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Energizing historical materialism: Fossil fuels, space and the capitalist mode of production

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ABSTRACT

In this paper, I present a theoretical argument that fossil fuel represents a historically specific and internally necessary aspect of the capitalist mode of production. Despite sustained attention to distributional conflicts between international capital and energy rich nation–states, few historical-materialists have paid attention to the relations between fossil fuel and capital accumulation in industrial capitalist societies. In opposition to ecological economic notions of fixed thermodynamic "laws", I first propose a dialectical conception of energy as embedded in dynamic social processes and power relations. Second, I review the historical importance of the energy shift from solar or biological sources of energy (muscles, wind, and water) to fossilized sources of energy (coal, oil, and gas). I then demonstrate how attention to fossil fuel energy forces a reexamination of the core insights of ecological Marxism and the political economy of nature. In the core argument of the paper, I reconsider the shift from biological to fossil energy as internal to the generalization and extension of capitalist social relations from two basic vantage points – (1) capitalist production based on wage labor; (2) the spatial conditions of capitalist circulation. I conclude by asking whether it is accurate to conceptualize capitalism as a "fossil fuel mode of production" and highlight the political urgency of a historical materialist perspective that takes seriously the importance of energy to the reproduction of capitalist social relations.

1. Introduction

In the first decade of the new century, it is apparent that any mode of analysis claiming to confront the contradictions of capitalism must "come to terms with nature" (Panitch and Leys, 2006). In particular, sustained questions into the politics of access to and control over energy-resources now take center stage from a variety of perspectives on the left in general (Hiro, 2006; Klare, 2004), and Marxist scholarship in particular (Altvater, 2006; Bina, 2004; Buck, 2006; Burkett and Foster, 2006; Harvey, 2003; Labban, 2008; Retort, 2005; Watts, 2006). Indeed, the ecological politics of climate change and the antiwar politics of Iraq both converge on a similar object of disdain – oil. The intense politics of oil at the present moment reflects a perhaps obvious, but nevertheless crucial point: capitalist social life is profoundly dependent on the abundant provision of fossil fuel energy, for example, coal powered electric power plants, oil powered transportation systems, and gas-fired furnaces. Yet, Debeir et al.'s (1991, p. xiii) statement that energy is one of the "main blind spots in Marxist thought" still holds true nearly two decades later.[1] Most of the work that does exist deals with the most overtly political aspects of energy–society relations focused on international oil companies and the (neo) colonial history of petroleum in the Middle East, Latin America, and Africa (Bromley, 2005; Coronil, 1997; Harvey, 2003; Nore and Turner, 1980; O'Connor, 1962; Sawyer, 2004; Valdivia, 2008; Watts, 2006). This work focuses on the *distributional conflicts* (see Emel and Huber, 2008) between oil producer states, international capital and the local communities proximate to sites of extraction. While hugely important to understanding the geography of energy conflict, such sustained focus on distribution neglects an analysis of how fossil fuel energy represents a necessary aspect of capitalist *production* and *circulation*.

In this paper, I offer a theoretical investigation into the *historically specific* relations between fossil fuel energy and capitalism conceived as a "mode of production". I first lay out a Marxist concept of energy with an analytical focus on *social relations*, as opposed to transhistorical biophysical fixities embedded in the laws of thermodynamics. Second, I review several insights stemming from environmental history, ecological economics, and world-systems theory, on the historical importance of the shift from solar-based energy sources (muscles, wind, and water) to fossil-based energy sources (coal, oil, and gas). Then, reviewing the classic goals of historical materialism, I appraise current approaches in ecological Marxism and explore the implications of a perspective on fossil fuel and capital accumulation. Finally, given the overwhelming attention paid to distribution, I provide a preliminary approach to

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[1] Although this is more and more rapidly not the case (e.g. Altvater, 2006; Buck, 2006; Burkett and Foster, 2006; Clark and York, 2005).

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understanding capitalism–fossil energy relations from two generally underexplored vantage points – capitalist production and circulation.[2] My aim is to demonstrate that the late-18th/early-19th century "energy shift" from biological to fossil modes of energy – at the time meaning coal[3] – coincided with the dramatic *social* shift toward the generalization of capitalist social relations.

2. Energy, history, and social theory

2.1. Energy as a social relation

The textbook definition of "energy" is the "ability to do work" ranging from photosynthesis to boiling water; from the steam to the internal combustion engine. Energy is the kind of "transhistorical" abstraction that applies to all human societies at all levels of interaction with the natural environment. The societal relation to forms of energy (muscles, wind, water, and fuel powered machines) is always a central factor shaping the ways in which people produce a livelihood, traverse space and form relations of exchange. But this importance must tread carefully in order to avoid a sort of "energetic determinism" that divorces historical development from its true social and political basis. While energy *matters*, it is important to retain a perspective of dialectical complexity that emphasizes the mutually constitutive relations between energy and society.

Ecological economics is perhaps the only sub-discipline to attempt a serious theoretical integration of energy into economic analysis. Martinez-Alier (1987) traces the long history of seldom-heard economists, natural scientists and philosophers calling for the application of thermodynamic principles to the analysis of economic systems. It took nothing less than the rise of the environmental movement, the OPEC-price shock of the 1970s, and the groundbreaking work of Georgescu-Roegen (1971)[4] to create a substantial disciplinary niche for ecological economics (Cleveland, 1999; Daly, 1996). Ecological economics critiques neoclassical approaches for their neglect of the biophysical foundations of all economic activity. Energetic theories of "value" have been proposed and hotly debated (Burkett, 2003; Daly and Umana, 1981). Others attempt to link standard macroeconomic growth indicators like gross domestic product (GDP) with energy intensity and energy quality to discern an empirically observable decline in "energy return on investment" (EROI), or the amount of energy gained above the amount of energy expended obtaining it (Cleveland, 2003; Cleveland et al., 1984, Cleveland et al., 2000). The historical trend toward declining EROI seemingly provides a biophysical "limit" to the production and reproduction of capitalist economic life based on fossil fuels.

While ecological economics is valuable for pointing to the biophysical foundations of modern capitalist economies, they tend to treat the economy in isolation and neglect the undeniable cultural and geopolitical factors that shape the use of energy in capitalist societies (Emel et al., 2002). Unduly concentrating on biophysical energy flows, ecological economics fails to grasp the more interesting aspects of how these flows are politically contested and struggled over. Moreover, the uneven distribution of world energy production and consumption makes the most important question not what is the absolute, biophysical "limit" to the future of fossil-based economies, but rather, what are the social and political implications of declining EROI?

A Marxist analysis of energy-systems could focus on precisely the social and political aspects that ecological economists neglect (see e.g. Burkett, 2003, 2005; Burkett and Foster, 2006; Schwartzman, 2008). In order to engage energy issues from a historical-materialist perspective, the literature must move from conceptions that understand energy as a "thing" or a "resource" towards a conception of energy as a "social relation" enmeshed in dense networks of power and socioecological change.[5] Furthermore, fossil fuel energy is a much more *historically specific* mode of energy and represents a concrete abstraction applicable to only the last 200 years of human history. While ecological economists stress the transhistorical laws of thermodynamics, a historical materialist analysis would emphasize both the particular conditions through which "fossil fuel" became such a useful source of energy and the social consequences of its peculiarly prolific capacities for enhancing productivity.

The prospects for cross fertilization between ecological economics and historical materialism (see Kaufman, 1987) are hindered due to long-winded debates over what Marx himself actually thought about energy, ecology, and sustainability. (Martinez-Alier, 1987, pp. 218–225) criticizes Marx and Engels because of their putative failure to take seriously the contemporaneous attempt by Ukrainian socialist, Sergei Podolinsky, to combine socialism with the laws of thermodynamics. Foster and Burkett (2004) refute this claim by showing that while Marx and Engles found Podolinsky's premises problematic, his focus on labor and energy interested them. Furthermore, Burkett and Foster (2006) go to great lengths to demonstrate Marx's nuanced ideas on socioecological metabolism and the relations between capitalist machine production, energetic power, and entropy. So, while Marxists have effectively refuted the "myths" held by ecological economists that Marx's thought was inherently unecological (Burkett and Foster, 2006; Foster and Burkett, 2000), there is much work to be done to rethink well-established Marxian concepts through the ecological lens of energy. But such a historical-materialist analysis must start from real history.

2.2. Energy and history

In the broadest terms, human history contains two fundamental energy shifts: the agricultural revolution, allowing humans to spatially concentrate available food energy, leading to increased population, social inequality, and sedentary settlement and the industrial revolution leading to the increased use of inanimate fossil energy sources such as coal, oil, and natural gas (Cipolla, 1978; Crosby, 2006; McNeill, 2000; Sieferle, 2001 [1982]; Smil, 1994; Wilkinson, 1973; Wrigley, 1988). Many environmental historians (Crosby, 2006; McNeill, 2000; Sieferle, 2001 [1982]), world-systems theorists (Marks, 2002; Podobnik, 2006), economic historians (Pomeranz, 2000; Wrigley, 1988), and ecologically minded social scientists (Cottrell, 1955; White, 1943) recognize the historical importance of the second shift from muscle-based sources of mechanical energy dependent on the direct conversion of solar

[2] This triad of production–circulation–distribution roughly aligns with the general outline of the three volumes of Marx's *Capital* (the third including competition and distribution among many capitals). I want to add that while one could include "consumption" as a separate category from which to analyze capitalism–fossil fuel relations, space prevents me from an explicit discussion. In Section 2 below, I will briefly discuss how capitalist production predicated upon the wage-relation also requires the development of "mass consumption" among large sectors of wage-workers; consumption that is thoroughly *powered* through fossil fuel energies (see Nye, 1998, for an exhaustive historical treatment).

[3] As I will make clear several times below, my argument is that the coal-fired economy represented the crucial shift from biological to fossil modes of energy. While the subsequent "shift" from coal and steam to electricity and oil is almost equally dramatic (Smil, 1994; Podobnik, 2006), it could not have happened without the historical momentum provided by the coal economy.

[4] It is rarely acknowledged, although see Daly (1996, p. 2) and Kaufman (1987), that Georgescu-Roegen's work calls for a *dialectical* understanding of economy-energy relations – in opposition to what he calls the arithmomorphic perspective (i.e. mechanistic, mathematical modeling) of neoclassical economics. He also makes use of Marx's simple-reproduction schemas throughout his long and difficult text. Needless to say most Marxists do not pay much attention to Georgescu-Roegen's work (although see Altvater, 2006).

[5] Harvey (1974) famously provided a similar framework for analyzing the relations between population and resources.

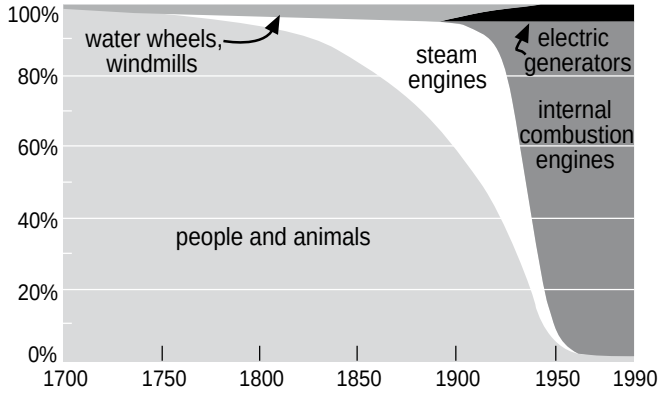

Fig. 1. Global shares of prime mover capacities (percent): 1700–1990, source: adapted from Smil (1994, Fig. 6.3, p. 230).

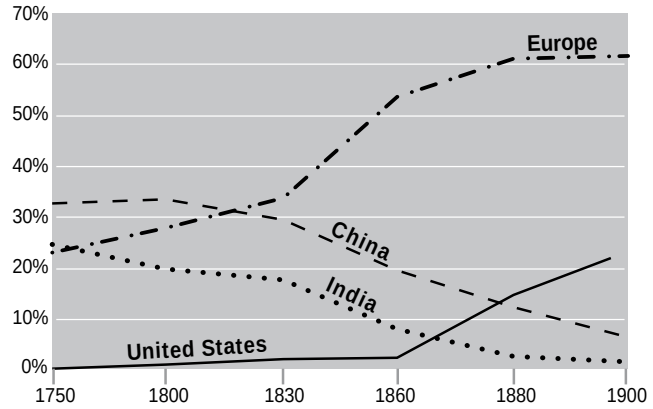

Fig. 2. Share of world manufacturing output: 1750–1900, source: adapted from Marks (2002), Fig. 5.2, p. 125).

energy absorbed in plants to energy systems based upon fossil fuel powered machines. Fossil fuel, or what Alfred Crosby (2006, p. 59) terms "fossilized sunshine", is the accumulated form of solar-based biological life (plant and animal matter) that has congealed underneath the earth's crust for millions of years. The substance of fossil fuel has served other useful purposes (e.g. petroleum was harvested for its medicinal qualities); only recently appearing as an important fuel to power engines and machines. McNeill (2000, p. 13) explains the crucial significance of fossil fuels to this energy shift:

> "The industrial revolution first augmented and then quickly outstripped human muscle power. Wherever it spread, it ended the somatic energy regime [based solely on immediate solar energy], replacing it with a much more complex set of arrangements that one might call the "exosomatic energy regime", but might better be called the fossil fuel age: to date the lion's share of energy deployed since 1800 has come from fossil fuels".

Prior to the industrial revolution, Cipolla (1978, p. 45) estimates that 80–85% of all mechanical energy came from animal and human muscle power; the balance coming from wind and water.[6]

The shift from productive systems based on the application of human and animal muscle power to systems based on "inanimate", or non-living, power represents a fundamental transformation in what Marx called the "labor process", or what ecological Marxists call the socionatural metabolism (Foster, 2000; Heynen et al., 2006; Swyngedouw, 2006). Fig. 1 reveals the extent of this historical transformation that began over the course of the late-18th century and continues to this day. Wrigley (1988, p. 29) also notes the importance of the coincident shift from what he calls an "organic" economy wherein the bulk of energy, food and fiber was derived from land-intensive resources (e.g., cotton, wheat, and livestock) toward a "mineral-based energy economy…freed from dependence on the land for raw materials". As industry moved from wood and natural fibers to iron-ore, aluminum and coal-energy the relief of what some call "the land constraint" was remarkable (Pomeranz, 2000, p. 264; Sieferle, 2001 [1982]).

In the course of this historical transformation, the economic geography of power was also completely reconfigured. Marks (2002) argues that prior to the industrial revolution in Great Britain, China and India were the world economic superpowers; masters of what he calls the "biological old regime", that is, productive systems based on solar energy. Fig. 2 reveals how during the 19th century, European countries, and later, the United States grew to represent the bulk of global GDP. Pomeranz (2000, p. 20) argues that Europe's ascendance was not only due to Britain's ample reserves of coal, but also what he calls a "new kind of periphery" in the New World growing large amounts of both land and labor intensive commodities such as cotton and sugar. Thus, this global conjuncture of European industrial emergence was at least partially based upon what Arrighi (2007, citing Sugihara on p. 34) describes as a new form of capital accumulation "based on…non-human resources"; that is, the enormous reserves of latent solar energy bound up in inanimate fossil energy. This has led many commentators to reflect on the relatively short-lived historical life of European power (Frank, 1998), and suggest that Asia's resurgence as a world superpower is on the horizon (Arrighi, 2007). Still, as Smil (1994, 2003) is always wont to point out, much of the world's population remains embedded in the biological old regime in that they derive much of their productive powers from human and animal muscle power.

2.3. Capitalism and fossil fuels – An underexplored connection

Despite the fact that many recognize the socio-historical importance of fossil fuel energy to the transformations of the 19th century, scholarship under the banner of "historical materialism" has been largely silent on the social, political, and ecological importance of fossil fuel to capitalist industrial development.[7] This oversight is all the more remarkable if one revisits Marx and Engels' (1978 [1846], pp. 149–150) classic epistemological statement on the premise and goals of historical materialism:

> "The first premise of all human history is, of course, the existence of living human individuals. Thus the first fact to be established is the physical organization of these individuals and their consequent relation to the rest of nature… The writing of history must always set out from these natural bases and their modification through the course of history".

In this sense, historical materialism has not, as yet, gone far in confronting this important "natural bas[is]" of the capitalist mode of production – fossil fuel energy.

[6] Cottrell, 1955, p. 39–79 illuminates the role of wind power in laying the conditions for mercantilism in the 15th through 17th centuries.

[7] As I said before, there have been many studies of energy politics in the developing world, but these studies do not confront the role of energy in the "advanced-capitalist countries". Coming out of the French Marxist traditions, Debeir et al. (1991) is perhaps the most comprehensive attempt to integrate energy into historical materialism, but their sweeping aim at most of human history allows them to miss some important relations between capitalism and fossil fuel. Altvater (2006) has recently offered a good discussion of "fossil capitalism" in relation to contemporary issues of oil and imperialism.

The "blind spot" on energy continues amidst a considerable flowering of Marxist debate on nature–society relations. Much insightful work debates Marx's concept of nature (Schmidt, 1971; Smith, 1990; Castree, 1995), unpacks the ecological contradictions of capital (O'Connor, 1988, 1998), examines capitalism's metabolic and biospheric "rifts" (Clark and York, 2005; Foster 1999, 2000), and offers a dialectical approach to nature–society relations (Harvey, 1996). Some do draw from the transhistorical notion of entropy bound up in the laws of thermodynamics (Altvater, 1993; Burkett, 2005; Martinez-Alier, 1987; O'Connor, 1994), but they owe their concept of entropy to the ecological economics and do not provide a dialectical-materialist conception focusing on social relations and the historical specificity of fossil fuels (cf. Schwartzman, 2008).

A focus on fossil fuel energy in relation to Marxian understandings of capitalism also forces a reexamination of emerging literature on the political economy of nature (Bakker, 2003; Bridge, 2000; Castree, 2003; Heynen and Robbins, 2004; McCarthy and Prudham, 2004). Much of this literature utilizes James O'Connor's (1988, 1998) breakthrough notion of the "second contradiction of capitalism" which claims capital tends to degrade nature (along with living labor and social infrastructure) as a "condition of production" provisioned by ecological processes *outside* the circuits of capital accumulation (Bridge, 2000; McCarthy, 2004). Some have combined these insights with Polanyi's (1957) theory of nature as a "fictitious commodity" to understand how natural processes (crop cycles, hydrological cycles, and timber maturation) regulate and pose barriers to the smooth commodification of nature (Benton, 1992; Bakker, 2003; Henderson, 1999; Prudham, 2005). Bunker and Ciccantell (2005, p. 15) also eschew a focus on internal capital–labor relations in favor of what they call, "the external dialectic of capital and nature". Although helpful in understandings nature's agency and the specifically capitalist exploitation of nature (pollution, land degradation), all of these perspectives treat "nature" as an external, "set of obstacles, opportunities, and surprises to capital" (Prudham 2005, p. 18) or an external "condition" of capitalist production. Rather than externally pose barriers or set conditions, fossil fuel *internally* powers the forces and relations of capitalist production. Therefore, following Emel et al. (2002) and Walker (2001), a focus on fossil fuels locates nature and resources not as an "external" factor, but as an internal and necessary basis for the capitalist mode of production.

In the next two sections, I will offer a theoretical account of fossil fuel's centrality to the capitalist mode of production. "Mode of production" is, according to Hall (1977, p. 54), the "master concept" of historical materialism, representing the "the conceptual or analytic matrix which allows us to think, systematically, the fundamental structure of relations by means of which men [*sic*], under determinant historical conditions, produce and reproduce the material conditions of life". Although the significance of fossil fuels (in particular oil and gas) to the capitalist economy has only deepened with time, I will pay particular attention to the *transition* to a fossil fuel powered economy to sketch out a concomitant transition toward the expansion and generalization of capitalist social relations. Just as Marx found nearly 150 years ago, I find examining the emergence of the "classic" industrial capitalist society, Great Britain, particularly instructive in this task.

3. Fossil fuels and capitalist production – on wage labor and muscles

In this section, I only focus on capitalist production; abstracting away from commodity circulation and distributional conflicts apart from the capital–labor relation. One of Marx's most basic discoveries was that the historical emergence of capitalist production depended on the particular social relationship of wage labor. In other words, the capitalist class, who own a monopoly over the means of production (space, machinery, and raw-materials), depends on a class of workers who have nothing to sell but their labor power in order to survive. This constitutes the irony of the notion of "free" workers who are, indeed, freed from any sure means of producing their own livelihood and free to sell their labor in exchange for a wage. Thus, as Marx details in his chapter on "primitive accumulation" (1976 [1867], pp. 873–942), the generalization of capitalist production depended on historical processes of "proletarianization", or divorcing the mass of the productive population from any means of producing a livelihood themselves (most importantly, land); a history "written in letters of blood and fire" (Marx, 1976 [1867], p. 875).

3.1. Energy and the productive forces

Any examination of the labor process must seek to explicate how the development of the productive forces articulate with the social relations of production at that particular moment in history. As Harvey (1982, p. 99) indicates, in the former one considers "the sheer power to transform nature" in the production of material life, and in the latter, "the social organization and social implications of the what, how and why of production". Since I have isolated wage labor as the key social relation to consider, the focus must shift to how fossil fuel energy transformed the productive forces or the power to transform nature. In fact, Martinez-Alier (1987) suggests that the "productive forces" represent the key concept to integrating "ecological" concerns into a Marxist framework.[8]

Again, one of the most important aspects of the "energy shift" to fossil fuels is a displacement of human muscle power as the core *productive force of production*. Prior to the fossil age, the societal power to transform nature was dependent upon the control over human and animal muscles. And the power of those muscles placed severe constraints on the scale and productivity of any labor process. In eras where human muscle power represented a major productive force of society (e.g. the American antebellum south, Egyptian civilization), slavery, or the direct ownership of human beings, can be seen as a sinister way to centralize and reproduce power relations.

> "Slavery was the most efficient means by which the ambitious and powerful could become richer and more powerful. It was the answer to the energy shortage. Slavery was widespread within the somatic energy regime, notably in those societies short on draft animals. They had no practical options for concentrating energy other than amassing human bodies" (McNeill, 2000, p. 12).

But during the 19th century, the emerging core productive force lies not in bodies, but in machines. Suddenly labor was "freed" from being the most productive *physical force*, and thus freed, in some sense, from the manual aspects of labor; allowing for a more complex division of labor. Moreover, "skilled labor" expresses itself in the machines and workplace design for maximum efficiency, while "manual" labor operates the machinery. This shift from productive forces based on human muscles, to one based on machines had grave social implications for the newly created mass of workers with nothing to sell but their labor:

> "… the motive mechanism also acquired an independent form, entirely emancipated from the restraints of human strength… the steam-engine was from the very first an

[8] He states, "The ecological view of the conditions of human existence *could* have been easily connected with Marxism through an adequate definition of the productive forces and productive powers. This was *not* done by Marx" (Martinez-Alier, 1987, p. 5). Burkett and Foster (2006) adequately demonstrate that this *was* done by Marx.

> antagonist of 'human power', an antagonist that enabled the capitalists to tread underfoot the growing demands of the workers, which threatened to drive the infant factory system into crisis" (Marx, 1976 [1867], pp. 499, 563).

For the first time in human history, the core energetic forces of production were *independent* of what Marx calls "human power". Thus, a class monopoly over the means of production (machines, tools, raw materials, and land) apart from the propertyless worker provides the social basis for the development of the productive forces based on capital (see also Burkett and Foster, 2006, pp. 130–140). The whole notion of workers divorced from the means of production began to make social sense only in the context where the worker is no longer a prime physical force of production. This puts the "free worker" in quite a precarious position: "For capital, the worker is not a condition of production, only work is. If [capital] can make machines do it, or even water, air, so much the better" (Marx, 1973 [1857], p. 498). This shift had dramatic consequences on the actual lived experience of the labor process. Eric (Hobsbawm, 1968, p. 50, 67) called the new factory system a "revolutionary form of work" in which the worker's activity was submitted to the "tyranny of the clock, the pace-setting machine, and the complex and carefully timed interaction of processes…".

As Burkett and Foster (2006, p. 131) recently note, the crucial social result of this energy shift in the productive forces was a dramatic expulsion of worker control over the labor process: "[t]he mechanization of tools means [capital is] freed from the limitations of the individual worker's labor power as the direct motive force". The worker became a less important physical productive force precisely because the bulk of productive energy now depends not on human muscles, but on inanimate, stored fossil energy. Indeed, in capitalism the worker more and more becomes a "living appendage of the machine" (Marx, 1976 [1867], p. 614).

Some broad trends in the early history of the textile factories in Britain reveal the increasing reliance on coal to power the productive forces. In 1835, cotton factories employed 110,000 power looms that more and more relied upon coal-fired steam power; by 1861 that had risen to 400,000 (Mitchell, 1988, p. 370). Cotton factory power rose dramatically: coal-based steam power accounted for 46 horsepower in 1850 and 299 horsepower in 1870 (*ibid*). Initially used mainly for heating British homes in lieu of a great scarcity of wood (cf. Siefrle, 2001 [1982]), over the course of the 19th century coal increasingly powered the industrial manufacturing and the factory system. As late as 1830, 10.7 million tons of coal, or 46% of overall coal use, was still used for domestic heating in the UK, with only 7 million tons, or 30%, used in industrial manufacturing (Mitchell, 1988, p. 258). By 1869, domestic use had fallen to 20% of overall use, with industrial manufacturing and iron and steel production accounting for 56.5 million tons or 59% of overall use (*ibid*). Overall, the mining of coal in the UK skyrocketed from 5.2 million tons in 1750 to 32 million tons in 1834, 68.4 million tons in 1854, and 123.3 million tons in 1874 (Mitchell, 1988, p. 247). What started in the textile factories of early industrial Britain spread to a "second" industrial phase (see Hobsbawm, 1968, pp. 88–109) based upon the production of iron, steel and railroads and signaled the real emergence of Wrigley's (1988) "minerals-based energy economy".

3.2. From muscle power to versatile bodies

But why did wage labor become a necessary social relation in a society dominated more and more by large-scale machine production powered by fossil fuel? The wage labor relationship is historically novel because the human's "capacity for work" becomes commodified (not the human-being themselves). The commodification of labor power, as Marx points out again and again, was indispensable to the specifically capitalist mode of production based on large-scale industry.

> "[L]arge-scale industry, by its very nature, necessitates variation of labour, fluidity of functions, and mobility of the worker in all directions… We have seen how this absolute contradiction does away with all repose, all fixity and all security as far as the worker's life-situation is concerned… (Marx, 1976 [1867], pp. 617–618)."

In earlier historical eras it was control over human power itself that allowed for the reproduction of entrenched power relations, but the social relations of capitalist production depend upon a "versatile" labor-force, capable of fluid movement from one sphere of production to another. It is the commodification of labor power that allows for such fluidity and movement in the context of what Polanyi (1957, p. 98) referred to as, "the flux and re-flux of industrial employment". In order for capital to adapt to the conditions of market exchange and competition, it must be free to modify, at will, the quantity invested in what Marx importantly calls *variable* capital (the value portion devoted to labor power). Of course, the constantly shifting uneven development wrought by processes of industrialization and deindustrialization are just as plainly visible today as in Marx's time.

The most significant socio-historical indicator of this process is the rise of the factory "proletariat" along with the rise of fossil-powered large-scale industry. Hobsbawm (1968, p. 66) details the significance, "[proletarians] have no source of income worth mentioning except a cash wage which they receive for their work. Preindustrial labour, on the other hand, consists largely of families with their own peasant holdings, craft workshops, etc., or whose wage-income supplements – or is supplemented by – some such direct access to the means of production". Hobsbawm (1968, p. 50) acknowledges that the number of "pure" proletarians in the early-1800s were few. In 1800 the UK cotton industry employed 100,000 factory wage laborers in comparison to 184,000 *handloom* weavers (Mitchell, 1988, p. 376); workers who still probably owned some means of production *and* relied on *human muscle power* as the core productive force. By 1862, there were 452,000 factory workers compared to 3,000 handloom weavers (*ibid*)[9], reduced to what Hobsbawm (1968, p. 47) poignantly described as, "starving wretches". The capacity of fossil-powered industry to destroy handicraft manufacture represents an unprecedented shift away from "human power" driving the labor process.

In this context, it is helpful to revisit Polanyi's (1957) classic institutional history. He contended that a true competitive market for wage labor – one, along with nature and money, of his famous "fictitious commodities" – only emerged fully in the throes of Britain's industrial transformation. Polanyi examined the Speenhamland regime (1795–1834) of providing wage-supports for large sectors of the working and non-working poor as a last vestige of an antiquated British notion that all individuals have a "right to live whether a man [*sic*] earned a wage or not" (*ibid*, p. 84). With the development of large-scale fossilized industry, provisioning "the right to live" did not suit the needs of the emerging industrial capitalist class: "…the steam engine was clamoring for freedom and the machines were crying out for human hands" (*ibid*, p. 92). Thus, the famous Poor Law Reforms of 1834 did away with the "right to live" and established for the first time a labor market "on a national scale" (*ibid*, p. 92). In Polanyi's view this was crucial to the requirements of an industrial economy where starvation and pauperism

[9] The footnote attached to these numbers warns that they are not meant to reflect the actual numbers of those employed in the cotton industry, but rather *the proportion between* factory workers and handloom weavers. In this case we can also compare the ratios as dramatically shifting from 25:46 (factory: handloom) in 1800 to 452:3 in 1862.

provided the basis through which a "reserve army" of unemployed could provide the check against wage-worker autonomy, power and control (*ibid*, p. 142).

3.3. Fossilizing production, generalizing wage labor

The historical emergence of the social relation of wage labor is thus part and parcel of the "energy shift" in the productive forces from biological to inanimate (fossil) sources of energy. But I do not want to suggest some sort of technological determinism that suggests fossil fuel energy-systems "caused" the development of wage labor relations. World-systems theorists (Frank and Gillis, 1994; Wallerstein, 1974), assert that "capitalist" social relations, including wage labor, preceded the industrial revolution by hundreds if not thousands of years. On the other hand, Robert Brenner (1977) notoriously critiques world-systems theorists for failing to situate the transition to capitalism as based upon *class and property* relations of wage labor and capital. How to reconcile these two conflicting positions? My point is not that the social relation of wage labor cannot exist without the displacement of human muscle power, but rather the emergence of large-scale fossilized production hastened the *generalization* and *extension* of the wage labor relationship on an expanded scale heretofore unseen. As Pomeranz (2000, p. 16, emphasis in original) notes, "no matter how far back we may push for the origins of capitalism, *industrial* capitalism, in which the large-scale use of inanimate energy sources allowed an escape from the common constraints of the preindustrial world, emerges only in the 1800s". In previous modes of production, such as feudalism, wage labor might have been one amongst many competing modes of labor (slavery or serfdom), while most social conflict centered upon the control and access over land and labor and the concentrated fruits of solar energy.[10]

The generalization of wage labor is predicated upon industrial capital's peculiarly mammoth levels of productivity. The emergence of large-scale, fossilized industrial production vis-à-vis the steam engine in England in the late-18th century led to a hundredfold increase in labor-productivity in the textile industry (Marks, 2002, p. 110; Wrigley, 1988, p. 6). This growth was predicated on the harnessing of non-living sources of energy powering machines that produce at higher speeds and all hours of the day (Altvater, 2006, p. 41). Indeed, the spectacular productivity of industrial, fossil-based production started in Britain and slowly spread to other parts of the world. Wrigley (1988, p. 109) reports that, during the 1790s, only 11% of UK gross capital investment was devoted to the industrial "minerals-based energy economy"; by the 1840s that number had risen to 50%. The rate of growth of industrial production in the UK through the early years of the 19th century was consistently high: 47.2% in the 1820s and 39.3% in the 1840s (Hobsbawm, 1968, p. 51). The industrialization of textile production began a process that is still ongoing in such diverse sectors as publishing, food processing and even agriculture. Insofar as the industrial "revolution" represented a slow and steady transformation of all productive processes, it consequently also required a slow and steady expansion of a class of society dependent upon wages for their everyday survival.

This augmentation of productive power also necessitates a further extension of the "market" for exchange and, therefore, widens the scope of commodity exchange (as I will discuss below). As the law of value entangles more and more sectors of production in competition with one another on a world scale, capitalist production depends on direct ecological help from the productive power of fossil fuel energy. Moreover, as the productive power of industry and, in turn, "the market", is augmented, the wage labor relation itself increasingly becomes the consumer medium for the products of capitalist industry. Especially visible in the postwar United States and Europe, mass production eventually yields mass (and wasteful) consumption rendering ecological crisis internal to the capital relation itself. In fact, this mass consumption has come to be ultimately dependent upon the provision of cheap energy to power privatized automobile transport and electrified/heated single-family homes (see Nye, 1998).[11]

3.4. The real (ecological) subsumption of labor

So it is not simply the presence of wage labor that connotes the emergence of industrial capitalist development, but an epochal development of the productive forces as well. One of the central characteristics of capitalism is the presence of a relentless competitive drive toward constantly revolutionizing the technological bases of the productive forces. The emergence of fossil-based large-scale industry is also understandable in terms of the transition from what Marx calls the "formal" to the "real subsumption of labor by capital (see Buck, 2007)".[12] "[the formal subsumption of labour] stands in striking contrast to the development of a *specifically capitalist mode of production* (large-scale industry, etc.); the latter not only transforms the situations of various agents of production, it also revolutionizes their actual mode of labour and the real nature of the labour process as a whole" (Marx, 1976 [1867], p. 1021, emphasis in original). In other words, the real subsumption of labor not only entails the social relationship of wage labor, but also a *technical revolution in the labor process*. The real subsumption of labor is also characterized by the production of *relative* surplus value, or the competitive struggle to increase labor-productivity vis-à-vis the introduction of labor-saving devices. The technological revolutions induced through the real subsumption of labor power also completely transform the competitive dynamics of the economy toward an increase in economies of scale, centralization and concentration of capital, and barriers to entry. As production becomes more capital-intensive and based on nonhuman fossil energy and the "dead labor" of machines (see Kirsch and Mitchell, 2004), more and more leading sectors of the economy come to be dominated by a handful of large producers. One need only look at the dynamics in the highly capital-intensive extractive sector toward both geographical expansion and organizational concentration (see e.g., Bunker and Ciccantell, 2005; Labban, 2008).

While some use Marx's "subsumption" theory to distinguish between the "formal" versus the "real subsumption of nature" (Boyd et al. 2001; Smith 2006)[13] it is left somewhat ambiguous if the labor process is fundamentally different in each. In the case of fossil-powered industry, "nature", or the many millions of years it takes to form fossil deposits, can be conceptualized as a crucial aspect of the *original* conceptual distinction between the formal and real subsumption of *labor*.

[10] As Altvater (2006, p. 42) puts it, "Although something like capitalist social forms occasionally could be found in ancient societies (in Latin America and Asia as well as in Europe), they could not grow and flourish without fossil energy."

[11] Thus, from this perspective, it is crucial to see "consumption" as internal to "production" in that the wage labor relation so central to production also becomes the medium through which mass *consumption* takes place on an expanded scale (the classic purveyor of this perspective is Michel Aglietta (1979) and the regulationists).

[12] As Buck (2007) warns, it is crucial not to attempt to "periodize" this transition into neat historical "epochs", but rather conceive of it as an ongoing process.

[13] A distinction based on capital's ability to literally harness the biological productivity of nature in the "real subsumption". The formal versus real subsumption of nature theory has its own value; specifically in analyzing "nature-based" industries such as agriculture and timber production. My only point is that the original conceptual distinction can be understood through a nature-society analytic as well.

3.5. The ecological specificity of fossil energy

But what is it about fossil fuel as a specific form of energy that must be seen as so necessary to capitalist production based on wage labor? Indeed, large-scale industry developed with innovations in machine technology and these machines could, and did, find other sources of power besides fossil fuel. It could be argued that the industrial revolution was powered by the flow of water, *not* coal. Hobsbawm (1968, p. 43) reports that as late as 1838 one quarter of Britain's cotton factories were still powered by water. Marx (1976 [1867], p. 499, emphasis added) recognized the superiority of coal over water in essentially geographical terms:

> "The flow of water could not be increased at will, it failed at certain seasons of the year, and *above all it was essentially local*… Not till the invention of Watt's second and so-called double-acting steam-engine was a prime mover found which drew its own motive force from the consumption of coal and water, was entirely under man's control, was mobile and a means of locomotion, was urban and not – like the water-wheel – rural, permitted production be concentrated in towns instead of – like the water-wheels – being scattered over the countryside".

Coal, unlike water, is a geographically mobile source of energy (Altvater, 2006, p. 41), which allows for the geographical concentration of society's productive power in central, urban spaces of production. As economic geographers point out, it is these "agglomeration economies" that allow for dynamic patterns of innovation and change. As Engels (1987 [1845]) noticed in his early studies of Manchester, it is the concentration of workers in factory towns that characterizes the ascendance of capitalism in the 19th century. Between 1760 and 1830, the population of Manchester multiplied from a lowly 17,000 to 180,000 (Hobsbawm, 1968, p. 40). The concentration of production also allows for a system of information diffusion and competition that makes the historical process of displacing human muscle power as the core forces of production that much more inevitable: "If on the one hand the concentration of many machines in large factories leads to the use of steam power, on the other hand the competition of steam with human muscles hastens on the concentration of workers and machines in large factories" (Marx, 1976 [1867], p. 604). Spatially concentrated production necessitates the *spatial concentration of workers*; thus, creating the conditions for profound political fermentation and resistance to the domination of capital.

Coal not only provides a geographically mobile source of energy, but an extremely concentrated source of energy; what energy scientists call high "energy density" (Smil, 1994, pp. 6–7). Surely steam-engines could use anything for fuel (e.g. wood), but only the concentrated "fossilized sunshine" of coal provided both a dense source of energy[14] and an underground reservoir of fuel that, unlike wood or crop-waste, did not require the use of large amounts of land for harvest.[15] In the context of 17th and 18th century deforestation in Britain, coal was referred to as a "subterranean forest" in that it provided the heat of wood without the land-use (Sieferle, 2001 [1982]). In the early history of the United States, early rail operators actually used wood to power the rail-system. It soon became apparent that not only is coal a more concentrated fuel, relying on timber would entail continental-scale deforestation (Cottrell, 1955).

In the above discussion, I have only considered the crucial role of the *shift* from biological forms of energy to fossilized coal in the development of the specifically capitalist mode of production. Of course, this "shift" to fossilized modes of industrial production did not end with coal (Crosby, 2006; McNeill, 2000; Podobnik, 2006; Smil, 1994). Although space prevents me from rehearsing the details, one cannot underestimate the importance of the dramatic development of the productive forces bound up in the transition to *electric* (not steam) powered production at the end of the 19th and into the 20th century. Some refer to this transition as the "second industrial revolution" (e.g., Brenner, 2004, p. 36). Compared to the bulky heavy machinery of the coal-steam age, this revolution was characterized by a dramatic increase in the versatility/efficiency of power transmission in industrial production. These dynamics were, of course, emblematized by Fordist "mass production" assembly lines (Beaudreau, 1999; Smil, 1994). Electrified industry is also powered largely through fossil fuel combustion, but also holds the possibility of other forms of power such as hydroelectric, nuclear and other emerging "alternatives" (e.g. wind and solar). My point is that these developments could not have unfolded if not for the historical momentum provided by the coal-fired "first" industrial revolution. It is during this period that the dramatic shift toward an economy based not on muscles, but on stored subterranean solar energy began to take shape.

4. Fossil fuels and capitalist circulation – the ecological annihilation of space by time

4.1. Spaces of circulation

Marx's perspective on the "circulation of commodities" was focused on capital as a process of "value in motion" (Harvey, 1982; Marx, 1977 [1893], p. 133). His main concern was with the circuits of value transformation from one form to another. In the abstract, all that mattered were these "transformational" moments, but Marx acknowledged that the abstract circulation of value comes up against various spatial and temporal barriers in the concrete world of commodity circulation. One of the most basic problems is that fossil fuel powered production produces an "immense collection of commodities" (Marx, 1976 [1867], p. 125), but in no way guarantees a market for exchange.

At a more basic level, the problem of exchange is a geographical one. When local markets are saturated, markets must be sought out in more and more distant places. Under capitalism the process of production creates *spatial conditions of circulation* that become part and parcel of the process of *becoming a commodity*. A commodity is not a commodity unless it is exchanged, and due to the enhanced productive power of fossilized industry, the sphere of commodity relations gets increasingly extended to the world scale. Bunker and Ciccantell (2005, p. xiii) conceive this as an ongoing process through which capitalist reproduction depends upon revolutions in technology that allow for "expanding economies of scale". They see this as a dialectical process through which increasing "economies of scale" come up against more difficult "diseconomies of space…expanded production transforms greater volumes of more different types of raw material. Increasing the amount and types of matter transformed requires procuring and transporting it across greater distances" (*ibid*, p. 3). The dynamic productivity of large-scale industry not only requires spatially widened markets for exchange, but also the expanding search for critical raw materials "to the ends of the earth" (Bridge, 2008). All of this requires increasingly expansive and efficient networks of commodity circulation.

First and foremost, the spatial conditions of circulation require revolutions in the means of transport similar to those seen in industry. (Marx, 1973 [1857], p. 524) describes this process in a

[14] For instance, the energy density of dried wood is 12–15 MJ/kilogram, compared to 28–32, for anthracite coal, and 40–44 for crude oil (Smil 1994, p. 12).

[15] Coal energy as a land-saving resource is highlighted by Wrigley (1988). Current political debates over the use of land for food versus biofuel (corn, sugar, palm oil) reveal the possible moral conflicts and social contradictions of a post-subterranean energy age.

famous passage of *The Grundrisse*, as the "annihilation of space by time" through which "capital by its nature drives beyond every spatial barrier". Marx was careful to point out that these revolutions stem from the realm of production, wherein increased productive power necessitated an extension of commodity relations.

When Marx claims that "capital by its nature drives beyond every spatial barrier", he refers to the competitive struggle between capitals to capture markets across space. There is also a competitive struggle to reduce the "costs of circulation" to an absolute minimum. From the perspective of circulation, the most important concept Marx lays out is that of "turnover time of capital", or the time between capital's initial outlays of money for means of production and labor to the time money is recovered in the market for exchange (M–M′). Harvey (1982, p. 186) lays out the concept of "socially necessary turnover time", that emerges through the "competitive struggle to accelerate turnover times" between capitals creating a "normal" time-period between initial investments and revenue streams. While Marx and Harvey focus most attention on the role of credit and other financial instruments in the acceleration of turnover time, a very basic material aspect of turnover is the time it takes to transport commodities through space. Indeed, as "socially necessary turnover time" is reached in a particular sector of production, certain conduits of transit become necessarily embedded in that sector's "costs of circulation". The competitive struggle locks-in socially necessary transportation networks that become an expanding orbit through which competing capitals seek to capture markets. This spatial orbit can only be sustained insofar as the revolutions in the means of transport mentioned above are functioning and maintained (Chisholm, 1990). Yet, the annihilation of space by time is not automatic, and it is important to clearly understand its social *and* ecological presuppositions.

4.2. Fossilizing circulation

Prior to the emergence of large-scale industry powered by fossil fuels, commodities were transported via walking, horse-drawn vehicles or waterways (rivers, lakes, and wind-powered sailboats). It is not likely that the magnitude of commodities produced by large-scale industry could find markets through these biologically based transportation systems. In his landmark study of Chicago and the American West, Cronon (1991, pp. 79–80) describes the ecological implications of the shift to fossil-powered railroads in the context of the United States:

> "All previous forms of land transport had relied on biological sources to power their movement, in the form of food calories consumed by people, horses, or oxen to move vehicles and goods through space… Speed of movement had well-defined biological limits, as did the total quantity of work that people or animals could perform in a day… the railroad broke this age-old restrictive relationship between biological energy and movement… they could pull enormous loads at better than twenty miles per hour for hours on end – far longer than horses or people could move a tiny fraction of that load at less than half that speed. No longer would solar energy and animal physiology set limits to human movement across the landscape… The greater speed, distance, volume and power of railroads enabled them to break free from the economic and environmental constraints of earlier transport systems…".

Thus, just like the biological constraints of muscle in the realm of production, the biological constraints of transporting goods were overcome with the use of fossil fuel and coal powered locomotives. This had concrete implications in terms of social organization as well, because the scale of rail systems demanded enormous capital investment and extensive coordination and management over space. In the United States, for example, the social power accorded to the vast "railroad trusts" became one of the most emblematic aspects of capitalist expansion and development (Cronon, 1991, p. 80–81). As indicated above, railroads also extended the "spatial orbit" of commodity relations: "Wherever the network of rails extended, frontier became hinterland to the cities where rural products entered the marketplace. Areas with limited expertise of capitalist exchange suddenly found themselves much more palatably within an economic and social hierarchy created by the geography of capital" (Cronon, 1991, p. 92). The geography of capital was powered by the ecology of stored, fossil energy.

Table 1 reveals the dramatic expansion of railroads across the world over the course of the 19th century. Railroads noticeably lowered the cost of transport allowing for national scale price convergence for basic commodities like wheat. Williamson (1974, p. 259, reported in Findlay and O'Rourke, 2003, p. 36) estimates that between 1870 and 1914 the price spread between New York and Iowa wheat dropped from 69% to 19%. Thus, wheat more and more could be traded *anywhere* at similar prices because of the dramatic decrease in transport costs. After roughly the 1840s, coal-fired steamships also began to dramatically lower the time commodities spent as ocean freight; a transatlantic voyage by sailboat that took 5 weeks in the 1840s only took 12 days by 1913 (Chiswick and Hatton, 2003, p. 69). Though not reducible to steam technology, it is during this period of the steamship's assent (1870–1914) that witnessed the protracted drop in ocean freight rates; dropping 41% over the same period (North, 1958, p. 549; see also, Harley, 1988). The result was what Findlay and O'Rourke (2003, p. 40) describe as an unprecedented historical development: "The nineteenth century marks a dramatic break with the past insofar as intercontinental commodity market integration is concerned, since…there was little…price convergence prior to 1800". Again, contra world-systems theorists, the emergence of fossil-powered transportation hastened a *specifically capitalist* world economy with *global* markets for the most basic of commodities only in the 19th century.

From the perspective of circulation, the fossilization of transport should be conceptualized as an internal and necessary aspect of the capitalist mode of production. For sure, since the generalization of capitalist social relations in the 19th century, transport systems have, by and large, depended on the inanimate power of dense concentrated fossil-energy. Insofar as "the annihilation of space by time" is characteristic of the rise of capitalism, its ecological presuppositions force a reframing of the process as an *ecological* annihilation of space by time. This ecological annihilation of space by time is still very much with us. Any analysis of a mode of production beyond capitalism, or the possible emergence of an "alternative energy economy", must come to grips with the deep embeddedness of fossil-energy in the most basic forms of commodity circulation. Just as coal-fired industry laid the groundwork for further revolutions in the fossilization of production, the emergence of coal-fired transport laid the groundwork for the development of perhaps the perfect transportation fuel – oil. Not only is oil "denser" than coal in energy terms (see footnote 14), but its *liquid* qualities make it incredibly cheap and easy to transport. Notwithstanding the dramatic revolutions induced by oil-fired transport, the crucial *historical break* toward a *specifically capitalist* regime

Table 1
World railway mileage opened per decade (to nearest thousand miles), *source:* Hobsbawm (1968, p. 93).

Year	US	Europe (incl. UK)	USA	Rest of the world
1840–1850	6000	13,000	7000	–
1850–1860	4000	17,000	24,000	1000
1860–1870	5000	31,000	24,000	7000
1870–1801	2000	39,000	51,000	12,000

of commodity circulation occurred in the 19th century transition from biological to coal powered transportation.

5. Conclusion

As Henri Lefebvre (1988, p. 84) said in his final years, "[Marxism] remains a point of departure, not a point of arrival". Thus, the goal for historical-materialists is to not only apply Marxian concepts to contemporary phenomena, but also to develop *new* and refine old conceptual tools with which to make sense of the constantly changing historical dynamics of capitalism. As the current political economy attests, energy issues are at the epicenter of not only the geopolitics of empire and the global climate crisis, but also the more banal, everyday reproduction of capitalist social life. What I have hoped to provide is a broad, preliminary framework for understanding the *historically specific* and internally necessary role of fossil fuel energy to the reproduction of capitalist social relations. Many questions emerge from this theorization of fossil fuel–capitalism relations. Should capitalism be viewed as a "fossil fuel mode of production"?[16] If so, when the fossil age inevitably declines, will capitalist social relations based upon wage labor and global commodity circulation decline along with it? David Schwartzman (1996, 2008) suggests that struggles over technical change in the energy mix need to simultaneously be *social and political struggles* over the ways in which energy-resources affect livelihoods for millions of people across the world. Thus, he believes that the movements for "alternative energy" must also be movements for a new mode of production; what he terms "solar communism".

Only when fossil fuel energy is seen as internal to the social life of capitalism, can the so plainly visible social and ecological contradictions of fossil fuel energy (e.g., war, violence, local socioecological degradation, global climate change, and suburban sprawl) be situated as part and parcel of the *internal contradictions of capitalism*. The contradictions of "fossil capitalism" are many. The unbelievable productivity of fossilized production ensures a concentrated production of industrial waste and pollution, a vast increase in material and energy throughput, and the degradation of the most seemingly natural processes – climate, soil fertility, and hydrological cycles. In particular, the emission wastes produced from burning fossil fuels have surely shifted important global-scale atmospheric processes in the direction of climate change (Clark and York, 2005; Intergovernmental Panel on Climate Change, 2008). Apart from the "outputs" of fossilized industry, and given the ultimately finite nature of fossil fuel, there are also specific geological limits to the use of fossil fuels as an "input" to capital accumulation (Emel et al. 2002). Concerns over the global "peaking" of petroleum production (Campbell, 2005; Deyffeyes, 2005), and "everything" else bound up in its wake (Heinberg, 2007), induce jittery public discussions on the prospects for a viable "post-carbon" economy. Finally, some of the most significant contradictions of "fossil capitalism" emerge from the uneven power relations shaping access to and control over energy systems. Indeed, today as in the 1970s, it is clear how the windfall profits for a particular sector of capital – multinational private- and nationally based energy companies – pose serious threats to the accumulation of capital as a whole. From a social justice perspective, the privileging of energy profits over the health and livelihoods of those living in proximity to oil production and refining facilities is a more pressing concern (e.g. Watts, 2006). The question of an economy beyond fossil fuel is not simply about losing "our" cars and light bulbs, but also about the bodies and muscles of marginalized populations that would likely be mobilized should "alternative" energies not replicate the productive force enjoyed by fossil energy.

Overall, while most discussions of energy transition focus upon technical innovation and economic/thermodynamic efficiency, a red–green politics is uniquely positioned to fight for not only a "green" energy future based upon "alternative technologies", but also a socially just reorientation of society's productive powers. This can allow an ecological politics for alternative energy to fuse with an antiwar politics against "blood for oil", to create a broad anti-capitalist politics of energy. Such a broad ecological politics is surely required to work toward the democratization of energy needed (i.e. social, rather than, private-for-profit control over energy-systems) to avert social, ecological and geopolitical calamities in the coming decades.

[16] I thank James McCarthy for suggesting this as a possible concept with which to understand capitalism.

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