nina Mollers and Karin Zachmann, 305-30. London: Transcript Verlag, 2012. https://www.jstor.org/stable/j.ctv1wxt7r.13.

Beckley, Michael. *Unrivaled, Why America Will Remain the World's Sole Superpower*. Ithaca: Cornell University Press, 2018.

British Petroleum, *BP Statistical Review of World Energy Sources*, 67th ed. (June 2018). https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf.

Clark, Gregory and David Jacks. "Coal and the Industrial Revolution, 1700-1869." *European Review of Economic History* 11, no. 1 (April 2007): 39-72. https://www.jstor.org/stable/41378456.

Cottrell, Fred. *Energy & Society*. Bloomington: AuthorHouse, 2009.

Ferguson, Niall. *Empire, The Rise and Demise of the British World Order and the Lessons for Global Power*. London: Basic Books, 2002.

Freese, Barbara. *Coal, A Human History*. New York: Basic Books, 2016.

Huntington, Samuel P. *The Clash of Civilizations and the Remaking of World Order*. New York: Simon & Schuster, 1996.

Kennedy, Paul. *The Rise and Fall of the Great Powers*. New York: First Vintage Books, 1989.

Miller, Lyman. "China an Emerging Superpower?" *Stanford Journal of International Relations* (Winter 2005). https://web.stanford.edu/group/sjir/6.1.03_miller.html.

Morgenthau, Hans J. *Politics Among Nations, The Struggle for Power and Peace*. New York: Alfred A. Knopf, 1963.

Nersesian, Roy L. *Energy Economics, Markets, History, and Policy*. New York: Routledge, 2016.

Nye Jr., Joseph S. *Soft Power, The Means to Success in World Politics*. New York: Public Affairs, 2004.

Pollard, Sidney. "A New Estimate of British Coal Production, 1750-1850." *The Economic History Review*, New Series 33, no. 2 (May 1980): 212-235. https://www/jstor.org/stable/2595840.

Radkau, Joachim. *Nature and Power, A Global History of the Environment*. New York: Cambridge University Press, 2008.

Ray, George F. "British Coal." *National Institute Economic Review* 130 (November 1989): 75-84. https://www/jstor.org/stable/23875878.

Rhodes, Richard. *Energy, A Human History*. New York: Simon & Schuster, 2018.

Smil, Vaclav. *Energy: A Beginner's Guide*. 2nd ed. London: Oneworld Publications, 2017.

———. *Energy and Civilization: A History*. Cambridge: MIT Press, 2017.

———. *Power Density: A Key to Understanding Energy Sources and Uses*. Cambridge: MIT Press, 2016.

Sorensen, Bent. *A History of Energy, Northern Europe from the Stone Age to the Present Day*. New York: Earthscan, 2011.

Straka, Thomas J., "Charcoal as a Fuel in the Ironmaking and Smelting Industries," *Advances in Historical Studies* (March 21, 2017): 56-64. https://file.scirp.org/pdf/AHS_2017032115340978.pdf.

Tombs, Robert. *The English and Their History*. New York: Vantage Books, 2016.

Tooze, Adam. *The Deluge, The Great War, American and the Remaking of the Global Order, 1916-1931*. New York: Penguin Books, 2014.

Tower, Walter S. "The Coal Question." *Foreign Affairs* 2, no. 1 (September 15, 1923): 100-16. https://www.jstor.org/stable20028275.

United Nations, *United Nations Development Programme*, *Human Development Report, 2018 Statistical Update*. http://hdr.undp.org/en/content/human-development-index-hdi.

United Nations, *United Nations Human Development Report 2007/2008, The Human Development Report*. http://hdr.undp.org/sites/default/files/reports/268/hdr_20072008_en_complete.pdf.

Voskuil, Walter H. "Coal and Political Power in Europe." *Economic Geography* 18, no. 3 (July 1942): 247-58. https://www.jstor.org/stable/141125.

Weissenbacher, Manfred. *Sources of Power, How Energy Forges Human History*, Vol. One, *Before Oil: The Ages of Foraging, Agriculture, and Coal*. Santa Barbara: Praeger, 2009.

_________. *Sources of Power, How Energy Forges Human History*, Vol. Two, *The Oil Age and Beyond*. Santa Barbara: Praeger, 2009.

Wrigley, E.A. "Energy and the Industrial Revolution," *Philosophical Transactions: Mathematical, Physical and Engineering Sciences* 371, no. 1986 (March 13, 2013): 1-10. https://www.jstor.org/stable/23364180.