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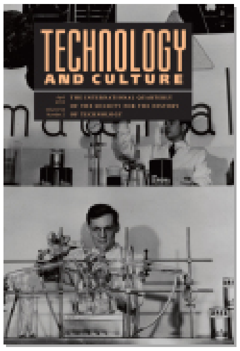

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The Nature of Power

Synthesizing the History of Technology and Environmental History

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On the evening of 2 May 1878, the Washburn A Mill in Minneapolis erupted in flames, sending the flourmill's concrete roof flying several hundred feet in the air. Neighboring buildings were flattened and pandemonium filled the streets. One-third of the city's business district burned to

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the ground, while the explosion shattered windows far across the Mississippi River in St. Paul. In all, eighteen people were killed.[1]

The Minneapolis mill explosion provides a touchstone for this essay on the intersection of the history of technology with environmental history. Interest in the intersection of these fields has grown rapidly over the past decade. Envirotech, a group of scholars in both the history of technology and environmental history, is one of the largest interest groups in the Society for the History of Technology.[2] Our goal here is not to review the burgeoning "envirotech" literature in any exhaustive way, which was first covered a dozen years ago in a *Technology and Culture* review essay that remains fresh in its coverage and insight. This now-classic review has recently been updated in a historiographic article included in a new collection of essays on specific themes sited at the intersection of the two fields.[3] Instead, in this essay we zero in on a concept that links the two fields and, we believe, could be used to develop fresh insights into history.

The concept is power. The idea for this essay began with the observation that historians use the term "powerful" in two senses. One sense is physical: the mill in Minneapolis experienced a *powerful* explosion. The other sense is social: the mill belonged to a *powerful* proprietor, formerly a Union general and Wisconsin governor. Usually, we think of physical and social power as distinct phenomena, a habit encouraged by the disciplinary structure of academic research. Physicists study physical power, social scientists study social power, and the two disciplines use different language and concepts to express their understanding. One can easily assume that physical power and social power are unrelated. If true, then the use of "powerful" to describe physical and social processes is simply a case of a word having more than one meaning: "powerful" might happen to work in both the physical and social contexts, just as "fast" describes both a rate of movement of an object and a hard-partying group of friends.

We wondered, though, if the use of the same term in two contexts might be more than a coincidence. Might the common use give us some

[1] Stephen F. Peckham, *The Dust Explosions at Minneapolis, May 2, 1878, and Other Dust Explosions* (New York, 1908); Ole Schei and August Smith, "The Washburn A Mill Explosion," Minneapolis Pioneers and Soldiers Memorial Cemetery History Page, http://www.friendsofthecemetery.org/history/alley_articles/MillExplosion_March2005.shtml (accessed 10 September 2010).

[2] In addition to gathering at SHOT conferences, Envirotech meets at conferences of the American Society for Environmental History, the European Society for Environmental History, and the World Congress of Environmental History.

[3] Jeffrey K. Stine and Joel A. Tarr, "At the Intersection of Histories: Technology and the Environment," *Technology and Culture* 39 (1998): 610–40; Hugh S. Gorman and Betsy Mendelsohn, "Where Does Nature End and Culture Begin? Converging Themes in the History of Technology and Environmental History," in *The Illusory Boundary: Environment and Technology in History*, ed. Martin Reuss and Stephen Cutcliffe (Charlottesville, Va., 2010).

analytical purchase on history? Might physical and social power have some common features? Might physical and social power originate, function, and affect the world in similar ways? Might they have some causal connection, with one influencing the other? Might they be two faces of the same coin? We were not the first to ask these kinds of questions, and this essay capitalizes on the insights of other scholars to develop an analytical framework for understanding power.

Our thesis is that all power, social as well as physical, derives from energy. From that insight, we can improve our understanding of the past by tracing the flow of energy and its application as power. This argument rests upon several propositions:

1. Most of the energy used by life on earth arrived as sunlight.
2. History is largely the story of the capture, transformation, and application of this solar energy.
3. Nature, technology, and people have all played essential roles in these transformations and applications.
4. Power is energy put to work, and all organisms use energy to stay alive, so all organisms exercise some power.
5. Energy can be concentrated, which has enabled some people to deploy more power than others.

These ideas can lead to a reconsideration of major events in history, as we demonstrate by reassessing some familiar chapters in the Industrial Revolution.

With their common interest in the material world, the history of technology and environmental history make a good team for assessing the links between physical and social power. Picture, for a moment, a chain that represents a product's lifetime. The chain begins with extraction of natural resources and ends (in the United States, at least) with consumer waste in a landfill or river. Roughly speaking, the median tendency of environmental historians has been to explore the beginning and ending links in the chain (resource extraction and waste), while the median tendency of historians of technology has been to study its intermediate links (product design, manufacturing, and consumption). Some scholars have done both.[4] Our task is less

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[4] The emergence of envirotech scholars seeking to blur these traditional disciplinary boundaries has produced important works that broaden their scope to examine the entire chain of a product's life. See, for example, William Cronon, *Nature's Metropolis: Chicago and the Great West* (New York, 1991); Richard White, *The Organic Machine: The Remaking of the Columbia River* (New York, 1995); Mark Fiege, *Irrigated Eden: The Making of an Agricultural Landscape in the American West* (Seattle, 1999); and David Igler, *Industrial Cowboys: Miller & Lux and the Transformation of the Far West, 1850–1920* (Berkeley, Calif., 2001). At least with White's study, this broader examination includes tracing energy flows through the socio-enviro-technical system constructed to harvest salmon on the Columbia River, as well as an analysis of the resultant power dynamics.

to articulate some new theory of power and more to highlight an area where important scholarship exists, but remains isolated. To remove unhelpful disciplinary boundaries, we suggest a study of power that takes from sociologists a passion for exploring the social manifestations of power, appropriates from physicists a definition of power that recognizes its energetic basis, borrows from historians of technology a commitment to revealing all factors influencing sociotechnical systems, and embraces environmental historians' interest in the manipulative powers of energy flowing through both human and nonhuman actors. We hope to encourage more such work.

Energy and Power

What are energy and power? In common parlance, people often use the terms "energy" and "power" interchangeably, and dictionaries define the words as synonyms. The authors of this essay have found it useful to distinguish the two concepts by using definitions from physics. Physicists define energy as the capacity to do work;[5] they define power as energy put to work, and quantify it as the rate at which work is done or energy is transformed.[6] Note the contrasts: energy is a quantity, power is a rate; energy is a capacity, power is the use of that capacity; energy can be stored, power cannot be; power is a process, energy is not.

We can discern the difference between energy and power in the ruins of the Minneapolis mill. First, let us walk through the ruins to trace the path of energy. Nuclear fusion in the sun sent energy to earth in the form of light. Wheat plants captured solar energy and transformed it into chemical energy by storing it in bonds between atoms in carbohydrate molecules. It was this stored energy that made wheat valuable to people. When the system worked as intended, chemical energy stayed in wheat molecules as the grain was ground into flour, baked into bread, and eaten by a person. Then cells in the person's body used the energy to fuel the body or stored it in the bonds of other molecules (glycogen or fat). As energy flowed in one direction, money flowed in the opposite one.

Now let us trace instances of power in the wheat-milling system. Wheat plants exercised power when they converted solar energy into chemical energy. Farmers used chemical energy in wheat to power their bodies while harvesting the wheat. The mill used energy to turn machinery that ground the wheat into flour. Railroads used stored solar energy in coal or wood to transport the flour to markets. Consumers of the wheat used the stored energy to do work. When money flowed upstream to the hands of mill owners, they could use it to exert power over the human or natural world—for example, by building houses intended to impress people with their

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[5] Joseph F. Mulligan, *Introductory College Physics* (New York, 1985), 138.

[6] Ibid., 157.

grandeur. But people did not completely control the energy or power of the system. When a source of heat, such as a spark, ignited the dust in the air of the mill, so many molecules released their energy as heat that the mill exploded and people died. People benefited when they retained control over the energy in wheat and used it for power; they suffered when they lost control over the energy and saw it transformed into destructive power.

The social power of mill owners and the physical power of the explosion flowed from a common root: the ability of mill owners to concentrate wheat in one building, which enhanced their control over a high value–added link in the product chain and increased their social power. If all of that wheat had been ground in hand-mills scattered among thousands of homes, the Minneapolis mill owners would have had little power, and any individual explosion would have been relatively weak. Indeed, Karl Marx argued that forcing people to abandon hand-mills and bring their grain to centralized watermills was one way in which capitalists gained power in Europe.[7]

In discussing his labor theory of value, Marx recognized the necessity of physical energy flows to sustain work, writing that "the minimum limit of the value of labour-power is determined by the value of the commodities, without the daily supply of which the labourer cannot renew his vital energy, consequently by the value of those means of subsistence that are physically indispensable." Further, in linking his concept of value to physical energy flows, Marx also hinted at the modern law of entropy, noting that labor, consisting of "a definite quantity of human muscle, nerve, brain, &c., is wasted, and these require to be restored." This entropy is the locus of class conflict for Marx, as contests arise over who controls labor power, and such control over energy dictates social stratification and power.[8]

Other, more recent work has tended to elide the connection between physical and social power. For example, Sidney Mintz's wonderful study on sugar and its use among Britain's working class notes the important caloric boost sucrose provided to laborers, but the focus remains on how "powerful" British mercantilists and industrialists spun "webs of signification" to make sugar's consumption seem natural and beneficial to workers, thus enhancing their position in relation to the "weaker" laboring masses. Likewise, the eminent historian of technology David Nye recognizes that America's massive sociotechnical energy systems are "social constructions that demand energy" from the humans who construct them, but then offers culture as a better explanation for America's energy choices.[9]

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[7] William H. Shaw, "'The Handmill Gives You the Feudal Lord': Marx's Technological Determinism," *History and Theory* 18 (1979): 155–76.

[8] Karl Marx, *Capital: A Critique of Political Economy* (1867; reprint, New York, 1936), 190, 192.

[9] Sidney W. Mintz, *Sweetness and Power: The Place of Sugar in Modern History* (New York, 1985); David E. Nye, *Consuming Power: A Social History of American Energies* (Cambridge, Mass., 1998), 5.

Material needs for thermodynamic energy continue to act upon systems throughout their existence. It is not enough to say that cultural or social factors shape systems until they reach a stage of "technological momentum," where the systems then do more to shape society; instead, we must recognize the continual need for energy to make these systems operate—perhaps *maintaining* or continuously *re-creating* their momentum—and investigate how this constant demand shapes the systems.

Our emphasis on the essential and integral nature of energy in systems contrasts with the concept of energy put forth by a pioneer of systems thinking in the history of technology. In *Networks of Power*, Thomas Hughes emphasizes that people were just as essential as technology for this system (leading to the term "sociotechnical systems")—an important conceptual advance. Hughes had less to say about the role of nature in systems; he excludes energy sources from his systems, because systems, by definition, control all their elements. To Hughes, energy supplies are exogenous, assigned to the category of environment.[10] But as our walk through the ruins of the Washburn A Mill illustrates, energy is an essential part of every system; it is what enables the system to work at all. Moreover, systems never exert complete control over their elements, partly because energy sometimes does things that systems designers do not wish. The mill exploded because operators lost control of energy essential to the system.

Our emphasis on the energetic basis for social power also diverges from the way that the patriarch of sociology, Max Weber, defined power as a function of social position. He wrote of power as "the chance of a man or of a number of men to realize their own will in a communal action even against the resistance of others who are participating in the action."[11] In his view, power is socially determined, related to but not necessarily dependent on material inputs, and defined in relation to the ability of others.[12] This view conceives of power as a zero-sum game in a world of finite power; some must lose power for others to gain it in this closed system.[13]

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[10] Thomas Parke Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore, 1983). Hughes writes: "Two kinds of environment relate to open technological systems: ones on which they are dependent and ones dependent on them. In neither case is there interaction between the system and the environment: there is simply one-way influence. Because they are not under system control, environmental factors affecting the system should not be mistaken for components of the system." See Hughes, "The Evolution of Large Technological Systems," in *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, ed. Trevor J. Pinch, Wiebe E. Bijker, and Thomas Parke Hughes (Cambridge, Mass., 1987), 53.

[11] H. H. Gerth and C. Wright Mills, eds., *From Max Weber: Essays in Sociology* (New York, 1962), 180.

[12] At least one scholar argues that Weber included "status" as an indicator of power precisely because he wished to refute Marx's materialism as the only determinate of power; see Gordon Marshall, "Power," in *Oxford Dictionary of Sociology*, 3rd ed., ed. John Scott and Gordon Marshall (New York, 2009), 591.

[13] John Scott, *Power* (Malden, Mass., 2001), 2.

Critiques emerged within sociology to challenge the notion that power derives from social structure.[14] Sociologists of science and technology assert that power is not something that can be held, but must be created through action. This observation rejects a priori assumptions that power is generated by some preexisting social organization, and shifts the focus toward the process through which power gets constructed. Ridiculing sociologists who had "mistaken the effect for the cause," Bruno Latour argues that "[a]ppealing to a reserve of energy, be it 'capital' or 'power', to explain the obedient behavior of the multitudes, is thus meaningless."[15] Instead, Latour explains that "[t]hose who are powerful are not those who 'hold' power in principle, but those who practically define or redefine what 'holds' everyone together. This shift *from principle to practice* allows us to treat the vague notion of power not as a cause of people's behavior but as the consequence of an intense activity of enrolling, convincing, and enlisting."[16]

The Washburn A Mill also illustrates the value of bringing another concept from physics—entropy—into the analysis of technological systems. Entropy is disorder, or the tendency of systems to lose energy and fall apart. The only way to stall or reverse entropy is to invest energy in a system. The Washburn A Mill needed continued investment of human labor to keep machinery and labor in order while the system operated. Despite these efforts, entropy prevailed when the system blew up, releasing energy and leaving disorder behind. Cadwallader Washburn reversed the entropy by investing more energy in the mill, rebuilding it in 1880 as the largest and most technologically advanced mill in the world. Management and workers continued to invest energy to keep the system functioning until 1965, when it was shuttered due to obsolescence. Entropy returned spectacularly in 1991 when a fire almost destroyed the mill. Another investment of energy in the 1990s rebuilt part of it, this time in the form of a museum.[17] Because of entropy systems do not stand still; they need the continual input of energy simply to hold the parts of the system together, even when the system is operating as designed.

Whence the energy for power? The source often goes unstated, but some scholars make it explicit. In his explanation of Portuguese naval expansion, actor-network theorist John Law includes forms of energy—wind and ocean currents—in a technological system. These forces stymied Por-

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[14] Weber's ideas about power remain so dominant in the sociological literature that a review of fifty sociology textbooks in the early 1980s found the Weberian interpretation used 63 percent of the time, with no other conception of power cited in more than two textbooks; see Warren R. Paap, "The Concept of Power: Treatment in Fifty Introductory Sociology Textbooks," *Teaching Sociology* 9 (1981): 57–68.

[15] Bruno Latour, "The Powers of Association," in *Power, Action, and Belief: A New Sociology of Knowledge*, ed. John Law (London, 1986), 276.

[16] Ibid., 273 (emphasis in original).

[17] Minnesota Historical Society, "Building History," Mill City Museum, http://www.millcitymuseum.org/building-history (accessed 25 September 2010).

tuguese efforts to sail in certain directions until sailors learned to follow a circular route that enabled them to use the wind and currents to accomplish round-trip voyages. Law contends that the Portuguese succeeded by converting currents, winds, and other forces from opponents into allies.[18]

Law's example illustrates that people use solar energy in forms other than for food. The winds that drove Portuguese ships developed because the sun heated air unevenly, which created pressure differentials, which led air to rush from one place to another. The energy that mills and hydropower plants capture from falling water is the result of the sun causing water to evaporate. Water vapor rises, condenses, falls as rain and snow on high places, and runs downhill in streams and rivers. The energy in fossil fuels originated in sunlight captured by plants eons ago and stored underground. Not all energy that people use is solar; for example, tidal energy derives from the gravitational pull of the moon, and nuclear fission comes from the splitting of atoms. Still, solar energy has powered the great majority of history.

Humans' reliance on solar energy led environmental historian Alfred Crosby to label our species "children of the sun." Like Crosby, several historians have made the need for energy central to their analyses of history, often detailing the various sociotechnical regimes that emerged to harness this force to do work.[19] These authors provide important reminders that while cultural and social factors influence the choices we make in organizing our societies to channel energy, energy itself is the lifeblood of these structures. As Rolf Sieferle explains: "Energy flows are basic features of [all interconnected] systems. It is energy that propels all material processes. When the energy systems of the past have been reconstructed, we will understand the natural framework that determines the physical boundaries of economic [or social, cultural, and so on] development."[20] Recognizing the necessity of energy in human systems does not mean energy is the only important factor. Vaclav Smil argues that it is "profitable and desirable to view energy use as a principal factor in analysis of human history. But not as *the* principal factor." Instead, "[t]he only rewarding and revealing way to assess energy's importance in human history is to find a path that neither succumbs to the simplistic, deterministic explanations buttressed by recitals of countless

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[18] John Law, "Technology and Heterogeneous Engineering: The Case of Portuguese Expansion," in *The Social Construction of Technological Systems* (n. 10 above), 120.

[19] Alfred Crosby, *Children of the Sun: A History of Humanity's Unappeasable Appetite for Energy* (New York, 2006); Lewis Mumford, *Technics and Civilization* (New York, 1934); Martin V. Melosi, *Coping with Abundance: Energy and Environment in Industrial America* (Philadelphia, 1985); Vaclav Smil, *Energy in World History* (Boulder, Colo., 1994); James C. Williams, *Energy and the Making of Modern California* (Akron, Ohio, 1997); Nye (n. 9 above); John Robert McNeill, *Something New Under the Sun: An Environmental History of the Twentieth-Century World* (New York, 2000).

[20] Rolf Peter Sieferle, *The Subterranean Forest: Energy Systems and the Industrial Revolution*, trans. Michael P. Osman (Cambridge, 2001), viii.

energy imperatives—nor belittles energy use by reducing it to a marginal role compared to other history-shaping factors, be they climatic changes and epidemics or human whims and passions."[21] These scholars offer the uncomplicated though crucial observation that energy makes possible the work of all systems; thus our histories must include a close investigation of the actions taken to obtain and manage this essential element.

Environmental historian Richard White analyzes the relationship of humans and nonhumans on the Columbia River through their exchanges of energy, defined as the "capacity to do work" by acting upon another body and moving it in the direction of the force. While White recognizes that both nature and humans have energy and do work, thereby shaping their environments and knowing each other in the process, he differentiates human work, in that it is "socially organized and given cultural meaning." White then investigates how energy flows influenced the way that human groups organized themselves to become powerful, adding that "[t]o be powerful is to be able to accomplish things, to be able to turn the energy and work of nature and humans to your own purposes."[22]

In a similar vein, environmental historian Elliott West looks at how groups organized to reap the energy resources of the midwestern plains during the nineteenth century. Recognizing that humans' unique ability to develop "visions" about their environment and act on those imaginings grants them "enormous manipulative power over their surroundings," West argues that energy flows existing beyond people's "perceptive environment" influenced how such dreams were carried out. People can imagine paths to power—which West defines as energy "captured and set to a purpose"—and organize themselves and their environment to effectuate that vision, but energy flows existing in the "effective environment" also work to structure society in unforeseen ways.[23] Native Americans of the Plains learned this lesson the hard way during the nineteenth century, as their imagined path to power depended upon the same precious energy sources—water, grass, bison, and timber—that migrating whites usurped for their own visions of power.

Struggles over power are the stuff of politics (and its extension, war). We cannot develop this theme in depth in a short essay, but we hope that energy and power become the twin foundations for a bigger bridge between environmental and technological historians, on one side, and politi-

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[21] Smil, 243 (emphasis in original).

[22] White (n. 4 above), 6, 13–14.

[23] Elliott West, *The Contested Plains: Indians, Goldseekers, and the Rush to Colorado* (Lawrence, Kan., 1998), xviii–xxiv. West explains the connection between "visions," "energy," and "power": "Of the imaginings that have made a difference, some of the most consequential have involved power, broadly defined. Part of an effective environment is the energy that moves continuously around us. All organisms draw on that energy, convert it, and use it in order to live. As energy is captured and set to a purpose, it becomes power. The application of energy is power in its widest meaning" (xxi).

cal historians on the other. Individuals and organizations have gained and lost political power by virtue of gaining and losing control of energy, whether they accessed energy directly (in their food) or indirectly (by controlling energy in other people's bodies and in machines). Some scholars have suggested that certain energy regimes have inherent political properties. James Williams's study of energy in California builds on the argument of Lewis Mumford (and others) that the secular trend of technology has been from democratic to authoritarian forms. In energy history, Williams points to water, wind, wood, and animal power as democratic, while fossil fuels and nuclear fission led to authoritarian energy regimes.[24] We hope more scholars will trace the sources, paths, and consequences of energy used by political organizations and regimes.

The Industrial Revolution Reconsidered

To illustrate how our framework can lead to new interpretations of history, we draw on the research of co-author Thomas Finger in the following case study.[25] Imagine a cotton mill in Manchester, England, circa 1880—a factory amid the Industrial Revolution. Under a single roof large numbers of workers tend machines that integrate all stages of cotton-textile production from raw materials to finished and dyed cloth. Imagine also that you are able to visualize the energy inputs that make this all possible. The most obvious input is the fossil fuel. You are able to see exactly where those fuels are burned; you see and smell the smoke rising from the factories, producing a dense cloud of smog hovering over the city. You can see pistons moving as a result of this burned energy, and you see how those pistons turn line shafts and belts throughout the vast structure, producing motion and, ultimately, work.

Historians of the Industrial Revolution have focused their attention on this kind of energy. Kenneth Pomeranz argues that industrialization in Britain occurred partly because it sat upon rich coal reserves.[26] David Landes outlines a progressive improvement of machines and knowledge that allowed humans to best channel those fossil fuels.[27] E. A. Wrigley goes so far as to say that the Industrial Revolution represented a near total switch from "organic" to "mineral" energy sources.[28] Our purpose here is not to refute

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[24] Williams, 3–4.

[25] Thomas Finger, "Harvesting Power: American Agriculture and British Industry, 1776–1900" (Ph.D. diss., University of Virginia [forthcoming]).

[26] Kenneth Pomeranz, *The Great Divergence: China, Europe, and the Making of the Modern World Economy* (Princeton, N.J., 2000), 66–68.

[27] David Landes, *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present* (London, 1969).

[28] E. A. Wrigley, *Continuity, Chance and Change: The Character of the Industrial Revolution in England* (Cambridge, 1988), 5–6.

these stories, but to emphasize that they focus only on one part of the energy equation. Think back to the mill and its energy inputs. Pomeranz, Landes, and Wrigley help us understand about how machines consumed energy and turned it into power. But what of the other energy consumers in that factory? What about the workers themselves?

To think more deeply about the sources of energy that fed those millworkers, we move from the history of technology to environmental history. Here, we find a chain of historical connections that brought energy out of nature for human consumption. In fact, if we want to talk about the energy inputs required for work in a Manchester mill, we must journey to an American wheat field. Industrialization in Britain succeeded not only due to fossil fuels, but also because it tapped American solar energy.

It is not surprising that this energy input has gone largely unnoticed. Fossil fuels are more dramatic and visible, and a greater departure from what came before; in short, they lend themselves to a great story. But calories for human consumption were no less important as an energy input—they were foundational to industrialization. That humans need to eat is not our novel claim here; rather, we argue that the *way* people eat has far-reaching implications in the reciprocal relationships among humans, nature, and technology. In order to tap American solar energy, British and American merchants constructed a technological system designed to convert solar energy trapped inside grains of wheat. The bodies of industrial workers converted this energy into work.

Using the frameworks of energy and power, we can begin to envision large-scale connections between the development of the nineteenth-century U.S. economy and British industrialization. This connection is not one of mere temporal alignment, but of active involvement and construction of a sociotechnical system designed to move energy from one place to another. Links in this chain—a railroad from farm to depot, a grain elevator in a milling center, or docks at an Atlantic port—were all essential in moving this energy. But they did not share equal parts of the power that derived from this system. This is because those who constructed and controlled this system had disproportionate access to the energy coursing through it; access increased their ability to convert that energy into power.

In their drive to obtain a steady supply of calories for industrial workers, British investors envisioned the United States as a fruitful place for their investment in agriculture and transportation.[29] This investment, however, was risky—one reason why it could also prove remunerative. The U.S. economy suffered from periodic panics and depressions, it lacked a suffi-

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[29] Nathan Miller, *The Enterprise of a Free People: Aspects of Economic Development in New York State during the Canal Period, 1792–1838* (Ithaca, N.Y., 1962); L. H. Jenks, *The Migration of British Capital to 1875* (New York, 1938); Morton Rothstein, "A British Investment in Bonanza Farming, 1879–1910," *Agricultural History* 33 (1959): 72–78.

cient transportation infrastructure to ensure that commodities could cheaply flow from interior to coast, and rudimentary communications systems raised transaction costs, particularly when droughts, floods, frosts, or pests brought sudden fluctuations in the price of grain.

To mitigate these problems, merchants built technologies that allowed them to influence the flow of energy. Grain elevators, railroads, and steel sailing freighters out of Scotland were all designed to ensure a steady flow of caloric energy from the United States to Great Britain.[30] Such technologies also increased the power of those who controlled them, which left other vital chains, such as farmers, with less power. But this does not mean that they had *no* power.

Let us take a moment to view this system from the perspective of an American farmer involved in the Patrons of Husbandry in the 1880s. By that time, a farmer in Iowa produced more wheat, owned more land, and worked it with more machines than had his father a generation ago in the fields of New York and Ohio. Because of this, the farmer found himself trapped in his own success: while he produced more wheat, each grain was worth less due to the sheer size of lands then being coaxed into production. In addition, railroad companies had re-created the grain market to favor the shippers rather than the producers. Understood from the perspective of this essay, while the farmer harvested more *energy*, the sociotechnical system that transferred that energy to England concentrated the *power* in the hands of those who controlled the flow of energy from one place to another. This was due in large part to the business strategies employed by grain merchants and railroad executives to ensure larger profits in a notoriously risky business.

As railroad companies tapped into British capital to expand into the American interior, they were beset with further managerial challenges. Railroad lines often extended into unsettled land, and the consequent high cost of construction resulted in higher risk to investors. To reduce this exposure, railroads promoted settlement along their lines, sold new settlers wheat seed, and constructed grain elevators to hold the newly produced wheat. These mechanisms facilitated greater wheat production, but also effectively shifted much of the risk from those who transported the grain to those who harvested it.

Due in part to these strategies, in 1880 the United States exported over ninety-five million bushels of wheat to Great Britain. This total represented nearly one-quarter of all wheat production in the United States, 53 percent of its total wheat exports, and 65 percent of all wheat imports into Great

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[30] William J. Brown, *American Colossus: The Grain Elevator, 1843 to 1943* (Cincinnati, 2009); Harry Fornari, *Bread Upon the Waters: A History of United States Grain Exports* (Nashville, 1973); Daniel Morgan, *Merchants of Grain* (New York, 1979); Cronon (n. 4 above).

Britain.[31] Farmers were quick to realize the implications of these numbers. As early as the 1860s and early 1870s and coinciding with a dramatic growth in the grain trade with Great Britain, their clamor to reform grain shipping and storage practices grew stronger.

Responding to a perceived loss of social and economic power, farmers banded together in communal organizations that sought to solidify their status as energy-harvesters. They proposed an alternate system, one where the extension of credit, land-use practices, and agricultural knowledge favored—in their own words—the producers over the shippers. The Granger movement, and later the Populist revolts of the 1890s, can thus be viewed in a wider context as social movements responding to the loss of power within a sociotechnical system designed to make solar energy harvested in one area available to another. By the very act of organizing, farmers transferred their status as energy-harvesters into political and economic arenas, and they did achieve some temporary success in bringing about legal changes to shipment and storage methods within the United States.[32]

Back to our Manchester cotton mill. Who would have guessed that we could have traced, in broad strokes, its energy connections back to the sun-baked fields of the U.S. Midwest? In doing so, we have glimpsed how tracing a chain of energy "upstream" can allow historians of technology and the environment to outline new connections. And we need both the history of technology and environmental history to completely tell that story. A chain of energy requires the management of humans, nature, and machines. And as we follow that chain, human action remains present a long way back. Humans devised baking to make calories more digestible in the human body. They constructed mills to grind out insoluble fiber, thus allowing their bodies to better absorb that energy. They constructed elaborate dock systems, canals, and railroads to reduce the cost of transporting the energy from one place to another. They built warehouses and elevators to ensure that the energy would be available year-round. They constructed threshing machines and mechanical reapers to raise the productivity of the energy harvest. And they took wild grasses and selected their grains to hold greater amounts of energy. In fact, the only section of this chain humans did not play an active part in shaping was the burst of energy from the sun.

Our point is that the ways in which human energy needs are satisfied have real implications for the ways in which sociotechnical actors manage nature, technologies, and other humans. In telling this story, we have highlighted, within the narrow constraints of a short essay, connections among well-known historical events. Crucially, our focus on energy flows helps us tell an integrated story, whereas previously these events and actors had

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[31] U.S. Department of the Treasury, *Report on the Internal Commerce of the United States* (Washington, D.C., 1881); W. Page, *Commerce and Industry* (London, 1919).

[32] Most notably in the U.S. Supreme Court case of *Munn v. Illinois* (1877).

been considered in isolation. The Industrial Revolution, the growth of the Atlantic economy, the rise of internal improvements and railroads in the United States, and midwestern agrarian revolts in the late nineteenth century were all parts of a chain that fed British industrialization with American solar energy. To this end, humans who participated in this chain organized and channeled energy to create power. This power was contested and shared unequally, but it was based ultimately on the basic need of all humans to consume energy and convert it into power.

Conclusion

We have suggested that the study of energy and power offers a rich common ground for the history of technology, environmental history, and science and technology studies. A simple observation makes this intersection possible: all power derives from energy—it is energy put to work. Ultimately, this power must originate in nature, especially the sun's solar energy. This energy is neither gained nor lost from the whole system, but it does change forms and moves within and across sociotechnical systems here on earth. People gain power by enlisting other people, nonhuman nature, ideas, and technology into networks supporting their goals, and energy courses through these networks. By following the energy flows, we can understand better the internal structures of sociotechnical regimes, as well as their power in relation to other systems. Certainly, energy does not determine the internal structure or overall effectiveness of these systems, but power derives from the particular way by which relationships are structured to harness energy. An analysis of energy flows and power through a sociotechnical system can help us understand, for example, why the Industrial Revolution, the Corn Laws, and the U.S. Granger movement sparked one another and changed the world. Such an analysis can provide similar insights to other histories.