Forces of Production, Climate Change and Canadian Fossil Capitalism

by

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B.A., Simon Fraser University, 2008

M.A., University of Victoria, 2011

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Abstract

The dissertation reinterprets the concept of forces of production through an ecological lens and analyzes the fettering of "green productive forces" in the context of the deepening climate crisis. In contrast to more established interpretations, I define forces of production broadly as *the practices, processes, relations and objects through which we are purposefully linked to and transform the rest of nature*. I demonstrate the basis for this interpretation in Marx's own work and develop its implication through contemporary scholarship. In present circumstances, it allows us to see that ecological knowledge itself, as well as associated developments in renewable energy technology and green infrastructure, represent advancements in productive forces. However, I argue that such green productive forces are today fettered by capitalist relations of production. The second portion of the dissertation analyzes this process through case studies focusing on Canadian fossil capitalism. In this context, I examine the deepening of fossil-fuelled productive forces and simultaneous blockages in the development and productive utilization of renewable energy and ecological knowledge. This includes a focus on carbon capital's strategic efforts to colonize such productive forces and fashion them in a manner that is consonant with the accumulation strategies and power relations permeating fossil capitalism.

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Introduction

The twenty-first century is one of profound and widespread recognition that the conditions for human-friendly life are destroyed in the pursuit of unending economic growth. Anthropogenic climate change represents the most flagrant and dangerous form of "mismanagement" of our metabolic relation to the rest of nature and makes clear the need to transform productive and consumptive practices in a fundamental way. While the scientific and knowledge consensus on global warming and on the imperative of timely climate action is well established, carbon emissions continue to rise (Tollefson 2018).

Marxist approaches have contributed powerfully to understanding the roots of ecological crises, providing commanding analyses as to how capitalism works through and degrades planetary nature, while simultaneously illuminating possibilities for radical political economic and ecological transformation. Building from this body of literature and aiming to contribute to it, this dissertation offers an ecological reinterpretation of the concept of forces of production and analyzes the fettering of environmentally progressive productive forces (those whose further development and use would enable the restoration and maintenance of our metabolic interchange with the rest of nature). The reinterpretation tilts towards the present climate crisis, while the analysis of fettering centres contemporary fossil capitalism.

In contrast to more established interpretations, I suggest that it is most helpful to define forces of production in expansive and ecologically focused terms, namely in the following way: *the practices, processes, objects and relations through which we are purposefully linked to and transform the rest of nature*. Such a conceptualization helps expose the ecologically destructive nature of capitalist development. Understood dialectically, it leads us to consider how under capitalism, forces of production take the commodity form and are embroiled within its (ecological) contradictions. This interpretation challenges certain inherited Marxist views surrounding the progressivity attributable to advancements in productive forces. Recognition of the forms of environmental destructiveness (and social domination) that are woven into productive forces complicates any notion that such forces can be 'unleashed' from capitalist shackles. It provokes a rethinking of the material foundations of a socialism for the 21st century; indeed, it points to the need for a green socialism that would, in decommodifying the forces of production, detach them from capital's growth imperative, and highlight the (ecological) use-value aspect of their development.[1]

Simultaneously, a broad and ecological conceptualization, drawn from Marx, allows us to consider aspects of productive forces that are critical to sustainability and ecological 'rift-healing' in the 21st century, but which are fettered and constrained within capitalism. In a clear sense, I argue, ecological knowledge itself, including recognition of the need to restore and maintain the indispensable 'metabolism between humanity and nature,' represents an advancement in the productive forces. Yet such thinking and knowledge is unfulfilled, languishing at the margins of an anti-ecological system. It has been employed to provide minor adjustments to capital's extant technical edifice, yet it is incapable of serving as broad guide or overarching framework to ensure a sustainable social metabolism.

[1] In developing this concept, I aim to help articulate a Marxism that is 'post-productivist' and that has the relation to the rest of nature at its centre. In doing so, I simultaneously draw lines of connection to materialist feminism and to de-colonial and anti-imperialist perspectives, opening avenues for more integrative forms of theorizing. While showing these connections, they necessarily remain partial within this study as the central focus is on the greening of Marxism with a view towards illuminating possibilities for ecological transformation.

While Marx himself could not have possibly foreseen the present climate crisis, some associated contemporary counter-practices and counter-technologies, such as the growth of renewable energy, 'green' infrastructures and agroecology – that which, together with ecological knowledge and science, we might term 'green forces of production' – are also vital for restoring balance in the carbon cycle.[2] However, their development, too, is fettered. Current obstruction and blockages in such practices and technologies speak simultaneously to the inability to have ecological (and thereby also human) well-being prioritized in "development," or to have any wide measure of sustainability itself a factor in what counts as an advance in forces of production, within the confines of current relations of production.

This reinterpretation builds on contemporary eco-Marxist scholarship. Three bodies of literature are central. First are John Bellamy Foster and Paul Burkett's kindred reconstructions and "rediscoveries" of Marx's ecology (Burkett 2005, 2014; Foster 2002, 2010, 2010; Foster and Burkett 2016). I draw closely from Foster's extensions of Marx's concept of social metabolism and theory of metabolic rift. I position productive forces as the (largely alienated) 'mediations' – or capacities and powers – through which that social metabolism takes place. I then highlight how their appropriation and development by capital in pursuit of maximum exchange and surplus value, especially relative

[2] Due to recent innovations and technological advances, more optimistic accounts suggest that energy needs today could be met by wind, water and solar power within two decades (Greenpeace 2015; Jacobson and Delucchi 2011; Schwartzman and Schwartzman 2013). While emphasizing the transition to renewables as a key component of green transformation, more "tentative" approaches have pointed to the divergences between the potential of renewable energy and contemporary processes and patterns of accumulation (Laxer 2015a; Malm 2013; Smil 2010; Trainer 2012, 2014), and more explicitly argue for developing renewable energy, while simultaneously scaling back production and consumption. I tend towards the second view, less on the basis of technological barriers and more on the recognition that capitalism is built on rising material throughput and that the endless production and circulation of things has negative ecological consequences even if powered by renewables.

surplus value,[3] generates metabolic rifts, particularly the carbon rift. Paul Burkett (2014, 2005) has perhaps done the most to challenge Promethean interpretations of Marx. Burkett demonstrates Marx's awareness of the wastefulness inherent in capitalism's development of the productive forces and advances an alternative view of Marx's belief in the historical progressivity of capitalism. I draw extensively from Burkett, and revisit and extend his insights regarding science and knowledge in particular, while developing their implications in regard to the current climate crisis.

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[3] While production for maximum exchange-value and for surplus value are not identical, the pursuit of each can be referred to somewhat interchangeably in understanding capital's systematic tendency to develop aspects of productive forces dedicated to quantitative output. As I show, Marx argued that in the development of a capitalist economy, exchange-value comes to subordinate use-value. Whereas in simple commodity exchange (C-M-C), use-value is the beginning and end of the process (use-value for others is produced in order to obtain use-values to satisfy one's own needs), in capitalist transactions wealth accumulation in the form of exchange-value (i.e. money) is the driving force (M-C-M). Capitalists start with money with which they purchase commodities (including the key commodity, labour power), which they mix together in a production process that produces other commodities, that are then sold for more money (M-C-M') (see Mann 2013, 24-33). Marx argued that labor power has the unique capacity to produce more value than it contains, and that the capitalist can retain and reinvest the surplus value created by the exploitation of labor power bought from the worker. As I will show, he goes on to further specify that surplus value can be augmented by increasing the amount of surplus labour performed (enabling the acquisition of 'absolute surplus value'), as well as by increasing the productivity of labour via the introduction of productivity-improving technology (enabling the acquisition of 'relative surplus value'). The growth in productive output that ensues, especially from the latter development, presupposes increasing matter and (at a system level) energy throughput and thereby rising emissions. While I endorse and adopt Marx's 'labour theory of value' in this study, understanding the mechanisms behind capital's growth imperative can also be gained by appeal to the systematic quest for exchange-value, without the labour-theoretical version of the argument (see Cohen 2000, 193-197). Indeed, what ever is the source of profit, the goal of the capitalist firm is to make money, which is achieved by selling commodities, which are produced in an environment of competition. Thus, while corporations are relatively uninterested in use-value *per se* (use-value is only a means at the service to exchange-value and profit), they continually produce it in the form of the ever-increasing output of commodities and in the process boost the aspect of forces of production dedicated to that growth. Therefore, Marx asserts that: "his [capital personified's] motivating force is not the acquisition and enjoyment of use-values, but the acquisition and augmentation of exchange-values. He is fanatically intent on the valorization of value; consequently he ruthlessly forces the human race to produce for production's sake. In this way he spurs on the development of society's productive forces… (Marx 1976b, 739). Moreover, throughout the dissertation I analyze the predominance of exchange over use-value as a means of understanding capital's systematic propensity to pursue that which is profitable (that which produces capitalist value) even if it is not useful or is even harmful (such as is the case with fossil fuels) and conversely to undervalue and underutilize other aspects of the productive forces that are socially and ecologically useful and contribute to the production of 'real wealth,' but are unprofitable, such as ecological knowledge.

Second is the lively fossil-capitalism literature, which has drawn attention to the dialectical or co-determining relationship between dominant modes of production and the forms of energy (and associated technologies/infrastructural configurations) available at a given historical moment (Altvater 2007, 2016; Angus 2016; Huber 2009, 2013b; Malm 2016). Drawing from Marx, it analyses the centrality of fossil fuels in mediating the metabolic interaction with the rest of nature since the advent of large-scale industry in the late 18th and early 19th century and it theorizes the deepening symbiosis between capitalism and hydrocarbons in the stages of the system's historical development to the present day. Moreover, it makes clear that the system of fossilized production ensures a concentrated production of waste and pollution and the degradation of natural processes – soil fertility, hydrological cycles and the carbon cycle.

Closely related to this literature and highly pertinent to this study is the recent work of Belgian ecosocialist, Daniel Tanuro. In a series of articles and books, Tanuro argues that Marx's view of rational regulation by the "associated producers" of the metabolic relation between society and nature would require a shift in the energetic basis of society, from fossil fuels to renewable energy (Tanuro 2005, 2010, 2014). While this is a common theme in recent eco-Marxist and green left theorizing, in *Green Capitalism: Why it Can't Work (2014)*, Tanuro provokes a re-thinking of the concept of productive forces by arguing that renewable energy and energy efficiency represent ecologically progressive aspects of those forces.[4] While pointing to the need to re-think the concept today and offering helpful and suggestive formulations, Tanuro's perspective is underdeveloped.

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[4] David Schwartzman (2012, 2016) has made similar arguments, suggesting that when we think of the 'development of the production forces' we think of industrial energy systems based on cleaner and renewable fuels.

The notion of green productive forces is asserted without any close discussion of the concept and for him appears to have little basis Marx's own thought.

In fact, according to Tanuro, there are two "blueprints" in *Capital,* which express contradictory logics (2014, 143-4). One is a cyclical, ecologically grounded vision, starting from issues of the soil and based on the idea of regulation of the exchange of matter, and the rational management of natural cycles modified by human impact. The second involves a "productivist ambiguity" – growth in productive forces, freed from shackles of capitalist development (ibid, 144). For Tanuro, because the cyclical approach that is applied to the soil is never extended to the field of energy, there is a major blind spot or "shadow zone" in Marx's thinking (ibid, 143). Failure to extend the ecological viewpoint to energy matters stems from a central failure: Marx and Engel's treatment of energy as 'neutral,' and their failure to distinguish between fossil fuels and renewables (Tanuro 2010, 2012). For Tanuro, the treatment of both fossil fuels and renewables as a single 'amalgam,' in addition to the fact that there could have been no knowledge of the atmospheric impact of carboniferous growth (since the conditions of the carbon cycle had not yet been adequately understood), created inconsistencies and flaws in Marx's thought. This confusion, or "major ecological flaw," left unattended in subsequent Marxist analyses, had serious consequences; it caused 'linear,' 'utilitarian' and 'productivist' notions to infect or contaminate historical materialism as a whole (2013, 144-8).

By pointing to ecologically progressive aspects of productive forces, Tanuro invites us to "green Marx's conclusions," grafting green thought onto his thinking from the outside (see Foster and Burkett 2016, 4-15). My reading of Marx in Chapter 4 challenges Tanuro's assertion that Marx saw fossil fuels as neutral, or treated all energy sources as an 'amalgam.' More fundamentally, however, by rethinking the concept of forces of production with and through Marx, we reconstruct Marxism internally and immanently, while showing the consistency of the 'two logics': advancement of productive forces, restoration and rational management of natural cycles.

In making these arguments, the dissertation develops in two parts:

Part 1: Reinterpretation of Productive Forces

The first portion of the dissertation is devoted to examining and reinterpreting the concept of forces of production. In Chapter 1, I identify the need to rethink the concept, outlining the still-common reproach that Marx harboured a Promethean view of extra-human nature, based on his faith in the growth of productive forces. While challenging this interpretation, I identify ambiguities and difficulties in Marx's own conceptualization, pointing to the need to reconstruct the concept, especially in today's changed historical circumstances. Chapter 2 begins this reconstruction, contrasting a narrower and 'productivist' understanding, with a broader and more ecologically embedded usage that is evidenced in Marx and encouraged by certain strands of 20th century Marxist thought. Chapter 3 puts the renewed conceptualization in dialogue with more contemporary eco-Marxist approaches, considering the explicit or implicit conceptualization of productive forces at work in them, clarifying and distinguishing the approach taken here. The longer Chapter 4 then demonstrates the basis for an expansive and ecologically grounded definition in Marx's own work.

The Fettering of Productive Forces by Relations of Production

As suggested above, the reinterpretation offered here aims at rethinking the notion of a contradiction between relations and forces of production in terms that bear on contemporary ecological issues, particularly the climate crisis. To recall, Marx argued that in class societies, including capitalist social formations, a key contradiction surrounded the drive to develop forces of production within production relations that come to act as obstacles to their further expansion. In a famous passage from the Preface to the *Critique of Political Economy* (a preparatory work for *Capital*) he wrote:

> At a certain stage of development, the material productive forces of society come into conflict with the existing relations of production or – this merely expresses the same thing in legal terms – with the property relations within the framework of which they have operated hitherto. From forms of development of the productive forces these relations turn into their fetters. (1976a, 21)

Adapting this argument in present circumstances and through a reconstructed concept of forces of production, I argue that today the development of 'green productive forces,' including ecological thinking itself and associated practices, such as the development of renewable energy, are 'fettered' by capitalist 'relations of production.'[5]

While the notion of 'fettering' is evoked in several places in Marx's writings, Marx himself never clearly defined the term. Fettering entails restraint or shackling; it involves keeping something within limits and to stop it from progressing. It is taken here to be synonymous with barriers, blockages, obstacles and path dependency. In addition to this basic definition, Johnathan Hughes (2000, 243-46) provides a helpful and textured interpretation of types of fettering. In his typology, he differentiates *absolute* from *relative* fettering. 'Absolute fettering' refers a situation of absolute stagnation, involving zero development (or even a regression) of productive capacities, potentials or

[5] Relations of production can be defined as "relations of ownership by persons of productive forces or persons *or* relations presupposing such relations of ownership" (Cohen 2000, 34-5). Relations of production include the distribution of the means of production and subsistence and the structured social relations of production (the relations between the immediate producers and those who appropriate their surplus product). They also include, as a specific aspect, the *objective of production* – i.e. production for the accumulation of surplus value. Therborn (1980, 375-386) succinctly demonstrates the interconnection between these three dimensions or aspects Marx's concept.

powers. By contrast, 'relative fettering' can involve a slower *rate of development* in productive forces, or it may be that a *smaller proportion* of existing capacity is *used*, relative to the rate and proportion to which they would develop or be used under alternative relations of production. Relative-proportional fettering then points to a situation of sub-optimal or ineffective *use* of productive forces, while relative-developmental fettering points to a slow rate in their *development*.

Table 1: Types of Fettering

Fettering (Absolute)	Absolute stagnation, involving zero development (or even a regression) of productive capacities, potentials or powers
Fettering (Relative-Proportional)	A smaller proportion of existing capacity is used than under alternative relations of production
Fettering (Relative-Developmental)	Productive forces develop more slowly than under alternative relations of production

Adapted from Hughes (2000)

In the case of ecological knowledge, I argue that the fettering we observe largely consists in the 'misuse' of an existing productive capacity. Therefore, while ecological knowledge continues to develop and deepen today (partially as an outgrowth of the ecological contradictions of capitalism), it is underutilized, languishing at the margins of an anti-ecological system. In so far as today we witness a thin "greening of capitalism," whereby ecological knowledge is applied to production, yet within narrow confines and limits (and for commercial purposes), the fettering is 'relative proportional.'

On the other hand, I argue that the fettering observed in relation to renewable energy is 'relative-developmental.' Despite technological advances that increase the potential and capacity of renewables and powerful movements for energy transition, the development of green energy has been slow. As studies have shown, for the most part non-fossil fuel energy sources have been added to the 'energy mix' only incrementally and on top of a net expansion in the consumption of fossil fuels (York 2012; York and McGee 2017).

Part 2: Canadian Fossil Capitalism and Productive Forces

The second part of the dissertation moves from an 'abstract-simple' analysis focused on reconceptualising the forces of production to a 'concrete-complex' examination of the development and fettering of forces of production within contemporary fossil capitalism.[6] Focusing on the Canadian context, I analyze the growth of fossilized and fossil-fuelled productive forces and the simultaneous fettering of green alternative forces via the accumulation of fossil capital. This more concrete-complex political economic investigation of fossil capitalism in action advances and applies the granular view of fettering offered by Hughes, while pointing to social and political transformations necessary to 'unshackle' ecologically progressive productive forces. Three distinct but overlapping case studies make up this component of the research.

Chapter 5 provides a 'mapping' of key crude oil and gas infrastructure networks in Canada and analyzes several key pipeline and infrastructural proposals that are currently contemplated to facilitate the expansion of these industries. It points to how carbon capital[7] and its allies are seeking to expand and accelerate the fossil fuel regime in a time of deepening climate crisis. Employing a 'networked' lens, it provides insights on the deep path dependencies of existing and proposed fossil capital infrastructure, while also identifying prominent firms and actors whose interests and modalities of power are expressed and embedded in them. Both the 'hard' lock-in of physical

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[6] The movement from abstract to concrete involves the increased concretization of a given phenomenon (i.e., fettering of green productive forces by capital as a mode of production in general to fettering within contemporary fossil capitalism), while the movement from simple to complex introduces further dimensions of a given phenomena (i.e., features and aspects of 'relative' developmental and use fettering within the current period of fossil capital development). The spiral movement is not purely theoretical; it involves empirical studies into actual tendencies. On the movement from abstract-simple to concrete-complex accounts and the methodological principles informing this, see Jessop (2002, 2007, 8-14). See also page 135 of this of this manuscript.

[7] Carbon capital is a 'fraction' of capital embedded within wider structures of corporate power, and linked to other fractions (including financial capital) via commodity chains and financial flows (Carroll 2017).

infrastructures and the constellation of interests and forms of power that underscore them reinforce a carboniferous social metabolism, obstructing a renewable energy transition.

In Chapter 6, I examine the strategies employed by Canadian carbon-capital firms to shape and control alternative energy. While carbon capital is actively engaged in supressing a rapid process of decarbonization and continues to expand its carbon networks relentlessly, I consider whether we are simultaneously witnessing signs of 'transition capture' as some oil, gas and coal firms invest in a gradual shift towards 'climate capitalism.' A climate capitalist project would slowly transform the energetic basis of capitalism, leading to large-scale installations under the control of big energy companies, especially fossil fuel corporations, who slowly subsume renewables under their centralized control (Adkin 2017; Candeias 2013b; Muller 2013; Sapinski 2015, 2016). In addition to Hughes' notion of relative fettering, it points to a possible slow and uneven development of renewable energy and in a manner that imbues the technologies with relations of class power. While we find limited evidence of a process of transition capture in the Canadian context, the study deepens our analysis of the sources and nature of fettering of these productive forces and opens to a consideration of effective strategies for a rapid, comprehensive and just energy transition.

Chapter 7 examines the way in which science and ecological knowledge are integrated into contemporary processes of carbon extraction. I mark the vital importance of this knowledge as a force in carbon-extractive processes through its incorporation into the extraction and production of unconventional oil and gas in Canada and more recently as a means of 'greening' that process via the production of 'clean technologies,' in response to the crisis of fossil capital. This research demonstrates the enormous capacity of the carbon extractive sector to influence technological choices and orient research and development. It provides a focused example of the underutilization or ‘relative-proportional’ fettering of ecological knowledge, elucidating how its colonization and co-optation supports a thin greening of carbon extractive development, in a manner that is of marginal ecological benefit and is consonant with the accumulation strategies of carbon capital. By showing how such knowledge is appropriated in service to the short and medium-term interests of the fossil fuel sector, the research points to how an alternative economic structure would further support and prioritize the growth and *development* of knowledge critical to ecological sustainability, including energy transition.

The final chapter brings out the implications for transformative practice of a more dialectical, green-Marxist take on forces of production. It brings together the empirical findings from cases studies with the theoretical issues raised in earlier chapters, considering how these help point toward effective strategies for a just transition to an ecologically sustainable future.

Chapter 1 – Forces of Production and the Ecological Critique of Marx

Despite longstanding efforts to undo such an interpretation, Marx continues to be dismissed as an archaic 19th-century European steeped in the ideology of "progress," achieved through the ever-advancing domination of the rest of nature. This understanding often stems from his optimism in the emancipatory potential of developing productive forces. This chapter outlines this interpretation of Marx, engaging both recent environmental and ecofeminist perspectives. I dispute the reading of Marx as having endorsed an energy- and resource-intensive future "automated paradise," as critics aver, while pointing to enduring tensions surrounding his argument that through its increases in productive output and the productivity of labour, capitalism creates the material conditions for future flourishing. I defend a weak version of this argument, while placing it in historical context and alongside his prescient ecological critiques of capitalism, which have been illuminated by recent eco-Marxists (e.g. John Bellamy Foster and Paul Burkett). This establishes the need to rethink the concept of productive forces (and the progressive potential of their development) in contemporary circumstances. While my focus is on ecological questions, the reading also carries important implications for connecting Marxism with materialist feminism and de-colonial politics.

De-Growth and the Green Critique of Marx

Hans Jonas' *The Imperative of Responsibility* (Jonas 1984) is an influential text in green thought and a key early work informing today's de-growth politics. In the *Imperative,* Jonas argues that in an approaching era of nuclear disaster and ecological catastrophe, we need to break with 'present-oriented ethics' and advance an ethic of responsibility geared to the survival of future generations. On this basis, much of Jonas's text is devoted to weighing the pros and cons of "capitalism versus Marxism" with respect their ability to provide a future oriented ethic and practice based on salvation from disaster, rather than "fulfilment of mankind's dreams" (144). The treatment is aimed at popular audiences and given its framing, it is inevitably terse; nevertheless, it captures in broad outline the green critique of Marx based on the notion of the development of forces of production.

Jonas begins his assessment by working to establish that Marx and Marxism have been "progressivist" from the beginning and like capitalism, thoroughly participate in the 'cult of technology.' In fact, according to Jonas, Marx and Marxists see capitalism as the crowning achievement of history to the present day, and conceive of revolution as a breaking of the fetters that hinder the development of forces of production, or technology. The fetters inhibiting the forces of production amount mainly to one fetter: capitalist ownership of means of production, which is the cause of anarchy and fragmentation in overall production and the unequal distribution of social surpluses.

This reading is confirmed mostly by appeals to the experience of 20th century Soviet socialism, which sought to establish a framework for 'catch-up' industrialization and produced models of development that largely mimicked capitalism in terms of its productivism. For Jonas, as witnessed in the Soviet Union, the goal of socialism was not only to deliver the fruits of capitalist industrialization (hitherto reserved for a minority in class society), but to be yet more productive than capitalism, by 'unleashing the productive forces' (through planning not only at the level of the factory but also the social level). Jonas provides little discussion of the historical circumstances surrounding the Soviet experience, raising it only to argue that a productivist impulse, which has been ruinous for the environment, is built deeply into Marxism.

The position appears to accord closely with Marx and Engels in *The Communist Manifesto*. As they wrote: "The proletariat will use its political supremacy to wrest, by degree, all capital from the bourgeoisie, to centralize all instruments of production in the hands of the State, i.e., of the proletariat organized as the ruling class; and to increase the total productive forces as rapidly as possible"(Marx 1969). The productivism underscoring socialism appears to be put in even sharper terms by Engels in a chapter in the *Manifesto* on 'the Principles of Communism': "Once liberated from the pressure of private ownership, large-scale industry will develop on a scale that will make its present level of development seem as paltry as seems the manufacturing system compared with the large-scale industry of our time. The development of industry will provide society with a sufficient quantity of products to satisfy the needs of all" (ibid).

Despite its deep productivist impulse, Jonas considers whether Marxism can renounce this vision and asks if classless society can form the 'condition of humankind's survival.' He begins by gesturing to the affirmative, registering certain positives to Marxist socialism. Chief among them are first, the development of an economy governed by real needs and the removal of the profit motive, which he notes, could remove one compulsion to extravagance – the (artificial and unending) market creation of needs and the goods and means to satisfy them. Second, socialism's apparently authoritarian character – its "vanguardist authoritarianism" and "centralized power and command structure" – would allow it to impose unpopular decisions, which Jonas believes the threats of the future require (146). Relatedly, he suggests that socialist societies are better able to stimulate devotion to a cause and a spirit of sacrifice as a life-style.

Yet these potential advantages are ultimately outweighed by the negatives; hence Jonas concludes that socialism would ultimately be worse. The reason is that the formal essence of the Marxist Utopia lies in leisure and leisure can only exist in comfort, with an assured supply of material goods and a minimum of toil in achieving them. Jonas again mostly reads the Soviet record onto

Marx and Marxism, but he does (partially) quote one passage from *Capital Volume III* on the 'realm of freedom' in support of this conclusion. In the full passage, where we find one of Marx's few overt discussions of an alternative future, he wrote:

> The realm of freedom really begins only where labour determined by necessity and external expediency ends; it lies by its very nature beyond the sphere of material production proper. Just as the savage must wrestle with nature to satisfy his needs, to maintain and reproduce life, so must civilised man, and he must do so in all forms of society and under all possible modes of production. This realm of natural necessity expands with his development because his needs do too; but the productive forces to satisfy these expand at the same time. Freedom, in this sphere, can only consist in this, that socialised man, the associated producers, govern the human metabolism with nature in a rational way, bringing it under their collective control, instead of being dominated by it as a blind power; accomplishing it with the least expenditure of energy and in conditions most worthy and appropriate for their human nature. But this always remains a realm of necessity. The true realm of freedom, the development of human powers as an end in itself, begins beyond it, though it can flourish with this realm of necessity as its basis. The shortening of the working-day is the basic prerequisite. (Marx 1993a, 958-9)

For Jonas, the vision presented by Marx is clearly one of super abundance and its toil free command, which could only be achieved through a 'perfected technology.' The vision would require on his view the magnification of industrialization first, through the 'reconstruction' or production of the earth itself — the raising of nature to a 'higher state' via fertilizers, agrarian maximization strategies and so on — and second, through the mechanization and automation of the labour process, which had in the past been consumed by human strength and time. To come anywhere near this utopia an "increased global production and heightened, more aggressive technology must be the order of the day – and *a fortiori* for the universal "leisure-cum-plenty" economy envisioned by [this] utopia: an altogether enormous enhancement by several orders of magnitude of both technology and its onslaught on resources" (187).

Jonas' treatment both reflected and helped further entrench a productivist interpretation of Marx in contemporary green thought. In *Farewell to Growth*, Serge Latouche (Latouche 2010), one of the leading proponents of today's 'de-growth' movement, approvingly sites Jonas and finds that Marx's own and subsequent Marxian critiques of capitalist modernity remain "terribly ambiguous" (90). He finds that with the Marxist critique, the capitalist economy is criticized and denounced for every scourge (from the proletarianization of workers, to their exploitation and impoverishment, to imperialism, wars and so on), while at the same time the growth of the 'forces' it unleashes (seen in terms of the production/jobs/consumption trio) are seen as a great virtue and described as 'productive,' even though they are as destructive as they are productive. Echoing Jonas, Latouche finds that capitalism and productivist socialism are therefore, "both variants on the same project for a growth society based upon the development of the productive forces, which will supposedly facilitate humanity's march in the direction of progress" (ibid, 89).

Materialist and eco-feminist work, while dealing much more carefully and dialectically with Marxian categories and concepts, has often advanced a similar reading of Marx based on the concept of productive forces. I turn to this in the following section.

Materialist Feminism and Marx

At the centre of materialist feminist critiques of Marx is the argument that he advanced a gendered theory of value and work (Arruza 2014; Federici 2012; Fraser 2013, 2014; Mies 1986). Critically, Marx's analysis of capitalism was hobbled by its blindness to the crucial nature of social *re*productive labour to the process of capital accumulation. To understand the accumulation process or the extended reproduction of capital, these theorists make clear that it is necessary to go 'behind Marx's hidden abode' of production (Fraser 2014) and to bring into view the largely untheorized, yet necessary, reproduction of 'social conditions of production,' which are essential to wage labour and surplus productive activity.

In a classic essay, "The Power of Women and the Subversion of the Community" (1975), autonomous feminists Mariarosa Dalla Costa and Selma James were among the first to analyze the strategic link between the unpaid housework of women and the paid wage work of men. They point out that what the housewife produces in the nuclear family is not only use-values, but the commodity labour power, which the husband sells as a 'free' wage labourer on the commodity market. In this way, the work of the housewife is not ultimately outside of surplus value production, but the very foundation of its eventual realization. Her productivity is the precondition for the productivity of the (typically) male wage earner. Despite its crucial importance in the total process of capital accumulation, non-waged work remained below the theoretical horizon of Marxist theorists focusing on the sphere of production and the (direct) extraction of surplus value. The blindness helped reinforce capital's ability to hide behind the productive paid wage work of men, so that women's unpaid work in the home "*appears to be personal service outside of capital"* (Costa and James 1975, 10). The recognition of housework as a condition for accumulation and commodity production provided a common political and strategic ground between house-working women and other exploited parts of the working population.

Contemporary reproductive feminist work draws on these rich insights and continues to emphasize that the highly gendered global division of labour and the immense amount of unpaid and undervalued social reproductive work. The latter continues to be overwhelmingly performed by women and especially immigrant women and women of colour; it is an essential condition of labour power (and immediate life) and a critical component of capital accumulation (Federici 2012; Mies 1998, Arruza 2014). Care work and 'affective activity' form capitalism's human subjects, sustaining them as natural beings, while also constituting them socially. Wage labour could not exist in the absence of child raising, housework, affective care, and a host of other activities (those such as schooling and health care, defined by Althusser as pertaining to the 'reproduction of conditions of production' (2014)), which help to produce new generations of workers, as well as replenish existing ones (Arruza 2014). By highlighting the entangled relationship among capitalism and patriarchy, this work forces us to consider the unity between production and reproduction. As a result, our conception of capitalism is broadened beyond concerns bound to immediate surplus value extraction, and includes the 'solidary relations' and affective dispositions that furnish "the appropriately socialized and skilled human beings who constitute 'labour'" (Fraser 2014, 72). Class politics then are inherently linked to struggles over the social conditions of production, including the living conditions that bear upon production.

Most Marxists recognize that Marx had an insufficient analysis of reproductive labour. The direction of much work in this area has therefore been to revise and update Marx through a rethinking or immanent critique of the category of labour power (see Lebowitz 2003). However, for autonomous and ecofeminists such as Federci, Mies, Salleh and Odih, Marx's blindness to reproductive labour speaks to a larger issue with his political and social theory. According to these authors, reproductive work fell below Marx's theoretical horizon largely or partly *because* of his underlying techno-Prometheanism.

Scarcity, as Silvia Federici notes (2012), was for Marx a major obstacle to human liberation and thus he anticipated that the expansion of the forces of production in the form of large-scale industrialization and its increases in the productivity of labour would create the material conditions for the transition to socialism. Subsequent to this understanding, Marx apparently viewed "the capitalist organization of work as the highest model of historical rationality, …[he] accepted the capitalist criteria for what constitutes work, and believed that waged industrial work was the stage on which the battle for humanity's emancipation would be played (95)." The privileging of the waged industrial proletariat as the main contributor to capital accumulation and as the key revolutionary subject, and the associated tendency to ignore reproductive work, originate largely from his "technologistic conception of revolution," whereby freedom comes through the machine and its increases in labour productivity (ibid).

The early Ariel Salleh (1997) concurs. Marx, she writes, was "entranced by the qualitative shift from tools to production by machine technology, and he impatiently waited on the large-scale industrialisation of agriculture"(1997, 77). Salleh, more than many readers of Marx, historicizes his views to some degree, arguing that his belief in the liberatory potential of capitalist technology emerged from his desire to transcend the immense suffering that he witnessed in the nineteenth-century factory system. His was therefore "wishful thinking, in the very best sense" (79). Had Marx been writing in another era, Salleh suggests he might have developed different vantage points, and that a critical view of technology is implied by his dialectic of internal relations.[8] Nevertheless, she argues that his "case for technology" remained largely argued outside of any ecological (or gendered) context and was not sufficiently conscious of its implications on these fronts.

In her excellent *Patriarchy and Accumulation on a World Scale* (1986), Maria Mies extends the critique of Marx's blindness in regard to women's work to his perceived blindness of other types human and non-human production that continue to form the 'invisible unground foundation' for the

[8] A dialectic of internal relations suggests that the only way we can understand the qualitative and quantitative attributes of "things," including physical objects such as machines, or the physical articles produced through them, is by understanding the processes and relationships which constitute them and which they internalize (See Ollman 1976, 26-40). The implication is that instruments of production internalize dominant social relationships and a bundle of associated contradictions.

accumulation process. In making this argument, she draws on Rosa Luxemburg's *The Accumulation of Capital* (2015), which argued that 'primitive accumulation' is co-existent with capitalist accumulation, rather than, as Marx intimates, a period prior to industrial capitalism. While Marx's model of accumulation appears to be based on an assumption of a closed system involving only wage labourers and capitalists, Luxemburg argued that capitalism always depends on an 'outside,' or non-capitalist 'milieu and strata,' for the extension of the labour force, resources and the expansion of markets. These non-capitalist milieu and strata were initially peasants and artisans and later colonies.

Mies connects this insight to the materialist feminist analysis of women's labour (and simultaneously moves beyond the focus on industrialized societies and housewives in those countries) by arguing that the appropriation of nature and subsistence production (mainly performed by women, contract workers and people in Global South) constitutes the perennial basis and precondition for capitalist wage labour and surplus value extraction (1986, 48). Capital accumulation, she asserts, is based on and requires the subordination, exploitation and appropriation of 'women, nature, colonies.'

For Mies, the apparent invisibility of these foundations in Marx are again related to a productivist view of emancipation. Citing the same above passage in *Capital III* on the 'realm of freedom,' Mies argues that for Marx "labour is considered as a *necessary burden,* which has to be reduced, as far as possible, by the development of productive forces, or technology" (ibid, 212). The reclaimed free time enabled by shortening necessary labour-time (defined as that aimed at satisfying basic human needs of clothing, food, shelter) forms the material basis for freedom, which is categorically excluded from the realm of work and possible only in the realm of 'leisure.' Subsequently, under socialism the replacement of human labour by machines and automats remains the main social goal and will be accelerated rather than slowed down. However, this paradise for some is hell for others: the bondage nature, women, colonies is the base for his (the White Man's) "unlimited development of forces of production, for the unlimited satisfaction of his unlimited wants (or rather addictions)" (1986, 216).

The Development of Forces of Production: A More Historical View

In the above interpretations, there is a pronounced tendency to equate productive forces narrowly with technology (the latter itself conceived narrowly as 'material hardware') and the social surpluses it (technology) generates. As indicated in the introduction, forces of production include social aspects (such as cooperation, the 'software' of technology) and other qualitative features (such as knowledge). These are part of the practices and processes by which we appropriate the rest of nature for human requirements, and they also possess metabolic or ecological use-value – i.e., can contribute to mending the metabolic rift. This more generous understanding of productive forces is advanced in Chapters 2 to 4. In the following sections of this chapter, I focus more narrowly on Marx's arguments surrounding the "quantitative" aspects of the development of forces of production under capitalism, seeking to place them in historical context, while asking if this commits him to a Promethean vision (albeit one that is in clear tension with his ecological views, which are increasingly well established).

Along the lines suggested by Salleh, it is critical to provide a more historically grounded view of Marx's arguments concerning the historical progressivity he ascribes to the quantitative development of forces of production under capitalism (i.e., increasing productivity and material output enabled by technological development). The priority that Marx placed on both the shortening of working day and the satisfaction of material needs in *Capital* reflected the conditions of the working class in England in the mid-19th century and the political struggles he was involved in. His arguments were made in a context of scarcity (i.e. where working classes lacked access to basic material goods) and where the capitalist appetite for surplus value appeared as the drive towards the "unlimited extension of the working day" (Marx 1976b, 346). This extension, combined with the low level of consumption among the workers in his time, was to render the working class virtually unable to reproduce itself, averaging a life expectancy as low as 25 and dying in its youth from overwork.[9] Given the condition of the working class in England at this time (and the majority of the earth's workers today), it seems hard to blame Marx for this argument.

While Marx's arguments necessarily reflect the political circumstances that he was embroiled in, as suggested by Federici, he made a wider argument in *Capital* and elsewhere that socialism is made possible by a certain material foundation or 'base' in productive forces. The capitalist development of the productive forces along the line of large-scale industry lays the 'material conditions' for a society beyond capital:

> But in so far as he is capital personified, his motivating force is not the acquisition and enjoyment of use-values, but the acquisition and augmentation of exchange-values. He is fanatically intent on the valorization of value; consequently he ruthlessly forces the human race to produce for production's sake. In this way he spurs on the development of society's productive forces, and the creation of those material conditions of production which can alone form the real basis of a higher form of society, a society in which the full and free development of every individual form the ruling principle. (Marx 1976b, 739)

The expanded productivity and diminished absolute scarcity resulting from capital's constant revolutionizing of means of production (under heavy competitive pressures) helps make socialism

[9] As Federici also notes (2012, 94-5) the fact workers in England in the early 19th century were barely being reproduced and that capital's pursuit of absolute surplus value required little investment in the conditions of (re)production, helps explain the absence of an analysis of reproductive labour in Marx. Therefore, as she suggests, paralleling the transition from formal to real subsumption of labour is the formal subsumption of reproductive labour to capital, which Marx had only begun to witness. The point does not excuse Marx for an insufficient analysis of gender.

more feasible, based on social control over the material conditions of life (and the radical egalitarian distribution of those conditions, including the social surplus and access to free time).

In a section from *Capital III* preceding his discussion on the 'realm of freedom' Marx argued more sharply that by developing productive forces, capital negates any material-scarcity rationale or justification for class monopolies over the disposition of society's surplus and labour time:

> It is one of the civilising aspects of capital that it enforces this surplus-labour in a manner and under conditions which are more advantageous to the development of the productive forces, social relations, and the creation of the elements for a new and higher form than under the preceding forms of slavery, serfdom, etc. Thus it gives rise to a stage, on the one hand, in which coercion and monopolisation of social development (including its material and intellectual advantages) by one portion of society at the expense of the other are eliminated; on the other hand, it creates the material means and embryonic conditions, making it possible in a higher form of society to combine this surplus-labour with a greater reduction of time devoted to material labour in general. (1993a, 958)

I note, in anticipation of later arguments, that in this passage Marx highlighted the bourgeoisie's monopolisation of "intellectual advantages" alongside more strictly 'material' ones. Nevertheless, capitalism's monopolization of social development and subsequent industrialization provides the potential for the elimination of much arduous human labour and the possibility for everyone to live comfortably off the social surplus, rather than just a ruling class minority. Socialism, Marx intimated, may entail more development of industry and be more productive that capitalism, in terms of both the productivity of labour and the growth of material surpluses.

Such arguments also need to be approached in light of the broad historical context of his writings. Marx, like Engels, considered industrialization necessary to the point at which it would be possible to "satisfy the material needs of all." However, in the context of mid-nineteenth-century industrial capitalism, Marx stood with most observers in assuming that use-values were produced to conform to genuine human needs. As Foster suggests (2013), it is only under 'monopoly capitalism,' beginning in the last quarter of the nineteenth century, and more sharply with the emergence of the recent phase of "transnational monopoly-finance capital," that we began to see the production of 'negative use-values' in the form of the growing output of useless and wasteful commodities and the non-fulfillment of human need.

Mies (1986) is right to point to the limitations of Marx's perspective that 'true freedom' exists outside of the sphere of activity 'determined by necessity and mundane considerations.' In adopting this perspective, Marx assumed that such activity is inherently unwanted, uncreative and not enjoyable and should therefore be reduced as far as possible. However, that this activity is often viewed as a necessary *burden* under capitalism speaks as much to the quality of work experience subsumed within the commodity form as it does to an inherent feature of activity that meets basic necessities (Ibid). Such activity could be pursued as an 'end in itself' (creatively and enjoyably), while also being necessary. The promise of increased leisure time also sits in tension with a recognition that increased human labour power in some fields or sectors, such as in agriculture (see the concluding chapter), are likely needed to support ecological sustainability (Garibaldi et al. 2017; Reganold and Wachter 2016).

These are important considerations, pointing to shortcomings in Marx's perspective. Yet in addition, several of the above critics project onto Marx the view that the reduction of working time would entail a broadening of anti-ecological mass consumption, creating a world of super abundance and previously unknown plenty. This argument is a-historical, in that the forms of anti-ecological mass consumption they envision exist *only in contemporary capitalism*. The suggestion that expanded free time enabled by reductions in work time would be filled with mass hedonistic consumption is not only a-historical, it also glosses over the human developmental content of Marx's arguments.

As Burkett argues (2014, 163-173), when Marx speaks to the expansion of *new* needs made possible by the development of productive forces, this includes broader access to use-values denied to large sections of the working class and the enrichment of the *composition* of use-values, rather than simply increases in general level of material consumption. Marx, as he explains, views free time as a condition for the aesthetic, cultural, and intellectual development of individuals, quite separate from expanding physical needs. In the context of a discussion of the struggles to reduce the length of the working day, he refers to "time for education, for intellectual development, for the fulfilment of social functions, for social intercourse, for the free play of the vital forces of the body and the mind…"(Marx 1976b, 375). Physical requirements must be met, but needs are social and include further, "the worker's participation in cultural satisfactions, the agitation for his own interests, newspaper subscriptions, attending lectures, educating his children, developing his taste, etc."(Marx 1993b, 287).

While Marx rarely specifies the content of future alternatives, when he does so, he emphasizes what he referred to as "real wealth" – things that truly contribute to human physical and social well being, including eco-system health (See Mann 2013, 30-33). Here he emphasized how a certain 'quantitative' foundation in the productive forces provides the condition for a non-arbitrary distribution of the means of life and for qualitatively richer consumption opportunities, rather than unlimited and ever-expanding material abundance. He pointed therefore to the possibility of the production of material wealth that does not have the production of exchange-value as its ultimate aim. Yet he argued that capitalist production contains no category for understanding material wealth beyond its single measure for calculating value – maximum production of surplus value – and capitalist society places no value on activities, capacities and forms of wealth outside of this foreclosure. Ascribing to Marx the notion of constantly increasing technological advancements and an unlimited access to a boundless supply of all material goods that exist in contemporary capitalism is therefore unsubstantiated and rooted in a misinterpretation.

Furthermore, while both Jonas and Mies employ the passage on the 'realm of freedom' from *Capital III,* as proof of Marx's productivism, neither reflects on his assertion there that freedom "in this sphere, can only consist in this, that socialised man, the associated producers, govern the human metabolism with nature in a rational way, bringing it under their collective control, instead of being dominated by it as a blind power; accomplishing it with the least expenditure of energy and in conditions most worthy and appropriate for their human nature" (958). The conclusion of the need for transforming conditions and practices to achieve a rational regulation of that metabolism was inspired by chemist Justice von Liebig and his work on the rupture in the nutrients cycle, due to industrialized capitalist agriculture and long-distance trade (see Foster 2000). Marx generalizes this rupture in developing a theory of a 'rift' in the metabolic interchange with nature – a notion that Bellamy Foster, Burkett, and others believe to be tailor-made to analyze the present climate crisis (see also chapter 4).[10]

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[10] Most of the work we have reviewed so far occurred before so-called 'second wave' eco-Marxist scholarship, especially the work of Foster (Foster 2000) and Burkett (1999/2014). First-stage ecosocialism, as Foster and Burkett (2016) have referred to it, involved various attempts to create a hybrid theory in which Green theory was overlaid on certain Marxian conceptions. Second-stage ecosocialism, in contrast, went back to the foundations of classical Marxism, attempting a major reconstruction and also rediscovery of historical materialism as a unique method of understanding the complex relationships between humanity, society, and nature. While simplistic productivist interpretations of Marx continue to be advanced in the literature, in part as a result of this work, critiques have become more nuanced. The later Salleh (2010) and Odih (2014), for example, show a deep appreciation for ecological insights in Marx (particularly the importance of his concept of social metabolism and the theory of metabolic rift), while pointing to 'oscillations,' 'tensions' and 'unresolved issues' in Marx between a more ecological position, which they suggest exists in tension with a more techno-Promethean one. This raises the question of why there is such oscillation. Drawing from Schmidt (1971), Odih (ibid) suggests that Marx was influenced by both romantic and Enlightenment currents that existed simultaneously in 19th century Germany. While the romantic strain is here assumed to ground Marx's ecological assessments, in my view, the tensions, along with the more developed ecological critique of capitalism found in Marx's later work, stem more from the increasing, although still partial, integration of emerging natural scientific

By reading Marx's arguments around free time through a productivist lens, critics here miss an opportunity to think of increased free time as a possible means of *reducing* the pressure of production on the environment. Indeed, reducing work time is an important means of reducing energy and matter throughput and emissions. As I argue in the concluding chapter, under conditions of present ecological overshoot, Marx's call for a rational regulation of the exchange with the rest of nature would also mean shifting human labour from the production of "things" to needs-oriented social services such as health care, childcare, education, research, nutrition, services which also entail less ecological impact. This refocusing of economies around reproductive needs could contribute to shaping gender relations in an emancipatory fashion, redefining and redistributing what we consider as "socially necessary labour," a point which accords closely with Mies.

Capitalism's 'Civilizing' Mission

Enduring tensions in Marx between an ecological position and a more techno-Promethean one surround the 'civilizing' mission that Marx, particularly in the *Communist Manifesto*, ascribes to capitalism. The argument is closely connected to the 'historical possibility thesis' seen above, while also involving Marx's perspectives on pre-and non-capitalist social formations. We turn to this below.

As ecofeminist and other critics point out, Marx at times appears to not only portray primitive accumulation as a historical phenomenon (in the sense of belonging only to a pre-industrial phase of capitalism), but also as a historically inevitable process that would ultimately have a beneficial effect on those drawn into the circuit of capital (Bartolovich and Lazarus 2002; Coulthard 2014; Salleh 1997). In the *Manifesto* and elsewhere, Marx and Engels recognized that the destruction of pre-capitalist social

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and ecological knowledge in his full critique of political economy, along with the shedding of a more speculative Hegelianism. On the former development see especially (Saito 2016).

formations could imply more miserable living conditions for populations subject to colonial domination. More traditional forms exploitation and domination[11] "veiled by religious and political illusions" are replaced with "naked, shameless, direct, brutal exploitation" (Marx and Engels 2010, 16). However, the bourgeoisie was seen to have a progressive historical mission to play (however unconscious it was); through its drive to revolutionize the means of production, that class would bring "barbarian nations" on the plane of world historical development and plant in them the seeds of development and change. The *Communist Manifesto* advanced this view, asserting the following:

> The bourgeoisie, by the rapid improvement of all instruments of production, by the immensely facilitated means of communication, draws all, even the most barbarian nations into civilisation. The cheap prices of commodities are the heavy artillery with which it batters down all Chinese walls, with which it forces the barbarians' intensely obstinate hatred of foreigners to capitulate. It compels all nations, on pain of extinction, to adopt the bourgeois mode of production; it compels them to introduce what it calls civilisation into their midst, i.e., to become bourgeois themselves. In one word, it creates a world after its own image. (Marx and Engels 1969, 16)

Though English colonialism was brutal and violent, it appeared to be justified in developmentalist terms, as liberation could only occur after or through the establishment of modern capitalist forms of production.

Marx adopted similar views in his early journalistic writings on India. English colonialism, he suggested, was there responsible for a 'double mission': "One destructive, the other regenerating the old Asiatic society, laying the material foundations of Western society in Asia" (Marx 1853). Marx is not complacent in describing this process: to locate the historical origins and primary dynamic of the

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[11] Marx and Engels suggested that pre-capitalist and 'traditional' societies were often not idyllic, but rather built upon pervasive forms of social domination. The creative-destructive logic of capitalism, in particular the objective development of productive forces, would help make socialism an "objective possibility" while undermining the institutional bastions of the old order, including forms of custom, tradition, superstition and above all religion that so often served to legitimize oppressive social and political relations.

world system in western Europe is not itself "Eurocentric." But in these writings he failed register the injustices of colonialism on their own terms and in their own right, and again appeared to emphasize the bourgeoisie's inevitably progressive role, writing that "whatever may have been the crimes of England she was unconscious tool of history" (ibid). With decidedly Eurocentric overtones, he contrasted the modernizing influence of Western capitalism with an India described as "stagnant," "uninteresting and unchanging" and which "has no history at all" (ibid).

The support that Marx appeared to show for integration of "backward" areas and economies into the circuit of capital, on the grounds it would develop capitalist forces of production (and therefore the historically necessary material foundations for socialism) was underscored by racist assumptions of non-capitalist social formations, and grounded in antiquated developmentalist notions (Coulthard 2014). As several commentators have pointed out, however (Anderson 2010; Coulthard 2014; Mauro Di Meglio and Pietro Masina 2013), Marx moved substantially away from this position in his later life, beginning in the late 1850s in the *Grundrisse* and especially in his writings of the 1860s. As Anderson details (2010), in his last decade of writing, Marx began to concentrate on non-Western societies, providing a much closer and sustained focus on a range of non-capitalist social formations, in an effort to understand what was at that time the periphery of an expanding world capitalism. In the process, he moved away from the position that all human societies were destined to follow a single path of development (that of nineteenth century capitalist England), leaving open the notion of multiple pathways for societies like Russia and India. Marx, writes Anderson, shifted from a 'unilinear' to a 'multilinear' philosophy of history (ibid).[12]

[12] However, see Gellner (1980) on Yuri Semyenov's defence of a 'unilineal' philosophy of history. As Gelner details, Semyenov formulates a Marxist 'unilinealism' (the notion of successive modes of production of which the concept of forces of production is integral), that effectively breaks from the idea of western-centred 'progress' as

Connected to a growing awareness of a multiplicity of civilizations and cultures (associated with his move to London – the cosmopolitan centre of world empire (Anderson 2002)) is the development of a critical perspective on imperialism and a shift away from the view that capitalism would create an increasingly unified world. Marx came to recognize that capitalist development in the metropolis continued to be supported by the extraction of raw materials and huge surpluses in the colonies and semi-colonies. Thus, in later writings he criticized the "bleeding process" by which the British extracted resources from India for the benefit of the British ruling class, speaking of how English "vandalism in India, pushes the Indigenous people not forward but backward" (Quoted in Kiely 2002). In *Capital I* Marx spoke of how "the veiled slavery of wage earners in Europe needs the unqualified slavery of the New World as its pedestal" (1976b, 925) and in Chapter 15 on the same work he remarked on how "a new and international division of labour, a division suited to the requirements of the chief centres of modern industry springs up, and converts one part of the globe

the motor force in history. In contrast to the customary understanding, in the Semyenov reinterpretation unilinealism does not imply that every society is required to go through all 'stages.' Indeed, he shows that it is quite implausible to think that any concrete continuous society has passed through all modes of production. Therefore, rather than crediting the succession of stages to single, continuous societies, Semyenov advances what Gellner calls a 'Torch Relay' theory of history (ibid, 761). In this view, humankind as a whole is at a given stage, when the most advanced and influential area happens to be at the stage in question. The criteria for influential is partly that it exercises a great deal of influence on surrounding peripheral regions and also that it is preparing the ground for the next stage in question. As such, the torch carrying zone can only be identified after the event, after the next stage is reached, while its powerful influence is such that societies lagging behind will no longer pass through the same stages as the pioneers. The history of humankind in this way may be 'unitary,' while there are many types of societies in existence. Moreover, in Semyenov's view, on occasion not only is the centre essential for attaining the next stage, but so is the periphery. Indeed, at various crucial transitions (e.g. slave/feudal) the historic periphery played a crucial role in the attainment of the next historic step. In fact, the feudalism/capitalism transition is seen as idiosyncratic as a centre-preserving transition. Although not fully spelled out, the same would now be true of the capitalism/socialism transition; the torch is often passed 'sideways' to peripheral regions that are essential for carrying forward progress, while dispensing of any obligation to 'pass evenly through all stages.' While it does not overcome all the problems facing unilealism, the Semyenov reinterpretation, as Gellner suggests, moves away from the Eurocentric and self-congratulatory customary understanding.

into a chiefly agricultural field of production, for supplying the other part which remains a chiefly industrial field" (ibid, 570-80).[13]

This sensitivity to uneven geographical development is also attuned to ecological questions. In Marx's view, the ecological rift is exacerbated, becomes "irreparable," due to long-distance wasteful trade and the spatial disjuncture (especially the antagonistic separation of town and country) in capitalist production. While Marx often shows enthusiasm for the potentiality of enhanced forms of human cooperation enabled by globalizing productive networks and associated infrastructures (see Chapter 4), already in the 19th century he recognized that production chains were overstretched and wasting resources (Tanuro 2012). While not explicit in *Capital*, contemporary perspectives calling for partial de-globalization, including the shortening of commodity chains, the re-municipalization of infrastructure, the re-localization of much production and food sovereignty, yet without entirely

[13] In these passages, Marx appeared to recognize that so-called primitive accumulation should not be confined to the genesis of (European) capitalism, but be considered a continuing process, an approach that accords closely with Luxemburg. He also spoke to struggles for independence from imperialism, as in the case of Ireland, which would be required for autonomous development. Therefore, while Marx and Engels are often considered to have had little to say on imperialism (Ashman 2013), these notes laid the foundation for later theories of imperialism and combined and uneven development to be developed by Lenin and Trotsky as well as Luxemburg. For a clear contemporary analysis of imperialism that explicitly centres the concept of forces of production see Kiely (2002). Kiely shows that integration into the world economy does not automatically equate to the development of forces and relations of capitalist production. While this does not mean that the world-economy is structured into a timeless core-periphery divide, as sometimes implied in earlier 'dependency' analyses, competition in the world economy is intrinsically unequal. Kiely, in contrast to many theorists of globalization, demonstrates that notwithstanding the breakneck development of a few southern nations such as China, late 20th and 21st century moves towards global "free trade" have only intensified uneven development. As such analyses show, integration into the circuit of capital can lead to widespread proletarianization and capitalism's tendency to develop forces of production in search of relative surplus value (and associated developments such as investment in technoscientific research and development), but it does not necessarily do so. Commerce can be introduced into countries that continue to export raw materials with little accompanying industrial development, while low wages and less robust class struggle at the shop floor encourage the extraction of absolute rather than relative surplus value. While differential growth within the world economy remains the key "scale" of analysis, uneven and combined development can of course be usefully pursued at "lower" scales, such as between nations and within regions of a country.

abandoning the 'global,' are quite compatible with Marx's critique of capitalism (Candeias 2013b; Klein 2011; Tanuro 2012).

Philosophies of history that imply obligatory successive stages of society must be rejected. Rejecting an outmoded developmentalism does not deny, however, that there are positive *potentials* that come from capitalism's material development of forces of production, or that that new *possibilities* in world history are opened by the advance of scientific-technological knowledge underlying the use of machinery in capitalism.[14] Increases in productive capacity and reduction of absolute scarcity make a basic egalitarianism of life conditions *more feasible*, while building something resembling socialism without a certain material 'base' in the productive forces is extremely difficult.

At the same time, rejecting such a developmentalism should lead to a greater attentiveness to the "articulation" of non-capitalist and capitalist modes of production. Vitally, as Coulthard (2014)

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[14] There is a 'modernism' at work in the *Manifesto* and running through Marx's mature work and which speaks more fully to the progressive potential he attributed to capitalism, beyond that bound up with increases in material output and productivity. By virtue not only of the technical powers, but also of the forms of knowledge and other unfulfilled human capacities that capitalism enables and potentiates(such as cooperation), Marx believed that humanity was more than ever in a position to intervene, realize and control its own functioning and production activities, to act upon itself and become 'architects' of its evolution. He viewed capitalist modernity as containing a potential enhancement of what Alain Touraine calls 'historicity' – an increased capacity for self-development and the self-production of society (Touraine, 1977). Such considerations lead David Harvey to assert that "for Marxists, there can be no going back, as many ecologists seem to propose to an unmediated relation to nature (or a world built solely on face-to-face relations), to a pre-capitalist and communitarian world of non-scientific understandings with only very limited divisions of labour….The emancipatory potential of modern society, founded on alienation, must continue to be explored" (Harvey 1993, 41). The perspective raises deep tensions and major paradoxes. These 'positive potentials' come with a separation and estrangement from a more immediate sensuous engagement with nature, often considered a vital component of self-realization. Moreover, machines and the divisions of labour bound to them, not only dispossesses workers of surplus value, but (at least in capitalist form) also deprive them of their knowledge, skill and talent, while mediating their relation to nature in alienating ways. As I suggest in Chapters 2 and 4, taking on these kinds of tensions and trying to wrestle with the 'alienated mediations,' while holding in some measure to the 'emancipatory potential of modern society founded on alienation' points to a much more circumspect view of 'liberating productive forces,' than implied by more "orthodox" Marxist views and a different view of socialism and the struggles and challenges it will entail. It negates a view of capitalist industry and technique as an altogether positive acquisition, not contaminated by history and relations of production and power.

suggests, this should include the ways in which the former can come to inform the construction of alternatives to the latter. The knowledge and lifeways of peoples who have experience with ways of being not overdetermined by capital are vital in forging alternatives.

There are aspects of Marx's work (particularly in his reflection on Russian communes) that provide some resources for this. On the important question of knowledge and skill, I believe his work falls short. I agree with Tanuro's suggestion (2010), that Marx does not do justice to the creativity, skill and knowledge belonging to peasant, or Indigenous and rural communities outside of wage labour. While his perspective shifts to some degree in later works, he continues in *Capital* to refer unhelpfully to the agricultural peasant producer as the "less advanced fraction of society" (Marx 1993a, 754). In rethinking the quote discussed above from *Capital III*, we should recognize that *these* rationalities also have a vital role to play in construction of ecologically sound alternatives.

Fruitful in this vein is again Ariel Salleh's work (2010, 2009). Reflecting from a global and "Third-Worldist" perspective, Salleh has highlighted the metabolic contributions of what she terms 'meta-industrial labour.' Meta-industrial labour denotes "workers, nominally outside of capitalism, whose labour catalyzes metabolic transformations – be they peasants, Indigenous gatherers, or parents" (2010, 212). The concept combines productive and reproductive labour on the basis that the non-monetized work meta-industrial labourers is fundamentally *regenerative* – it sustains everyday life. Furthermore, she emphasizes that much Indigenous work, peasant reproductive provisioning and subsistence farming are critical to the maintenance and reproduction of natural environments. This labour is often 'rift-healing' (ibid, 205) and possesses 'metabolic-value (212),' denoting its contribution to sustaining and supporting ecological integrity.

In the process, Salleh works to (re)valorize the grounded knowledge and skills of various 'meta-industrial' labourers. As she suggests, it is vital to recognize these diverse labourers as skilled ecological managers, and to consider how they can inform alternatives to capitalist ways of relating to nature. Her work, in combination with the thesis advanced here, points to the necessary, though admittedly difficult task of integrating local and Indigenous knowledges (and environmentally useful technologies developed prior to capitalism), with ecological sciences (more formally understood) in the construction of alternatives.

Conclusion

Despite longstanding efforts to undo such an interpretation, critics of Marx continue to see his optimism in the emancipatory potential of developing productive forces as proof of a deep-seated techno-Prometheanism. On this view, Marx's vision of socialism is reduced to an outmoded and anti-ecological 'automated' paradise, which simultaneously and substantially continues rather overcomes a patriarchal, imperialist and colonial "mode of living."

Marx, as I showed, demonstrated enthusiasm about the heightened productivity and increased material output enabled by the capitalist development of productive forces along the lines of large-scale industry. This provided the 'material conditions' for a society beyond capital where the material needs of all would be met and arduous human labour would be greatly reduced. In some instances, particularly in earlier works, he implied that socialism would increase this productivity and that capitalist production was not mechanized enough. In such statements, he did not yet, as Amy Wendling puts it, "question the use-value of production's amplification in increased material output" (2011, 206).

In this chapter, I argued that this perspective needs to be approached with greater sensitivity to the historical circumstances of his work, as well as the human developmental content of his arguments. Marx suggested that the further development of industry may be required to "satisfy the material needs of all" from a perspective of scarcity, while he was also clear that the scientific and technological resources accumulated during the capitalist period could enable qualitative changes. They make possible the development of forms of wealth that exceed a 'productivist' dimension: especially the development of the artistic, social, political, intellectual capabilities of human societies. While this wealth is potentiated by capitalist society, Marx argued that it is suppressed by the regime of value and could only be reached if control over society's productive powers was no longer in the hands of only one part of society (capital).

Furthermore, Marx's enthusiasm regarding the heightened productivity of capitalism needs to be considered in light of his arguments surrounding the wastefulness and destructiveness inherent to capitalism's development of the productive forces. These arguments (which are found particularly in his later works, and are amplified in recent eco-Marxist theorizing) reject the possibility of ascribing to Marx an overly positive verdict on capital's development of productive forces. This invites us to unpack more carefully the complex historical progressivity that he ascribed to capitalism, including its unfulfilled potentialities and a consideration of what might be worth retaining from that view today. These issues animate the next chapter, where I provide a more sustained reconstruction of the concept by engaging twentieth-century Marxist approaches.

Chapter 2 – Marxism and Forces of Production: Towards an Ecological Conception

This chapter reconstructs the concept of productive forces, pointing to the importance of a more expansive and generous understanding that moves beyond its narrow identification with technological 'hardware' and increases in productivity and material output. I begin by first considering how the productivist interpretation has been bolstered from within the Marxist tradition, focusing especially on Gerald Cohen's influential *Karl Marx's Theory of History: A Defence* (KMTH hereafter). In contrast to Cohen, and drawing on Bertell Ollman (1976), I point to the more qualitative side of Marx's concept and to the enthusiasm he shows for the growth of capacities and powers such as cooperation and ecological knowledge. Next, I contrast the neutral view of technology implied by theorists like Cohen with more open, dialectical and political treatments of the concept located in the work of Mao, as well as in late 20th century labour-process and autonomist-Marxist approaches. This provides the grounds for (re)-evaluating the destructiveness of capital's tendency to develop productive forces, without foreclosing the ecological and other positive potentials bound up with their advancement.

Productive Forces and Technological Determinism

Gerald Cohen's KMTH provides helpful definitions of the concept of productive forces, initially working against the grain of treatments (as glimpsed in Chapter 1), which tend to reduce the concept to bundles of technology or technological 'hardware.' At the same time, he produces a powerful late 20th century defense of a more deterministic and productivist account of Marx. His work provides a helpful starting point for our reconstruction.

KMTH represents an attempt to apply the rigors of analytic philosophy to Marx's various statements on historical change, in an effort to pinpoint and tie down the specific causal mechanism(s) in Marx's interpretation of history and then to test that theory across historical epochs. This so-called "no bullshit" Marxism is pitted against dialectical thinking, which offered a relational, interdependent and more contingent understanding of change, and which for Cohen, "thrives only in an atmosphere of unclear thought" (2000, xxiii.). In contrast to dialectical approaches, he argues that Marxists need to provide rigorous analyses and explanations of the specific micro-mechanisms through which epiphenomenal events emerge, rather than enlist teleological reasons or enter into the morass and push and pull of theories of 'co-constitution.'

Cohen works towards a definition of the forces of production by creating a catalogue or list of items that contribute to production. As he writes, "to qualify as a productive force, a facility must be capable of use by a productive agent in such a way that production occurs (partly) as a result of its use, and it is someone's purpose that the facility so contribute to production" (2000, 32). Within this understanding, Cohen treats productive forces as consisting primarily in labour power and the means of production. Labour power is defined as the productive faculties of producing agents. This includes strength, skill, and knowledge, encompassing the productively "relevant" parts of science (ibid, 45). Scientific knowledge for Cohen is neither "superstructural" nor ideological, and in so far as it is productively relevant and "useful," and involved in the construction of instruments of labour, he includes it in his understanding of the productive forces. He defines means of production as either instruments of production, raw materials, or geographical spaces. By contrast, relations of production are framed as "[e]ither relations of ownership by persons of productive forces or persons *or* relations presupposing such relations of ownership" (34). In terms of ownership, Cohen clarifies that we think of this not as a legal relationship but as one of *effective control* (ibid, 35).

In KMTH, Cohen subsequently argues that Marx was committed to the belief that history is based on the growth of human productive powers and that the economic structures that come to determine the form of society (such as slavery, feudalism and capitalism) rise and fall according to how they enable or impede that growth. Cohen exposes the reader to key statements in Marx on the forces and relations of production. He then proceeds to show analytically, that while Marx often asserts that productive forces produce changes in social relations and mental conceptions of the world, arguments suggesting a reverse 'dialectical' movement are nowhere to be found in Marx's corpus and in any event simply do not hold. While Cohen admits some difficulty in reconciling his primacy thesis in KMTH with his recognition that capitalist property relations provide a clear stimulus to the development of the forces of production, he is able to side-step this problem and re-assert primacy. He does this via a functional explanation: phenomena are explained by their tendency to bring about certain effects. For Cohen, property relations underpinning capital clearly spur on the productive forces, but this does not contradict his primacy thesis, in so far as relations of ownership and control function to develop the forces, and exist given their capacity to do so. Put differently, the forces of production are understood to *choose* social relations and political/ideational structures and arrangements according to their capacity to promote further development.

Cohen's initial definitions of both productive forces and relations are quite expansive and insightful. The suggestion that both modern science (as instrumentalized under capitalism) and geographical space be considered productive forces, is particularly helpful. Yet, beyond this initial conceptual exegesis, in KMTH Cohen analyzes the forces of production and their emancipatory potential almost exclusively with respect to the productivity increases they enable. Productivity for him means that less direct labour is required in order to make a larger product, such that productivity equals size of product/ amount of direct labour to produce it. Most fully, the power of the productive forces refers to "the amount of surplus production [they] enable," or the amount of the day that remains after the labouring time required to maintain producers has been subtracted (2000, 61).

Cohen subsequently positions the drive for increased productivity as a trans-historical motor force of development.[15] In doing so, he appeals to an exogenous force behind the development of productive forces: human rationality and the basic impulse of human beings to better their life situation, reduce toil and overcome material scarcity by boosting productive forces. This enables Cohen to boil down his concept to the point where he understands technological development as an autonomous historical force that continually smashes through anachronistic forms of property ownership, creating a clear path towards socialism.

In Cohen's view, capitalist relations of production necessarily exist because they promote productivity, and they will also change because a new technological power has arisen to which they are ill-adapted. As capitalism clearly continues to stimulate some forms of technological progress, he must offer an alternative view of "fettering," which goes beyond the suggestion that capitalism will continue to exist so long as it permits *any* increase in productivity. Developing an account of fettering similar to that outlined in my Introduction, Cohen argues that relations of production fetter the productive forces when an alternative economic structure would better promote the further

[15] An analysis of Cohen's entire theory of history is beyond the scope of this study. Miller (1981) provides an excellent critique of the notion that economic structures throughout history exist and endure by proving maximum productivity. While capitalism is driven towards and includes substantial increases in productivity, it is particularly hard to sustain the view that feudalism was maintained by its ability to promote the growth of productive forces towards this end. For a critique of functionalist explanations undergirding Cohen's philosophy of history, see Agar (2003).

development or use of those forces. An economic structure thereby lasts only so long as it is *optimal* for both the *development* and *use* of its accumulated productive power (ibid, 297).

Based on this notion of fettering (which, following Hughes, I have called relative-fettering) and Cohen's focus on advancements in productivity (understood to encompass the reduction of labouring time required to maintain producers), Cohen argues that the central contradiction of advanced capitalism surrounds the priority given to the creation of exchange-value over use-value, such that "the structure of the economy mitigates against the optimal use of its productive capacity and functions to the detriment of general human welfare" (2000 310). More specifically, Cohen argues that advanced capitalism displays a distinctive bias towards expanding output, as against reducing toil. The productivity improvements enabled by capitalism are in his view open to two 'uses' – reducing toil and extending leisure – while maintaining output or (alternatively) increasing output, while labour stays the same. However, as he argues, a productive process oriented to exchange-values promotes only the expansion of consumptive goods, but cannot reduce toil, even when the option of greater leisure is more desirable for most people. Based on its single measure for calculating value – maximum production of surplus value – capitalist society places no value on diminishing labour. Capitalism,

> "cannot realize the possibilities of liberation it creates. It excludes liberation by febrile product innovation, huge investment in sales and advertising, contrived obsolescence. It brings society to the "threshold of abundance" but locks the door. For the promise of abundance is not an endless flow of goods but a sufficiency produced with a minimum of unpleasant exertion." (307)

In the notion of a bias towards expanding output as against reducing toil, Cohen outlines a central contradiction of contemporary capitalism. His is also not an anti-ecological vision in the end. While he, like Marx, views capitalism in an earlier historical period as an engine for producing material wealth from the standpoint of scarcity, the priority given to the creation of exchange-value over use-value renders the system reactionary in more advanced stages, characterized by a blind and boundless pursuit of (often wasteful and superfluous) consumption goods.

Nevertheless, difficulties in Cohen's work encourage the construction of an alternative and ecological view. They do so in two ways. First, his exclusive focus on productivity greatly restricts a discussion of what the productive forces *are* and consequently the unfulfilled potential of their overall advancement today. While the concept is adopted from liberal political economy, the Marxist variant refers not only (or even primarily) to quantitative phenomena such as improvements in productive output or increases in labour productivity in the way Cohen suggests.[16] Instead, the concept is a tool to provide a socio-historical analysis of the growth of *human capacities and powers to use and modify natural environments purposefully, in a way that is conducive to their own sustenance and reproduction, in a given society and at a given historical interval.* Of course, capacities and powers concern surplus production and productivity increases; this dimension of their development should certainly not be discounted. Yet, to focus exclusively on this quantitative dimension is reductive; it is a form of reification, which reduces our conception of the world to quantities, on the model of money (see Lukács 1972). It effectively forecloses a consideration of capacities and powers necessary to maintain, restore and improve ecosystem health, and an analysis of how capitalism critically denies the ecological use-value aspect of the productive forces.

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[16] Therborn (1980, 353-386) provides an excellent account of the genesis of the concept through classical political economy.

Productive Forces and the Dialectic of Capacities and Needs

That forces of production can be understood as expressions or manifestations of historically developed capacities and powers to transform the rest of nature, is contained in Bertell Ollman's account of the dialectics of needs and capacities, found in his classic, *Alienation* (Ollman 1976). Following Marx, Ollman makes a distinction between 'natural-being' and 'species-being,' on the basis of capacities or powers on one hand and needs or desires on the other. Needs, as he explains, are felt desires, drives or wants, and they are attached to, or dialectically coupled with, the powers or capacities necessary for realizing them. Natural-being involves powers or capacities and needs or desires that human beings share with all living entities. They are the "processes of life devoid of human attributes" (ibid, 83). The needs associated with natural being involve biological and corporeal requirements of human beings as living parts of nature, such as requirements for food, water, shelter and procreation, and are coupled with the powers to satisfy them, such as labour, eating and sex.

> Centering practices that sustain life, Ollman suggests that natural-being involves powers or capacities and needs or desires that are directed toward and realized in the external world: Take eating as a natural power, man's impulses which drive him to eat are clear enough: he is hungry. The abilities which enable him to eat include all that he does when eating. The tendencies which direct him toward satisfactory objects are his taste and his general knowledge as to what is edible and what is not. (Ollman 1976, 78)

Because natural-being powers are directed towards the external world and realized through it, the powers together with the external world are fundamentally intertwined. Citing Marx, Ollman continues:

> If man's powers can only manifest themselves in and through objects, he needs these objects to express his powers. Hunger is an example of such a need for objects. Marx says that hunger "needs a nature outside itself, an object outside itself . . . to be stilled. Hunger is an acknowledged need of my body for an object existing outside it indispensable to its integration and the expression of its essential being. (ibid)

Ollman places corporeal intertwining with the world at the heart of practices that sustain life. Natural-being is an embodied, ecologically embedded experience.

Species-being, on the other hand, reflects social activities through which humans develop, alter and expand their powers, needs and a sense of self in relation to others. Species powers include a broad array of items and various senses such as seeing, hearing, touching, smelling, tasting, knowing, judging, making love, thinking, being aware, wanting, procreating and loving. Vitally, Ollman argues that species powers extend natural powers and build upon the already ecologically embedded character of human life (natural-being). As he writes "If natural powers can be viewed as establishing the framework within which life itself goes on, then man's species powers express the kind of life which man, as distinct from all beings, carries on inside this framework" (ibid, 83). Species powers are means by which people learn about, interact and establish particular relationships with nature (both nonhuman nature and other people as parts of nature).

Ollman suggests that the extension of species powers through the senses is captured in Marx's distinctive understanding of 'appropriation.' As Ollman explains it, "'appropriation' means to utilize constructively, to build by incorporating":

> For Marx, the individual appropriates the nature he perceives and has become orientated to by making it some way a part of himself with whatever effect this has on his senses and future orientation. To "capture" a sunset, it is not necessary to paint, write or sing about it. It becomes ours in the experience of it. The forms and colors we see, the sense of awakening to beauty that we feel and the growth in sensitivity which accompanies such an event are all indications of our new appropriation. To paint the sunset, or to write or sing about it, if joined by genuine emotions, would achieve an even higher degree of appropriation, would make this event more a part of us. (1976, 89)

Appropriation here can be read as a process in which bodies interact with and are affected by sensuous engagement with the world. Appropriation affects the experiences humans can have and their stance toward the world. Moreover, appropriation transforms species powers; in the case above, it increases one's ability to differentiate colour and appreciate a sunset.

This theory of the human relationship to nature and its 'appropriation' is exceptionally broad. It encompasses all the human capacities and powers (including the five senses and their contents, as well as other actions and functions) by which we become aware, learn about, interact with or otherwise 'contact' nature (both human and non-human). As Ollman suggests, various 'spheres' of life (such as art, literature, the family, politics), provide occasion and materials for the objectification and alteration of species powers.

Material production is, in this light, but one crucial area of life within which the fulfillment, alteration, and expansion of powers or capacities and life-needs take place. Conscious, purposive activity in the productive process, or as Marx puts it, "purposeful activity aimed at production of use-values," "appropriation of natural substances to human requirements" (1976, 290), is a key arena for the objectification and development of species-life, or humanity's powers. Moreover, the *forces* that are adopted, applied and developed within the productive process, reveal and are themselves expressions of powers and capacities to purposively transform the rest of nature and meet needs. Productive forces and species powers are as Ollman suggests but "two sides of the same relation" (ibid, 96). The perspective finds its origins in is reflected in Marx and Engels, who in the *German Ideology* wrote that, "The history of the evolving productive forces…is, therefore, the history of the development of the powers of the individuals themselves" (91). Later in the same text, and in view of the 're-appropriation' of the productive forces from capital under socialism, they asserted that, "the appropriation of these forces is itself nothing more than the development of the individual capacities corresponding to the material instruments of production" (96).

From this perspective, I argue that an adequate account of productive forces should include the capacities and powers that are collectively available to us (and reflect a need) to transform and appropriate non-human nature in a manner that *maintains, restores and improves ecosystem health*. The limitations of Cohen's view from this perspective are most immediately evident in his discussion of knowledge and science. While Cohen helpfully includes science and knowledge as a productive force, commensurate with Marx who repeatedly describes them as such, they are included in Cohen's list of productive forces only in so far as they intervene in the transformation of nature in order to advance productivity.

By contrast, when Marx and Engels discuss the growth of science and its potentiality, their enthusiasm centers new forms of ecological knowledge and understanding. Marx points for example to developments in the field of agronomy, aimed at soil restoration and the management of the environmental impacts of capitalist agriculture (see Chapter 4). As Burkett (2014, 158-163) shows, he also expresses enthusiasm for the growth of new and more *universal* forms of ecological understanding and awareness, which capitalism unwittingly propels by virtue of its intensive globalized appropriations of nature and accompanying ecological dysfunctions. Engels captures this succinctly:

> Thus at every step we are reminded that we by no means rule over nature like a conqueror over a foreign people, like someone standing outside nature - but that we, with flesh, blood, and brain, belong to nature, and exist in its midst, and that all our mastery of it consists in the fact that we have the advantage over all other beings of being able to know and correctly apply its laws…And, in fact, with every day that passes we are learning to understand these laws more correctly, and getting to know both the more immediate and the *more remote consequences* of our interference with the traditional course of nature. In particular, after the mighty advances of natural science in the present century, we are more and more getting to know, and hence to control, even the more remote natural consequences at least of our more ordinary productive activities. (quoted in Burkett, 162; my emphasis)

In this and other passages, Marx and Engels showed excitement for new forms of ecological knowledge, gesturing to the interdependence of specific sites and increased more universal understanding and consciousness of the unintended consequences of our productive metabolic interaction with nature. They view this growth in knowledge as an augmentation of social productive powers and capacities and corresponds to or fulfills a need to sustain the natural conditions that support friendly human life and flourishing. The conditions are not in opposition to the productive forces, but a part of them.

Such knowledge is densely tied to the capacity for human 'cooperation' – part of the knowledge generated from our interaction with nature that should be shared and used consciously and purposively to 'plan for tomorrow' (see Chapter 4). Marx argued that such knowledge is common knowledge, belonging to the 'associated producers' or the 'collective worker,' and that its conscious and comprehensive application would form a vital component of humanity 'rationally regulating their interchange with nature.' However, as he suggested, this power is appropriated by capital and applied or 'objectified' in only limited and circumscribed forms as it is harnessed to the production process under the broad impulse of competitive monetary accumulation. In the process, it is simultaneously fettered – remaining underutilized and applied only narrowly.

Second, and relatedly, Cohen's intentionally undialectical and "cumulative" view of increases in labour productivity means that the political aspects of the mode of production relate primarily to ownership of means of production, or 'effective control,' while productive forces appear not to be tied to substantial variations of a social and political kind, but rather subject to linear and purely technical development. On this view, Cohen (like some critics in seen in Chapter 1) has Marx endorsing capitalist industry as an altogether positive acquisition, not contaminated by history and relations of production and power. Socialist production (including associated forms of work organization) is directly inherited from capitalism, while activating a better use of its technological mixes.[17]

In the next section, I bring out the limitations of this view by engaging more dialectical and political treatments of forces of production, located first in the work of Mao as well as in neo-Marxist work of the 1970s pertaining to work organization and technology, as forms of labour control. These perspectives point to how class relations are inscribed within forces of production, challenging the neutral view of science, technology and technique implied in analyses like Cohen's. Despite lack of attention to non-human nature, they raise questions that remain relevant to today's left and help expose the complexity and challenge of discovering and advancing those aspects of productive forces appropriate to a democratic green socialism for the 21st century.

Lenin, Mao(ism) and Forces of Production

As suggested in Chapter 1, 20th century Soviet socialism sought to establish a framework for 'catch-up' industrialization and produced models of development that largely mimicked capitalism in terms of its productivism. This included enthusiastic support for the growth of science and technology geared towards rapid modernization and heavy industry. Therefore, Lenin's vow that "no

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[17] Cohen is able to sustain a neutral view of the forces of production and to see their development as an autonomous result of the effort to overcome natural scarcity, in part by also excluding important social and relational dimensions of forces of production, such work relations and work organization.[17] As will be shown in Chapter 4, this does not fit well at all with Marx's classification. For example, in *The German Ideology* Marx and Engels wrote that "By social we understand the cooperation of several individuals, no matter under what conditions, in what way and to what end. It follows from this that a certain mode of production or industrial stage is always combined with a certain mode of cooperation, or social stage, and this mode of cooperation is itself a 'productive force'" (1976, 76). Marx continually invoked this conception throughout his mature work. As the labour process theorists reviewed below suggest, it is clear that work organization and work relations are governed to a large extent by a concern for labour discipline and social control, rather than being the result of the drive to increase productivity.

dark power would be able to withstand the union of representatives of science, proletariat and technique" (quoted in Werskey 2007, 404) and the massive increases in technical scientific workers and research facilities following 1917 (ibid) both understood the progressive historical force of science in terms of its practical role in advancing industrialization. The new Soviet Republic officially viewed heavy industry and technology as an expression of applied scientific knowledge. In regard to 'technique,' Lenin also praised the most advanced American methods of production and set up factory systems similar to those created by US corporations. In his 1918 piece, 'The Soviets at Work,' he suggested that:

> The possibility of socialism will be determined by our success in combining Soviet rule and Soviet organization or management with the latest progressive measures of capitalism. We must introduce in Russia the study and teaching of the Taylor system and its systematic trial and adoption (Lenin 1918).

Echoing the sentiment in a later speech delivered Moscow in 1920, he famously described socialism as "Soviet power plus the electrification of the whole country" (Lenin 1920).

As intimated in Chapter 1, Lenin's perspective on the growth of productive forces (including his advocacy of Henry Ford's moving assembly line for mass production and Taylorist work organization) needs to be considered in view of historical circumstance. He worked in the setting of a 'backward capitalism' and Soviet society's underdevelopment. Logically enough, the development of socialism implied a rapid growth of forces of production centred on increasing output and 'durables.' The immediate problem with capitalist production technologies was therefore not with the 'techniques' or technological mixes, but with their use to produce surplus value for the capitalist, rather than enough output to build up the young Soviet Union and (ultimately) satisfy the material needs of all. Moreover, the exigencies of the Revolutionary moment – war and mass disruption –

gave a strong impetus to the process of rapid industrialization, with priority assigned especially to heavy industry (Harvey 2010). The leadership saw this as a means to safeguard the revolution and provide military defence against foreign aggression. Lenin was therefore partially justified in turning to the most advanced capitalist technological forms in order to revive and extend production and safeguard revolution. However, in the long-term, this was a problematic strategy.

Interestingly, Chattopadhyay (2014) has shown that the early Soviet Union from 1917-1930 developed the most advanced ecological science in the world. It revolutionized fields such as climatology, while pioneering forms of conservation, especially in the area of forestry. Werskey (2007) similarly recalls various early dissenters to soviet-style 'industrialized science' within the scientific community in the Soviet Union, and the production in the 1920s of various visions and advanced practices aimed at producing a 'leaner and greener' socialist society. However, once firmly under Stalin's custodianship, an 'alliance of science, the proletariat and technique' that might have moved in a more ecological direction was obliterated (with violent purges aimed at its leading ecological thinkers in the 1930s and 40s) and the Soviet Union became bent on rapid industrialization in its efforts to outpace the United States in per capita production (ibid).

While working under broadly similar conditions (in terms of levels of economic development, including relatively undeveloped capitalist industry and peripheral position within world capitalism), Mao and the other political thinkers of communist China more often presented an alternative model and method of developing productive forces. This stems from an understanding of the 'transition society' and the problem of building the material foundations of socialism.

Some of Mao's best known contributions to Marxist philosophy come from his elaborations on the notion of contradictions in *On Contradiction* (1947) and later in *On Correct Handling of Contradictions Among the People* (1957). The dimension of Mao's work that is most often discussed from the former concerns his writings on the principal *aspects* of a contradiction, which challenged the Stalinist orthodoxy of the time. As he wrote:

> …in the contradiction between the productive forces and the relations of production, the productive forces are the principal aspect; in the contradiction between theory and practice, practice is the principal aspect; in the contradiction between the economic base and the superstructure, the economic base is the principal aspect; and there is no change in their respective positions. This is the mechanical materialist conception, not the dialectical materialist conception. True, the productive forces, practice and the economic base generally play the principal and decisive role; whoever denies this is not a materialist. But it must also be admitted that in certain conditions, such aspects as the relations of production, theory and the superstructure in turn manifest themselves in the principal and decisive role. When it is impossible for the productive forces to develop without a change in the relations of production, then the change in the relations of production plays the principal and decisive role. ….When the superstructure (politics, culture, etc.) obstructs the development of the economic base, political and cultural changes become principal and decisive. (1947)

For Mao, impulses for social change often derive from a central structural contradiction between forces and relations of production, yet how these impulses are channelled, whether or not they give rise to social change, and what the content and character of subsequent transformations: all these questions, on his view, were matters of political and ideological struggle. Mao here appeared to have emphasized the "subjective" factor (that is the role of theory, of consciousness, of politics), in the process of historical struggle aimed at social transformation. As Lenin also remarked in critique of central European Social Democracy, revolution is not a mechanical working out of fatalistic contradictions, which given sufficient maturity would somehow automatically lead to proletarian victory. In the face of structural contradictions, he argued for the 'primacy of politics' arguing that the outcome of struggle depends on the creativity of political leadership offered by antagonistic classes. Within this view, Mao was himself a Leninist, who insisted on combining faith in the masses with a vanguard party. Additionally, he pointed to the importance of building class alliances between proletarians and dispossessed peasants and argued that revolutionary practice in China could be built around poor peasants together with an urban proletariat, which remained a relatively marginal class in China in this period (D'Mello 2009).

However, the notion of 'primacy of politics' or 'politics in command' concerned not just the organization and building up of revolutionary forces, but also the long-term process of building a revolutionary socialist project. In the formation of socialism following a revolutionary rupture, Mao emphasized the continued importance of education and of transforming consciousness. This attention given to ideology and transforming attitudes has been understood and critiqued as representing a "voluntarist turn" to the superstructure (Mamo 1981). Yet, as Rossana Rossanda (1971) suggests, the notion of 'politics in command' is not only (or even primarily) a matter of consciousness, of ideological struggle. Instead, it concerns fundamental questions of the 'transitional society' – that is of how to effect a break with the capitalist mode of production and in a manner than resolves its multiple contradictions. Such a break would need to go deep into the structure and the 'material base.'

For Mao, the capitalist mode of production is not reducible to the relation of private ownership of the means of production; instead, he argued that this relation is embedded within the web of relations that constitute capitalist accumulation, including work organization and divisions of labour. Thus, the break with the capitalist mode of production would mean breaking not only with private ownership, but also with the capitalist form of these productive forces (or at least their radical transformation). 'Politics in command' is therefore a strategy aimed at a transition away from capitalism on which a great deal of the mode of production survives, "not as a vestige of the past but as an intrinsic feature of the present" (Rossanda 1971, 62). In Rossanda's view, this understanding was precisely what was lacking in the official Soviet model from 1917, on which was based on the conviction that socialism could be built only in accordance with technologies and a production model similar to the industrial revolution, save ownership of the means of production and the social distribution of the product. Such a model would inevitably re-produce contradictions in the relation to nature (including an increase in the gap between town and country), renew capitalist divisions of labour in the workplace, and entrench privileged position for technique and intellectual labour, in comparison with manual labour. Rossanda proposes that the Cultural Revolution too is often misunderstood – it was not primarily aimed at bringing about "ideological" changes, but rather aimed at achieving changes in the development of technology, work organization and in the relationships between labour, knowledge and authority (ibid).

This position was prefigured in the first Great Leap Forward beginning in 1958. The Great Leap was premised on a strategy of advancing productive cooperation in steps or stages, first by incorporating individual peasant households into systems of mutual aid, then into producer cooperatives, and on into larger collective economic and political units (communes) (D'Mello 2009). The vision, as Hinton writes, was "dialectical, projecting a society in constant development, communities at different levels all moving towards higher levels of multifaceted cooperative development at speeds determined by their own potential and internal dynamism" (1994, 4). Within this view, Mao criticized the Soviet model's bias towards heavy industry and centralization, to the neglect of light industry, agriculture and local participatory initiatives (Li 2008). Mao thereby helped initiate the development of rural industries, premised on using 'appropriate technologies,' along with a more decentralized planning process that encouraged greater initiatives from localities and grassroots workers (ibid).

The Great Leap Forward, which lasted until 1962, produced some initial breakthroughs and also had catastrophic concrete effects. In its first year, the strategy produced important technological advancements, led to the construction of industrial and agricultural infrastructure and enabled millions of peasants to gain preliminary experience and knowledge of modern industrial production (Li 2008). However, the economic surge of 1958 gave way to several years of major economic turmoil and wide-spread food shortages. From 1959-1962 China experienced a massive famine in which up to 30 million people are reported to have died (Dikötter 2011). In addition to internal political tensions that led to fundamental divisions over development strategy and policy (Hinton 2004) and external factors (poor weather), major mistakes and failures in agricultural policy and planning under Mao's leadership contributed to the famine. The application of untested ideas of Soviet agronomist Trofim Lysenko and his followers, such as close cropping, deep plowing and applying unusual fertilizer mixtures, led to decreases in agricultural production (ibid, 39). Breakdown in communication also contributed to massive misallocations of resources (Li, 2008). As the government failed to recognize that grain production was much lower than reported, China remained a substantial net exporter of grain during this period (Dikötter 2011). Grain was requisitioned from the country-side, while a large amount of labour was also diverted from agriculture to steel production and construction projects, such that harvests were left to rot uncollected in some areas (ibid). The problem was aggravated by locust swarm caused by a disastrous Great Leap campaign against sparrows for their toll on grain stocks and rice (Kreston 2014).

Despite the very concrete failures of the Great Leap Forward, its initiatives are not without merit and were in some ways well conceived in their method of involving the masses in the development of the productive forces in agriculture and small industry. Contained in the initiatives is a recognition that human beings themselves are part of the productive forces – that people's skills, tacit knowledge and creativity could be 'unleashed' and that human capacities for cooperation and democratic problem solving in communities and workplaces could be built up as the result of human activity and practice (as well as via investments in education and health).

A focus on matters of 'labour, knowledge and authority' could also be seen in Maoist politics concerning the 'politicization' and practical application of science and also in tensions between 'reds and experts.' Mao understood natural science to be inherently political. Its techniques and aims were seen to be deeply shaped by historically determinant social relations – reflective of certain economic priorities and class interests. The aims and conduct of science under socialist social relations and in the 'transition society,' would therefore need to look quite different. Science would need to be politicized directly through the guidance of the party, so that it could be conducted in the service of the 'interest of the masses.' Moreover, for Mao, the productive utilization of science under conditions of labour's subjection to capital also hampered the *diffusion* of scientific knowledge of natural conditions. It forced an extreme separation or distinction between scientists/experts and workers/lay people and separated knowledge from practice and practical experience. These separations needed to be overcome or diminished as far as possible; on Mao's view, socialist praxis would encourage people to be both 'red and expert.'

The politics of the Cultural Revolution, which grew out of the first Great Leap Forward, were characterized by Mao's "mass science" imperative, which sought to undermine 'elite science,' and were based on the tenets of integrating experts and the masses in scientific endeavours and combining Indigenous and Western science (Brock and Wei 2012). This included efforts to have scientists concentrate on immediately useful projects and practical problems, such as in agriculture and industry and efforts to involve uneducated masses in research work, such as plant breeding and pest control. The educative components of the Cultural Revolution therefore sought to expand the ranks of scientific and technical personnel via basic professional training programs, especially in rural areas, and were conceived as a project of human capacity building (ibid). Agronomists and geologists went to the countryside to collect information and engage peasants concerning their knowledge of crop variety, the location of useful minerals, and folk knowledge of precursors of earthquakes, such as levels of water in wells or the unusual behavior of domestic animals (ibid).

Strong currents of anti-intellectualism also accompanied the Cultural Revolution, as the practices of natural science and the attitudes of scientists were often positioned as being as opposed to the interests of the masses. Brock and Wei (ibid) thus point to an oscillation in Maoist China between science being viewed as productive force (and scientists concomitantly viewed as 'workers') and its periodic reclassification as part of the 'superstructure' (with scientists subsequently viewed as belonging to the suspect intellectual camp). There was also a depreciation of scientific theory in this period, as science was directed only at immediate and practical problems and often on a trial and error basis. Indeed, the period displayed some of the dangers of "Lysenkoism," a movement in the 1930s to 1960s in the Soviet Union which was an attempt at a scientific revolution, including a political campaign against emerging genetic theory and certain forms of science-based agriculture (See Levins and Lewontin 1987, 163-196). The latter were disavowed and repressed as they contradicted the official party line (genetic theory, for example, was considered to contradict Soviet views surrounding the social malleability of human character). In such approaches there was no sense of interaction between "socialist and bourgeois science" and as Levins and Lewontin write, "a one-way external interaction between philosophy and science, in which philosophers interpreted and blessed or condemned particular scientific views" (ibid, 195).

The harshest excesses of the Cultural Revolution yielded to relative stability by the 1970s, as the Great Leap Strategy of advancing productive cooperation in steps or stages, was revived and proved more successful (Schmalzer 2012). Within this approach, China's development model emphasized an ethic of 'doing more with less" and subordinating technological development to human social development. In rural areas in particular, there was a focus on the development of small-scale industries, such as small damns and local irrigation systems, as well as programs to use waste materials such as biogas as an energy source, suited to using local resources and meeting local needs. Priority placed on the health of the people and healthy living conditions led to coordinated sanitation efforts aimed at cleaning up rivers, factories and eliminating pests, in combination with preventative medicine (Brock 2012).

It is not the purpose of this chapter to conduct a careful or detailed study of what happened during the Cultural Revolution and its aftermath. This is a highly contested history, while recent work, as reflected here, suggests a more nuanced and complicated view than that found in narratives of absolute failure (Li 2008). I point rather to certain aspects of Maoist politics that remain relevant to today's left in the "age of the Anthropocene."

One such aspect concerns the politicization of science and tensions between 'reds and experts.' In Maoist China, we observed a long unease regarding the role of science in developing alternative political economic projects, for fear of the formation of a scientific-technological elite, and of institutionalized technocratic power that runs counter to democratization. This fear can contribute and has historically contributed to a dismissive attitude towards science and hostility to scientists themselves. Such a dismissive attitude continues on the left today, yet it is thoroughly self-defeating in so far as vital sources of information about present ecological circumstances and future effects of human activity (and which form part of the radical critique of capitalism) are coming from ecological and geosciences sciences, including climate science. Indeed, as Wark (2016) suggests, exiting today's climate crisis requires an unprecedented collaboration of 'workers' of all kinds, including workers in scientific and technical fields. Tensions surrounding the class politics of knowledge therefore remain pressing and pertinent to today's projects for green transformation.

More broadly, with Rossanda, I point to how Mao's view of the transitional society breaks with assumptions that had dominated much Marxist thought in the period, especially concerning the construction of alternative futures. For her, one point is critical: the need for a critique and often "rejection, a ceaseless re-examination of the elements of historical continuity that the capitalist epoch hands on to subsequent epochs" (Rossanda 1971, 76). In short, socialism is seen not as merely a new way of managing a society which has been inherited – a renovated version of what we already have – but also as an act of "creative-destruction," and reconstruction followed by a "new condition of social being" (ibid, 77).

Marxism and the Labour Process

Neo-Marxist work of the late 1960s and 1970s, particularly labour process approaches, produced similar challenges to any presumption that socialism could involve straightforwardly inheriting productive forces and putting them to new productive uses. Driven in part by the insufficient attention to class relations and the absence of social critique that often accompany more 'productivist' understandings of Marx, they provide more systematic analyses of how the class relations and forms of power that prevail in capitalist societies not only assert themselves politically and economically, but also enter deep into the process of production and subsequently 'fashion' science, technology and labour organization (Braverman 1998; Dyer-Witheford 1999; Noble 1986; Panzieri 1976, 2005).

A classic work in this area is Harry Braverman's *Labour and Monopoly Capitalism* ([1974]/1998). Extending Marx's analysis of 19th century capitalism, Braverman showed how jobs that once required the worker both to conceptualize as well as to execute tasks had been reorganized into, on the one hand, a mass of jobs requiring little or no conceptualization, and on the other hand, a smaller number of elite managerial and technical-scientific jobs that require little else. Braverman referred to the overall decline in society of the number of jobs that require both conceptualization and execution, i.e. skill, or craftsmanship, as the 'degradation of work.'

Braverman understood, like Marx, that the labor process is a process of exploitation, as well as a struggle for control, whose outcome is shaped by social power. He illustrates this through a close analysis of Taylorism and scientific management, in which the motions of workers were broken down into the smallest possible components in order to be separated, reorganized and recombined in such a way as *simultaneously* enhance control over workers, and increase the rate of exploitation.
While evident in the 19th century, Taylorism came to be applied systematically in the twentieth century with the advancing development of 'monopoly capitalism.'

Braverman is sometimes criticized for focusing extensively on Taylorism, which is considered to be a thing of the past, superseded by work organization methods and principles that incorporate the 'human factor' neglected by Taylor (such as in post-fordist "flexible work" schemes). Yet such criticisms miss the essential contribution of Braverman's critique of scientific management (See Foster 1998). For Braverman, Taylor's system at its strictest (before being superseded by more accommodating versions) represented the key to understanding of the labor process. Taylor broke down capitalist managerial imperatives into their most basic elements, and presented these imperatives not as a technical necessity, or as a Weberian 'despotism of rationality,' but as an expression of an open and undisguised concern for the steepest possible rate of the exploitation of labour. Key to Taylor's system was the 'disassociation of the labour process from the skills of the workers' – the gathering and development of all traditional knowledge and skills of craftspeople which are classified, tabulated and a codified into 'science'– and a clear-cut and novel division of manual and mental labour, or a separation of conception and execution, throughout the workshops.

Following from this control over knowledge was the ability of 'management to control each step of the labour process and its mode of execution' (see 77-82). It also provides the basis for the process by which science is fully inducted into capital accumulation. While capitalism begins to apply science routinely to the production process during the Industrial Revolution, Braverman analyses the historical passage, along with the emergence of monopoly capitalism beginning in the last two decades of the 19th century, by which capital went from sporadically appropriating science (exploiting the accumulated knowledge of the physical sciences as a "free gift"), to the later capitalist endeavour to systematic organize, harness and fund science. Braverman calls this the scientific-technological revolution:

> The contrast between science as a generalized social property incidental to production and science as capitalist property at the very centre of production is the contrast between the industrial revolution, which occupied the last half of the eighteenth and first half of the nineteenth centuries, and the technical-scientific revolution, which began in the last decade of the nineteenth century and is still going on. (1998, 108)

While Braverman's analysis is sometimes reduced to a conception of generalized deskilling, on these terms, he did not argue that the general level of skill in society would decline as a result of the division of labour under capitalism. As he writes, "the labour processes of society have come to embody a greater amount of scientific knowledge, clearly the "average" scientific, technical and in that sense "skill" of the labour process is much greater now than in the past" (294). His central question, however, was whether the scientific and educated nature of the labour process tended towards polarization, to which he answered in the affirmative.

By explaining scientific managerial imperatives as a class imperative (exercised in the name of rationality) Braverman launched a powerful attack on technological deterministic approaches, which Cohen had reproduced and which Lenin also appeared to support on the assumption that work relations were technically determined and that socialism had to use Taylorism. For Braverman, however, capitalist managerial imperatives do not have their essential character in the machine logic itself, but rather in the class basis of the division of labor, logically independent of machinery. The machine on this view is then partly made possible by these tendencies, and partly brought into being in order to accelerate them. The implication is that both work organization and technology are forms of work control and express social domination. Put differently, machines are bound to pose problems, given that they internalize and express social relations, ways of living and producing.

While this implication remained somewhat implicit in Braverman, it is more sharply expressed in certain strands of autonomous Marxism or Italian *operaismo*, which draw heavily on Marx's notion of the real subsumption of labour to capital. Exemplary is the early work of Raniero Panzieri (1976). Here we find a potent critique of "orthodox" Marxist understandings of the development of the forces of production (and the possibilities for their immediate 'planning' by a socialist state). Panzieri posed a direct challenge to what he called 'objectivist' Marxist positions that posited technological 'rationality' as a self-moving development of scientific innovation, as part of politically neutral forces of production.

In the so-called objectivist approach, politics is external to the technical labour process, as a movement towards the eventual assumption of technological processes, achieved through socialist planning. The conjunction of objectivist and planning positions is evident in Lenin, expressed in the passage quoted in Chapter 1 calling for the adopting the latest 'progressive' measures of capitalism, including Taylorist work organization. However, as Panzieri suggests, for Marx (as for Braverman), technical forces develop not within a logic of neutral scientific progress, but as a means of consolidating a particular form of the extraction of value. The introduction of machines on a large scale in the factory and the technical principles of the machine –"the technically given speed, the coordination of the various phases and the uninterrupted flow of production imposed on the will of workers as a 'scientific necessity"' – are the direct manifestation, and also naturalization, of capitalist power and control (1976, 9).

On this view, any socialist assumption of a more efficient planning and advancement of the technological forces of production directly inherited by capital was a misguided approach that failed to recognize sufficiently the immanence of capitalist relations to technics. Thus, for Panzieri the 'collective ownership' of production made little difference to the continued capitalist functioning of the machine. He concludes:

> Faced by capital's interweaving of technology and power, the prospect of an alternative (working-class) use of machinery can clearly not be based on a pure and simple overturning of the relations of production (property), where these are understood as a sheathing that is destined to fall away at a certain level of productive expansion simply because it has become

> too small. The relations of production are within the productive forces, and these have been 'moulded' by capital. (1976, 12)

By showing that class relations are inscribed within machinery, such accounts present important challenges to inherited understandings of the progressive potential of advances in the latter. While authors championing such potential often ask us to accept continual technical growth, in so far as it carries an underlying movement towards a higher social order, labour process and autonomist theorists remind us that the assembly line and the fragmentation and division of work upon which the growth of those forces is premised, appears in large part as progress only within or against a particular socio-political background.

Braverman's analysis of the centrality that science came to occupy in the forces of production beginning under monopoly capitalism, also complicated the notion that scientific knowledge might be 'liberated' under alternative social arrangements. While the early Soviets saw science being fettered under conditions of market anarchy, monopoly capitalism had given rise to the overt politicization and planning of "capitalist science." By pointing to the planned and thoroughgoing subordination of science to the production of exchange-value, it became increasingly difficult to see it as value-free, or as a socially neutral progressive force.

Although such works maintain that a transition to socialism requires a certain base in the forces of production (that is, they seem at least implicitly to uphold that new possibilities in world history are opened by the advance of scientific-technological knowledge underlying the use of machinery in capitalism), the implication is that the technologies, forms of knowledge and other relations that could really sustain something like socialism will to a substantial degree develop in the context of social transformation, in a 'transition society' where a great deal of the capitalist mode of production survives. While we cannot avoid adapting and making use of capitalist legacies,[18] this work forces a recognition that the technological mixes (including forms of knowledge, work organization and divisions of labour) that are inherited from capitalism will need to be significantly transformed in ways that better accord with eco-socialistic relations and other kindred political projects, be they feminist or de-colonial.

Ecological 'Forces of Destruction'

The labour process scholarship discussed above is helpful in reconceptualising the development of forces of production and critical for deepening socialist politics. Concerned as it was to renew Marx's critique of work organization and class analysis at the shop floor, it mostly stopped short of engaging the ecological content, implications and promise of his work. As such, "nature" in this work continued to serve as the untheorized substratum for the unfolding of social relations.

With growing recognition of the ecological destruction brought by capitalist development, attributing progressivity to advancing forces of production becomes yet more fraught. Writing in the same period as Braverman and Panzieri and reflecting on ecological issues accompanying capitalism in its monopoly phase, Ernest Mandel presciently observed that "growing productive forces, with

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[18] While some Marxist approaches suggest an uncritical endorsement of the development of productive forces in light of the different uses to which they may be put under an alternative set of social relations, McKenzie Wark (2015) worries that today the pendulum has swung too far in the other direction such that the critique of capitalist "technoscience," often now leads to a total rejection, dismissal and disdain of the technologies, forms of knowledge and infrastructures that sustain much of modern life. Indeed, the radical left stance of "no compromise with capitalism," "total rejection of capitalist techno-modernity" (as an exemplar see Ho (2013), contains some quite problematic tendencies. While a transition to post-capitalism will not necessarily be smooth, it is very difficult to imagine, for example, how we can immediately shut down the vast productive networks, infrastructural configurations and built environments ("re-worked second natures") that currently support and sustain huge swaths of human life, without courting ecological disaster. Transforming and transitioning away from these entails some inevitable "compromise" with the forms of social organization and social relations that produced them. It is quite dangerous and potential deadly to suggest otherwise. Any future society, to paraphrase Marx, is necessarily stamped with the birthmarks of the old one.

growing commodity-relationships can in fact move a society farther from the socialist goal instead of bringing it closer" (quoted in Tanuro 2014, 146). The depths of the anti-ecological deployment and materialization of science and technology (the corporate-technoscientific complexes bound up with hydraulic fracking and the Canadian Tar Sands, for example) and a recognition of the severity of the climate crisis were not yet apparent to Mandel. Yet, already in the 1970s, and reflecting political currents following 1968, he pointed to the growing output of useless and wasteful commodities, the proliferation of environmentally damaging technologies and the role of science in these developments. Mandel emphasized how under capitalism, forces of production substantially take the commodity form and are thus entangled in its (ecological) contradictions.

Conclusion

The works discussed above challenge a neutral view of technology, science and technique, found in some well-known Marxist analyses, implied at times in Marx's own work and expressed in 20th century Soviet practice. They make it clear that the technologies (including forms of knowledge, work organization and divisions of labour) that are inherited from capitalism will need to be significantly transformed and reconfigured, rather than simply reproduced.

Today this conclusion is inescapable, and also carries new significance. What Mandel had glimpsed by reference to 'destructive forces' has become increasingly clear; capitalism, particularly in the Global North,[19] has gone too far in the way it develops quantitative dimensions of productive forces. In the circumstances, I argue that the socialist alternative no longer implies growth in the

[19] While I argue that there is an over-production of goods that are consumed in the Global North, as I show, in our era of neoliberal globalization, large swaths of materialized productive forces that are over-feeding the Global North are now in the Global South. This complicates considerations of a 'retreat' in these productive forces.

processing of natural resources and the production of things requiring matter and energy throughput, but instead implies a retreat in this aspect of their development. To sustain the natural conditions that support friendly human existence, highly polluting industries and entire branches of production will need to be shut down.

To take on these challenges a much more circumspect view of 'liberating productive forces,' than implied by more "orthodox" Marxist views (and a different view of socialism and the struggles and challenges it will entail) is needed. This means looking beyond bundles of technology and increases in productivity and material output and rethinking some of the most basic of productive forces, such as ecological knowledge, which is not 'opposed' to productive forces but part of them. It is in reference to the future enhancement and current fettering of the capacities and powers collectively available to us for the maintenance, restoration and improvement of natural conditions that it is most helpful to retain Marx's view that capital is not "the *absolute* form for the development of the forces of production…it is a discipline over them, which becomes superfluous and burdensome at a certain stage of their development, just like the guilds etc" (Marx 1993b, 415; my emphasis).

Chapter 3 – Ecological Critique and the Productive Forces

In the previous Chapter, drawing on Ollman, I pointed to Marx's broad understanding of humanity's relationship to nature and its 'appropriation.' This encompassed all powers and capacities by which individuals learn about and interact with nature, including their own natures. Within this understanding, I noted that Marx focused on production, or the appropriation and transformation of natural substances for human requirements. Within this perspective, I then suggested that productive forces most helpfully refer to *the practices, processes, objects and relations through which we are purposefully linked to and transform the rest of nature*. Like all concepts, the notion of productive forces is an abstraction – it is mental construct that allows us to think about reality by breaking down the world in which we live, in all its complexity, into manageable parts. It sets apart, focuses and puts emphasis on one (albeit a broad) feature or aspect of the world, which is temporarily perceived as standing apart from the whole.[20]

While this is a broad definition, focusing on such processes and practices requires that we analytically separate them from other species powers and practices that have to do with establishing relationships with non-human nature and with other people, as parts of nature. It excludes activities

[20] See Ollman (2003, 59-112), on the process of abstraction within a dialectical method. As Ollman explains, a dialectical methodology rests on a relational ontology that considers reality to be composed of an infinite number of mutually dependent processes, with no clear or fixed boundaries between them and which coalesce into a loosely structured whole. The epistemological moment then involves (as part of a philosophy of internal relations) abstracting out chief or common patterns in which change and interaction are seen to occur, as well as the main parts through which they occur, through the use of categories and concepts that convey these patterns. This allows for the 'dance of the dialectic': the reconstruction of the present in its current relationality, then finding its preconditions in the past, next projecting its likely future, and finally seeking out preconditions for this future in the present.

and associated capacities through which individuals 'contact' and appropriate nature, but do not consciously and purposively transform non-human nature so as to create concrete use-values. Appropriating a sunset, or simply breathing air, which is also a form of appropriation and constructive utilization of nature, are such examples.

I also find it necessary analytically to separate productive from *re*productive labour. As we have seen, reproductive labour (along with the broader social environment within which workers are brought up and live) is a vital component of the "total conditions" of production. As Mies (1986) suggests, this work is 'appropriated' by capital, as 'free gift' and as though it were a natural resource. However, we are dealing here with two kinds of production (and their associated 'forces'), both of which are amenable to historical materialist analysis. Reproductive labour entails social labour, centred on the reproduction of the workforce and also on socializing and caring for human beings. Procreation is also a form of production and it is a conscious, human, social and historical activity. Yet, in procreation women act upon and appropriate their *own* natures, their capacity to give birth and to produce milk (Mies 1986, 53). Analytic distinctions of this sort do not imply valuation and hierarchy. While forces of production and reproduction are analytically distinct, in a broader view they should be recognized as internally related moments of an articulated totality (see Ollman 1976, 26-40).

The above conception consequently locates humanity within an expansive system of interdependent relations with non-human nature, while focusing attention to the dimension of human existence by which we are purposefully linked to and transform the rest of nature to meet needs. It allows us to understand humans not only as natural beings, but also as social beings who have unique capacities and powers to transform nature to create use-values (and in turn transform human nature). A green-dialectical understanding allows us to consider how in class societies,[21] in particular in industrial and monopoly capitalism, these powers and capacities, as they are expropriated and developed through capitalist production relations, become transformed into 'destructive forces,' undermining the natural conditions that support human existence and the existence of many other species.

This perspective allows for an examination of how the productive forces under capitalism largely take the commodity form (are organized and developed in service to quantitative exchange over qualitative use-value), with the former closely connected to capital's growth imperative, which is caught up in the drive to increase labour productivity. However, an ecological-dialectical interpretation also opens space for recognizing aspects of the productive forces that are crucial to (or help meet the need for) the renewal and restoration of ecosystems that enable and undergird human life (such as cooperation, ecological knowledge and science and associated practices as such as renewable energy and agroecology). While such potentialities may emerge or expand within capitalism, this context simultaneously constrains their potential.

This chapter puts this re-conceptualization in dialogue with contemporary eco-Marxist frameworks charting the ecological character, costs and consequences of capitalist development. I begin with the quasi-Marxist variant of the de-growth perspective advanced by Serge Latouche, as

[21] The notion of a dialectic of forces and relations of production, as a guiding thread for understanding societal change (and change into qualitatively new forms) is analyzed by Marx at the 'level' of class society broadly conceived (to include slavery, feudalism, capitalism). While Marx sometimes extends the dialect to this 'level of generality,' he concentrates on the contradiction within capitalism, and therefore the dialectic of *capitalist* relations and forces of production. In evoking the notion of 'level of generality,' I am again drawing from Ollman (2003, 86-99), who demonstrates the way that Marx's methodological abstractions move between different levels of generality, from the 'human condition,' to class society, to capitalism, to modern capitalism (the very recent development of capitalism, such as the last 20 years), while noting that most of his abstractions are chiefly focused on understanding capitalism as a distinctive historical mode of production.

well as contemporary frameworks offered by James O'Connor and Jason Moore. A full review of their works is beyond the chapter's scope. Instead, I point to differences (sometimes implicit) surrounding the concept of productive forces and consider how this informs our understanding and approach to the current climate crisis. Engaging them helps to distinguish and sharpen the vantage point offered here.

Latouche and Radical De-Growth

Serge Latouche is one of the leading figures of today's de-growth perspective. His *Farewell to Growth* (2010) articulates a radical version of the degrowth perspective, while positioning this against strains of contemporary thought, including that of 'productivist socialism.' Latouche argues that Marx's critique of capitalism is essential as it captures the internal logic of the system, including 'production for production's sake.' However, because the critique remains wedded the project of realizing the abundance generated by capitalism, it continues to express an ideology of "progress," achieved through the ever-advancing domination of nature. For this reason, it fails to provide, and is incapable of providing, a critique of the "growth society." Therefore, an alternative perspective needs to be developed. The basic principle for Latouche is that we need to 'de-grow' to get human production and consumption in line with the biosphere's capacity for regeneration. While this unites various strands of de-growth politics, Latouche belongs to the radical wing of this movement, such that de-growth is understood to entail a broad contraction of the economy (or an 'exit' from it, whatever that means), which is impossible to harmonise with the capitalist system.

Latouche's project is aimed at achieving 'sustainable de-growth,' encompassing a vision for a transition that is just and equitable. Many of Latouche's proposals for such transition (such as those for reducing working hours, local food and energy co-operatives) are helpful. Problems arise, however, in identifying the drivers of the growth society. While Latouche provides some analysis of the economic activities that propel energy throughput, he strongly emphasizes the sphere of consumption. In this sphere, Latouche mentions a host of under-specified sources of growth: “turbo- and hyperconsumers” (20), “workaholic managers” (20), “the capitalist and techno-economic marketing mega-machine” (3), “Western states” (30), and “dominant ideologies.” Since Latouche informs us that he has assumed Marx, we might anticipate that consumerism will be understood as reinforcing ‘production for production’s sake,’ but we find little explicit and focused analysis of their interaction. The cultural criticism of consumerism is important, but without an analysis of the deep complementarity of production-consumption (or as I would argue, the overdetermination of consumption by production), Latouche’s analysis becomes focused on ‘consumption for consumption’s sake,’ while lacking material anchorage.

Bound up with this shallow analysis of consumerism is a vague and problematic critique of “development.” Latouche boasts a radical anti-capitalist position, asserting that the critique of “consumption and development” is “ipso facto a critique of capitalism” (2012, 75). However, in place of a sociological or historical analysis of the specific character of capitalism, its logic and the nature of its historical development, we find a perspective that criticizes over-consumption, while at the same time roundly condemning all development. Capitalism and productivist socialism are in his view “both variants on the same project for a growth society based upon the development of the productive forces” (90), variants the de-growth perspective opposes. His is an effort to overcome both these modes of production, “the fantasy of an alternative economy, an alternative growth and an alternative development” (89). In a recent article in *Capitalism Nature Socialism*, Latouche re-affirms this view, arguing that de-growth is not about “substituting… *good* growth or *good* development for a bad one and repainting it green, or social, or equitable...It is about *exiting* the economy" (2012, 77).

The perspective fails (in fact appears to refuse) to come to terms with the distinction between qualitative and quantitative aspects of growth and development (Schwartzman 2012; Tanuro 2014). It side-steps the debate around what kinds of development are needed, in what regions and levels of the world system and advanced by whom. Latouche misses the likelihood that various developments, including in the productive forces, will be critical to avoiding catastrophic climate change and mending the metabolic rift. As I have argued, the development of industrial energy systems based on renewable energy (including the expansion of non-fossil fuel transportation infrastructure) are advancements in the productive forces that are necessary to mend the climate rift. Ecological knowledge is also an aspect of the productive forces that is presently underutilized. In addition to the 'misuse' of this existing productive capacity, we can consider how alternative economic arrangements would encourage the further *development* of ecological knowledge, through increased funding and support for various forms of sustainable earth science, pursued on the basis of their ecological or metabolic use, rather than exchange, value.[22] Development of these forces implies precisely 'alternative growth,' 'alternative development'.

Like many environmental perspectives (and other radical left ones, including anarchist), Latouche places strong emphasis on the need to "re-localize," and the "local" is positioned as the exclusive scale where solutions to environmental problems should be found. In an existing world of globalised flows and evolved political and economic interdependencies, practical barriers limit the

[22] Saed (2011) for example, points out that there is a current dearth of knowledge on large-scale organic crop yield potentials for local consumption and of mechanical harvesting methods not based on fossil fuels.

effectiveness of potential local solutions. The return to "the local" also seems explicitly to rule out cooperation in climate and atmospheric mitigation and 'adaptation,' which would require coordinated redistributions to respond to issues such as pandemics of water-supply failures and reduced agricultural yields, as well as new governance mechanisms and institutions to accompany them. Latouche implies that grand changes and global redistributions will occur, yet it is hard to see how this could take place without some sort of a planned large-scale economy (including some empowerment of organizations that enable complex forms of coordination across multiple sites and scales). A re-thinking of one of the most basic productive forces – cooperation – with a view towards an alternative mode of its development is called for (see Chapter 4).

James O'Connor and Ecological 'Conditions' of Production

One of the earliest and most powerful attempts to understand the contemporary ecological crisis through a Marxian framework and vocabulary came from sociologist James O'Connor (O'Connor 1988). In an effort to reframe the terms of the debate in the late 1980s, O'Connor re-visited Marx's argument that social transformation is driven by the contradiction between the forces and relations of production. He argued that a largely ignored 'second contradiction' emerges in Marx's analysis of capitalist reproduction, revolving around the 'underproduction' and 'undermining' of the social and natural bases or conditions that underpin and furnish production. O'Connor argued that while the 'first contradiction' of capitalism revolves around social control over the forces of production (machine technologies, scientific knowledge and skill, as well as labour power), capital accumulation and expansion is also premised on the use and transformation of social (reproductive) conditions, as well as "external physical conditions of production" (ibid, 17). The latter are in many cases non-renewable (such as water, ore and oil), and their diminishment and degradation were leading to a specific and new form of crisis in capitalism.

O'Connor predicted that capitalism's tendency to undermine these conditions of production would lead to increases in the costs of production,[23] erecting a barrier to continued capitalist growth in the long run, as well as producing a whole series of unanticipated costs for individual companies that limit accumulation in the interim. The reproduction of external physical conditions of on-going growth and accumulation are understood to involve a whole host of unexpected 'externalities' (such as replenishing trees, restoring soil-eroded land, cleaning up hazardous waste sites, fishing well off-shore as stocks run thin and inlets become more polluted, and having to drill for oil in evermore remote and precarious places). Ultimately, these amplify ecological degradation, while driving up the costs of production and depressing profit.

Thus, by re-framing Marx's explicit ecological reflections in *Capital* (which O'Connor viewed as unsystematic and incomplete), he argued that 'the second contradiction' is contributing to and re-enforcing a wider crisis in accumulation. This has the associated effect of forcing companies to spend billions of dollars to innovate in order hold down costs associated with production under conditions of scarcity and leads to corporations attempting to off-load the social and environmental costs of this process on to a broader public. In this way, underproduction problems and crises bleed into society at large, often obliging the state or other governmental bodies to regulate problems of scarcity and environmental degradation. Attempts by capital and state to cope with rising ecological

[23] In addition to costs of reproducing external physical conditions, rising costs of reproducing social conditions of production at the system level include items such as the health care costs necessitated by capitalist work and family relations; drug rehabilitation costs; the vast sums expended as a result of the deterioration of the social environment (e.g. police costs)(O'Connor 1997, 166-7).

costs would create further fault lines, creating an opening for social movements to push the system in a green direction. Environmental movement successes would generate even more costs by pressing for the imposition of various environmental regulations.

O'Connor's work was path-breaking and powerful. It drew fruitful connections with social reproductive feminism and work on new social movements in theorizing the environmental movement as one focused on a revalorization and radical defense of conditions of human reproduction. While O'Connor himself envisioned more acute and economic crisis-induced forms of planning, this perspective can speak to the vast panoply of technocractic and elite-engineered forms of regulation (developing eco-efficiencies, technologies such as carbon capture and storage), designed to manage and mitigate the damage inflicted upon the rest of nature. This points to a system that strives towards 'sustainable degradation' (Luke 2006).

As powerful as O'Connor's framework was, it had crucial limitations. Chief among these was the tendency to subsume environmental contradictions within economic crises, failing to consider how ecological crises are problems in their own right (Foster and Burkett 2016). Thirty years after O'Connor's initial thesis, we find little evidence of feedback mechanisms that are translating ecological degradation into economic crises, demanding an immediate response from capital. More broadly, it may well be vital to recognize how the contradiction leads to dynamism within the system and that capitalism can continue to advance and prosper indefinitely even when threatening the planet as a place of human habitation.[24]

[24] It is possible that the costs have been deferred into the future, a position that accords to some degree with Moore's (discussed next). Firms have indeed shifted production to regions with less environmental regulation and where other elements of compensation (e.g., health insurance) are lower, such as from Detroit and other American centres of the mid-West and East to the American South, China, and Southeast Asia. The thesis may therefore be defensible, but I maintain that there is no current compelling evidence that capital cannot continue to accumulate

Furthermore, while O'Connor provides helpful tools for registering the destruction of nature, his framework is simultaneously hobbled by an under-theorization of the category of non-human nature and an uncritical acceptance of nature's externality to production (Huber 2009). By seeing "nature" as an external condition that imposes a set of 'barriers, obstacles and conditions' (rather than being substantially socially, politically, culturally and economically situated and constituted), it is limited in its ability to register socio-ecological transformation and development. We need a more robust assessment of the ways that extra-human nature and resources are constituted by historically distinct processes, relations and material practices, without denying that nature has its own dynamic, turbulent and contingent processes, which are outside of human production and which come to bear on the social. In short, we need a fuller analysis of how capitalism develops *in and through* the rest of nature. Jason Moore's work (2015, 2016) which we consider next, attempts to give full expression to the latter.

Jason Moore and 'World Ecology'

Moore has offered an ambitious outline of an ecological history of capitalism in an approach he calls *world-ecology*. The approach draws on the historical sociology of World-System Theory (WST) and also shares much with O'Connor. Moore's framework centers on a reinterpretation of capitalist processes of appropriation in the production of surplus value, arguing that the exploitation of labour and capitalist increases in labour productivity depend on a tight relation to the 'zone of appropriation.' In making this argument, Moore takes on a standard reading of Marx's 'law of value' considering how capital strives to boost labour productivity in sphere of production. He argues that

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in conditions of ecological devastation. Indeed, as Naomi Klein demonstrates through the notion of a 'disaster capitalism complex' (2008), corporations have learnt how enhance profits through natural disasters.

these efforts (which require an ever-greater quantity of inputs), are united with another imperative: capital must ceaselessly search for, and find ways to produce, 'Cheap Natures' as inputs to commodity production. Advances in productivity, and every act of producing surplus value, he argues, is bound up with the appropriation of Four Cheaps: labour-power, food, energy and raw materials (ibid, 17).

Continually cheapening staple food is key to keeping the costs of labour power low as household expenditure accounts for much of the base of hiring workers. Foisting the reproduction of labour onto unpaid workers, especially women, is also vital. The easiest way to obtain Cheap nature and labour, however, is to look outside of the capitalist economy in search of new 'commodity frontiers.' Capitalist firms seek out new sources of cheap inputs such as displaced farmers, unploughed soils or minerals drawn from the 'commodity frontiers' of uncapitalized natures.[25] On Moore's view, frontiers lie outside the commodity system, but within the reach of capitalist power.

Arguing for the centrality of 'appropriation' alongside exploitation in capital's overall expansion (with exploitation now appearing somewhat subordinate to appropriation), Moore maintains that the 'law of value' is accompanied by and dependent upon a 'law of cheap nature,' a zone of appropriation that manifests as a series of growing commodity frontiers. At the core of this law, which is operative from the inception of capitalism in the "first" sixteenth century (1450-1550), "is the ongoing, rapidly expansive, and relentlessly innovative quest to turn the work/energy of the biosphere into capital (value-in-motion)" (2015, 13-14). In terms of the processes by which the products of people and nature working outside the capitalist system enter commodity circulation, Moore highlights accumulation by dispossession, whereby not only natural use-values but the labour

[25] Commandeered assets such as land and dependent agricultural labour also generate low-cost means of subsistence for waged-workers in the form of food and clothing. Appropriated (cheap) nature therefore lowers the cost of reproducing labour power, reducing wages and raising the rate of exploitation.

of millions of dispossessed peasants enter as cheap inputs. He also discusses "capitalization," wherein a capitalist sets up a mine or mill and hires wage workers, but the land, resources and workers come cheap as land has been seized from Indigenous people, little has been paid in rent for the land lease, or the displaced people have been coerced into the workforce. Although not explicitly discussed by Moore, with ecofeminists we could also point to the way that the products of subsistence farmers and small commodity producers become drawn into capitalist markets (See Federici 2004, 44-115; Salleh 2010).

On the basis of the importance of 'Four Cheaps' to maintaining rising labour productivity since the 'long sixteenth century' (1450-1640), one of Moore's aims is to challenge the importance placed on the industrial and fossil revolution in the second half of the 18th century (Moore 2016). This narrative, prominent in eco-Marxist and non-Marxist green thought, is seen to ignore the massive increases in labour productivity and epochal revolution in landscape change (in terms of speed, scale, scope) that occurred between 1450 and 1750. These changes are again premised on a 'fundamentally new law of environment making': capitalism's law of Cheap Nature. And this law is premised on new imperialisms, new sciences and new forms of state power.[26] Such processes, for Moore, historically include a revolution in 'technics' – including new strategies of global appropriation, new administrative technologies and new knowledge regimes in surveying, navigation, road building – suited to identifying, coding, rationalizing and delivering the work of Nature on the cheap (2016). However, these fundamental transformations in early capitalism's way of "organizing

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[26] For Moore, fundamental to this surveying and coding of the web of life for what it can do for capital accumulation has been the construction of a binary of Humanity/Nature, with most humans – Indigenous peoples, Africans, nearly all women, and even many white skinned men (Slavs, Jews, the Irish) – regarded as belonging to the latter and being treated accordingly.

nature," are missed in approaches that treat the Industrial Revolution as the lodestar of the transformation (and destruction) of nature on a planetary scale.

In Moore's reconceptualization, so long as there are frontiers of Cheap Nature and so long as the costs of reproducing labour power, food, energy and raw materials are kept off the books, periodic productivity and accumulation crises can be overcome. However, he identifies barriers or counter-tendencies to capitalism's ability to appropriate Cheap Nature indefinitely, and which in fact worsen over historical time. From this follows Moore's view of the current systemic crisis, which are "crises of what nature does for capitalism, rather more than what capitalism does to nature" (2015, 17). Since the 1970s, he asserts, the possibilities of appropriating Cheap Natures have narrowed and we have begun to see an exhaustion of the centuries-long model of appropriating unpaid work/energy outside the cash nexus (2016). There has been no revolution in agricultural productivity (in fact, its rate of growth has slowed since mid-1980s) and no major sources of cheap energy have appeared (rather only unconventional sources based on high cost frontiers have expanded).

There are different reasons why capitalism's Cheap Nature strategy is currently being exhausted and why it must eventually lead to system-wide and terminal accumulation crisis. Chief among them, and echoing O'Connor, is that the capitalization of the Four Cheaps outstrips their contribution to labour productivity. Increasingly, we find that capitalism must "capitalize rather than appropriate" – hence the importance of factory farmed animals, tree plantations and aquaculture (2015, 92-3). Similarly, many oil companies now spend more on exploration and production than they earn for every barrel of crude that they extract. While capitalization can have middle run benefits of increasing labour productivity, it also leads to rising costs of production (due to rising costs of labour and nature as inputs) generating an "underproduction crisis." Another barrier that

Moore discusses is the degradation of the biosphere through carbon emissions, soil erosion, biodiversity loss, acidification, and so on. The degradation of natural conditions themselves threatens to raise the cost of the Four Cheaps (especially food and in turn labour) in ways that will make the valorisation of capital impossible.

Moore's world-ecology approach has contributed numerous conceptual innovations and captured many components of historical and contemporary capitalism. The framework is laudable in its attempt to intersect with (eco)feminist and post and anti-colonial analyses, pointing to vital importance of expropriation and 'unpaid work' to capitalist development and accumulation. The basic insight that commodity production will cost least where *both* workers and materials cost least is helpful. The point may seem obvious, but the importance of cheapening 'circulating capital' has often eluded Marxian value analysis. The focus on technological innovations aimed appropriating work/energy from the rest of nature – in the means of "discovery and extraction" – is also highly pertinent to our discussion of forces of production, while the notion of declining cheap nature provides a broad framework for understanding the resort to tar-sands and other forms of "extreme energy" that are increasingly costly (both economically and ecologically). Much of this can be taken on without adopting Moore's proposed methodological framework or following him to his specific conclusions.[27] I raise here a few points of disagreement, for our purposes.

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[27] Moore has been strongly challenged on the coherency of his value analysis (Foster 2016; Nayeri 2016). It also remains unclear to me what it could really mean for nature to "do work" or for this work to be "unpaid." If the work is unpaid in a metabolic sense (i.e., a taking from nature without return or compensation) Moore would appear to be embracing a theory of metabolic rift, which he considers to be 'dualist,' and based on a nature-society binary. Moore's critique of 'dualism' within Marxist ecology and virtually all quarters of contemporary green thought has produced the strongest reactions and led to quite polarized debate surrounding his work. I cannot offer a comprehensive account here. As my embrace of the theory of metabolic rift suggests, I find Moore's criticism of dualism on this front to be incoherent. As Foster argues in response, dialectics which are decisively non-dualistic, are fundamentally about the *mediation* of totality, the process that both *separates and unites* individuals and society, humanity and nature, parts and wholes (Foster 2016).

First, Moore, like O'Connor, wants to read ecological and economic crises together. He writes:

> The crises of capitalism-in-nature are crises of what nature does for capitalism, rather more than what capitalism does to nature. This point of entry offers not only a fresh perspective – one that includes, centrally, the work of human natures – but also provides an opportunity for synthesizing two great streams of radical thought since the 1970s: the theory of accumulation crisis and the study of environmental crisis. (2015, 17)

He is yet more forceful in his claim, suggesting that approaches that treat crises separately are again a form of dualism and that prominent analysts of the 2008 crash are guilty of 'nature blindness.'

As suggested above, ecological and economic crises interact, but they do not determine each other. Moreover, Moore's focus on crises of what nature does for capitalism narrows our understanding of the current ecological crisis and its human effects. Moore's framework centres resource crises for capital (or how the raising costs of the Four Cheaps undermines capital valorization), however, the erosion and degradation of the conditions that support and sustain human life exceeds this dynamic. Moore's framework can speak to some of the human effects of climate change (e.g. rising food costs and lower agricultural productivity can have devastating human consequences), but climate change and other ecological crises compromise the material conditions of the world's inhabitants, especially the planet's "third-class passengers" (Davis 2010), in ways that have little to do with the (potential) rising costs of the Four Cheaps.

A further point of disagreement concerns Moore's view of a fundamental transformation in capitalism's way of "organizing nature" during the long sixteenth century. While his perspective is presented in some degree in opposition to the Marxist view, much of what Moore writes of the historical processes of 'accumulation by appropriation' (or what can much more coherently be referred to as 'accumulation by *expropriation*,' that is appropriation without exchange (Foster and

Clark, 2018)), is consistent with Marx. While there are differences in periodization, Marx recognizes the origins of capitalism in the mercantilist age from mid-fifteenth to mid-eighteenth century and the importance of expropriating what Moore calls 'Four Cheaps' in this period (see Altvater 2016). His analysis of primitive accumulation and the 'free appropriation' of natural conditions focuses on land enclosures in England, yet as part of even greater age of global expropriation in which land and labour were seized through colonization, enslavement, and the plundering of resources (see Foster and Brett 2018; Harvey 2010, 299-313). In this analysis of "early capitalism," he registers profound transformations and accelerations in production, circulation, reproduction, communication and consumption.

Yet, as Altvater suggests (2016), the onset of fossil-fuel driven production and transportation in the late eighteenth and early nineteenth century amplified, accelerated and generalized these trends. Modern machinery, concentrated in large factories, allowed for new technical divisions of labour and produced a decisive increase in labour productivity. With it came the first great transition of agricultural labour into urban factories. Therefore, while Braudel and others from the WST tradition may be right to see the origins of capitalism in the long sixteenth century and in the quest to appropriate Cheap Nature, the Industrial Revolution also produced a decisive shift, marking the end of a "protoindustrial capitalism" and signalled the rise of modern industrial capitalism. From the totality of historical capitalism, Altvater considers both positions (what he calls the "Braudel and Polanyi hypotheses") to be correct (ibid).

The view of the Industrial Revolution as a decisive shift, producing new forms of work and new ways of life is contained in Marx's notion of the transition from the formal to the real subsumption of labour (and nature) to capital. Marx writes that 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 transforms not only the situations of various agents of production, it also revolutionizes the actual mode of their labour and the real nature of the labour process as a whole" (Marx 1976b, 1021). Real subsumption activates the potential for *relative* surplus value, or the competitive struggle to increase labour productivity and reduce the worktime necessary to produce commodities through the technical reorganization of the labour process. This is one of the central dynamics of capitalism, and it completely transforms the competitive dynamics of the economy, leading to the socialization of forces of production via the modern corporation, as well as new dynamics of dependency and imperialism. Moreover, the real subsumption of labour under capital implies a parallel 'subsumption of nature' through the technological development of objects, forces and life forms of nature, and as scientific knowledge is applied to the production process (Burkett 2014). On these terms, the Industrial Revolution is a watershed not only in terms of crystalizing social relations, but also the *societal relation to the rest of nature*.

One of Moore's objectives in challenging the historical view that equates capitalism with the industrial revolution and the exploitation of fossil fuels, is to argue that since the problem goes deeper than fossil capitalism, so must our solutions. Moore, presumably responding to theories of fossil capitalism, such as those of Elmar Altvater, Matthew Huber and Andreas Malm (reviewed in Chapter 4), writes, "To locate modernity's origins through the steam engine and the coal pit is to prioritize shutting down the steam engines and coal pits, and their twenty first century incarnations. … Shut down a coal plant, and you can slow down global warming for a day; shut down the relations that made the coal plant, and you can stop it for good" (2016, 94). In both popular writing and social movement campaigns, the critique of fossil dependency and the politics of energy transition are often cast narrowly, in the way Moore suggests. However, the focus on keeping oil in the soil is strategic, while a comprehensive political economic and ecological perspective on decarbonization opens to deeper structural critiques, not only of Big Carbon, but of capitalism itself.

Fossil fuels play a vital role in mediating the metabolic relation of capitalist human society to the rest of nature; the fossil fuel regime (both fossil energy and products made from hydrocarbons) has become embedded in the entire economic structure, from industrial production to plastics and petrochemicals, to the agro-industry, to transportation, and all else. Moreover, as I argue in Chapters 5-7, carbon capital is a powerful fraction of capital that will actively resist any such transformation. It is also embedded in wider power structures and densely connected to other fractions of capital, including the financial sector. Accomplishing a democratic and just transition within the current "carbon budget" will therefore *require* deep incursions into capitalist property, shifting us away from the logic of private capitalist accumulation. It will require new forms of democratic planning, different forms of social property and the socialization and democratization of investment (Candeias 2013b; Carroll 2017). As Naomi Klein (2014) has so effectively argued, a transition to a future based on cleaner and renewable fuels is also an opportunity for just social transformation. A decentralized energy system, based on a diversity of renewable sources under collective control, can provide a foundation and lever for a wider transformation of patterns of production and consumption (including a move away from imperialist relations), gender relations, and relations with First Nations communities. The vision is not imposed from above, but has roots in and takes its cues from social movements working to build alternative futures.

While Moore criticizes a focus on *fossil* capitalism in terms of the political strategy it implies, it is unclear how Moore's renewed historical interpretation produces an alternative strategy, beyond a call to shut down a system of social relations that is over 500 years old. While we can appreciate conviction in the need for fundamental and revolutionary change, it is entirely unclear from his work how or where to begin a reversal in the relations of production. Perhaps at some point in the not-too-distant future, we will encounter ecological limits that make sustained capital accumulation impossible. But then there would still remain the problem of how to continue to feed, clothe and house eight billion people without destroying their conditions of existence. Capitalist relations of production have produced the climate crisis, but the challenge of climate stabilization also exceeds those relations (Wark 2015). Based on these considerations, I find it vital to contemplate alternatives and possibilities that emerge both within and outside the conditions set by the current mode of production.

Conclusion

This chapter advanced an alternative definition of productive forces and placed it in dialogue with contemporary eco-Marxist frameworks. While the latter offer valuable insights into the ecological costs and consequences of capitalist development, I pointed to important differences of methodology and understanding, and suggested that the green-dialectical understanding productive forces developed here offers some distinctive advantages, particularly in understanding and coming to terms with the contemporary climate crisis. In the next chapter I go back to Marx, providing an ecological reading of the concept of forces of production in his work, while drawing out and advancing its implication through recent scholarship that implies, but does not adequately develop such a renewed conceptualization. This will allow us to fully elaborate the concept of forces of production from Marx right through to recent literature, contributing greater theoretical depth to the arguments advanced so far.

Chapter 4 – Marx and the Critique of Political Economy and Ecology

This chapter provides an ecological reading of the concept of forces of production in Marx. I begin with classic methodological statements from his early work, especially from the *German Ideology*, before focusing especially on his 'mature' political economy of the *Grundrisse* and *Capital*, through which he analyzed important "environment making" processes and practices that were emergent in early capitalism and which were greatly extended through the Industrial Revolution. This demonstrates how capital's appropriation and development of the forces of production torques them in a quantitative direction bound up with the compulsion to increase labour productivity and output as a means of extracting relative surplus value. Marx gleans emancipatory potentials based on large-scale industrialization, but he does not blindly endorse this development. Already in the 19th century, he was clear that this growth was achieved at the expense of annihilating the sustainable metabolic interaction between humans and extra-human nature. Simultaneously, he pointed to more "qualitative advancements" in our social productive powers, including, productive cooperation and vitally, ecological knowledge, thinking and science. The implications of this analysis for coming to terms with the ecological crisis (especially the climate crisis) are drawn out through contemporary literature.

Labour Process, Metabolism and Forces of Production

In a classic statement outlining the aims and goals of historical materialism from the *German Ideology* Marx and Engels asserted the following:

> 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 relationship to the rest of nature.… All historical writing must always set out from these natural bases and their modification in the course of history through the action of men and women. (1976, 37)

The fact that we are embodied, sensuous and physiologically needy, means that we have inescapable requirements for basic natural substances that reside outside of ourselves and which are, "the everlasting nature imposed conditions for human life" (Marx 1976b, 493). While the appropriation of nature is characteristic of all 'natural-beings', Marx and Engels developed a co-evolutionary approach to society-nature relations and insisted that we maintain a focus on the human relation to nature in its social and historical evolution.

For them, human beings are unique among animals in our capacities to produce with foresight and intention. The capacity to modify and improve upon prevailing productive forms and techniques (to produce new forms of social organization and instruments of labour), to produce according to a plan on grand scale over and above what is required by natural necessity and to do so through a learned history, are seen as distinctively human capabilities.[28] The development of the powers and processes by which we interact with the rest of nature are subject to a continual process of transformation. Critical to their development are the historically specific relations among the producers and among the producers and appropriators of the social product. The conception is materialist and dialectical in so far as the social form of production and the material content of human production are mutually constituted. Thus, Marx and Engels suggest in the *German Ideology* that each historical stage "contains a material result, a sum of productive forces, a historically created relation to nature *and* of individuals

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[28] While Marx and Engels are sometimes accused of harbouring a 'species imperialism' in light of the comparisons they draw between animals and humans (see Benton 1993, 32-44), establishing qualitative differences does not imply a deficiency of animal capacities. Wilde (2000) is especially clear on this point. Moreover, as he argues, Marx's view of establishing a sensitive and responsible metabolic relation to more than human nature, includes an ethical and compassionate relation to other species. For other kindred contemporary attempts to rethink the concept of a "species-being" with a view towards distinctive human powers and capacities to reconstruct our relationship with the rest of nature that avoids any semblance of 'species imperialism' see Harvey (2000) and Dyer-Witheford (2004).

to one another, which is handed down to each generation from its predecessor" (1976, 62; my emphasis).

The relation of human beings to the rest of nature constantly evolves, while the dependence of human beings on nature is an insurmountable material fact. From this foundational position, Marx interprets historical development, at one of the most basic levels, as a process whereby in order to reproduce themselves, people enter into social relationships and work to appropriate nature. They do so in a manner that is consistent with those relationships and forms of knowledge and means of production that are historically developed and available. It is from this basis that we encounter the simplest and perhaps most helpful understanding of forces of production, comprehended broadly as the practices, processes, objects and relations through which we are purposefully linked to and transform the rest of nature.

While the ecological foundations of Marx's early work are more often recognized, the later work does not depart from this position. His 'mature' political economy continues to focus on the labour or production process with a view to the production of use-values, which Marx saw as constituting the main 'metabolic' interaction between humans and the rest of nature. As Marx defined it in *Capital*:

> The labour-process is purposeful activity aimed at production of use-values. It is an appropriation of what exists in nature for the requirements of man. It is the universal condition for the metabolic interaction between man and nature, the nature imposed condition of human existence, or rather it is common to all forms of society in which human beings live. (1976, 290)

The "process between humanity and nature" is viewed here (and since the *Grundrisse*) in terms of a social 'metabolism.' This notion of metabolism is more than just analogy or metaphor; it emanates from 19th century natural science,[29] and is transformed by Marx to understand the complex material interchange between human beings and natural systems. The notion of mutual interdependence and exchange contained in the concept breaks with the unidirectional Enlightenment idea of humanity "utilizing" nature (Schmidt 1971).

Therefore human societies, as Marx stressed, emerge within and are dependent upon a wider earthly or 'universal' metabolism, which in turn is independent of labour and which precedes the appearance of human life itself. The labour process, which is human action aimed at producing use-values, is a condition for the material interchange between society and the rest of nature and requires the appropriation of natural substances not produced by labour. In this definition, Marx abstracted from the social and historical character of the labour process, defining moments that are common to all such processes, independent of the *form* of society. While the labour process is defined here in a trans-historical sense, production is always historically specific and the metabolic interaction or exchange between society and nature is necessarily socially and historically "mediated." As Burkett writes, "the production relation between people and nature must be treated as a socially mediated natural relationship" (Burkett 2014, 29) and thus human beings can be conceived as 'self-mediating beings of nature' (Meszaros 1986). The *forces* of production, on this view, refer to the distinctive set of powers and capacities through which that relation or exchange occurs.

The specific form and content of this "mediation"– that is of the various practices, processes, objects and relations through which we are purposefully linked to extra-human nature – is again a socio-historical product. In contrast to the view offered by classical economists, Marx writes that,

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[29] The concept of metabolism was first developed in the 1830s by cellular biologists and physiologist and then applied to chemistry. For a detailed discussion see Foster (2013).

"capital did not begin the world from the beginning, but encountered production and products already present before it subjugated them beneath its process"(Marx 1993b, 675). As Van der Pijl (1998, 28) puts it, capitalism 'annihilates' previous disciplines over the productive forces, while prioritizing the process of accumulation in their development over any inherent (re)productive needs of society. In the next section, I outline Marx's analysis of the social separation of producers from natural conditions and produced instruments of production and the conversion of these into private property and into the powers of capital. The process of appropriation and conversion is seen as a vehicle and overall condition for the historically unprecedented growth of the productive forces.

Primitive Accumulation, Expropriation and Nature's 'Free Gifts' to Capital

For Marx, one of the illusions that capital evokes is that of its own comprehensiveness. This includes obscuring the fact that capital is rooted in violent processes of expropriation. In the final chapters of Volume 1 of *Capital* Marx took up the historical processes of land enclosure and dispossession, which he viewed as integral to the establishment and reproduction of capitalism as a way or mode of life. As Marx described, so-called primitive accumulation forcibly tears Indigenous societies, peasants and other small-scale agricultural producers from their access to means of subsistence and 'natural conditions' of production (that is to access to such land, food, shelter, clothing, tools and work, as can be obtained without having to go through labour markets). Through the agency and power of the capitalist classes (typically backed by the deployment of violent sovereign power), collectively held lands and resources are actively enclosed and shared resources are transformed into the private property of a small minority.

In this process, we find the dissolution of people's prior, more communal relations to the land (and of their more communal forms of property) by capitalist relations of production. A decisive aspect of capitalism is therefore private property in the means of production and subsistence, which presupposes the separation between producers and the social and natural conditions of production and existence and therefore a division between workers and capitalists.[30] This separation typically compels immediate producers to enter daily the exploitative realm of the labour market as wage-labourers for their survival. On Marx's view, labourers are 'freed' in a double sense: first, in terms of a legal status, they are not enslaved, enserfed or bound to a particular master; but second, they are "freed" from access to means of subsistence, production and survival. This separation makes possible the exploitation of wage labour (the appropriation and extraction of surplus value from workers), the central pivot on which capitalism's peculiar production of profit and value depends.

The dispossession of collectively held lands through enclosures in England is part of a greater age of the global expropriation of wealth, as land and labour were seized through colonization, enslavement and the plundering of resources (Dawson 2016; Foster and Clark 2018). Women were also 're-enslaved' in the long transition to capitalism. This took various forms, including the burning of witches and the selling of wives, both of which enforced capitalist patriarchy (Federici 2004). Primary accumulation is also ongoing and not limited to a prehistory of capitalism. The violent extraction of natural resources continues throughout Africa in particular, and the expropriation of peasant populations in Latin America and throughout East and South Asia is still with us. In settler colonial contexts like Canada, the dispossession of Indigenous peoples of their land and self-determination continues, while it is often achieved in recent years less overtly through coercive and

[30] While these are the 'basic' or 'fundamental' classes, of course neither group is homogenous. For a more textured and elaborated sociological account of modern class formation that builds from Marx, see Wright (1998, 2015)

violent means and more through "asymmetrical exchange of mediated forms of state recognition and accommodation" (Coulthard 2014, 15).[31]

Marx's analysis of primitive accumulation extended not only to the expropriation of use-values embedded in the land, but also the appropriation of existing means of production, along with the forms of knowledge bound up with them. Capital therefore develops production on the basis of the "technical conditions" it inherits. The way these existing forces are harnessed and then converted and developed in the labour process as a means of producing commodities in the quest for accumulation (and following the separation of producers from the land), establishes the historically specific content and character of industrial capitalist people-nature relations. We turn to Marx's analysis of this historical development now.

Instruments of Labour and Primitive Accumulation

In his analysis of the capitalist labour process, in Chapter 7 of *Capital*, Marx reminded us that the 'appropriation' of nature is characteristic of all of human history. The human body, including the hand and the head, are the most basic productive forces through which that purposive-appropriative relation occurs:

> Labour is, in the first place, a process in which both man and Nature participate, and in which man of his own accord starts, regulates, and controls the material re-actions between himself and Nature. He opposes himself to Nature as one of her own forces, setting in motion arms

[31] While land dispossession and primitive accumulation is a persistent component of the operation of capitalism, we can also point to a 'dialectic of exploitation and expropriation' or to historical shifts in the 'inner and outer dynamics' of the system (Foster and Clark 2018; Harvey 2005). Put otherwise, there are periods where primitive accumulation and dispossession are more pronounced in the system's dynamics (in relation to the systematic exploitation of formally free labour), and these ebbs or shifts are closely related with stagnation in the accumulation process. Thus, as Foster and Clark suggest (ibid), in the monopoly phase of capitalism in the late nineteenth and twentieth centuries, the tendency towards stagnation in the accumulation process propelled the overall thrust of the system towards accumulation by dispossession. Similarly, in the context of the 2008 economic crisis, the dynamic of land dispossession and land grabs has again re-asserted itself as central lever for accumulation (Franco, Martinez, and Feodoroff 2013). This helps explain the renewed emphasis placed on this dynamic in recent accounts of global capitalism.

> and legs, head and hands, the natural forces of his body, in order to appropriate Nature's productions in a form adapted to his own wants. (Marx and Engels 1976, 283)

These elemental productive powers and capacities – the forces of the body, the head and the hand – can be transformed and augmented through various means such as through social organization, by the accumulation and transmission of knowledge, as well as through various 'adjuncts' such as tools and physical infrastructures. As we will see, the development of instruments of labour or produced means of production[32] (together with the skills and forms of knowledge they embody) are critical in capital's effort to increase the productivity of labour. However, they first need to be produced:

> Nature builds no machines, no locomotives, railways, electric telegraphs, self-acting mules etc. These are products of human industry; natural material transformed into organs of the human will over nature, or of human participation in nature. They are *organs of the human brain, created by the human hand*; the power of knowledge, objectified. (Marx 1993, 706)

In this well-known passage from the *Grundrisse,* Marx evokes the notion of instruments of labour as 'organs,' which also meant tools, regarded as 'artificial organs' of human beings.[33] Marx is here extending an insight that reaches back to the *Economic and Philosophical Manuscripts*, that our relation to nature is mediated not only through human labour, but through tools and infrastructures (bodily

[32] I refer to 'produced' instruments of labour as a shorthand to designate technologies and built infrastructures. In his analysis of the capitalist labour process, in Chapter 7 of *Capital I*, Marx considered means of production to consist in 'instruments' and 'objects' of labour, both of which originate in non-human nature and have a persisting non-human component. Objects of labour, or raw materials, may be given more or less directly by non-human nature or are natural objects modified by previous labour processes. The instruments category is very broad and includes tools and machines manufactured out of natural materials, and even the earth itself (which serves as an 'instrument' in agriculture). At times Marx defined instruments of production in yet more expansive terms, to include various natural conditions (including physical, biological and climatic natural systems) that while not directly 'conducting' human labour processes and practices, are necessary conditions for it (see Burkett 2014, 38-41). Based on the definition offered here the latter are part of the total conditions of production, but not productive forces.
[33] See Foster and Burkett (2016, 65-78) on Marx's use of the term organ, which is derived from ancient Greek usage.

organs) – themselves products of the human transformation of nature and materializations of a distinctive mental capacity.

Capitalists take control of the instruments of labour, through the process of primitive accumulation: "at first capital subordinates labour on the basis of the technical conditions within which labour has been carried up to that point in history" (Marx 1976b, 425). However, as the drive for the production of surplus value becomes ever more powerful, capitalism must build technologies and infrastructures, as well as an evolving knowledge system and set of skills *adequate for its own purpose*. In this, the development of machinery is vital:

> The development of the means of labour into machinery is not an accidental moment of capital, but is rather the historical reshaping of the traditional, inherited means of labour into a form adequate to capital. The accumulation of knowledge and of skill, of the general productive forces of the social brain, is thus absorbed into capital, as opposed to labour, and hence appears as an attribute of capital, and more specifically of fixed capital, in so far as it enters into the production process as a means of production proper. (Marx 1993b, 694)

Capital historically expropriates and then reshapes productive forces in a manner 'adequate to its form' through the only way it knows: via commodity production. This occurs within a work process that is internally organized by capital, while the proletarian alienation from productive forces that ensues is an alienation of this class from the inherent and distinctive capacities of the human species. In *Capital* Marx analyzed the process through the categories of formal and real subsumption of labour to capital.

Formal and Real Subsumption of Labour to Capital

Under formal subsumption, which Marx analyzed in relation to what was called the 'putting out system,' we find relatively independent workers working for capital. Merchant capitalists would take materials to labourers in their cottages and collect the worked-up product at a later date. Capital here draws into itself an *existing* labour process, which continues much as before in terms of the techniques, skills and methods of labouring that are employed; however, by monopolising the workers' means of subsistence, the merchant *compels* the worker through the latter's need, to submit to wage-labour. The cottagers depended on merchants for a wage and did not own the products they produced.

Real subsumption, on the other hand, begins when workers are brought into the factory where capitalists direct and supervise their activities and intensify production by making every effort to ensure that as little socially necessary labour time as possible goes into making a unit of the product. Making workers work longer, harder or more intensively is sufficient for the production of "absolute" surplus value. Real subsumption, however, entails not only the bringing of the labour process under the supervision of the capitalist, but more broadly, the subordination of the technical labour process to the process of value expansion (Van der Pijl 1998). Put differently, it involves not only a social relationship of wage labour, but also an internal reorganization and a technical revolution in the labor process at the hands of the capitalist manager. Production has now been wholly colonized by an alienated form – commodity production.

This reorganization and technical revolution raises the productivity of labour to an unprecedented degree and enables the acquisition of 'relative surplus value.' The raising of productivity in pursuit of relative surplus value was historically accomplished through 1) the organization of the factory system through scientific management (with separations of occupations, divisions of labour and specializations of work functions); 2) the introduction of machinery (whose development on a large-scale requires the motive power of fossil fuels and also implies the reorganization of work and divisions of labour); and 3) the conscious application of scientific knowledge to production.[34]

As discussed in the sections below, the effects of this drive for relative surplus value via increased productivity in the form of large-scale industry are rising matter and energy throughput and greater total waste output (including carbon emissions). The immense collection of commodities that are produced also necessitate the expansion and opening of new markets and the creation of the spatial conditions that allow for their circulation through means of transportation and in fixed, heavy, secure, durable and often immobile physical infrastructures. Moreover, the real subsumption of labour to capital can be seen to entail a parallel "subsumption of nature" – or an "appropriation and technological development of the objects, forces, and life forms present in nature as a whole," through the application of science to production (Burkett 2014, 66). This process simultaneously provokes steady developments in the means and methods of search, discovery, and extraction of natural resources over time, another form of "scientific progress."

The technological revolutions introduced through real subsumption further propel an increase in the centralization and concentration of capital. As production becomes more capital-intensive, based on fossil energy and machinery, it becomes dominated by a handful of large corporations. Paralleling this process is the partial socialization of the forces of production, hence

[34] While Marx appeared to predict a tendency from formal to real subsumption, the relationship is not strictly speaking historical (in the sense on one leading to the other), except that real subsumption presupposes formal subsumption (Boyd and Prudham 2017). Formal subsumption may develop alongside and even displace real subsumption in particular historical situations (Swidler 2018). It is also important to note that in numerous parts of the global South, petty-commodity production and subsistence agricultural practices, which are neither formal nor real subsumption to capital, continue to meet the needs of large segments of the population. Indeed, as Shiva reports (2016, 16), the world's peasantry, mainly women, produce almost 70% of the world's food. Nevertheless, the transition from formal to real subsumption of labour to capital, is a central dynamic of modern capitalism and its implications from a society-nature perspective are legion.

"the conscious technical application of science, the planned exploitation of the earth" (Marx 1976b, 929; my emphasis). On these terms, the emergence of capital industrial development implies nothing less than a radical transformation of the forces of production and therefore in the *societal relation to the rest of nature.*

In the following sections, I provide a closer analysis of these various interlinked processes and develop their implications via contemporary scholarship. I begin with the chapter on 'Machinery and Large-Scale Industry' in *Capital I* where we find the core of Marx's analysis of how large-scale 19th-century industry came into being during the industrial revolution. I emphasize the importance placed on the transition from human and animal muscle power as a key physical force of production to fossil fuels, while gesturing to interlinked processes (divisions of labour and the application of science to the production process).

Capitalist Industrialization: What Technology Reveals

In the chapter in *Capital I* on 'Machinery and Large-Scale Industry,' Marx began by interpreting Darwin's work as showing "the formation of the organs of plants and animals, which serve as the instruments of production for sustaining their life." Subsequently he asked, "Does not the history of the productive organs of man, of organs that are the material basis of every particular organization of society, deserve equal attention?" (Marx 1976, 493). Technology, Marx then asserted, does not dictate or determine socio-ecological relations; instead, it "*reveals* the active character of man to nature, the direct process of production of his life and thereby it also lays bare the process of production of the social relations of his life, and the mental conceptions that flow from these relations" (ibid; my emphasis).

Stemming from his suggestion that technologies help *reveal* or *disclose* the relations and practices linking us to nature, Marx started piecing together the transformations in machinery and large-scale industry with a discussion of the transition from tools to machines:

> The machine, which is the starting point of the industrial revolution, replaces the worker, who handles a single tool, by a mechanism operating with a number of similar tools and set in motion by a single motive power, whatever the form of that power. Here we have the machine, but in its first role as a simple element in production by machinery. (Marx 1976, 497)

Machinery performs the same operation as the worker formerly did with tools. It is the starting point of the Industrial Revolution, as it allows the capitalist to separate the tool from the worker and install it in the machine. Given this function of machinery, it is given primacy over power supply and the mechanism that is used: it is set in motion "whatever the form of that power." Marx is here pointing to the primacy of social relations, as the power of the capitalist to separate the tool from the worker and the subsequent application of science for the improvement of machinery in search of profit, presumes that the worker has been separated from the means of production.

On these terms, Marx was quite clear that the steam engine itself did not give rise to the Industrial Revolution. It was, "on the contrary, the invention of machines that made a revolution in the form of steam-engines necessary" (Marx 1976, 497). While Marx asserted the pre-eminence of the machine as a point of departure, this did not prevent him from grasping the crucial enabling role of fossil power in the development of large-scale capitalist industry. He noted that with the growing scale of machinery human sources of motive power were displaced and supplemented by 'natural forces':

> Increase in the size of the machine, and in the number of its working tools, calls for a more massive mechanism to drive it; and this mechanism requires, in order to overcome its resistance, a mightier moving power than that of man, apart from the fact that man is a very imperfect instrument for producing uniform continued motion. But assuming that he is acting simply as a motor, that a machine has taken the place of his tool, it is evident that he can be replaced by natural forces. (ibid)

The displacement of human labour power as a core force of production by 'natural forces' started with a call for the application of animals (especially horses), water and wind. Marx noted that water power remained the principal motive source of energy well into the nineteenth century (dominating the initial stage of industrialization or 'machinofacture'), before being replaced the steam engine, which drew power from coal and water. As he suggested, the transition to coal allowed capital to separate industry from local and geographically embedded sources of power (water- wheels and biomass), and to concentrate industry in urban centres, as the material elements and means of production could effectively be shipped anywhere. Thus, Marx noted that the storability and transportability of coal was the principle advantage over water power for capital:

> Despite this, the use of water, as the main motive power brought with it various added difficulties. 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 power 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 waterwheel – rural, permitted production to be concentrated in towns instead of – like the water-wheels – being scattered over the countryside, and finally, of universal technical application, and *little affected in its choice of residence by local circumstances*. (Marx 1976b, 498-9; my emphasis)

The shift to fossil powered large-scale machinery simultaneously led to the formation of a more complex division of labour, as 'skilled' labour was expressed in machines and workplace design for maximum efficiency and 'manual labour' was charged with machine minding. The process brings with it the conscious technical application of science to production. As machinery becomes a key instrument of labour, Marx suggested "it assumes a material mode of existence which necessitates the replacement of human force by natural forces and the replacement of the rule of thumb by the conscious application of natural science" (508).

The result, moreover, was a dramatic reduction of worker power and control over the labour process, as capital was freed from its reliance on labour as a crucial *physical* force of production, which could be replaced by inanimate stored fossil energy (See Burkett and Foster, 2006). As Marx emphasized: "The steam engine was from the very first an 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" (1976, 562-563).

Elsewhere Marx emphasized that energy is a key aspect of the means of production. Within the instruments category, he made a distinction between resources which form the 'principal' substance of a product, from those that enter its formation as an 'accessory,' and allow for the conduct of work itself. As Marx wrote:

> An accessory may be consumed by the instruments of labour, as coal under a boiler, oil by a wheel, hay by draft horses, or it may be mixed with the raw material in order to produce some modification thereof, as chlorine into unbleached linen, coal with iron, dye stuff with wool, or again it may help to carry on the work itself, as in the case of the materials used for heating and lighting workshops. (1976, 181)

Marx here distinguished between coal and other fuels as sources of energy, as opposed to materials that are transferred to the product itself in the course of the labour process.

Fossil Capitalism

These are foundational points for analyzing the role of fossil fuels as a key force of production. Indeed, a rich and bustling body of historical materialist scholarship under the rubric of 'fossil capitalism' explores this role and the necessary role of extractive industries to that relationship (Altvater 2007; Angus 2016; Huber 2009, 2013b; Malm 2016). Historically, it argues that the consolidation and diffusion of capitalist relations is closely bound up with the shift from energy 'flows' (energy from rivers, the sun or wind) to mineralised energy 'stock' (condensed inanimate energy contained in the crust of the earth).

For Elmar Altvater (2007), who is often credited with introducing the term 'fossil capitalism,'[35] capital's attraction to fossil fuels is partially explained by the qualities of coal and oil themselves. Extending Marx, he argues that hydrocarbons fulfill the requirements of the capitalist process of accumulation in three ways: first, as fossil fuels become the key source of energy, the local availability of energy resources is no longer the main reason for the location of manufacturing and industries; instead energy resources can be transported anywhere in the world; second, in contrast to solar energy, fossil energy can be stored and then consumed without reference to natural time patterns (used 24hrs a day, 365 days per year); third, fossil energy allows for the speeding up of production by technical means and the annihilation of space by time. There is therefore a 'tight fit' between the physical properties of fossil fuels and both the socio-economic logic and 'spatiotemporality' of capitalist development.

Building from Altvater, Matthew Huber (2009) adds both theoretical sophistication and historical depth in accounting for the interplay between capitalist development and fossil fuels. Treating energy as a social relation, Huber avoids any semblance of "energy determinism" by arguing that fossilized production "hastened the *generalization* and *extension* of the wage labour relationship on a scale hitherto unseen" (2009, 110).[36] In line with the perspective advanced here, Huber argues that while something like capitalist social forms pre-exist the Industrial Revolution, the

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[35] A similar term 'carboniferous capitalism' was introduced by Lewis Mumford in *Technics and Civilization*, originally published in 1934 (Mumford 2010).

development of a specifically capitalist mode of production involves not only the generalization of the wage, but requires large-scale industry. In contrast to approaches like O'Connor's, which tend to treat nature and resources as an external condition or factor of production, he explicitly argues that fossil fuels should be thought of as the core "productive force of production" or as *internally powering* the forces and relations of capitalist production (Huber 2009, 108).

In his *Fossil Capital*, Andreas Malm (2016) adds historical depth and theoretical rigour to this body of research. In a masterful rereading of the eclipse of water by steam power in the period 1825-1850, he argues that nineteenth-century mill owners switched from water power to coal power not because coal was cheaper, more reliable, or more abundant, as conventional views suggest. Instead, Malm argues that ultimately the transition to steam power offered capital the ability to discipline labour. The transition from energy 'flow' to 'stock' allowed for the relocation of production to settings with a high surplus population, enabling capital to seek out the most profitable pools of labour power, to level down wages, and to enforce an accelerated industrial output. What Malm reveals therefore is that the emergence of the fossil economy is a bourgeois class project from the outset, concerned with squeezing the most out of labour as possible. As he writes, "The edge of steam, in other words, was its unique suitability not for the generation of power per se, but for the exploitation of labour" (2013, 33).

That the transition was motivated by a desire to defeat labour militancy and workers' agitation in the mid-19th century (especially demands for limits to the length of the working day and increases in wages) offers a key insight as to why capital has continued to fuel climate change. A crucial aspect of capital's response to growing labour militancy in this period was to speed up and expand the use of machines, an approach maintained throughout its history. For Malm, capital's mid-19th century response to labour insurgency (to speed up machines through high-pressure steam and thereby extract relative surplus value) was therefore key in the emergence of fossil fuels as the "general lever for surplus value production" (Malm 2016). In a competitive market, the compulsion to accumulate capital by the speeding up production by technical means is translated to "grow by burning *or die*" (Malm 2016). Moreover, the correlation between capitalist industrial growth and increasing emissions since the 1800s has been so close that for Malm it amounts to a general law: "where capital goes, *emissions will immediately follow"* (353).

The shift towards coal in the early nineteenth century, not only transformed societies within Europe, but had far-reaching global consequences. As Bruce Podonik writes:

> This energy shift became intimately associated with a new process of conquest that forcibly incorporated new regions into an expanding world-system. Coal powered ships and railroads allowed Britain and its continental rivals to seize control over territories in Asia, Africa, and the Middle East that had long resisted conquest. (Quoted in Angus 2016, 130)

Steam-powered gunboats were critical in shifting the balance of military power between Europe and Asian and African societies. Further, a key task of British naval expeditions was to locate and take control of coal deposits and establish coaling stations in order to fuel further colonial ventures (Angus 2016).

While much of the literature is concerned with the emergence of fossilized modes of industrial production, the "making" of fossil capitalism of course did not end in the 19th century. Indeed, the symbiosis between capital and fossil fuels has only deepened subsequently. At the end of the 19th and into the 20th century, the transition to electric (rather than steam) powered production dramatically transformed the technical bases of the forces of production. Electrified industry enabled the transition from the heavy machinery of the coal age, to the Fordist mass production assembly lines (Smil 2010).[37] Meanwhile, 'automobilization,' especially in the United States, before the First World War to 1929 exploded and transformed the carbon extractive industry into a supplier of gasoline (Baran and Sweezy 1966). In the decades following World War II, the production of synthetic substances – from plastics to fertilizer to napalm to pesticides – further accelerated our consumption of petroleum. The whole 'petrochemical complex,' and the associated production of prodigious waste grew exponentially in the so-called "golden age" of capitalism (Angus, 2016).

In *Lifeblood*, Huber (2013) extends this understanding and focuses on the sphere of social reproduction more sharply, by analyzing how fossil energy has provided the ecological foundation for a "peculiarly privatized sociospatial existence" (xvi). He considers how beginning in the postwar period, oil has been fundamental to the growth of "the American way of life" for a specific stratum of workers, based on privatized social reproduction, single-family housing and automobility. The entire 'electric-oil-auto complex' he argues, reconfigured the geographies of social reproduction for many workers, allowing for the postwar social construction of life as composed of "homes, cars, yards" (ibid, xiv). In this material transformation of social reproduction, he argues that the productive forces of capital (large-scale industry based on fossil fuels) have been extended "to the reproductive forces of everyday life" (ibid, xv) or that there has been an "industrial revolution of the reproductive forces of everyday life" (ibid, 16).

As Altvater suggests (2007), the enhanced globalization of production and consumption that has accompanied the recent phase of neoliberal capitalism beginning in the 1970s, has only come

[37] While still overwhelmingly powered by fossil fuels, electrified transmission also contains the potential for alternative forms of power such as hydroelectric, solar, and wind.

about with the development of extremely energy-intensive systems of production and transport.[38] Newly industrializing countries have added to the consumption of fossil fuels by already industrialized countries, with China and India now ranking as the second and third largest consumers of oil, respectively (International Energy Agency 2018). While this industrialization produces commodities that serve domestic markets, as numerous authors demonstrate (Malm 2012, 2016, 327-367; Minx et al. 2011), in the case of both China and India much of this development has taken place through foreign direct investment by transnational corporations and has a strong export-orientation, such that most of the commodities produced in the host countries are exported. As Malm argues (2012), the "offshoring" of production from high income to low income countries (motivated mostly by the search for cheap and disciplined labour), requires the establishment of new (carbon) infrastructure, and leads to more extended and dispersed supply chains, meaning that more oil will be burnt in trucks, trains and supertankers.

In a little more than two centuries the fossil fuels energy regime has therefore become embedded in the entire economic structure, from energy to transportation to plastics to agro-industry and all else. While capitalism existed before fossil fuels were introduced into the production process, since the 18th century the development of the productive forces based on capital has become heavily dependent on them. While Marx himself did not (and could not have) fully registered the ecological implications of the transition to fossil-powered industry (specifically the 'by-product' of rising carbon emissions), he reflected on rising matter and energy throughput under capitalism, to which we turn next.

[38] This includes the development of energy-intensive agro-exporting industries, which has given rise to a global livestock complex supplied by international chains of feedstuffs, alongside growing shipments of fruits, vegetables and seafood (see McMichel 2007).

Matter and Energy Throughput

As we have seen, the development of fossil-powered machinery, along with the conscious application of science to production, leads to an unprecedented increase in the productivity of labour. Marx referred to profit making through asymmetry in such productivity advances as relative surplus value. In numerous passages he uses this to explain why individual capitalists are engaged in an unrelenting search for new technologies and constantly driven to introduce technical change. This extends to the competitive dynamics of an advanced market economy: under the 'whip of competition,' the firm that innovates gains an extra measure of profit over its competitors (better sales or lower unit costs), and one that fails to adopt newer and better methods will be driven out of business over time. Thus, the competitive position of capitalist society's industrial decision-makers compels them to increase the productivity of production processes. This perpetual tendency to redeploy the social surplus into technologies that increase the productivity of labour reveals capital's abiding drive and mission: "Accumulation for accumulation's sake. Production for production's sake" (Marx 1976b, 742).

The rise in the productivity of labour means that modern industry generates an ever-greater mass of commodities, which requires an ever-larger quantity of inputs, whether of wood, iron, water or energy. As Marx suggested: "the increasing productivity of labour is expressed precisely in the proportion in which a greater quantity of raw materials absorbs a certain amount of labour, i.e. in the increasing mass of materials that is transformed into products, worked up into commodities, in an hour for example" (quoted in Foster and Burkett 2016, 158). In addition to raw materials, Marx also reflected specifically on how rising productivity means an ever-greater consumption of energy sources: "after the capitalist has put a larger capital into machinery, he is compelled to spend a larger capital on the purchase of raw materials and the fuels required to drive the machines" (ibid). Investments in productivity gains do include improved environmental efficiency (individual firms in a competitive system work to reduce the costs of waste and inefficient use of materials). Efficiency, moreover, extends to carbon emissions: more efficient use of resources leads to lower emissions intensity per unit of production. However, this does not reverse the rising *absolute* flow and consumption of materials and energy and the accompanying rise in *total* volumes of emissions, which more than offset intensity gains (ibid). Indeed, research on the 'Jevon's paradox' shows that decline in carbon intensity in developed nations has been accompanied by a rise in total emissions (Foster, York, and Clark 2011, 169-181; Lohmann 2013, 30-48).[39]

This view, which points to what is now often referred to in the environmental sociology literature as the 'treadmill of production' (Gould, Pellow, and Schnaiberg 2004; Schnaiberg 1980), coloured Marx's analysis of the relation between production and consumption, as he considered the latter to be mostly determined by the former. The goal of capital in the sphere of production is to produce more commodities containing surplus value. However, capitalists themselves, as Marx noted, do not want the commodities; instead, they aim to sell them. They must thereby enter the sphere of circulation, this time as sellers of commodities, to realize their potential profits. The capitalist producer, however, faces a barrier to such realization, based on the extent of the market. Just as capitalists seek ways to increase surplus value in the sphere of production (through

[39] The Jevons paradox is a shorthand for a set of theses associated with the 19th-century British economist William Stanley Jevons. Jevon's argued that the economical use of fuel is not equivalent to diminished consumption. The above authors similarly examine how efficiency increases in one or more sectors augment energy use across a whole industrial society or system over the long term. In industrial capitalist societies, efficiency makes more funds available not only for consumption but also for new rounds of capital investment, leading to an expansion of the overall scale of production.

productivity advances or driving down wages), they must also work to expand markets as the means of realizing capital, of selling commodities. The 'sales effort,' the production of new needs, is vital in this process (see Lebowitz 2006, 23-6).

Capital's problem in the sphere of circulation, in realizing the potential profits, is moreover, tied to its tendency towards the 'overproduction' of capital. There is a recurring tendency, as Marx noted, for capital to expand productive capacity more than the existing market will justify. The propensity derives directly from capital's drive to increase the rate of exploitation and extract relative surplus value. The inclination towards overproduction correspondingly produces an immense drive towards the boundless pursuit of consumption goods. In effect, consumer demand becomes bloated because production does not have 'consumption-values' as its controlling goal; that is, if the production process were oriented to the consumption of use-values rather than exchange-value, many fewer consumption goods (much less use-value) would be produced and consumed (Cohen 2000). The capitalist, Marx therefore wrote, is "also a producer of overproduction, production for others. Over against this overproduction on one side must be placed overconsumption on the other, production for the sake of production must be confronted by consumption for the sake of consumption" (quoted in Lebowitz 2006, 32).

The problem of realizing capital also drives Marx's analysis of infrastructural formation. He pointed out that expanded reproduction in relation to the immense productivity of fossil-powered large-scale industry requires the concomitant creation of infrastructures and the spatial conditions that allow for the circulation of commodities and the expansion of markets. We turn to this below, while emphasizing its ecological dimensions and significance.

Spaces of Circulation and Fixed Capital

A key component of forces of production is infrastructure – what Marx considered fixed capital of a 'large-scale and great durability.' This category refers to a broad array of items such as ships, docks, canals, ports, dams, factory buildings, blast furnaces, pipelines, highways, electrical power transmission lines, power stations, railways and so on. They structure, process, mediate and enable the flow of resources appropriated from the rest of nature. They are part of the means of production, enabling the biological and social reproduction of most of contemporary humanity.

Marx reflected on how early industrialists in England acquired much of their fixed capital by putting old infrastructures (mills, barns, transport systems) to new productive uses. Through appropriation, conversion and primitive accumulation, a vast reservoir of assets could be put to new productive uses. Yet if capital is going to produce on an extended scale, it must be able to carry out such projects on a capitalist basis (while it will continue to appeal to and seek to involve the state where possible).[40]

While emphasizing the role of the credit system and other mechanisms as conditions enabling the development of fixed capital of 'large-scale and great durability' (discussed below), Marx paid close attention to the formation of physical infrastructures of transport, circulation and exchange, conceiving of them as instruments through which we are purposefully linked to the rest of nature. He analysed two interrelated dimensions surrounding their formation. The first aspect concerns the movement of raw materials from sites of extraction to sites of production. As we saw,

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[40] Harvey has provided a fruitful analysis of the imbrication of capital and the state in the construction of the built environment, pointing to the contemporary predominance of private-public partnerships and how the coordination and management of monetary flows required for large-scale infrastructural projects draw the state and capital together in what he calls the 'state-finance nexus' (2011, 48).

Marx remarked on the geographical separation of extraction from production in the case of coal, and reflected on the long-distance transport of fibre into the cities, for textiles and other manufacturing purposes. As stated in the *Grundrisse,* infrastructural networks enabling the transport of both raw materials and more finished commodities belong to capital's development of productive forces: "Whether I extract metals from mines, or take commodities to the site of their consumption, both movements are increasingly spatial. The growth of the means of transport falls into the category of the development of the productive forces generally" (1993b, 523).

Marx noted that the commercial viability and value of raw materials depend in part on transport costs, writing that "an individual product might be made so much more expensive, owing to the transport costs, that it could not be sold" (ibid). Capital is then driven to produce innovations in transport infrastructure in order for a mass of extracted raw materials to reach often distant points of production. He pointed to the growth of 'economies of scale' in transport in order to reduce costs and to match the mass extraction of raw materials.

The second, closely related feature concerning capital's revolution in this dimension of productive forces concerns the so-called 'production-consumption disconnect.' Here the dynamic productivity of large-scale fossilized industry (its vast panoply of commodities) comes up against concrete physical and geographical barriers, which capital "cannot abide." While capital produces an immense collection of commodities, this in no way guarantees their sale; the realization of this productivity requires expanded markets for exchange, as well as the creation of extensive and long-term investments in the form of fixed, often immobile infrastructural networks that connect points of production to points of consumption.

As Marx asserted, "Economically considered, the spatial condition, the bringing of the product to the market, belongs to the production process itself. The product is really finished only when it is on the market…The reduction of the costs of this real circulation (in space) belongs to the development of the productive forces by capital" (Marx 1993b, 533-4). By reducing circulation costs individual firms increase profits and gain a competitive edge over other firms. In a well-known passage in the *Grundrisse*, this drive to overcome space by revolutionizing the means of transport is described as follows:

> Capital by its nature drives beyond every spatial barrier. Thus the creation of the physical conditions of exchange – of the means of communication and transport – the annihilation of space by time – becomes an extraordinary necessity for it. (1993b, 524)

As Huber suggests (2009a), prior to the emergence of fossil-powered large-scale industry, commodities were transported by horse-drawn vehicles, by waterways (rivers, lakes, sail boats) and by walking. However, the sheer magnitude of commodities produced by large-scale industry could not find markets through transportation systems based these sources of power. Fossil powered production was therefore simultaneously hastened by the emergence of "fossilized" transportation and infrastructural networks, which radically reduced the amount of time required for transporting commodities and allow for the geographical expansion of markets.

Malm, drawing on Henri Lefebvre's distinction between absolute and abstract space, further reflects on how fossil fuels have been vital to the construction of space "steeped in exchange-value"(2016, 300). 'Absolute space,' as he explains, is made up of components of nature located at sites chosen for their intrinsic qualities (such as caves, springs, rivers, mountain-tops, valleys). It involves building, dwelling and producing around the inherent properties of these sites, such as building a sanctuary around a well, or constructing an industrial watermill. However, these natural features and qualities are 'smashed' by capitalism, and replaced by the abstract space of accumulation. In 'abstract space',

> capital tears material components from their natural beds and heaps them up in places of its own choosing. Instead of going reverently to mountain tops and rivers and establishing businesses there, as some temples on holy ground, capital carries away what it needs and pours it out in places where the production of more exchange-value can best proceed." (301)

Capital strives to emancipate itself from 'natural space' (and its qualities) and produce space in its own image. Malm argues that only the 'stock' of energy resources, with its key quality of abstractness (its storability and transportability), could have permitted this "breakout into spatial abstraction" (ibid, 302). However, this results in a paradoxical situation: a great immobile strata of concentrated energy, along with techno-industrial complexes fixed to the ground are required to extract and process fossil energy. Furthermore, as we see in Chapter 6, an enormous network of physical infrastructures – pipelines, railways, processing plants, petrochemical complexes, refineries, tankers, and urban gas and electricity distribution infrastructures – amounting to entire landscapes in their own right, are required to process, move and subsequently suffuse the economy as a whole with fossil fuels.

Capital therefore 'produces' and organizes space (Lefebvre 1992) via infrastructures (often fossil powered), to try and annihilate space. The transformations to the physical landscape wrought by capital in its drive to overcome every spatial barrier and produce space in its own image are nothing short of staggering.

So far we have considered how capital's efforts to increase the productivity of labour and nature produce (1) the transition to large-scale industry and machine-based production and with it the replacement of labour power with fossil fuels, as the key motive source of energy, and (2) the spatial conditions that allow for the circulation of an "immense collection of commodities," through means of fossilized transportation and in fixed, heavy, secure, durable and often immobile physical infrastructures. Closely intertwined with and enabling these developments is the emergence of the modern corporation. The 'socialization' of productive forces – their concentration and centralization in large firms, as well as their control and planning both within and across firms – provides a critical foundation and platform for their development based on capital. In the next section we outline this development.

Corporate Capitalism and the Concentration and Centralization of Productive Forces

As intimated above, competition between different capitalists in the pursuit of increased profits and enlarged markets, leads capitalists to reinvest profits into the development of new machinery, technologies, and productive techniques. Those who cannot keep up with the application of the latest technology and technique produced at a higher cost are undercut by their competitors. In this manner, competition between different capitalists leads not only to intensive growth but also over time to a concentration and centralization of capital.

For Marx, capital concentrates in few hands, firstly through the process of compound growth, as in each round of accumulation the capitalist acquires an increasing mass of capital in the form of money power. While this is a slower and more gradual process, concentration also occurs through a process of centralization of capital. This is achieved as larger-scale capitalists gobble up smaller ones through ruthless competition (and via means such as takeovers and mergers). Competition between different capitalists leads to a concentration and centralization of capital in the form of large firms or the corporation. While corporations were not fully consolidated until the 20th century, Marx here bears witness to some of the earliest corporate forms, which emerged from growing accumulation and the need to have a structure that reflects that accumulation and its unending expansion. The corporation allows for the aggregation and 'socialization' of key aspects of forces of production: it concentrates labour power, while capturing, organizing and internalizing science and technology. It also provides a structure for raising and pooling capital.

Marx reflected on the latter development in the third volume of *Capital,* through his notes on the emergence in the nineteenth century of the modern 'joint stock company' (JSC). With the JSC and its accompanying form of shareholder ownership, barriers to raising capital for large-scale capital-intensive projects (such as infrastructures and machinery) were overcome by shares issued on the stock exchange. In the JSC, available money capital becomes less of a barrier to expansion, as firms gain access to a larger pool of capital and are no longer dependent on concentrations of individual property. With this aggregation of capital, there was also a growing need to separate ownership from management, since ownership took the form of shares and no share or group of shares carried the sole right to manage.[41]

The second major path to the concentration and centralization of capital occurs through credit and the credit system. As Marx noted, the source of money capital in the productive circuit may come in the form of a loan to a "productive capitalist." Marx referred to this form of money capital as 'interest bearing capital,' that is, money lent out for a price in the form of interest for which the lender relinquishes control of the sum lent. The process of financing constitutes a

[41] As Marx intimated, the corporate form assumes the expansion of a managerial class that becomes relatively autonomous from the owners of capital. Conceptualized sociologically and in terms of power, this separation of management and ownership means that at the apex of the corporate hierarchy and endowed with final authority over the affairs of the corporation, is the board or directors. Thus, directorates are key *sites* of authority within corporate power structures, while individual directors are *agents* of corporate power (Carroll 2004).

relationship between financial and industrial capitalists, with the former earning interest by lending to the latter. Credit therefore emerges from exchange relations between different fractions of capital.

Yet the supply of interest-bearing capital requires *recurrent* access to idle (hoarded) savings of all capitalists.[42] In a developed credit system, financial institutions pool idle savings and turn them into concentrated money capital resources available to a few industrial producers (Marois 2013). Credit therefore relieves individual capitalists of the burden of hoarding massive amounts of capital in advance of the purchase of fixed capital and converts the payment for that fixed capital into an annual one. This enables capital-intensive development and more aggressive accumulation, while leading to further centralization of capital. As Marx writes of the credit system:

> In its first stages, this system furtively creeps in as the humble assistant of accumulation, drawing into the hands of individual or associated capitalists by invisible threads the money resources, which lie scattered in larger or smaller amounts over the surface of society; but it soon becomes a new and terrible weapon in the battle of competition and is finally transformed into an enormous social mechanism for the centralization of capitals. (Marx 1976b, 777-778)

Possession and control over socialized means of production (and the social surpluses that ensue) and capital endow corporations with an enormous amount of power. Given huge concentrations of economic resources, workers, communities and states are 'unilaterally dependent' on large corporations that may (or may not) choose to invest in a given time or place (Carroll 2010). This power enables corporations to frame agendas, make decisions and secure compliance (ibid). Because money capitalists can decide whether to finance a firm (or a governmental or non-governmental organization), they are a particularly powerful fraction of capital. By virtue of control over credit they exert 'allocative power' (Carroll 2010; Scott 1997). And while this raises the potential for intra-

[42] Harvey (2007, 239-282) updates this by examining how capitalists gain access to idle savings of not only other capitalists, but also individuals and collectives who are drawn into the financial system through interest on savings, mortgages, pensions and so on.

class conflict (the particular interests of money capitalist may not correspond to the general interests of capital), both investment and credit in industrial operations often pull financial firms and industry together into a tight association, expressed in the concept of 'finance capital' (Hilferding 2006; Marois 2013).[43]

Several interlinked processes accompany this concentration and centralization of forces of production and capital. As Marx writes,

> Hand in hand with this centralization, or this expropriation of many capitalists by few, other developments take place on an ever-increasing scale, such as the growth of the co-operative form of the labour process, the conscious technical application of science, the planned exploitation of the soil, the transformation of the means of labour into forms in which they can only be used in common, the economising of all means of production by their use as the means of production of combined, socialized labour, the entanglement of all people in the net of the world market, and with this, the growth of the international character of the capitalist regime. (1976b, 929)

Historically, capitalism concentrates previously scattered means of production into giant monopolistic firms and develops them to the point of establishing an interconnected capitalist world market. The expanded scale of production leads to the growth of the cooperative form of the labour process, the conscious technical application of science and the introduction of elements of planning and control and, both in the plant and in the wider economy. I turn to these in more detail below.

[43] While large corporations are the key organizational form enabling the concentration and socialization of forces of production, capital never exists as a unified entity but as many units, of which corporations are the most important. Just as the expanded scale of capital requires an extensive financial apparatus for the circulation and consumption of commodities, surplus value is competitively subdivided among not just among industrial, resource and financial capitalists and corporations, but along all lines of investment, including in areas such as real estate and retail commerce (Carroll 2010; Van der Pijl 1998). These functional divisions within total capital are part of what Marx refers to as 'fractions of capital.' As in the relation between industrial and finance capital, there is both competition and repulsion between these various fractions, as well as *attraction*.

Cooperation, Divisions of Labour, Planning

As suggested in Chapter 2, Marx consistently treated cooperation as one of the most basic productive forces. As Marx and Engels asserted in *The German Ideology:* "a certain mode of production or industrial stage is always combined with a certain mode of cooperation, or social stage, and this mode of cooperation is itself a 'productive force'" (1976, 76). Further along in the same work, they state that the "social power" which arises through the "cooperation of different individuals as it is determined by the division of labour" is a productive force (ibid). This understanding is carried through the *Grundrisse* where Marx speaks of the "productive force arising from social combination" (1993b, 700) and how the "association of the workers – cooperation and division of labour" is a "unification of their forces" and an "increase in their productive force" (ibid, 585).

In *Capital* Marx analyzed how socially combined production in the form of large-scale firms brought together and augmented previously scattered means of production, skills, techniques and knowledge. In the process, wealth-creating powers of fragmented workers become developed as collective social powers in a way that was not possible with production organized around personal, family or only local ties. In the chapters from "Cooperation" through "Machinery and Large-Scale Industry" he reflected also on the enhanced and growing scale and increasingly complex forms of cooperation found not only within the workplace or firm, but also beginning to extend beyond it, through wider divisions of labour. Machine technology for example, presupposes complex levels of cooperation between firms, as well as between knowledge workers or scientists and between firms and states. Similarly, the infrastructures and communication networks that support globalizing production networks both enable and pre-suppose an increasingly complex, variegated and universal form of 'cooperation.' Reflecting on these developments Marx wrote, "not only have we an increase in the productive power of an individual, by means of cooperation, but the creation of a new power, namely the collective power of the masses" (1976b, 443).

Marx's reflections on the 'mode of cooperation' created by capitalism are complex. In general, he was laudatory towards the complex networks of human production created by capitalism. He continually stressed the *potentiality* of cooperation and socialized labour, in contrast to the alienated and often negative form it takes under capitalism. Despite his often-scathing reflections on capitalist work relations, Marx saw capitalism enabling and potentiating ever larger, more varied and cosmopolitan communities of cooperation. Based on both the centralization of capital in large-scale firms and capital's need expressed in the *Manifesto* to "nestle everywhere, establish connections everywhere" (Marx and Engels 2010), capital provided a foundation for more universal-communal people-nature relations and for networks collaboration and mutual aid. Cooperation and well-organized divisions of labour are from this perspective, considered as positive human capacities that add to our collective powers.

Marx therefore recognized that cooperation within the firm, as he described, took place under the despotism of capitalists who organized and directed a supervisory authority, while broader networks of socialized production fragmented the working class into distinctive hierarchical groupings (especially along gendered and racialized lines), materializing imperialist economic interdependencies. However, what drives Marx's analysis is his insistence again and again in *Capital* that the productive force of cooperation is a common property belonging to the "associated producers" and that capital is merely appropriating it, distorting it and putting it to its own particular advantage. He maintained that, "the special productive power of the combined working day, is under all circumstances, the social power of labour, or the productive power of social labour. This power arises from cooperation itself" (Marx 1976b, 447). It is, however, seized upon by capital through real subsumption and developed for its capacity to augment the productivity of labour in search of relative surplus value. He wrote:

> The socially productive power of labour develops as a free gift to capital whenever the workers are placed under certain conditions, and it is capital which places them under these conditions. Because this power costs capital nothing, while on the other hand it is not developed by the worker until his labour belongs to capital, it *appears* as a power which capital possessed by its nature – a power inherent in capital. (ibid, 451; my emphasis)

Capital appropriates, 'mystifies' and turns into a private power the fruits of a vast and collaborative process of socialized labour.

Moreover, he argued that while capitalists love planned organization of production in the factory, they continually resist conscious social planning of production in wider society (See also Harvey 2010, 183-188). There is a deep contradiction, in Marx's view, between socialized production and private appropriation, leading him to suggest that under socialism society-wide planning would eliminate capitalist "anarchy of production," ensuring a more rational allocation of economic resources, eliminating economic crises and developing productive forces to augment the material well-being of everyone (Marx 1976b, 477).

How we think of cooperation and divisions of labour is of vital importance in addressing large-scale planetary problems, like climate change. Capitalism's increasingly large-scale and intensive system of biopsheric appropriation generates problems that are collective in nature and global in scope. Planning is required to not only to augment material well-being in the sense of satisfying basic consumptive needs, but also from the perspective of managing the human metabolism with nature in a rational and sustainable way. While capitalism develops limited (predominantly market-based) forms of eco-regulation and a modicum of planning and coordination of divisions of productive labour across society, these are highly limited. The ability across the system to 'plan for tomorrow,' to learn from past experience, is highly circumscribed.

In the current context, this could suggest that a 21st century socialist alternative would develop new forms of (planetary) productive associations and enhanced modes of cooperation (new productive forces). It could also develop new institutions and means for coordinating and planning those associations (new relations of production), in terms not only of 'resource management,' but also in the regulation, management and mitigation of global eco-metabolic problems. The re-affirmation of collective design and conscious planning (in a way that is non-homogenizing and avoids the disastrous legacy of the command state in favour of more participatory processes) has been a theme in contemporary eco-Marxist theorizing. David Harvey (2000, 199-212) has interestingly set his arguments in the context of 'species being' capacities and powers raised by the young Marx. Against the romanticism of spontaneous rhizomatic connections, he highlights the role of collective deliberation and foresight in all projects of social emancipation. The view is nicely anchored in Marx, who in one of his few references to species being in *Capital* wrote: "When the worker co-operates in a planned way with others, he strips off the fetters of his individuality, and develops the capabilities of his species" (Marx 1976b, 447).

Knowledge and Science as a Force in the Production Process

I have argued at various points that knowledge and science are part of the forces of production. Marx suggested that historically, while capitalism does not invent science, the system is unique in so far as it "is the capitalist mode of production which first [systematically and routinely] puts natural sciences to the service of the direct production process"(Marx 1992). In its productive application, he suggested that scientific knowledge is again 'appropriated' by capital as a 'free gift.' This is the case in so far as knowledge and its conceptual and methodological underpinnings are typically not the products of wage labour: "Apart from the natural substances, it is possible to incorporate in the productive process natural forces, which do not cost anything, to act as agents with more or less heightened effect. The degree of their effectiveness depends on methods and scientific developments which cost the capitalist nothing" (Marx 1956). Like cooperation, knowledge is understood as a capacity of the collective worker, a common property that can be mobilized in the service of (re)making the world. Yet under capitalism, the collective nature of the productive force of knowledge, is mystified: "The accumulation of knowledge and of skill, the general productive forces of the social brain, is thus absorbed into capital, as opposed to labour, and hence *appears* as an attribute of capital" (Marx 1993b, 694; my emphasis).

While science is relatively autonomous from capital and is not totally subsumed to the dictates of the accumulation process, Marx saw capitalism propelling and profoundly shaping its development. As with other aspects of forces of production, the growth of science occurs by socially separating knowledge from the control of the direct producers. After being separated from the producer vis-a-vis proletarianization and placed in the hands of management (as analyzed in detail by Braverman), the application of science to the production process takes numerous forms. The creation of the physical hardware for production, exchange and communication itself requires scientific knowledge. Marx also emphasized the importance of science for pressing 'natural agencies' (such as coal and water) into the service of capital. This function of science is vital in capital's effort to increase the productivity of labour: "Large scale industry raises the productivity of labour to an extraordinary degree by incorporating into the production process both the immense forces of nature, and the results arrived at by natural sciences" (Marx 1976b, 509).

The heightened productivity that capital achieves (which "frees" social labour time for new productive uses), combined with its need to expand constantly the circle of production and consumption, leads to the development of new branches of production, based on discovering, appropriating and developing the objects and forces in the rest of nature:

> Hence exploration of all of nature in order to discover new, useful qualities in things; universal exchange of the products of all alien climates and lands; new (artificial) preparation of natural objects, by which they are given new use-values. The exploration of the earth in all directions, to discover new things of use as well as new useful qualities of the old; such as new qualities of them as raw materials etc.; the development, hence, of the natural sciences to their highest point; likewise the discovery, creation and satisfaction of new needs arising from society itself. (Marx 1993b, 409)

Capital works to ceaselessly to discover, develop and subject to itself all aspects of nature that are conducive to accumulation. Techno-scientific and organizational efforts aimed at more extensively transforming the objects and forces of nature in service to the accumulation process can be described as the 'subsumption of nature by capital' (Boyd, Prudham, and Schurman 2001; Burkett 2014). Burkett (ibid, 64-68) follows Marx in connecting the real subsumption of labour to the subsumption of nature. As he suggests, Marx's views surrounding the "new (artificial) preparation of natural objects" and the "subjugation of the forces of nature" (1993b, 700) on a large-scale coincide with or parallel the techno-scientific and managerial transformation of the labour process. As we have seen, fossil capital theorists similarly focus on the harnessing of "buried sunshine" as internal to the transition to industrial capitalism, based on the real subsumption of labour to capital (see especially Altvater 2016; Huber 2009).

While they do not directly connect the issue to the real subsumption of labour, Boyd et al. (2001) analyze "nature-based industries" – those that confront the rest of nature directly in the process of commodity production, such as industries based on raw material extraction, as well as those based on cultivation – through the lens of the subsumption of nature to capital. Additionally, they introduce a distinction between the formal and real subsumption of nature. In the formal subsumption of nature, which applies mainly to extractive industries, there is an appropriation and technological development of "objects" in nature, but for the most part, the natural processes upon which they are based remain unchanged. The oil and gas sector, for example, can enhance drilling and recovery techniques, as well as develop new uses for hydrocarbons, but firms cannot increase the absolute quantity of oil or gas. The real subsumption of nature, by contrast, applies mainly to 'biologically-based' industries that depend upon 'cultivation', and wherein there are manipulations or intensifications of biological processes. As witnessed in cultivation-based industries such as aquaculture, forestry, and agriculture, real subsumption entails efforts to target and enhance the productivity of biophysical process, through means such as selective breeding and genetic modification (Boyd and Prudham 2017; Boyd et al. 2001).

The concept of the subsumption of nature to capital helps capture the ways that capital accumulation involves the extensive and intensive appropriation and technological development of natural conditions. The notion of the real subsumption of nature is particularly helpful in analyzing aspects of the development of productive forces in 'biologically-based' industries. The "industrialization" and reworking of natural processes to facilitate production and increase profit rates are part of the practices and processes by which we are linked to and transform the rest of nature. Large fields of applied science are devoted to such processes (Boyd 2001; Prudham 2003). The real subsumption of nature framework can also potentially be extended beyond its original context to consider attempts to mitigate environmental problems and degradation(Carton, Jönsson, and Bustos 2017). Geo-engineering processes, for example, aim to consciously change and re-work atmospheric conditions, evoking the logic of real subsumption at the planetary level (ibid).

While these are productive lines of inquiry, Boyd and Prudham (2017) point out that their framework of formal versus real subsumption of nature was not intended as the basis of any broad theory of socio-ecological transformation. It has been taken in this direction by scholars who strongly emphasize the real subsumption of nature as an ever-deepening process. Thus, Smith suggests that in the 21st century, capitalism's real subsumption of nature goes "all the way down"(2007, 29). This position tends towards seeing nature as completely internalized by society and appears to leave little space for considering how non-human nature has its own dynamic, turbulent and contingent processes, which are outside of human production (Foster and Clark 2016).[44]

As suggested above, Marx's gestures towards the subsumption of nature emphasized the subordination of new scientific understandings into the dynamics of capitalism. While this encourages the growth of science to an unprecedented degree, Marx pointed to its less progressive aspects. Like Braverman, he recognized that the unification of science within the production process entailed the progressive alienation of the process of production from the worker, including the separation of the intellectual potentialities of the process from the individual labourer, which became concentrated in the hands of management.[45]

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[44] As Foster and Clark (2016) note, Moore extends this logic, declaring through his world-ecology framework that capitalism appropriates and subsumes nature "*all the way down, across, and through*" (2015, 152).

[45] Marx again glimmered possibilities on the side of labour, stemming from capital's use of divisions of labour. Marx wrote: "Large Scale industry, through its very catastrophes" means that "the partially developed individual who is the bearer of one specialized function, must be replaced by the totally developed individual, for whom the different social functions are different modes of activity he takes up in turn" (Marx 1976b, 618). Marx thereby suggested that the mass of workers may be paradoxically freed from being the bearers and possessors of a narrow specialization that previously characterized craft production and instead may increasingly

As Burkett shows (2014, 158-161), Marx also saw capital placing an "anti-ecological" character on the development of science, which is rooted in capital's treatment of nature as a vehicle for the production of saleable use-values. This delimited both the development and application of ecological knowledge to production in several important ways. As he suggested, the concern among competing capitalists for immediate useful effects and commercial purposes of new discoveries promotes a narrow emphasis on monopolizable knowledge, or knowledge that can earn rents (Marx 1993b). This inhibits the development of science generally, but leads particularly to the *underdevelopment* and under *prioritization* of ecological insights that are needed for a sustainable co-evolution of society and the rest of nature (Burkett, ibid).

At the same time, as we have seen, Marx recognized that based on its increasingly intensive appropriation of nature and environmental dysfunctions, capitalism cannot help producing new and also more universal forms of ecological consciousness, knowledge and science. With Engels, he showed enthusiasm for emerging forms of ecological understanding, which took account of the ecological interdependencies between different locations and of the unintended consequences of our metabolic interaction with nature. As Engels wrote: "…with every day that passes we are learning to understand these laws [of nature] more correctly, and getting to know both the more immediate and

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be able to perform a variety of social tasks, as perpetual innovation and development demands the prevalence of 'all around skill' and flexibility in adapting to differing modes of activity. Elsewhere, Marx argued that public education arose (and continues to adapt in part) out of the need to produce the literate, flexible and well trained labour force required for constantly changing conditions of production, and he was an enthusiast for the potential future development of an education that would emphasize the multifaceted potentiality of human beings and schools that would provide basic training in a variety of technical, agricultural and vocational matters, as opposed to specialized and private teachings, often required for past forms of production. For Marx, the goal of finding a form of production that would allow for the cultivation and realization of all the qualities of the human social being, was continually thwarted by the social relations and class power that configure our forms of labour and that employ people to perform narrow, monotonous and repetitive tasks.

the more remote consequences of our interference with the traditional course of nature" (quoted in Burkett, 162).

That ecological knowledge would continue to be *underutilized* and applied only narrowly, so long as production is shaped by the dictates of the market and profit-making, is most clearly reflected in Marx's views on the possibilities associated with the conscious application of new forms of scientific knowledge to agriculture. In *Capital,* Volume III*,* he expressed enthusiasm for the development of soil chemistry that was required to improve fertility undone by capitalist agricultural techniques. In his view, this produced the "material conditions for a new and higher synthesis" between agriculture and industry (Marx 1976, 673). He argued that it was "one of the great results of the capitalist mode of production" that it transforms agriculture into a "conscious application of agronomy" (ibid, 754). While capitalism develops limited forms for the application of ecological science to agriculture, Marx argued that this development in the forces of production was continually fettered by the drive to accumulate capital. The application of agronomy to agriculture occurred only narrowly and "in so far as this is at all possible within the conditions of private property" (ibid). He subsequently concluded that "the entire spirit of capitalist production, which is oriented towards the most immediate monetary profit – stands in contradiction to agriculture, which has to concern itself with the whole gamut of permanent conditions of life required by the chain of human generation" (ibid).

Socialization and the Cadre Class

Key strategic implications of the 'socialization' of productive forces, including knowledge and science, are elucidated by Kees Van der Pijl (1998, 2004). While Marx largely neglected them, Van der Pijl notes that paralleling the expropriation of skills and knowledge from the workers is the rise of a techno-scientific and managerial cadre. The cadre class, which represents a middle stratum of workers between capital and labour, emerges with changes to the labour process, reflecting the need to organize production within large-scale factories. Yet, as corporations take part in mutual exchanges in a market setting, an element of organization, planning and control exceeds the confines of the individual firm.[46]

The expanded scale of production requires organization in combining different activities, planning the availability of goods and control of the process in its entirety. As the socialization of labour occurs both at the level of the firm and at the level of all firms connected by market relations, in competition, cadres are increasingly tasked to organize and subtend socialized labour in a broad sense. Employed not only by large-scale corporations, by also by the state and quasi-state bodies and entrusted with conception and direction in production, as well as reproduction and normative unification of the social more broadly, the cadre engages in limited forms of planned cooperation, use of science, collective use of means of production, across wider society.

Importantly, Van der Pijl argues that capital pays a major price as it increases the number of functionaries and intermediaries that are required to make sure that socialization remains subject to its domination. The ruling class, he writes, "cedes aspects of its rule to the cadre stratum with every advance in the complexity of production and social organization generally" (1998, 139). The result is

[46] Just as there are cross appointments among industrial firms, the boards of different fractions often interlock, forming an intercorporate network, and bringing directors into a socially integrated corporate elite (W. Carroll 2010; Pijl 1998). These interlocks are an expression and manifestation of the elements of control, organization, planning that reaches into the market – a socialization of relations of production that parallels the socialization of productive forces. While the directorate forms the 'leading edge' of the ruling class, to the extent that corporations have 'internalized' science and technology, scientific-technocratic workers, while subordinate to capitalists themselves, often hold prominent positions within corporations and provide expertise that is vital to corporate business (Van der Pijl ibid). Organic intellectuals (lawyers, consultants, academics, other professionals) also perform intellectual functions vital to the operations of the modern corporation and occupy important positions in civil society that align them closely with the needs and interests of corporate capital (Carroll ibid).

a major fault line in capitalist re-production, as Van der Pijl portrays the managerial-technical cadre as fluid in perspective and potentially open to left initiatives (2004).

The Metabolic Rift and the Growth of Ecology

While Marx expressed optimism surrounding certain productive powers generated by capitalism, he recognized that capital's development of the productive forces came at the expense of disrupting the metabolic interaction between humans and more-than-human nature. He clearly regarded the rehabilitation of the metabolism between humanity and nature as a central project of socialism. While evident in *Capital,* Volume III, this understanding is expressed most powerfully in last section of Chapter 15 of *Capital,* Volume I, which is focused on large-scale industry in the sphere of agriculture. Marx wrote there that industrialized capitalist agriculture constitutes nothing less than a "rift" in the metabolic relation between human beings and nature. It "disrupts the metabolic interaction between man and the earth, i.e. it prevents the return to the soil of its constituent elements consumed by man in the form of food and clothing; hence it hinders the operation of the eternal natural condition for the lasting fertility of the soil" (Marx 1976, 637).

He concluded that capitalist production exhausts the sources of capital's productive performance, taking from human laborers more than it returns in wages, *and* taking from nonhuman nature more than it replenishes in usable energy and biological life:

> All progress in capitalist agriculture is a progress in the art, not only of robbing the worker, but of robbing the soil; all progress in increasing the fertility of the soil for a given time is the progress towards ruining the more long-lasting sources of that fertility. The more a country proceeds from large-scale industry as the background of its development, as in the case of the United States, the more rapid this process of destruction. Capitalist production, therefore, only develops the techniques and the degree of combination of the social process of production by simultaneously undermining the sources of all wealth – the soil and the worker. (Marx 1976, 638)

The problem is exacerbated and becomes "irreparable" due to long-distance trade. Capitalist production "collects the urban population together in great urban centres" (Marx 1976b, 637), forcing long-distance trade and producing an antagonistic separation of town and country. Marx highlighted that the rift is global in character, writing that "for a century and a half England has indirectly exported the soil of Ireland without even allowing its cultivators the means for replacing the constituents of the exhausted soil" (Slater and McDonough 2008).

Therefore, far from automatically preparing the conditions for human emancipation, the development of productive forces under capitalist relations of production causes a deep alienation of human beings from nature in the form of a 'metabolic rift.' As suggested above, the depletion of the soil was in no way undone by the development of scientific agricultural techniques, and Marx recognized that soil sciences were incapable of being developed in a manner than would ensure the longevity of the natural basis of life, subservient as those techniques were to the capitalist development and the prerogatives of capital accumulation.

John Bellamy Foster's work has been particularly central to advancing the contemporary relevance of Marx's use of the concept of metabolism (understood as the complex relationship of material exchange within and between human beings and natural systems) and his theory of rift. By reconstructing the historical basis of Marx's arguments, Foster (2000, 2010) shows that his analysis of capitalist agriculture was strongly influenced by the work of 19th century natural scientists, in particular by the German chemist Justus von Liebig. The latter had discovered that natural systems, like the nutrient cycle, have their own metabolism which operates independently from the social and allows for longevity and re-generation.[47] From his diverse research in the natural sciences, Marx developed a materialist critique of modern agriculture, employing the concept of a 'metabolic rift' to understand how capitalist operations were undermining the regenerative capacities of ecosystems.

While soil erosion was a chief concern of environmental degradation in Marx's time, Marx also extended the analysis of metabolic rifts to deforestation and stock farming (see Saito 2016). Researchers have further extended Marx's model of the metabolic rift to understand the interruption of the cycling of material elements that support various ecosystems, including ocean metabolisms, hydrological cycles, and up to the "level" of the biosphere to understand how capitalism has (primarily via the burning of fossil fuels required to furnish compounding growth), created an expanded rift in the carbon cycle, which leads to global climate change (see especially, Clark and York 2005; Foster 2010).

In line with the arguments advanced here, part of the impetus behind this rethinking of Marx's concept and analysis of social metabolism and ecological rifts has been to further a historical materialist interpretation of ecological degradation and stress the importance of integrating natural scientific knowledge within the critique of capitalism. While the science of ecology and the knowledge of the unintended consequences of our actions was relatively limited in Marx's time, such understandings have since developed and deepened.

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[47] As Magdoff (2011) explains, metabolism refers to the work done inside an organism or a cell as it goes about its normal operations. It involves the building up of new organic chemicals and the breaking down of others, the recovering of energy from some compounds, and the use of energy to do the work. However, a critical part of the metabolism of a cell or large organism is constituted by the exchange of materials with its environment and with other organisms: obtaining energy-rich organic molecules and individual elements necessary to make all the stuff of life, including oxygen, carbon dioxide, nutrients (such as nitrogen, phosphorus, potassium, and calcium), and water.

By virtue of the sheer scale, complexity, scope, and consequences of contemporary socio-ecological transformations, ecologists and climate scientists have learned more about how the global climate system actually functions and the pressures that our actions exert on various ecosystems. In Foster's work, as in several other eco-Marxist analyses (see especially Angus 2016), there is therefore a clear enthusiasm for the development of ecological science and ecological thinking, seen as representing a movement towards more relational, complex, historical, and materialist forms of analyses (Foster 2010). Ecology is itself an important historical development, emerging as it does within the explosive development of capitalism and its global impact. It aims at a dialectical unification of social and natural phenomena and breaks down dualistic understandings by explaining the complex interdependencies of organisms in the environment and bringing forth knowledge concerning the protection and well-being of humans and other species.

At the same time, Foster expresses a serious concern with an anti-scientific tenor he locates in many left and Marxist perspectives. This reflects his contention that the world's physical and natural scientists should be joined by those providing an analysis of the dynamics of capital accumulation in order to understand the full extent of the ecological crisis. Furthermore, for him, scientific knowledge producing high-quality, complex descriptions and understandings of anthropogenic climate change should be one of the key sources of information contributing to the eventual resolution of environmental degradation under socialistic conditions (See especially Foster, York, and Clark 2011, 35-8 and 289-343).

At the level of strategy, the implication is that winning over these intellectuals is an important component of today's counter-hegemonic politics. In the context of the deepening crisis, the "class affiliations" of this group remain very much in question, as does the issue of whether they might actively participate in an anti-capitalist or anti-neoliberal movement. Indeed, we have already begun to see the emergence of "scientist activists," some of whom recognize the systemic nature of ecological degradation and at times position themselves directly against capital and call for drastic social transformation. While most are not explicitly revolutionary, their support of the status quo is clearly tenuous.

Conclusion

In contrast to narrow interpretations of the concept of forces of production that reduce them to technological 'hardware,' Marx's concept was much more ecologically embedded. It can be taken to refer to the dimension of human existence through which we are purposefully linked to the rest of nature. This broad usage provided him with a means of examining how capital's appropriation and development of such forces torques them in a quantitative direction (bound up with the compulsion to increase labour productivity as a means of extracting relative surplus value), and activates epochal transformations and developments in them. From this vantage, he did not blindly endorse the "total development" of the productive forces, as critics (and some supporters) aver. Instead, he considered how such development took place at the expense of disrupting the sustainable metabolic interaction between humans and the rest of nature, eroding the material conditions for sustainable and friendly human life. Reflecting this understanding, the potentials he gleaned in the productive forces included qualitative capacities, such ecological knowledge and (planned) cooperation, which allow us to appropriate aspects of non-human nature in ways that preserve and enhance rather than degrade ecosystem health.

Part 2 – Canadian Fossil Capitalism and Productive Forces

As Lefebvre suggests (1988), refining conceptual tools from the Marxist canon is a basic procedure of historical materialism. As he contends, concepts and the hypotheses derived from them are not given once and for all; instead, they require reinterpretation according to changed historical circumstances and new conjunctures. Such a procedure can lead to partial rejection, as well as to conceptual recalibration and regeneration. It can enable a renewed analysis of the practices and contradictions that constitute a mode of production and a social formation, while illuminating potentialities for change that exist within the present.

The first portion of the dissertation focused on reconceptualizing the forces of production. I began by outlining ecological critiques of Marx based on his optimism in the potential of developing aspects of productive forces dedicated to advancing productivity and productive output. Such views need to be approached in light of historical context, as well as in regard to the qualitative and human developmental content of Marx's arguments, which have little in common with 'productivism.' Following this, I challenged both the thesis of neutrality of forces of production that predominated much Marxist and left thought in 20th century, as well as the strict identification of productive forces with advances in productivity and productive output. In contrast, I pointed to the forms of environmental destructiveness (and social domination) women into the structure of productive forces as they are developed in service of capital accumulation, while arguing that forces of production also include capacities and powers that reflect the need to maintain, restore and improve ecosystem health. The latter understanding opens to an analysis of how capitalism critically fetters the ecological use-value aspect of the productive forces.

Next, I provided an ecological reading of the concept of forces of production in Marx's own work, while drawing out and advancing its implications through recent scholarship. A broad and ecological conceptualization can be seen in Marx, providing the contours of his historical and sociological analysis of capital's appropriation of and discipline over the process, powers and capacities through which we are linked to the rest of nature. As analyzed by Marx, capital (via processes of primitive accumulation) expropriates and then reshapes productive forces in a manner 'adequate to its form.' This occurs within a work process that is internally organized by capital and derives its character via commodity production, hence, from the dominance of the value form. The forms of knowledge that are subsequently pursued, the networks of productive collaboration that are instantiated and the technologies and infrastructural networks that are developed, are increasingly revolve around the quest for exchange-value. Under the 'whip of competition,' firms (increasingly large monopolistic corporations) moreover are compelled to increase the productivity of production processes, which entails and presupposes rising matter and (at a system level) energy throughput and thereby growing emissions. Such an account provides us with an indispensable foundation for understanding the deep structural relations and processes driving contemporary ecological crises and points to the alienation and perversion of humanity's productive capacities and potentials under capitalism.

While not the only form of ecological degradation and not disconnected from other markers of metabolic rift, climate change issues from the flagrant and dangerous "mismanagement" of the metabolic relation. In the context of today's deepening climate rift, gaining social control over the 'mediations' through which the social metabolism takes place is an urgent matter. In decommodifying the forces of production, a 21st century green socialism must detach these mediations from capital's growth imperative and begin a process of their democratic creative-destructive transformation.

Moreover, I have argued that a generous conception of productive forces, read in light of recent Marxist scholarship, helps not only reveal the wastefulness and destructiveness that accompanies capital's development of productive forces, but also discloses nascent and unfulfilled productive capacities vital for developing a less antagonistic coevolution with the rest of nature. While they were already glimpsed by Marx, today, in our era of global ecological crisis, we can more clearly see that ecological thinking and knowledge themselves as such an advancement in the productive forces. Yet such knowledge is clearly underutilized, operating at the margins of an anti-ecological system. It has provoked only minor adjustments to the system that do not halt, but instead narrowly mitigate ecological degradation.

Associated contemporary technologies, such as systems for harnessing and transmitting renewable energy flow, are also part of the development of productive forces and vital for restoring the carbon cycle. Indeed, the scientific consensus on global warming and on the imperative of timely climate action is clear. A rapid shift away from fossil fuels and a transition to renewable energy sources is an urgent necessity within the next two decades.[48] However, the development of green energy has been slow and studies have shown that for the most part non-fossil fuel energy sources have been added to the 'energy mix' only incrementally and on top of a net expansion in the consumption of fossil fuels (York 2012; York and McGee 2017).

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[48] Estimating our current 'carbon budget,' Oil Change International finds that between 68 and 85 per cent of extractible fossil fuel reserves must remain in the ground if we are to have a realistic chance of limiting global warming to 1.5 to 2 degrees Celsius (Muttitt 2016).

Part 2 of this dissertation moves from an abstract-simple analysis focused on reconceptualizing productive forces (accompanied by a limited analysis of their development and fettering by 'capital in general,' and with reference to core structural features of capitalism) to a concrete-complex analysis of fossil capitalism in action. Focusing on the Canadian context, I analyze the deepening of fossil-powered productive forces – pointing to the infrastructures, technologies and knowledge networks bound up with unconventional fossil fuel extraction, processing, transport – and the simultaneous fettering of renewable energy and ecological knowledge itself. On this analytic plane, the examination of fettering includes an investigation into carbon capital's strategic efforts to colonize and fashion such green productive forces in a manner that is consonant with the accumulation strategies and power relations permeating fossil capitalism.

Part 2 and the Dual Movement from Abstract-Simple to Concrete-Complex

As Jessop (2002) explains from a critical realist perspective, the movement from abstract to concrete entails the increasing *concretization* of a given phenomenon (such as crisis tendencies), seeking greater understanding of its specific forms in specific conjuctures. In this regard, I shift from the preceding focus on a 'generic' contradiction between forces and relations of production (by appeal to the basic structural features and overlapping contradictions of capitalism as a mode of production) to the development and fettering of productive forces in the current period of fossil capitalism, and within a national variant. In the process, the mechanisms which 'fetter' productive forces are developed and refined. Within relations of production, I emphasize modalities of corporate power, particularly the power of 'carbon capital,' including the science and technology infrastructures that support the sector, without losing sight of how these forms of power and linkages are rooted in structural features of capitalism. The second movement from simple to complex introduces *further dimensions* of a given phenomena (Jessop 2002, 5-6). Here I outline further features and aspects of 'relative' developmental and use fettering of green productive forces, analyzing them not only theoretically, but through empirical study into actual tendencies. In the movement from simple to complex, a greater number agencies (concrete institutions, firms, organizations and network linkages) which maintain and stabilize the accumulation of fossil capital and reflect the interests and priorities of large corporations are brought into view, producing a more complex picture. As Jessop maintains, the movement from abstract-simple to concrete-complex analyses is strategically necessary as capitalism's contradictions cannot be solved (even if partially and provisionally) in the abstract. How the current contradiction between the forces and relations of production (particularly here the fettering of ecological knowledge and renewable energy technology) is resolved, will be decided through the formulation–realization of specific strategies and projects at various economic and political scales in specific spatiotemporal contexts.

While the focus on fossil capitalism in motion furnishes a more detailed and nuanced view of the fettering and development of productive forces in the present, it necessarily limits the focus of a green-dialectical take on them to one urgent feature of contemporary interlinked ecological crises and to the urgent present impasse of fossil capitalism as it is posed in a specific national context.

I begin by 'mapping' key crude oil and gas infrastructure networks in Canada and analyzing several key pipeline and infrastructural proposals being contemplated to facilitate the expansion of these industries. This provides context and background on fossil fuel development in Canada, while pointing to the inertia posed by fixed fossil capital development.

Chapter 5 – Climate Change and the Networked Infrastructures of Canadian Fossil Capitalism

Building from Marx, as well as recent literatures on industrial metabolism, this chapter provides a networked and metabolic analysis of the infrastructures that surround, process and move mined carbon in Canada, and highlights pipelines and other fixed capital proposals designed to facilitate the expansion of the fossil fuel industry. First, I trace the flow of oil and gas through a system of pipelines, processing plants, petrochemical complexes, refineries, tankers, and gas distribution infrastructures,[49] and highlight the patterns of production, consumption and waste (especially emissions) that surround them. Second, I elucidate the networks of corporate power expressed and embedded in them. I concentrate on the three largest carbon transporters in Canada – Enbridge, Kinder Morgan and TransCanada – while revealing their connections to other carbon and industrial firms along the commodity chain, as well as to financial fractions of capital via shareholding and lending relations. Together, these two 'networked lenses' provide insights on the deep path dependencies of existing and proposed fossil capital infrastructure, while also identifying prominent firms and actors who are working to lock in a petroleum powered metabolism, and lock out alternatives. A focus on these unelected 'architects' of our social metabolic future informs a discussion of the barriers to a rapid and comprehensive decarbonisation of the energy system, while an analysis of energy infrastructures invites reflections on the spatial dimensions of alternative energy futures.

[49] I stop short of following oil into the retail fossil fuel network of gas stations. This retail network does, however, form a critical part of the fixed capital investment that locks-in fossil fuel commitments.

As a point of departure, I revisit Marx's insights on the dynamics of infrastructural formation (see Chapter 4, 116-121 for the more detailed account). His perspective provides a foundation for contemporary interdisciplinary research on the urban or industrial metabolism via 'networked infrastructures,' which we review following Marx. This literature sets the context for the analysis of fossil fuel infrastructures in the Canadian context.

Social Metabolism and the Role of Infrastructure

The concept of metabolism emanates from 19th century natural science, especially biology, and refers to the internal processes of an organism. Organisms maintain a continuous flow of exchange of materials with the environment and other organisms to provide for their production and reproduction. The concept entered the social sciences via Marx, who as we have seen introduced the notion of the 'social metabolism' to understand the complex material interchange between human beings and natural systems. He analyzed the human interchange with the rest of nature through production and commodity circulation (both of which belong to the process of production broadly defined), as well as in terms of the wastes this produces.

Production and commodity circulation proceed through constructed instruments of labour (tools and machines), including means of transport and circulation, together with the knowledge and skill they embody. As Marx suggested, "Nature builds no machines, no locomotives, railways, electric telegraphs, self-acting mules etc. These are products of human industry; natural material transformed into organs of the human will over nature, or of human participation in nature" (Marx 1993, 706). While Marx pointed here to the importance of both machinery and means of circulation in 'mediating' our relation to the rest of nature, in *Capital* he focused on infrastructures more sharply, defined as fixed capital of 'large-scale and great durability.' The category refers to a range of items such as ships, docs, canals, ports, damns, factory buildings, blast furnaces, pipelines, highways, electrical power transmission lines, power stations, railways and so on.

While relatively few society-nature researchers examine large-scale infrastructure formation, Marx considered them to be a vital component of that relation. They are constructed from natural materials, often involve the re-organization of ecologies, and subsequently process, structure and mediate the flow of resources to sites of production and consumption. In and of themselves, infrastructures are not negative; they do not necessarily imply the conquering of or even control 'over' extra-human nature. Infrastructures like other aspects of the productive forces do, however, express certain political and economic priorities, interests and power relations, and have important social and ecological consequences.

As we saw in Chapter 4, Marx analysed two interrelated dimensions surrounding their formation under the dynamics of 'generalized commodity production.' The first aspect concerns the movement of raw materials from sites of extraction to sites of production. The commercial viability and value of raw materials, he intimated, depends in part on transport costs, and therefore capital is driven to produce innovations in transport infrastructure (including growing 'economies of scale' in transport), in order for a mass of extracted raw materials to reach often distant points of production. In this connection, we noted that innovations in one part of the 'commodity chain', such as new techniques for extracting gas from shale formations via hydraulic fracking, demand and often stimulate innovations at further points in the chain, such as in the production of LNG tankers, designed to move liquefied natural gas over long distances to reach de-liquefaction plants.

The second, closely related feature concerning capital's revolution in this dimension of productive forces, concerns the separation-in-unity of production and consumption. By virtue of the dynamic productivity of large-scale fossilized industry, capital produces an immense collection of commodities, yet, as Marx suggested, this in no way guarantees their sale. The *realization* of this productivity requires expanded markets for exchange and the creation of extensive and long-term investments in the form transport networks (typically powered by fossil fuels) and fixed, often immobile infrastructures that connect points of production to points of consumption. Capital will continually seek to 'overcome' spatial barriers in an effort to reduce the time between the production and exchange of commodities: "Capital by its nature drives beyond every spatial barrier. Thus, the creation of the physical conditions of exchange – of the means of communication and transport – the annihilation of space by time – becomes an extraordinary necessity for it" (Marx 1993b, 524).

While already staggering in Marx's time, today's continent-spanning 'mega-corridors' (Hildyard 2017) and the associated re-engineering of ecologies and geographies they entail, dwarf those he could have possibly imagined. While Marx glimpsed the beginnings of this process, particularly in the nineteenth-century development of railway networks, the geographies of raw material extraction, production and consumption have been reconfigured to an unpresented degree, such that these are often thousands of kilometres from each other. As Hildyard details (ibid), this unprecedented geographical fragmentation has meant that the choice of location for commodity manufacturing no longer rests on intrinsic qualities of places and proximity to sources of raw materials (or consumers), but is rather driven primarily by a concern for maximum surplus value, thereby embracing considerations such as labour costs, the skills of the available work force, the local regulatory environment and tax regime.

Concentration of Capital and Credit

As with other forms of fixed capital (i.e. machines), Marx emphasized the tendency of infrastructures to return their value piecemeal, rather than all at once. They require a considerable initial outlay of resources, resources that do not immediately generate a complete return on the initial investment. Fixed capital's lack of flexibility also means that once it is installed, it can only be used in a single way, and subject to particular spatio-temporal parameters. It is frozen into a given functionality. Because fixed capital can return the value invested in it only piece by piece, it can also do so only so long as the conditions for its functionality are maintained.

In the early stages of English industrial capitalism, Marx noted that large infrastructural projects were rarely carried out on a capitalist basis, but instead at communal or state expense. Given the massive outlays of capital required for large-scale fixed capital projects and the risks associated with them, this dynamic is ongoing and individual capitalists, as Marx already noted, continually seek to "shift the burden onto the shoulders of the state" (Marx 1993b).[50] Yet for accumulation to function smoothly and consistently, capital must be able to produce large-scale infrastructures within its own production process. Marx highlights the concentration and centralization of capital in the form of the corporation and the credit system as necessary enabling conditions. Without these developments, large-scale capitalist infrastructural projects would be virtually impossible.

[50] David Harvey has provided a fruitful analysis of the imbrication of capital and the state in the construction of the built environment, pointing to the contemporary predominance of private-public partnerships and how the coordination and management of monetary flows required for large-scale infrastructural projects draw the state and capital together in what he calls the 'state-finance nexus' (see Harvey 2011, 46-50).

While the corporate form was not fully consolidated until the 20th century, in the third volume of *Capital* Marx reflected on its early emergence in the nineteenth century in the form of the modern 'joint stock company' (JSC). The JSC represents the aggregation and pooling of socialized forces of production. Moreover, with the JSC and its accompanying form of shareholder ownership (ownership taking the form of shares issued on the stock exchange), barriers to raising capital for large-scale and infrastructural projects could be overcome. Therefore, in the JSC, available money capital becomes less of a barrier to expansion, as firms gain access to a larger pool of capital and are no longer dependent on vast concentrations of individual property.

The second major path to the concentration and centralization of capital occurs through credit and the credit system. As Marx noted, the source of money capital in the productive circuit may come in the form of a loan to a 'productive' capitalist. Marx referred to this form of money capital as 'interest bearing capital,' that is, money lent out for a price in the form of interest for which the lender relinquishes control of the sum that is lent. The process of financing constitutes a relationship between money capitalists who earn interest by lending to productive capitalists. Credit therefore emerges from exchange relations between different fractions of capital. Yet the supply of interest-bearing capital requires *recurrent* access to idle (hoarded) savings of all capitalists.[51] In a developed credit system, financial institutions pool idle savings and turn them into concentrated money capital resources available to a few industrial producers (Marois 2013). Credit therefore relieves individual capitalists of some of the burden of hoarding massive amounts of capital in

[51] In contemporary capitalism, corporations gain access not only to idle savings of other capitalists, but also of individuals and collectives who are drawn into the financial system through interest on savings, mortgages, pensions and so on.

advance of the purchase of fixed capital and coverts the payment for that fixed capital into an annual one.

Metabolic Rift

Based on his diverse research in the natural sciences, Marx developed a materialist critique of large-scale capitalist industrialization. Emphasizing the notion of a rift in that metabolic relation, he showed that capitalist operations (especially in the agricultural sphere) were undermining the regenerative capacities of ecosystems (Foster 2000, 2013). He considered specifically how minerals and nutrients in food, fibers and agro-industrial raw material were transported long distances to cities, while the waste resources and animal waste were not returned to the soil. Already in the 19th century, he saw that production chains were overstretched and wasting resources. Indeed, Marx likened 19th century industrialized agriculture to a 'robbery system,' pointing to a one-way movement by which the transportation of food and fibre over long distances between the country and the city meant that the soil was depleted of essential and regenerative nutrients, which rather than being retuned to the land, ended up contaminating open sewers and polluting rivers. This led in his time to a severe crisis in soil fertility and severe crises of urban pollution and public-health disasters.

As Foster (Foster 2000; Foster et al. 2011) argues persuasively, Marx's theory of rift was not merely an incidental observation or limited to the sphere of agriculture, but rather a logical extension of his analysis of the outward expansion of capitalist industry up to that point. It was used to analyze the problems in capitalist production of accelerated tempo, scale of production and spatial disjuncture (especially the antagonistic separation of town and country). Ecological researchers have subsequently utilized the theoretical perspective of Marx's metabolic-rift analysis to understand and address further contradictions in a number of areas, including in the carbon metabolism or in constraints in the metabolism of atmospheric 'sinks,' which have generated the global climate crisis (Clark and York 2005b).

In the next section, I turn to recent research on the 'industrial or urban metabolism', which extends Marx's perspective on the social metabolism and ecological rift by analyzing material and energy flows through such networked infrastructures and in light of the wastes (especially carbon emissions) this produces.

Industrial Metabolism and Networked Infrastructures

Work in environmental sociology, and urban political ecology on the 'industrial' and 'urban metabolism,' draws heavily from Marx's concept of social metabolism and his analysis of fixed capital formation. Such approaches frame and analyze this metabolism, broadly, as a dialectical process by which the raw materials of nature are transformed into commodities, services and finally wastes. There are two distinct but closely related approaches advancing this view.[52] 'Industrial ecology' is concerned especially with quantifying material and energy flows in 'socioeconomic systems,' be they the global economy, a nation state or national economy, a regional unit such as a city, or an economic sector (Fischer-Kowalski 1998; Fischer-Kowalski and Hüttler 1998; Girardet 1996; Pauliuk, Majeau-Bettez, and Müller 2015). It follows the circulation of materials and energy in industrial society through the chain of extraction, production, consumption and disposal and has introduced a suite of metrics to measure these flows. These include techniques such as Material Flow Analysis (MFA) (a systematic assessment of the flows and stocks of materials within a system

[52] For historical and comparative reviews of 'industrial ecological' and 'urban political ecology' approaches see (Newell and Cousins 2015) and (Wachsmuth 2012).

defined in space and time) and Lifecycle Assessment Analysis (LFA) (which evaluates multiple environmental impacts of a product from "cradle to grave") (Pauliuk et al. 2015).

Most commonly, the approach is used to map the ecological 'footprint' of nation states, cities, economic sectors or industrial processes and to develop strategies for reducing throughput and optimizing resource use (Newell and Cousins 2015). It has also been used to address broad historical materialist questions concerning transitions in modes of production (such as from agrarian to industrial societies) (Fischer-Kowalski and Haberl 1993; Haberl 2007), and has been fruitfully combined with world-systems approaches to analyze unequal patterns of development and ecological exchange (Hornborg 2010). Girardet's (1996) influential work draws heavily from Marx's analysis of metabolic rifts in framing the flow of raw materials from an ecological "hinterland" into the metropolis, as entailing 'linear metabolisms.' While nonhuman nature is sustained by a series of 'circular metabolisms' (the waste of one organism is the sustenance of another), with growing urbanization (especially mega cities) there argued to be a proliferation of one-way flows – resources in, wastes out (see also Wachsmuth 2012).

The closely related literature in urban political ecology (UPE), a hybrid field at the intersection of political ecology and urban geography, focuses on the socio-natural metabolism of cities, mapping the flows of goods, materials, water, nutrients and waste into and out of the metropolis (Kaika and Swyngedouw 2000; Monstadt 2009; Scott 2013; Swyngedouw 2006). Such flows, the literature emphasizes, enter and exit the city and communities via 'networked infrastructures,' such as energy, water, wastewater and transport systems (Kaika and Swyngedouw 2000; Monstadt 2009; Scott 2013). These infrastructures are themselves part of the transformation of nature through labour and also structure and facilitate the process of socio-environmental transformation and metabolization. They act as a critical 'interface' between society and non-human nature (Kaika and Swyngedouw 2000).

In a metabolic analysis, infrastructures, such as the 'end' of a pipeline, are thereby conceived of as systems in which labour processes convert raw materials (crude oil, gas or bitumen), energy and labour, into commodities (gasoline, liquefied gas, petrochemicals) and into waste (especially water and atmospheric pollution) (Scott 2013). While emphasis is often placed on the complex networks of circulatory systems within urban environments or "socio-natures," the urbanization process extends beyond the city's (indeed also the nation state's) political borders (Ghosn 2010; Swyngedouw 2006). Infrastructures in this view are understood to extend and accelerate the ecological metabolism of the city, connecting the metropolis to often distant sites of resource extraction and production that sustain them and which in turn act as a sink for its emissions (Monstadt 2009). The perspective is echoed in the global cities literature, where mapping the flow of goods through networked infrastructures reveals relations of interdependence and unequal ecological exchange between the 'metropolitan core' and 'extractive periphery' (Sassen 2009).

While a number of commodity flows are analyzed in these literatures, corresponding to growing environmental concerns with climate change, the role of energy flows and energy networks (and in turn their contribution to rising emissions) underscoring urbanization is increasingly theorized (Castree and Christophers 2015; Granoff, Hogarth, and Miller 2016; Huber 2015; Monstadt 2009; Sayre 2010). Carbon arteries, like other infrastructures of commodity transport, fix capital in place to move fossil fuels from sites of resource extraction to energy intensive industrial sites and urban environments. Carbon powered electricity networks energize production sites and cities, while oil and gas pipelines connect to refineries and a further network of tanks, trucks, ships, roads, rails, as well as gas distribution infrastructures, further fuelling industry, transport, buildings and homes.

As Huber (2015) suggests, echoing Mitchell (2011), 'following the carbon' through infrastructural networks reveals the extent to which the built environment has been constructed around fossil fuels and how these networks work to lock in carboniferous forms of production, circulation and consumption, and therefore to ensure rising emissions. While many analyses of the uses of fossil energy focus on individual consumption in the residential sector, a focus on infrastructural networks encourages us to 'scale up' our view of use, pointing to the importance of large industrial consumers such as in industrial, transport and commercial sectors. As Sayre (2010) submits, the infrastructures of carbon capital steer and regulate energy related behaviour in ways that are often beyond the 'user's' control. Transportation infrastructure, for example, shapes the flow of materials and people, while electricity generation and energy infrastructure largely determines the emissions intensity of buildings, homes and factories. Given its fossil fuel dependence, the built environment, he writes, "mediates economic production, exchange, and consumption in ways that both presuppose and reinforce high rates of GHG emissions" (2010, 85).

These infrastructures are a key component of the fixed capital of urbanization, yet once completed they are "buried underground, invisible, rendered banal and relegated to an apparently marginal, subterranean underworld" (Kaika and Swyngedouw 2000). They are part of our "energy unconscious" – a component of a series of interconnections that are often out of sight and out of mind (Shannon et al. 2011). In their construction, however, especially in the current landscape, they are highly contested.

Canadian Carbon Corridors and Power

In the Canadian context, Danya Nadine Scott (2013) has recently provided an overview of key networked infrastructures of unconventional carbon extraction, centering the environmental justice implications of new oil pipelines and their associated infrastructural complexes. With the shift to 'unconventional' carbon extraction (fracked gas and oil, the tar sands, deep offshore oil and gas) or "extreme energy" (see Pineault 2016, 2018), she notes that these corridors of transport have become increasingly diffuse and the fixed capital sunk in extractive chains to process and refine carbon has become more costly, both economically and in terms of ecological impacts. Moreover, by mapping these infrastructural arteries, she reveals that the immediate environmental costs of this connectivity are typically born not in urban centres, but upstream at sites of extraction, midstream in rural and First Nation communities, as well as downstream at 'end of the pipes' often located at the outskirts of cities where the inputs of labour, capital and technology (in the form of refineries and shipping depots) required to transform energy into usable form are located. As she argues, the routes of a chosen pipeline reflect existing (and geographically embedded) power relations and further cement the spatial organization of environmental inequalities in Canada.

While Scott points to the skewed distribution of costs locally, a sizeable body of literature in Canada draws from Harold Innis and the notion of a 'staples trap' or 'resource curse' to analyze carbon extractive chains and transport corridors in relation to Canada's economic development more broadly (Clarke et al. 2013; Haley 2014; Pineault 2014; Watkins 2006). As this literature suggests, with the current bitumen development model in Canada, classic features of a "staples economy" are evident. This is reflected in enormous investments in production and transportation infrastructure for the export of bitumen in raw form to more powerful industrial centres in the global economy (especially the U.S.), high levels of reliance on foreign capital and enhanced political influence of carbon corporations, which together help constitute the formation of a 'first world petro-state' (Adkin 2016b; Clarke et al. 2013).

Laxer (2015) provides a concise history of pipeline development in Canada, emphasizing the export orientation of fossil capitalism in Canada, while pointing to the role of neoliberal deregulation and free trade agreements in cementing that orientation. He notes that the building of gas and oil pipelines heading south to the U.S and the eclipse of east-to-west routes began in the 1970s and that the 1989 Canada-US free trade agreement and the 1994 NAFTA bolstered these patterns (ibid). As he explains, the proportionality clause in NAFTA, drafted under input from carbon corporations, formerly mandated that three-quarters of Canadian oil production and just over half of its natural gas are made available for export to the U.S. Under proportionality, Canadian exports of oil and natural gas could rise or fall through "market" changes (essentially, the decisions taken by carbon corporations) – but the federal government could not legally reduce carbon energy exports to cut emissions, nor redirect oil currently exported to the U.S. to eastern Canadians. These investor rights provisions, which empower foreign investors, would thwart efforts at reducing emissions, including the development of a national decarbonization plan. However, a new trade agreement that builds on and modifies the trade policies of NAFTA, called the "United States-Mexico-Canada Agreement" (USMCA) was created on October 1, 2018. While USMCA has not yet been ratified, it removes NAFTA's "energy proportionality clause," eliminating this barrier to sunsetting the tar sands.

In the analysis that follows, I trace the flow of Canadian oil and gas through a network of pipelines, processing plants, petrochemical complexes, refineries, tankers, and gas distribution infrastructures. I concentrate on the networks operated by Enbridge, TransCanada and Kinder

Morgan and detail a relentless push by them to expand and deepen these and the flow of oil they represent. These firms account for the vast majority of Canadian oil and gas transport and as we find, continue to concentrate capital within the Canadian carbon transport sector, through mergers and acquisitions. This concentration of capital is simultaneously a concentration of corporate power (Carroll 2016).

By examining these carbon transport systems in terms of webs, configurations or systems we bring into view the extensive fossil energy networks that underscore contemporary production circulation, consumption and waste flows (especially emissions), networks which are often hidden to those of us like myself who live in cities.[53] I consider how new pipelines and ongoing investments in the 'technology intensive industrial enclave' (Zalik 2011) that surrounds mined carbon will produce path-dependencies and contribute to the sense of inevitability surrounding the current (fossilized) infrastructural configuration. Next, I reveal their connections to other carbon and industrial firms along the commodity chain, as well as to financial 'fractions' of capital via shareholding and lending. These relations bring financial firms into a close relationship with the fossil fuel industry and produce a strong vested interest in pipeline expansion and the increased flow of oil they represent.

To provide context for the analysis (and the analyses in subsequent chapters), I begin with a broad overview of oil and gas development in Canada, before highlighting the extensive oil and gas infrastructure operated by the 'big three' transporters and their push to develop new large-scale

[53] In pointing to the 'geographies of consumption' I have conflated industrial and personal (individual every-day) use of hydrocarbons and the infrastructural networks that support them. Therefore, I have conflated fixed capital as part of productive forces strictly speaking from fixed capital that could be seen to belong to the 'reproductive forces of everyday life' (See Huber 2013c). The electricity grid, for example, powers both homes and production, while gasoline stations fuel trucks that move commodities to sites of further production or consumption, as well as enabling privatized automobility.

pipeline proposals across North America that would significantly expand unconventional oil and gas development in an era of deepening climate crisis.

Canadian Oil and Gas Boom

As Carroll (2017) remarks, in the same period during which the climate crisis has become widely recognized as the most urgent existential threat facing humankind, the Canadian economy has come to be focused significantly around carbon extraction. Indeed, the boom in unconventional fossil fuels – especially bitumen from the Alberta tar sands and fracked shale gas – has precipitated changes to the structure and composition of the Canadian economy, steadily elevating the importance of hydrocarbon resource extraction as a core industry (MacNeil 2014). In early 2014, at the peak of the oil boom, the extractive sector accounted for nearly 25 per cent of private investment, up from less than 5 per cent in the early 1990s (Pineault 2016). At this time, Canada also experienced a version of the "Dutch Disease," whereby the effects of the unconventional oil and gas boom caused an inflated dollar, leading to a decline in manufacturing and other export sectors, thereby further torqueing the economy towards carbon extraction (Laxer 2015).

Concomitant with this shift, we have witnessed a spate of new federal regulatory rollbacks and the formation of policy frameworks aimed at facilitating oil and gas development and other resource extraction (Carter 2014; Gibson 2012; MacNeil 2014). Most notably, amendments in 2012 to the Canadian Environmental Assessment Act eliminated much of the core of federal environmental assessment in Canada (Gibson 2012). In practice, the changes have meant that approximately 90 percent of major industrial projects that would previously have undergone federal environmental review no longer do (Johnston 2015). In the case of large pipelines and energy infrastructure projects, which cross provincial and international borders, the 2012 changes transferred responsibility for environmental assessments from the Canadian Environmental Assessment Agency to the National Energy Board (NEB), which must also conduct its own "national interest" assessment.[54]

Political regime changes federally, with the election of the Trudeau Liberals in 2015, appeared to portend a more circumspect approach to carbon extractive development, including the likelihood of tougher environmental regulations on industry and a serious commitment to achieving climate targets. During the 2015 election campaign, the Liberals promised to "modernize" the NEB and the environmental regulatory process as a whole, in order to restore credibility to the review process. In June 2016, the government began a formal review of Canada's environmental laws, as part of plan to revise laws that were introduced under CEAA 2012. In February 2018, the government introduced a bill (Bill C-69) to the House of Commons, which is meant to overhaul the assessment process for major natural resources and energy projects. While environmental groups have pointed to some overall improvements in environmental assessment processes, Bill C-69 is seen as a step backwards with respect to specific issues (particularly in regards to offshore oil and gas development in Atlantic Canada, where it appears to give oil and gas boards more power to participate in environmental assessments for drilling projects (MacDonald 2018)). It also provides few concrete measures for making assessments less susceptible to corporate pressure, a key feature

[54] The Trudeau Liberals promised to revamp existing environmental assessment processes, and in 2016 introduced an 'interim review process' that includes additional steps for oil and gas pipeline projects currently undergoing regulatory review. In June 2016, the government began a formal review of Canada's environmental laws, as part of plan to revise and overhaul laws that were introduced under CEAA 2012. It subsequently appointed an expert panel to examine the issue and then on June 29, 2017 published a discussion paper. In February 2018, the government introduced the bill to the House of Commons. At the time of writing, it is being reviewed by the Senate.

of any attempt to make environmental assessments credible (Fitzgerald 2018). At the time of writing the bill is being reviewed by the Senate.

Along with changes to environmental reviews, Trudeau actively campaigned on a shift away from the Harper government's model of limited consultation with First Nations surrounding resource development. After years of federal Conservative inaction on the file, the Liberals pledged to adhere to the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP), which requires free, prior, and informed consent for large-scale industrial projects.

Following his assumption of office in 2015 and in advance of COP 21, Prime Minister Trudeau further announced that:

> Canada looks forward to playing a constructive role at COP 21…We have an opportunity to make history in Paris – an agreement that supports a transition to a low-carbon economy that is necessary for our collective health, security, and prosperity. Canada is back, my good friends.[55]

The later ratification of the Paris Agreement in 2016 appeared to confirm this change of direction on climate policy. In Paris, Trudeau's Minister of Environment Catherine McKenna promoted a target of 1.5 degrees Celsius while most of the talks were about not exceeding two degrees of warming.

Yet federal policy continues to move away from the commitments made in Paris[56] (Hughes 2016; Lee 2017), while Indigenous rights and title are disregarded in favour of fossil development.

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[55] Prime Minister Justin Trudeau, speaking at the UN Paris climate talks on November 30, 2015.
[56] That this was a target that Canada had no intention of meeting became more apparent in the following year (see Gutstein 2018, 154-171). Indeed, the Liberals merely carried over Harper's previous goal of reducing greenhouse gas emissions by 30 per cent below 2005 levels by 2030. Interestingly, as Gutstein suggests (ibid), McKenna was among those insisting at Paris that there be a clause in the agreement authorizing carbon trading to assist governments in achieving their nationally determined contributions. The clause, which now appears in Article 6 of the agreement, means that high emitters like Canada can putatively reduce their

Trudeau's 2016 Pan-Canadian Framework on Clean Growth offers a policy program of slow domestic and market-based energy transition, to be funded by expanding capacity for bitumen production and transport in the medium term, alongside the taxation of those same resources when used domestically. Within this framework, the government has approved and actively championed new pipelines, despite affected Indigenous communities withholding consent to date, and despite clear evidence that the pipeline is at odds with Canada's commitment to lower its greenhouse gas emissions.

Canadian Oil Extraction and Infrastructure

Canada is currently the fourth largest producer and third largest exporter of oil in the world, and the fourth largest producer and exporter of natural gas (Natural Resources Canada 2017). Most oil production in Canada (nearly 80 percent) occurs in the province of Alberta, with the remaining 13.5 per cent occurring in Saskatchewan, 4.5 per cent in the province of Newfoundland and Labrador and 1 per cent in both British Columbia and Manitoba. Most of the oil produced in Alberta comes from its tar sands – an enormous unconventional petroleum deposit containing a tar-like mixture of sand, clay and water saturated with a dense and extremely viscous form of petroleum – bitumen – found under Alberta's boreal forest and wetlands, in a region that is larger than Florida. The tar sands are estimated to contain 1.7 trillion barrels of crude oil (the world's third largest reserves) or 98 per cent of Canada's established reserves (ibid), though a significant fraction of that total is non-recoverable at current levels of technology and market conditions. Tar sands development is possibly the largest industrial project in the world (Berman 2017).

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emissions by buying credits from other nations. The arrangement keeps the door to tar sands expansion open.

The first decade of the 21st century was a period of unprecedented expansion for Canadian bitumen development, the bulk of which has flowed south to the U.S. Indeed, approximately 70 percent of oil produced in Canada is exported, 98 percent of which goes to the U.S, especially the Mid-West (ibid). Oil and gas pipelines continue to be built for American consumption and we have recently witnessed a growth of pipelines that connect Canadian crude to refineries in the U.S. Gulf. The latter is home to the world's largest concentration of complex refineries that have coking units to break down heavy crude into lighter refined products.

Increasingly, however, the expansion of infrastructure for tar sands is justified as a means of getting bitumen from inland regions to new markets (especially China) via pipelines to "tidewater," where it would be loaded onto tankers for export. As Laxer (2015b) suggests, two key factors produced changes leading to the "search" for tidewater access. First, the discovery of major unconventional gas and shale oil reserves throughout North America has led to a North American oil and gas glut and depressed prices. Second, in 2011 President Obama halted the Keystone XL pipeline, prompting the need to find other markets for new additional volumes coming from Alberta's tar sands. While expanding the infrastructure to transport bitumen is publicly justified as a means of reaching East Asian and other developing global markets, many analysts suggests that there is little to no demand for tar sands oil in Asia (McKay 2018; Mikulka 2018). They therefore understand the push for tidewater access as a desperate and highly speculative move by an oil industry with few other options to increase production and suggest that any new coastal pipeline terminals are likely to ship their product overwhelmingly to the U.S. While issues of national unity and U.S. influence have not entirely disappeared from the conversation, pipeline debates in Canada today increasingly centre questions of increased pipeline capacity and "tidewater access," while robust and growing social movement opposition centres on ecology (both local environmental concerns and climate change) and violations of First Nations rights, title and sovereignty (Laxer ibid).

Tar Sands Growth and Infrastructural Networks

Until the mid-1990s the tar sands were deemed to be too risky and not commercially viable in the immediate future. However, with the combined effects of rising oil prices, the peaking of conventional production, and the creation of an investment friendly royalty regime and low tax rates, production from Alberta's tar sands increased by 260 percent between 1990 and 2010 (Huot and Grant 2012). It has taken huge capital investments to get the industry off the ground, not only in extraction but also for processing, refining and transport. By 2014, McCormack and Workman (2015) find that nearly 35 percent of business engineering structures in Canada (buildings, engineering construction such as roads and dams, machinery and equipment) were owned by firms that operate in Alberta. In fact, Alberta's oil and gas industry alone holds 26 percent of the country's entire business engineering capital stock, representing an enormous commitment to the production of fossil fuels (ibid).

Most bitumen production takes place in open-pit mines, some as large as three miles wide and 200 feet deep. Only a fraction of the reserves are close enough to the surface to be mined in this way, while bulk of the established reserves (over 80 percent) are deeper and must be extracted by an energy intensive process of 'steam assisted gravity drainage' (SAGD). The latter entails injecting high pressure steam into the ground to soften the bitumen so that it can be pumped to the surface. The tar sands and its appetite for energy have simultaneously spurred the development of natural gas pipelines and other infrastructure, while opening up new areas of natural gas drilling, especially in

Northeast BC. At the tar sands, natural gas is used both as an energy source to fuel the mining of bitumen via SAGD, and natural gas condensate is used to dilute bitumen (create dilbit) so that it can flow through pipelines.[57] Ben Parfitt (2018) reports that from 2007-2017 Alberta-bound shipments of natural gas from northeast BC increased by more than 230 per cent. In fact, he finds that virtually all the sizeable increase in BC's overall gas production in this period went to Alberta, where the largest consumer is the heavy oil industry (ibid). Demand for condensate has also led to the construction of pipelines carrying diluting liquids north such as Enbridge's Southern Lights, which runs from Chicago-area refineries to Edmonton. The Vantage pipeline, owned and operated by Pembina and commissioned in June 2014, also delivers ethane from North Dakota to Alberta.

The massive expansion of tar sands development requires an extensive network of pipelines heading south, as well as construction of new refineries and upgrading of existing ones designed to handle tar sands bitumen. About 40 per cent of Alberta's bitumen is upgraded into a lighter, higher-value crude oil (bitumen is transformed into an intermediate crude oil product by fractionation and chemical treatment) before being piped downstream to refineries for further processing.[58] There are four upgraders at the tar sands, one each at Suncor's base site, Syncrude's Mildred Lake, CNRL's Horizon, and Nexen's Long Lake operation. Whether upgraded or piped as dilbit, bitumen reaches a series of oil way stations, storage tanks, railheads and pipeline terminals on the outskirts of Edmonton, as well as in the small town of Harsity just south of Fort McMurray. The region

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[57] As a result, the accumulation strategies of prominent Canadian natural gas producers are densely tied to tar sands expansion. For example, Encana Corporation has been targeting condensate rich shale gas regions such as in the Montney and Duvernay regions of northeast BC and central Alberta (Encana 2016. Annual Report. See pages 16 and 17. Available from <http://www.encana.com/pdf/investors/financial/annual-reports/2016/2016-annual-report.pdf>.

[58] To remove the carbon, bitumen is heated in large steel coke drums at higher temperatures (480 degree Celsius) and for longer periods of time than typical conventional oil refinery is capable of. Hydrogen is added afterwards to make bitumen more like a liquid-fuel.

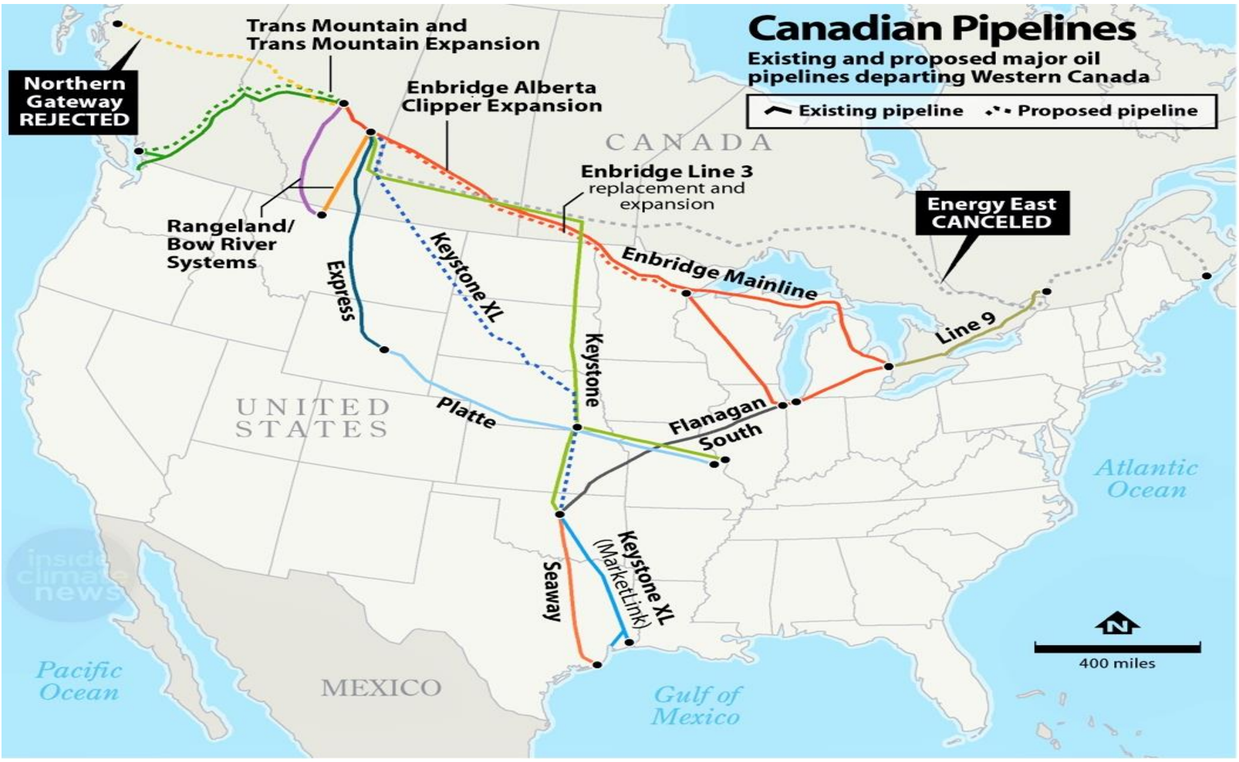
northeast of Edmonton past Fort Saskatchewan, often referred to as "Alberta's Industrial Heartland," is home to more than forty industrial facilities, mostly hydrocarbon related, including numerous petrochemical plants – the largest operated by Dow Chemical and MEGlobal (Turner 2017). In all, there are eight upgraders across Alberta, seventeen tank farms at six terminal sites and fourteen oil-by-rail terminals (ibid).

Only a specialized refinery with a coker unit can process bitumen and turn it into refined products such as fuel and only four refineries in Alberta and one in Ontario have them. Tar sands production has prompted coker builds and expansions in the U.S., especially between 2008-2013 (the construction of which has huge capital costs of US$2 billion) (Stockman 2013). After being refined, the tar sands oil that remains in the U.S. is primarily used to produce fuels (gasoline, diesel, jet fuel, heating oil) and petrochemicals. In 2016, transportation accounted for nearly 70 per cent of total U.S. fuel consumption, with 24 percent consumed by industrial production (U.S. Energy Information Administration 2016).

Given the energy intensive extraction process and extensive processing, upgrading and refining required to transform bitumen into commodified energy, recent studies have found that the lifecycle emissions (from extraction, upgrading, pipeline or tanker transport, refining and use) of bitumen from the tar sands range from eighteen to twenty-five per cent higher than conventional crude (Cai et al. 2015). As a result, tar sands products are the fastest growing source of greenhouse gas emissions in Canada.

Below I provide a closer view of the flow of oil through existing and proposed fossil capital infrastructure. Map 1 displays major Canadian export lines to the United States. As seen here, Alberta's tar sands feed four major export lines that provide the bulk of export capacity leaving the province: Enbridge's Mainline System, Kinder Morgan's Express and Trans Mountain Pipelines, and TransCanada's Keystone.

Map 1: Major Canadian Oil Export Lines (current and proposed)



Map Source: Inside Climate News (2019)

Enbridge's Oil Pipeline Network

Enbridge operates the world's longest crude oil and liquids pipeline system, with 30,040 kilometres of active pipe. It delivers approximately 2.8 million barrels of crude oil each day, primarily through its Mainline pipeline network (consisting of interconnected numbered lines), and transports roughly 64 percent of Canadian crude oil destined to the United States. One of Enbridge's main export pipelines in the Mainline system, Line 3, carries crude from Hardisty, Alberta, to Superior, Wisconsin. There it feeds into a network that carries oil to refineries in the U.S. Midwest and, increasingly, to the Gulf Coast, via Exxon Mobile's Pegasus pipeline. The latter carries diluted bitumen for 858 miles from Patoka, Illinois to refineries in Nederland, Texas. Enbridge has also recently completed construction of the 800 km Seaway pipeline (seen in Map 1) from Cushing to Freeport, Texas, with its joint partner Enterprise Products. The Seaway system has 400,000 barrels per day (bpd) capacity and reaches a terminal and distribution oil network originating in Texas City, Texas that serves all of the refineries in the Greater Houston area.

Enbridge is currently seeking to expand and replace Line 3, the largest project in Enbridge's history. The $7.5 billion project is positioned by Enbridge principally as a replacement and upgrading of existing pipes, yet Line 3 will also boost the capacity of its main export pipeline by 375,000 barrels per day, with the ability to expand it further in the future. The expansion is also being used to justify a second new pipeline, Line 66, from Superior onward across Wisconsin. The new larger pipeline would subsequently carry 760,000 barrels of diluted bitumen per day and would have the capacity to do so for the next 50-60 years. Considering only the upstream GHG emissions in Canada[59] (emissions from the extraction and processing of crude oils prior to their injection in the Line) Environment and Climate Change Canada estimates that the Line 3 project would contribute between 19 and 26 megatonnes of carbon dioxide equivalent per year (Natural Resources Canada 2016).

Line 3 expansion faces active on-the-ground resistance. An Indigenous led prayer camp near the Canada-US border south of Winnipeg is protesting construction already underway in Canada,

[59] Environment and Climate Change Canada considers only upstream emissions associated with new pipelines based on the assumption of a "presumed substitution effect" (that is, if we do not extract, other regions will).

and direct-action protests have been held at the Wisconsin-Minnesota state line to protest the Minnesota regulator's decision in July 2018 to approve a certificate of need for the project.[60]

TransCanada's Main Oil Lines

TransCanada operates an approximately 4,300-kilometre oil transport network. Its Keystone pipeline, pictured in Map 1, runs from Hardisty, Alberta, east into Manitoba where it turns south and crosses the border into North Dakota. From there, it runs south through South Dakota to Steele City, Nebraska, where it splits: one arm runs east through Missouri for U.S. refineries in Wood River and Patoka, Illinois, and the other runs south through Oklahoma to Cushing. From Cushing, crude is pumped to U.S. Gulf Coast refineries and distribution networks via TransCanada's 700,000 bpd Marketlink Pipeline System, completed in 2015.

Keystone XL is a proposed extension of the Keystone pipeline, involving a 2,785 kilometre route that would carry roughly 800,000 bpd from Alberta to refineries along the Texas Gulf Coast, passing through Indigenous territories in Montana, South Dakota, Nebraska, Kansas and Oklahoma. The Obama administration repeatedly delayed the pipeline and ultimately rejected it in November 2015, yet President Trump has since reversed Obama's rejection of Keystone XL and signed executive orders aimed at facilitating its construction. TransCanada has recently won approval for

[60] Enbridge also headed up the Northern Gateway Pipeline, a project that would have piped diluted bitumen and condensate between Kitimat in Northern BC and the tar sands region in Alberta. If constructed, Northern Gateway would expand the Kitimat Marine Terminal to include two ship berths and 19 storage tanks for diluted bitumen, while also increasing tanker traffic on the coast – bringing to up to 220 oil tankers per year that would navigate the waters of the Great Bear Rainforest. The project provoked widespread opposition from First Nations whose territories would be impacted, and in 2015 eight First Nations, four environmental groups and the private sector union launched a joint case claiming that the federal environmental assessment had failed to consider the threats to wildlife, oceans and Indigenous rights which the project posed. In 2016, the Federal Government rejected the Northern Gateway application.

the pipeline, and despite enormous resistance from environmentalists, landowners, Indigenous groups and municipalities, is championing its development.

Canada already exports about 3.76 million barrels of oil a day to the United States. Line 3 and Keystone XL would add 1.2 million barrels a day to that total, much of it destined for the U.S. Gulf Coast. It is unclear whether any Canadian crude reaching this coast will be exported. Currently, shipping the fuel from the U.S. Gulf Coast to Asia involves a 25-day trip through the Panama Canal, or a 50-day trip around South America. Reaching BC tidewater would cut travel time to twelve days, however, as suggested above there appears to be little to no current demand for tar sands oil in Asia.

Kinder Morgan Canada

Kinder Morgan Canada is a fossil fuel pipeline and terminal company operating in BC, Alberta, and Saskatchewan. It is majority-owned by Texas-based Kinder Morgan Inc., one of the largest energy infrastructure companies in North America. Kinder Morgan Canada holds a series of pipeline and storage assets and formerly owned the Trans Mountain pipeline (TPL). In a move that expresses the Government of Canada's deep commitment to sustain the oil industry, in 2018 the Government bought the TPL and its expansion project (discussed below) from Kinder Morgan for $4.5 billion.

The TPL transports both crude oil and refined products from Edmonton, Alberta to the west coast, with a capacity of approximately 300,000 barrels per day. In the Greater Vancouver area, transportation fuel (such as gasoline, jet fuel, and diesel) and lubricants reach the Burrard Terminals (three separate facility locations in both Port Moody and Burnaby) operated by Suncor. Suncor distributes the products on land (by train and truck) and on water via barges to distribution stations held by Petro-Canada (a subsidiary of Suncor).

Conventional crude from the TPL is processed at several marketing terminals and refineries in the central British Columbia region and the Greater Vancouver area. Of the oil that remains in BC, Chevron's Burrard Inlet area refinery and distribution terminals receive the most. Crude arriving from the TPL is transformed here into approximately 55,000 barrels of jet fuel, diesel, gasoline, asphalts, heating fuels, heavy fuel oils, butanes and propane each day.[61] An additional 30 per cent of crude transported by the TPL (or roughly 85,000 barrels per day) arrives at the Westridge Marine Export Terminal, in Burnaby. For every ten tankers that leave Westridge, eight go to California, one goes to the Gulf Coast and one goes to China.

The Trans Mountain Expansion Project (TMX) proposes to expand the existing TPL system by twinning the existing pipeline through Alberta and British Columbia. The project would increase pipeline capacity from 300,000 to 890,000 bpd. In addition to the construction of the new pipeline, the project includes new pump stations and storage tanks, and a new dock at the Westridge Marine Terminal in Burnaby, British Columbia. Considering the GHG emissions associated with extraction, upgrading, and refining within Canada, Environment Canada estimates that the expansion to the Trans Mountain pipeline system would contribute approximately 13 to 15 megatonnes of carbon dioxide equivalent per year to Canada's total emissions, bringing the total emissions of a 890,000 barrels per day pipeline to 21 to 26 megatonnes of carbon dioxide equivalent (CO2 eq) per year (Canadian Environmental Assessment Agency 2016). The further operation-related GHG emissions of the expanded TMP system have been estimated to be 407 kilotonnes (kt) per year of CO2 eq and

[61] The refinery supplies nearly 30 per cent of the province's gasoline, 25 per cent of the commercial diesel and 40 per cent of the jet fuel used at the Vancouver International Airport (Chevron Canada n.d.; Moreau 2012). In 2016, Chevron's refinery produced 506,166 tonnes of CO2 equivalent (Government of Canada 2016).

GHG emissions as a result of project-related marine shipping have been estimated to be 68 kilotonnes per year.

At the time of writing, growing protests and legal challenges organized by Indigenous, environmental, and local citizen-driven groups are underway against the Trans Mountain Pipeline Expansion (Zeidler 2018), and the provincial government in BC has made some moves to hinder the pipeline's construction (Nikiforuk 2019). Mounting anger and counter-protests have also been developing in Alberta and to some extent Saskatchewan (Patterson 2019).

Growing Natural Gas

Currently, nearly two-thirds of Canada's gas production take place in Alberta with a further 30 percent occurring in British Columbia and just 6 percent in the rest of Canada (Hughes 2015). With declining conventional reserves, the potential for Canada's gas future lies primarily in developing fracked shale and tight gas which are found in substantial plays in Northeast British Columbia and Northwest Alberta.[62] As intimated above, Alberta's oil sands operations currently account for more than 25 per cent of Canadian natural gas demand (National Energy Board 2017), while an addition fifty percent of Canada's remaining gas production goes to the U.S. Here the industrial sector is the largest consumer of gas, accounting for nearly 40 percent of consumption (U.S. Energy Information Administration 2016). Major natural gas consumers in the U.S. include the petrochemical industry (where natural gas is used as a feedstock in the production of methanol,

[62] The largest potential sources are in BC. Optimistic estimates suggest that up to 449 trillion cubic feet (tcf) of marketable gas is contained in the Montney (the most developed play), with a further 78tcf, or 12 percent, in the Horn River Basin, putting them on par with some of the larger basins in the United States (National Energy Board 2013). This amounts to 71 percent of the remaining recoverable gas in the Western Canada Sedimentary Basin, which contains the bulk of Canada's gas resources. The Bakken shale play which extends from Montana into Saskatchewan also is expected to contain an 2.89 tcf of marketable natural gas (National Energy Board 2015).

ammonia, and fertilizer) and other energy-intensive industries that use natural gas for heat and power. The second largest area for natural gas consumption is in electricity production, with use split nearly evenly across residential, commercial and industrial sectors (ibid).

Facing a North American gas glut, and in order to benefit from what appeared a few years ago to be a substantial mark-up between North American natural gas prices and those in Asia, the natural gas industry also began aggressively pursuing the development of a number of liquefied natural gas (LNG) facilities on BC's west coast aimed at reaching Asian markets. Developing LNG export would require a massive expansion of natural gas production and entail large-scale infrastructural development throughout northeast British Columbia, a region covered by territories of First Nations.

Protagonists promoting development of natural gas often characterize it as a "bridge" fuel, capable of aiding in the transition to renewable sources of energy. The bridge fuel argument is that natural gas burns cleaner and more efficiently than coal (in particular) and that, by coupling renewable energy with "low carbon" natural gas, renewable power's intermittency problem can be overcome by "firm" power available for the electricity grid. In BC, because Asian markets are the intended target, industry proponents argue that exporting LNG will enable reductions in coal use in particular (which is commonly used for electricity generation in South Korea and China), contributing to the construction of a "global green economy." However, the climatic merits of natural gas are often based solely on emissions from its combustion, while the lifecycle GHG emissions of natural gas (which include extracting, processing and transporting the gas; liquefying and regasifying in the case of LNG; and then combusting the gas to supply heat, generate electricity, or move vehicles) are significantly greater (Howarth 2014; Hughes 2015; Stephenson, Doukas, and

Shaw 2012). In the case of BC LNG, geoscientist David Hughes estimates that the liquefaction, transport, and regasification process would consume close to 20 percent of the total extracted gas (assuming gas-driven facilities) (ibid). In considering the lifecycle emissions of LNG extracted from shale and tight gas plays, Hughes along with other researchers (Howarth 2014) have found emissions levels higher than coal.[63] Other studies suggest that if methane emissions are minimized and the energy intensity of transport is reduced, the lifecycle GHG emissions of LNG are marginally lower than those of coal (see Council of Canadian Academies 2014). Nevertheless, marginal emissions benefits over coal are no grounds for the 'transition fuel' claim.

Licences and permits for exports fall to the National Energy Board, which has to date approved eighteen LNG export terminals in the province.[64] As with other "extreme energy" projects (Pineault 2016, 2018), LNG development requires massive amounts of capital outlay: terminals often involve investments of $10 billion or more, in addition to large expenditures on pipeline and upstream infrastructure. As a result, BC has seen some foreign investment and the announcement of a number of joint ventures between some of the largest global oil and gas companies.[65] Below I

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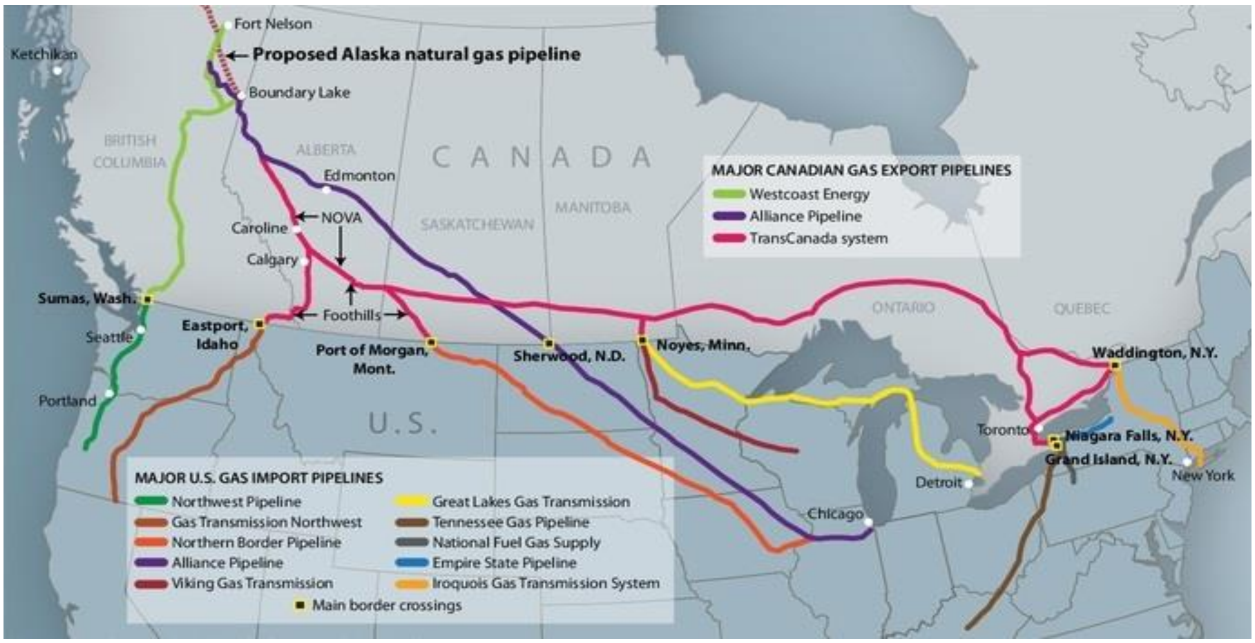
[63] Based on the high energy intensity involved in LNG transport, as well as high levels of methane leakage from fracking, Hughes estimates that over the next fifty years BC LNG exports to China would increase overall GHG emissions when compared to state-of-the-art coal facilities.

[64] For a list of approved terminals and terminals currently under review by the NEB, see https://www.neb-one.gc.ca/pplctnflng/mjrpp/lngxprtlcnc/index-eng.html.

[65] Aside from initial site preparation, to date there has been little actual sunk capital in these proposed projects. Companies have, however, purchased stakes in properties in the region (held mainly by Canadian gas and oil companies). For example, in March 2010, Encana signed an agreement with Korea Gas that saw the Asian company buy a 50 percent stake in properties in the Horn River and Montney shale gas plays. In August 2010, Penn West Energy Trust entered a gas joint venture with Japan's Mitsubishi Corporation to develop properties in the northeastern corner of British Columbia. Malaysia's national oil company Petronas is also invested $1.07 billion to gain access to shale gas assets in northeastern BC. LNG Canada (a consortium including Shell Canada, PetroChina, Korea Gas Corporation, and Mitsubishi) has proposed an LNG facility near Kitimat, BC, which would deliver fracked gas from the Montney region via TransCanada's Coastal GasLink. At the time of writing this last project is the most advanced and appears to be proceeding against a stream of resistance.

provide a closer view of key existing and proposed natural gas infrastructure networks, focusing on major lines operated by Enbridge and TransCanada who are also Canada's largest natural gas transporters and own substantial midstream operations. Map 2 displays major Canadian export lines to the United States.

Map 2: Major Canada, U.S. Export-Import Gas Pipelines



Map Source: Office of the U.S. Federal Coordinator (2014)

In addition to its extensive oil transport network, Enbridge is Canada's largest natural gas distribution company with 330,598 kilometers of natural gas pipelines across North America and the Gulf of Mexico. It also has a large, growing interest in natural gas storage and midstream operations. A large proportion of its natural gas infrastructure takes place through subsidiaries. Enbridge is 50% owner of Alliance Pipeline seen in Map 2, which transports fracked gas from northeastern BC and northwestern Alberta, underground through Saskatchewan, North Dakota, Minnesota, Iowa, to Chicago. Gas from the Alliance Pipeline connects to natural-gas processing venture, Aux Sable (which is jointly owned by Enbridge and Veresen and one of the largest natural gas processing plants in North America). Aux Sable's Channahon facility near Chicago supplies natural gas for home and industrial heating, and the natural gas liquids (NGLs) produced by Aux Sable are used in crude oil refining and gasoline blending, crop drying, as feedstock for the petrochemical industry and in the production of products such as polyethylene, rubber, plastics, solvents and foam materials.

In 2016, Enbridge began the process of a takeover of Houston-based Spectra Energy, which operated natural-gas pipelines (including the Westcoast Energy pipeline), local distribution companies and processing plants throughout North America, creating a $127 billion energy infrastructure company (Pulsinelli, 2016). As seen in Map 2, Enbridge's Westcoast Energy pipeline transports fracked gas produced in the Western Canadian Sedimentary Basin throughout BC and through interconnecting pipelines to other Canadian provinces and the United States. The system in BC accounts for 55% of gas produced in the province, while the gathering, processing and transmission of gas along Enbridge's Westcoast pipeline contributed a staggering 4,115,429 tonnes of CO2 eq in 2016,[66] approximately 35 percent of all emissions from large industrial processing facilities in BC.

Within the province, the Westcoast connects to TransCanada's Nova Gas Transmission system (described below) and Fortis BC's extensive local distribution system in BC's Lower Mainland. At the Canada-U.S. border near Huntingdon, British Columbia, it connects to Williams

[66] This is defined as all industrial facilities that emit the equivalent of 10 000 tonnes. The BC system includes its Dawson Plant, Fort Nelson Gas Plant, Fort Nelson North Processing Facility, Jedney I Gas Plant, McMahon Cogen Plant, McMahon Gas Plant, Pine River Gas Plant and West Doe Plant. See (Government of Canada 2016).

Northwest Pipeline, which is a nearly 7,000-kilometer bi-directional pipeline system crossing the states of Washington, Oregon, Idaho, Wyoming, Utah and Colorado.

TransCanada for its part operates over 91,000 kilometres of gas distribution, connecting with virtually all major gas supply basins in North America. It is also the continent's largest provider of gas storage and related services. Its longest pipeline system, the Nova Gas Transmission Ltd (NGTL), is an extensive gathering and transport system for gas produced in the Western Canadian basin, especially the Montney and Duvernay shale gas plays, which are located in northeast BC and central Alberta, respectively. The NGTL system continues to expand at a rapid pace, and TransCanada has added more than $2 billion in facilities between 2010 and 2015. New supply has entered the system, particularly from the Montney shale formation in the northwest portion of the system. The NGTL interconnects with TransCanada's Mainline at Empress near the Alberta-Saskatchewan border. The Mainline serves as a long-haul delivery system transporting natural gas from the Western Canadian Sedimentary Basin across Canada to Ontario and Québec to deliver gas to downstream Canadian and U.S. markets.

TransCanada is currently moving ahead with an additional $2-billion expansion to its NGTL system. The project focuses on increased gas transmission infrastructure in the Montney and Duvernay shale gas plays. NGTL expansion would include five new and separate pipeline section loops, totaling 230 kilometres, and the addition of two compression facilities, new meter stations and other associated facilities. The new pipelines would connect to TransCanada's larger conduits, enabling the company to ship growing volumes of gas to Ontario and south to the U.S. Pacific Northwest, California and Nevada markets. The upstream (pre-transmission) GHG emissions in Canada associated with the production, gathering and processing of the additional volume of natural gas to be transported by the NGTL System alone are estimated to be 1.2 and 1.4 megatonnes of carbon dioxide equivalent per year (Canadian Environmental Assessment Agency 2016).

The company is also actively pushing for liquefied natural gas (LNG) export development in BC. It has proposed major gas pipelines aimed at facilitating the growth of the industry. The most advanced proposal is the Coastal GasLink, a 670 km pipeline to deliver fracked gas from the Montney region to a proposed LNG facility near Kitimat, B.C. Here the gas would be liquefied for export by LNG Canada (a consortium including Shell Canada, PetroChina, Korea Gas Corporation, and Mitsubishi) and shipped to Asia by tanker. The LNG export terminal in Kitimat, British Columbia, has an estimated cost of approximately $40 billion, and would produce 8.6 megatonnes of emissions per year beginning in 2030 and rising to 9.6 megatonnes in 2050 (Heerema and Kniewasser 2017). This would account for 3 to 11 per cent of Canada's total 'carbon budget,' designed to limit warming to 2°C.

<u>Pipeline Financing and Networks of Corporate Power</u>

While Canada's big three carbon transporters connect to various other producers, midstream operators and other fossil-fuel related industrial firms along the commodity chain, they are also densely connected to finance capital. Financial capital is a crucial 'enabler' of carbon-extractive development through its ownership of shares and financing of carbon-extractive development. In the following section, the connections between finance capital and the big three carbon transporters are highlighted through shareholding and pipeline financing data.

<u>Shareholding and Financial Lending</u>

The crucial enabling role of financial capital in carbon extractive development occurs in part through shareholding, as major financial firms purchase blocks of shares in large corporations (through which they in turn gain a portion of a company's profits in the form of dividends). Table 5.1 displays the top ten shareholders in TransCanada, Enbridge and Kinder Morgan Canada,[67] as of 2017.

Table 5.1: Ownership Shares in Canada's Big 3 Carbon Transporters[68]

Investor	Location	TransCanada	Enbridge	Kinder Morgan Canada	Total Shares
Capital Group	US	1.96%	12.34%	0.00%	14.30%
Royal Bank of Canada	CA	7.21%	5.44%	1.01%	13.66%
Toronto-Dominion Bank	CA	3.66%	3.10%	1.11%	7.87%
Power Corporation of Canada	CA	3.38%	2.76%	0.39%	6.53%
Bank of Montreal	CA	3.53%	2.18%	0.00%	5.71%
Canadian Imperial Bank of Commerce	CA	2.22%	2.32%	0.71%	5.25%
Vanguard group	US	2.55%	2.40%	0.00%	4.95%
Deutsche Bank	DE	3.18%	1.58%	0.00%	4.76%
Province of Quebec	CA	1.70%	2.65%	0.00%	4.35%
Bank of Nova Scotia	CA	2.71%	0.77%	0.00%	3.48%

Given its large ownership stakes in Enbridge, U.S.-based Capital Group has the highest percentage of total shares. Also among the top ten are Canada's 'big five' banks: Toronto Dominion, Royal Bank of Canada, Canadian Imperial Bank of Commerce, Bank of Nova Scotia, and the Bank of Montreal.

In addition to ownership of shares, financial firms supply credit and loans to carbon capital. This financing is vital given the highly capital-intensive nature of carbon extractive development,

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[67] The 2018 purchase of TPL and its expansion by the Canadian Government means that ownership shares in Kinder Morgan Canada (were they updated beyond 2017) would now refer to storage terminals and other pipeline assets held by the company (such as the Cochin pipeline system, which travels from Alberta to Windsor, Ontario). However, in addition to Canadian banks purchasing stocks in Kinder Morgan Canada in a mid-2017 Initial Public Offering, which displays their commitment to pipeline expansion (discussed below), Royal Bank Canada and Toronto Dominion Bank have made a more recent financing arrangement with Export Development Canada to support the TMX project (Meyer 2018).

[68] Ownership data obtained from Orbis – Bureau van Dijk, a global corporate information database. Ownership data is current to 2017.

especially in the initial construction of pipelines and other large-scale infrastructure. TransCanada receives nearly $6 billion of financing via a number of term loans and revolving credit facilities for general corporate finance. This includes $1.5 billion revolving credit from JPMorgan Chase and $4.22 billion revolving credit from the Bank of Montreal (Donaghy 2017). Enbridge also receives over $12 billion of financing via a number of term loans and revolving credit facilities for general corporate finance. These loans in include $4.39 billion in revolving credit from Toronto Dominion Bank, $2.22 billion revolving credit from Bank of Nova Scotia and $1.11 billion revolving credit from Bank of Montreal (ibid). Kinder Morgan Canada has gained over $10 billion in credit, including $6 billion revolving credit from Barclays and $4.07 billion revolving credit from Canada's "leading energy bank" – Royal Bank of Canada. Additionally, a mid-2017 Initial Public Offering (IPO) of investment shares in KMC, valued at $7.25 billion, saw Canada's 5 largest banks holding 73.6% of the IPO, valued at $1.28 billion (McLachlan and Hatch 2017).

Conclusion

Drawing from Marx, recent political ecology research analyzes the vital role of infrastructures in mediating the metabolic interchange between humanity and the rest of nature. Fixed capital of 'large-scale and great durability' belongs to the productive process, enabling and structuring the flow of extracted resources to sites of production and consumption. The context of the current climate crisis has increased attention towards fossil fuels and the infrastructural complexes that support them. As this literature suggests, hydrocarbons are but one bundle of commodities, albeit a central one, whose production, transport and refining has vital social and ecological consequences.

Building on this literature, I provided an overview of the expansive networked infrastructures of Canadian fossil capitalism, focusing on the systems operated and proposed by the 'big three' transporters – Enbridge, TransCanada and Kinder Morgan – firms which have the support of leading financial institutions. In addition to large-scale technological complexes that enable the extraction of deeply buried hydrocarbon concentrations, we glimpsed the enormous physical infrastructures, amounting to entire landscapes in their own right, that are required to process, move and subsequently suffuse the economy (and everyday life) as a whole with fossil fuels and petroleum products. These infrastructures carry a high degree of inertia, working to lock-in carbon extractive development, and themselves contribute significantly to the emissions that accompany fossil fuel production.

Moreover, despite the ecological imperative to launch an energy transition and increased public commitment on the part of some states and corporations to shift from fossil-based energy sources to non-fossil ones, carbon infrastructural networks are being relentlessly advanced in Canada, as in many other capitalist states. This further locks in a carbon economy, ensuring rising emissions and other negative impacts on the biosphere, while producing in Canada continued clashes with First Nation's rights and title and with many local communities' enjoyment and economic use of adjacent lands and waters. While industry's push to expand extractive development is often legitimated by governments at the federal and provincial levels, no credible policies currently detail how such massive developments can take place in accordance with the need to rapidly decarbonize energy globally within the next two decades to avoid catastrophic climate change. Instead, new oil pipelines and burgeoning LNG exports, with their associated sunk costs and networked infrastructures, will only further lock in carbon-intensive development in a period of deepening climate crisis and cement the economic interests driving the carbon-extractive sector.

While recognizing the inertia that accompanies fixed capital, David Harvey points out that the forms that capital assumes, including its infrastructural 'hardware,' are historically contingent. Capital, he writes, must "build a fixed space (or "landscape") necessary for its own functioning at a certain point in its history only to have to destroy that space (and devalue much of the capital invested therein) at a later point in order to make way for a new 'spatial fix' (openings for fresh accumulation in new spaces and territories) at a later point in its history" (Harvey 2001a, 25). Following Marx and Joseph Schumpeter, he speaks to the "creative-destructive" tendencies inherent in capitalism. For him, the process of fixed capital (creative) destruction is part of overcoming capitalist crises historically. It is a response to an immediate crisis of profitability (specifically a crisis of overaccumulation), which acts as a temporary solution to the perennial 'surplus capital absorption problem' (Harvey 2011).

Today, a comprehensive 'decarbonization' and a rebuilding of the entire energy system, is urgently needed. Yet such a process will not primarily be a function of short-term profit seeking. It is necessitated in large measure by the long-term viability of ecosystems and their ability to support human life. As such, the development of alternative energy will need to be detached from the reign of exchange-value. Holgersen and Warlenius (2016) point to the value of strategically supporting state-led green new deal programs and proposals that have emerged since the economic crisis of 2008. These promise to catalyze the growth of green productive forces via a massive program of publicly directed investment in renewable electricity grids and infrastructure networks, along with major investments in public transportation, and retrofitting of houses and buildings for energy efficiency. At the same time, the authors encourage a recognition of the "darker side" of such a process of creative-destruction, arguing that averting climate change will simultaneously require policies trained at the active and planned dismantling and demolition of large parts of existing fossil infrastructure.

As Holgersen and Warlenius recognize, a planned wind-down of fossil fuel production, along with the dismantling of existing fossil infrastructure before the end of its useful life, is something carbon capital (and other closely linked industrial producers) will fiercely resist. Moreover, as we observed in the Canadian context, there is a relentless effort by industry to not only defend but also deepen fossil infrastructure. In this, carbon corporations are endowed with an enormous amount of power, based on their possession and control over means of production (and the social surpluses that ensue). Given huge and increasing concentrations of economic resources, workers, communities and states are 'unilaterally dependent' on these large corporations that may (or may not) choose to invest in a given time or place (Carroll 2016). Prohibitions on new fossil fuel infrastructural development, let alone the enforced wind-down of production and stranding of capital assets, is consequently an immense challenge. The concentrated power of carbon capital reinforces the 'hard' lock-in of physical infrastructural systems, obstructing a transition to a post-carbon future.

Moreover, a 'networked' lens on fossil capital development encourages us to look a degree beyond carbon capital *per se* by pointing to the financial sector's intimate relationship with it and the strong vested interest of financial capital in valorizing its massive investments in fixed carbon capital and in the flow of hydrocarbons they represent. Major intuitional investors continue to be resolutely "dirty and brown", foreclosing the possibility of a 'capital switch' or for re-routing private finance capital towards more ecological ends (See Castree and Christophers 2015; Zadek 2013).

In this context, divestment, which seeks to withdraw capital from further investments in the production of fossil fuel, is an important movement tactic. It can work together with 'blockades' along carbon commodity chains that disrupt the smooth flow of carbon and the functioning of those chains. The combination can serve to prevent the expansion of the industry, while also opening space for alternatives. (Rowe, Dempsey, and Gibbs 2016) argue that the power and 'secret' of divestment lie in its ability to withdraw legitimacy from the fossil fuel industry, by exposing the destructiveness of their activities. Viewed as a movement capacity-building action, they see it as a potential "gateway campaign" that opens participants to deeper structural critiques not only of Big Carbon, but also of capitalism itself. As divestment campaigns develop, activist learn that financial enablers of carbon capital are just as complicit as the producers and transporters, promoting a recognition of short-sighted and speculative investments that support ecological destructivity and relations of colonial domination. Divestment can thereby open to a critique of the 'allocative power' of finance capital – that is, of the fact that although the world is awash in capital, control over it and the choice of where it flows (and thereby control over our economic, ecological and social futures) continue to belong to a group of unelected financiers. It can encourage a more direct challenge to the corporate control over capital, exposing that the 'directed destruction' of existing fossil infrastructure and heavy and re-directed investments towards green energy systems, will require bringing the financial sector itself under democratic control (Candeias 2013b; Carroll 2017). Democratizing and establishing social control over the energy and financial sectors is vital to a rapid and comprehensive energy transition.

In addition to a greater focus on democratization, green-Marxist transition theories might yet go a (creative) step beyond the vision of energy transformation implied by Holgersen and Warlenius.

This perspective, as well as that of other ecosocialists such as David Schwartzman (2011, 2016), who also advocates strategic support of a green new deal, implies a massive program for directly substituting an industrial energy system built on fossil fuels for one based on cleaner and renewable sources, grid for grid, pipe for pipe. In this view, as Matthew Huber argues, "fossil fuel energy needs to be viewed as a material condition of an emancipatory future based on cleaner and renewable fuels" (2013b, 167). As Huber suggests, there is no blank slate upon which an alternative energy system can be constructed. Nevertheless, it is still worth imagining a transformation in the energy system that goes beyond a change of fuels.

The current fossil energy system, as we have seen, is highly centralized and wasteful; it is built around "extreme energy" frontiers and reliant on long infrastructural networks that connect fuels from distant points of extraction to sites production and consumption. It has been broadly constructed to support the 'abstract space of accumulation' and is geared to the underlying over-production of goods. An alternative energy-system, organized in the long-term to mend and restore our metabolic relation with the rest of nature, would need to look quite different. It would need to be constructed around sustainable production for use and would be much more decentralized, working towards lessening the spatial antagonism in contemporary production, helping to help make "town and country" whole again.

Chapter 6 – Canadian Fossil Capitalism, Corporate Strategy and Post-Carbon Futures

As seen in the previous chapter, carbon capital continues to expand fossil fuel production and actively works to suppress a *rapid* process of decarbonisation. This chapter investigates the extractive sector's simultaneous efforts to establish control over alternative energy. It provides an empirical examination of the strategies adopted by Canadian fossil fuel corporations in relation to renewable energy development and consider whether we are witnessing signs of "transition capture" as some oil and gas producers invest in a gradual transition towards 'climate capitalism.' This transition would be in some tension with the notion of fettering in the development of productive forces.

First, using recent financial reports, I investigate the extent to which the top ten Canadian carbon corporations (based on 2016 revenues) are diverting capital into renewable energy, in anticipation of declining future demand for fossil fuels. Second, I analyze intersectoral relations via a social network analysis of interlocking directorate relations between the fossil fuel sector and the renewables industry, including Crown corporations, renewable industry associations and climate-capitalist civil society organizations.

To provide further context for the analysis, the chapter begins with a brief review of research on the political economy and ecology of fossil capitalism, highlighting social and political obstacles to the 'decarbonisation' of the energy system. First, I recall key insights from the literature on capitalism's deep dependency on fossil fuels; second, the ensuing political transformations that reinforce an oil dependent economy; and third, the organization and power of carbon capital. While capitalism remains decisively carboniferous, recent studies in this field consider how the climate crisis has provoked emergent and competing visions or models of development, based in different class fractions and interests (Adkin 2017; Candeias 2013b; Muller 2013; Sapinski 2015, 2016). They point to the diverging political-economic projects of 'climate capitalism,' based on monopoly ownership and control of renewable energy technologies by large energy firms on the one hand, and 'energy democracy' founded on decentralized and democratic control of such technologies on the other hand (Adkin 2017; Muller 2013). In addition to the notion of 'relative fettering,' an analysis of elite-driven process of energy transition, in the form of a 'climate capitalist project' considers how renewable energy may develop slowly, unevenly and in a manner that imbues the technologies with relations of class power.

Fossil Capitalism

In Chapter 4, I outlined scholarship on 'fossil capitalism' which explores the crucial role of fossil fuels in mediating the metabolic relation to the rest of nature (Altvater 2007, 2016; Huber 2009, 2013b; Malm 2016). To recapitulate, within this literature, capital's deep dependency on fossil fuels is partially explained by the qualities of coal and oil themselves. In contrast to energy 'flows' (energy from rivers, the sun or wind) mineralised energy 'stock' (condensed inanimate energy contained in the crust of the earth) is easily stored, transported and then consumed without reference to natural time patterns (used 24 hours a day, 365 days per year) (Malm 2016). It also powers the machines that allow capital to accumulate through *relative* surplus value – the speeding up of production by technical means (Altvater 2016). As such, fossil energy has been key to disciplining labour and breaking resistance by subjecting workers to the rhythm of machines, allowing for the relocation of production, and enforcing an accelerated and regular industrial output (Abramsky 2010a; Malm 2016).

In addition to transforming the labour process, fossil fuels are recognized as critical to the production of spatial conditions for the circulation of goods and commodities under industrial conditions of production. Historically, the creation of a specifically capitalist world economy with global markets is premised on the emergence of "fossilized" transportation and infrastructural networks (Huber 2009). And as glimpsed in the previous chapter, today, the material landscapes of our fossil fuel society are as robust as ever. Indeed, much of our built environment has been constructed around affordable and abundant oil and gas, which in turn steers and regulates energy-related behaviour.

In *Lifeblood*, Huber (2013) brilliantly analyses the cultural practices attached to (or which can be seen as spatial expressions of) carbon-based energy systems. He considers how in fossil capitalism's epicentre, the United States, oil has been fundamental to the growth of suburbanized consumerism and lifestyles. As oil became capital's 'lifeblood,' and as petroleum products come to saturate everyday life, parts of the working class have been "energized," gaining a form of privatized power (2013: 151). All this gives the suburban consumer a stake in the endless growth of carbon-driven consumer capitalism, creating the geographies and material structures of a 'petro-culture' that are a critical barrier to movements for a just transition.

In addition to theorizing capitalism's deep dependency on fossil fuels and the inertia that shapes society's relationship with energy, this literature exposes the steep environmental costs of this reliance, effectively linking struggles against capitalism to the protection of planetary ecosystems. It makes clear that the system of fossilized production ensures a concentrated production of waste and pollution and the degradation of natural processes – soil fertility, hydrological cycles and especially the carbon cycle.

Petro-Politics and Petro-States

Building from the literature on 'fossil capitalism,' recent political ecology approaches under the rubric of 'first-world petro-politics,' examine the long-run political implications and path-dependencies associated with fossil fuel development (Adkin 2016b; Carter 2014; Carter and Zalik 2016; Nikiforuk 2010). Drawing from work on 'rentierism' and staples theory, heavy reliance on hydrocarbon exports is argued to pose a series of political economic challenges, often producing a 'resource curse,' or a 'staples trap' (Haley 2014; Pineault 2014; Shrivastava 2015; Watkins 2006). The literature finds that reliance on oil exports may lead to revenue unpredictability, while also undermining efforts to diversify the economy's productive base (Laxer 2015a). Importantly, fossil fuel production is highly capital-intensive, meaning that employment in the sector is slight in relation to other industrial sectors and relative to output and emissions (Albo and Yap 2016).[69] On the other hand, local communities, including First Nations in the regions where industry is located and downstream, continue to suffer numerous negative environmental effects from fossil fuel development (Flanagan and Grant 2013; Grant, Angen, and Dyer 2013; Hansen, Mulvaney, and Betcher 2013).

Structural dependence on fossil fuel revenues (combined with distinctive political-institutional configurations and policies[70]) has also produced negative political impacts, with

[69] The oil economy has also been profoundly gendered and booms have not created nearly as many jobs for women as they have for men (O'Shaughnessy and Dogu 2016).

[70] While pointing to reliance on oil revenue as an explanation for 'democratic deficits,' the authors cited here recognize the crucial importance of policy and governance directions in 'petro-state' formation. They point to the need to avoid undue focus on the commodity of oil itself, in favour of more complex explanations that include a focus on royalty and taxation regimes, as well as public ownership frameworks in accounting for state-society relations (see especially Carter 2016; Shrivastava 2015). Studies here often point to Norway's success in overcoming some of the challenges of resource revenue dependence, citing the political-institutional context undergirding the government's ability to reap economic and political benefits and achieve comparatively better environmental records (ibid).

troubling implications for democracy (Adkin 2016a; Carter and Zalik 2016; Shrivastava 2015). In the Alberta context, research points to the heightened deterioration of the link between the state and citizens, as oil rents release the state from reliance on tax revenue, contributing to its privileging of corporate interests over democracy and environmental sustainability (ibid). A resource-extractive economy driven by short-term profit-making also produces frequent clashes with First Nations rights and title (Adkin and Stendie 2016; Coulthard 2014; Manno, Hirsch, and Feldpausch-Parker 2014; Thomas-Muller 2014), while First Nations and other communities in the regions where industry is located and downstream, continue to suffer numerous and disproportionate negative environmental effects from fossil fuel development (Flanagan and Grant 2013; Grant, Angen, and Dyer 2013; Hansen, Mulvaney, and Betcher 2013).

States or regions suffering from a resource curse may also experience a 'carbon trap,' or policy deterioration due to the "institutional molding effects" of oil revenue dependency (Carter 2014, 26). Here government reliance on fossil fuel revenues combined with royalty regimes and tax structures geared to carbon-extractive interests are argued to obstruct progress on carbon emissions reduction and environmentally progressive policies, making future climate adaptation and post-carbon transition all the more difficult (Adkin 2016b; Adkin and Miller 2016; Carter 2014; Carter and Zalik 2016; Nikiforuk 2010).

Corporate Power and Carbon Capital

Work examining the political inertia that characterizes fossil fuel dependent economies is complemented by a recent literature that combines the sociology of corporate power with the political economy and ecology of fossil capital (Carroll et al. 2018; Adkin et al. 2017; Carroll 2017; Carter and Zalik 2016; Graham 2017). Emerging research from Carroll (2017) provides a wide-angle view on the organization and architecture of the carbon sector in Canada, mapping its internal structure as a network of interlocking directorates and its ties to the financial sector and other segments of corporate capital – national and transnational. The research finds the architecture of corporate power in and around the carbon-capital sector in Canada to be densely integrated "to the point of resembling an entrenched oligarchy" (Carroll 2017: 254). Importantly, it reveals that carbon corporations are a central component of a wider power structure, demonstrating also the financial industry's extensive directorate links (which are underscored by financing, insurance and speculative interests) to the oil and gas sector.

Moreover, this research demonstrates that where carbon extraction comprises a leading sector, corporate power invests deeply in maintaining conditions for the accumulation of fossil capital. Studies here trace the reach of carbon capital into political and civil society and at regional, national and international scales. In the political field, research has focused on corporate lobbying (Carter 2016; Elsner and Kasper 2015; Graham 2017; Klein 2014), political party donations (Graham 2017), and 'revolving door' relations or close personal ties between the corporate community and the state apparatus (Adkin and Miller 2016; Apeldoorn and Graaff 2012; de Graaff 2012b; de Graaff and Apeldoorn 2017; Taft 2017). Such avenues of influence allow carbon capital to shape the so-called policy planning process, erecting barriers to the development of robust environmental regulations, including policies aimed at carbon emissions reduction and pro-clean energy policies.

In circumstances of increased public criticism and robust social movement opposition, carbon capital's accumulation strategy also demands careful ideological legitimation. Therefore the power of the sector reaches into civil society, as carbon-capital fractions and their allies participate in the governance and funding of organizations such as policy-planning groups, think-tanks, media outlets (Bonds 2016; Brulle 2013; Elsner and Kasper 2015; Carroll et. al 2018), as well as research institutes and universities (Adkin and Brtittany Stares 2016; W. K. Carroll, Graham, and Yunker 2018; Gustafson 2012). Business influence over such sites of knowledge production and dissemination helps institutionalize a 'new climate denialism,' whereby the climate crisis is acknowledged while effective and robust climate action is forestalled (Derber 2010; Klein and Daub 2016). The new denialism centers policies and actions that purport to solve the climate crisis by developing forces of production (environmental efficiencies, new technologies that reduce emissions, as well as policies aimed at incremental change), under capitalist control. These appear to be credible responses to the scientific consensus on climate change but do not impede the accumulation of carbon capital.

Post-Carbon Futures and Corporate Strategy

The research reviewed above helps illuminate powerful social and political barriers to energy transitions. Given these obstacles, it remains an open question as to whether capitalism can, however slowly and unevenly, 'decarbonize.' However, while earlier writing on fossil capitalism tended to imply that a social formation based on renewable energy would be necessarily be post-capitalist (see for example Altvater 2007), recent research avoids this close identity. As Abramsky (2010a) suggests, the future transition to a new energy system is uncertain and will largely depend on how it is brought about, by whom and on whose terms. In this vein, it has become increasingly clear that there are two broad paths in the expansion of renewable energy (Muller 2013). One leads to large-scale installations under the control of big energy companies, especially fossil fuel corporations, who slowly subsume renewables under their centralized control. The other leads to an increasingly democratic energy sector, based on diversity of sources, owned publicly and developed substantially[71] at the community level (ibid).

Clearly, the idea that the fossil fuel industry would voluntarily shut down its operations and replace it with a renewable energy system overnight, stranding vast sunk assets (glimpsed in Chapter 5), is ludicrous. However, while oil and gas companies are driven by short-term profit seeking, we should not discount their ability to also develop long-term strategies that are geared toward both protecting current investments and ensuring future profit streams. While carbon capital is actively supressing a rapid process of decarbonisation, the sectors' strategic attempts at self-preservation are potentially supported by a longer-term strategy of participating in a slow and "managed transition" to more climatically benign sources of energy. As suggested in existing literature, the fossil fuel sector, certain organizations, or key individuals within it, may support a drawn-out transition to 'climate capitalism,'[72] as a project which gradually transforms the energetic basis of capitalism towards hydropower, solar, wind, tidal, wave and nuclear, while leaving its class structure untouched,

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[71] In outlining 'two paths' in the expansion of renewables a binary is often made in the literature surrounding the 'scale' of renewable energy development, with a climate capitalist political economic project involving large-scale installations (such as DESERTEC and large off shore windparks) and a green-left project consisting of small-scale, local and community level developments. While small-scale developments are often most desirable both from an ecological perspective and in view of the democratization of energy, such a binary or 'scaler determinism' can prove unhelpful in some cases. As I have suggested, planning, including the coordination of energy flows, even at a global level, will be required in some instances and is integral to green socialism. Despite the failures of command-style state socialism, and what neoliberalism tells us, large-scale installations could be publicly owned and democratically managed.

[72] Newell and Paterson describe the project of climate capitalism as, 'a model which squares capitalism's need for continued economic growth with substantial shifts away from carbon-based industrial development' (2010, 1). As Sapinski (2016) describes, it is a post-carbon but pro-capitalist political economic project, proposing the ecological modernization of the energy base of capitalism, by redirecting flows of capital away from fossil fuels, and toward more climatically benign sources of energy including hydropower, solar and wind. This climate capitalist vision can thereby be read as engendering a form of what Antonio Gramsci (1971) referred to as 'passive revolution.' This consists of an elite engineered process of social transformation, that partially and selectively satisfies oppositional demands from below, while simultaneously denying subaltern groups the initiative and ability to engage in self-leadership (Sassoon 1982; Thomas 2011). By contrast, their intellectuals are absorbed into the power bloc (Candeias 2013a).

including the concentration of economic power in the hands of a relatively small group of major investors, executives and corporate directors (Adkin 2017; Derber 2010; Lohmann 2011; Muller 2013; Sapinski 2015, 2016). The research here focuses on the Canadian context, asking *in what ways the fossil fuel sector in Canada is shaping and controlling the development of renewable energy and conversely, and how has the development of renewables shaped the fossil fuel industry itself?*

Sample and Data

To investigate this question, I examine the extent to which the top ten Canadian fossil fuel companies (based on 2016 revenues) are diverting capital into renewables.[73] This includes wind, solar, hydro, tidal, geothermal and biofuels.[74] These large companies are the most likely to be investing given that they have the capital to hedge. Information on the capital expenditures of these 'majors' is obtained from annual reports covering 2012-2016. This five-year period allows us to consider short-term trends in capital investment and includes both the highest years for recorded profits in the sector in 2013 and early 2014, and the relative decline of profits due to falling oil and gas prices beginning in late 2014 and into 2015.

[73] Based on revenue in Canadian Dollars these are : Enbridge (34, 560, 000, 000), Imperial Oil (27, 354, 000, 000) Suncor (26, 807, 000, 000), Husky (12, 919, 000, 000), TransCanada (12, 505, 000, 000), Cenovus (12, 282, 000, 000), Canadian Natural Resources (11, 098, 000, 000), Teck (9, 300, 000, 000), Fortis (6, 838, 000,000) and Parkland Fuel (6, 266, 000, 000). Data for 2016 revenues is obtained from online business databases (ORBIS and Oilweek) and confirmed through annual corporate financial reports. I have included only publicly traded corporations with an independent Canadian board of directors and publicly reported revenue data. These criteria lead to the inclusion of Imperial among the Canada-based 'majors' (despite being majority owned by Exxon Mobil), while excluding fully owned subsidiaries such as Shell Canada or Total Canada.

[74] I include companies broadly involved in renewable power development, operation and transmission, as well as energy products, services and power storage. Nuclear energy, which provides 14 percent of Canada's electrical power in addition to that from renewables, is excluded (Laxer 2015a). Studies have found that nuclear power stations may use more useful energy over their life cycle (in mining, transportation, decommissioning the power stations and managing waste) than is generated over the power station's lifetime (ibid).

Next, I analyze inter-sectoral relations via a social network analysis of interlocking directorate relations between the fossil fuel sector and the renewables industry. To represent the carbon extractive corporate sector, 238 corporations in this industry were selected, all based in Canada with 2014 assets of at least $50 million. The renewables industry sample includes 51 publicly traded Canadian companies and five Crown corporations.[75] I also include energy "hybrids" – companies (both private and Crown) with a mixed energy portfolio consisting of at least 20 percent renewables assets,[76] or diversified corporations with renewable energy divisions alongside their other operations. In total, the sample includes seven private or independent hybrids and eight Crown hybrids.[77]

Subsequently, I investigate the Canadian fossil fuel sector's participation on the boards of key Canada-based civil society organizations that emphasize accelerating renewable energy development in Canada and transitioning to a low-carbon future. This includes nine Canadian renewable industry associations. Industry associations are governed almost exclusively by corporate directors from the renewables sector, allowing the industry to define issues of common importance and to organize strategies for advancing its interests. They are effectively part of the green energy

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[75] See Appendixes 1 and 2 for a listing of companies and organizations. Also included are foreign controlled multinationals with a Canadian subsidiary company or division (including Canada-based corporate directors). There were eight such companies. The sample is intended to capture the renewable industry in Canada as a whole, but comprehensive listings are lacking. To identify companies I drew from governmental listings (Foreign Affairs, Trade and Development Canada 2014), as well as renewable industry association reports. Several companies listed in these reports are either private or do not have boards of directors (or publicly available information). They were dropped from the sample.

[76] In cases where renewable asset figures were not available, I used total power generation capacity (from renewable and non-renewable sources) as a proxy measure.

[77] Data on the names of the directors or governors of these renewable energy corporations and organizations and on names for directors and top executives of the 238 carbon extractive corporations, is gathered as of yearend 2016. Sources included online business databases (ORBIS and FP.Infomart), as well as company websites and annual reports. Wherever there was ambiguity as to whether two name entries referred to the same person, the situation was investigated further to confirm the multiple affiliation.

sector; they form its political arm and reach into political and civil society by creating and circulating policy briefs, research reports, and lobbying different levels of government. Further, I include seven advocacy organizations, whose remit centres on advancing a 'green,' or 'clean' capitalist vision.'[78] These organizations bring together multi-sectoral business leaders, non-government organizations, policy experts and unions in an effort to advance green capitalism as a 'hegemonic project.'[79] More than lobby organizations, these groups participate in the creation of the discourses and practices of climate capitalism, and mobilize them by reaching out to economic elites (Sapinski 2016).

Together, these methods provide insight into the relations between Canadian fossil corporations and renewable energy firms. They allow us to investigate strategies employed by the carbon extractive sector aimed at asserting controlling over the energy field, while simultaneously keeping fossil fuels in the 'energy mix' for the foreseeable future.

Renewable Energy Development in Canada

A 'wave' of global investment in renewables, including by fossil fuel firms, began in the late 1990s and early 2000s, as momentum built around reaching a global climate agreement (Switzer 2013). However, in the immediate aftermath of the financial crisis of 2007-2008, political support for renewable energy waned and investment levels decelerated and even fell in some regions (Sweeny

[78] The civil society associations reflect a judgement sample of the key organizations in the field. See Appendix 3 for a listing of organizations.

[79] Jessop (1983) distinguishes analytically between an 'accumulation strategy' and a 'hegemonic project.' He suggests that an accumulation strategy defines a specific 'growth model,' including the various 'extra-economic' preconditions and strategies appropriate for its realization. In contrast to an 'accumulation strategy,' a hegemonic project involves the mobilization of support behind a concrete program that brings about a unison of different interests. Here while an accumulation strategy is primarily oriented towards the relations of production and to the balance of class forces, hegemonic projects are typically oriented towards broader issues grounded not only in economic relations but the whole field of civil-society relations and the state.

and Treat 2017). Since 2010, investment in renewable power and fuels have made a steady recovery globally, and reached a record $348.5 billion in 2015 (Frankfurt School-UNEP Centre 2016). There was a relative decline in 2016, with investments falling to $287.5 billion (Bloomberg New Energy Finance 2016).

Canada, for its part, is the 4th largest renewable power generator in the world (National Energy Board 2016). Close to 60 percent of this comes from hydropower, most of it already constructed in the form of large 'legacy' dam projects, with Crown corporations playing an important role (Laxer 2015a). These provide a tremendous base from which to transition to a low carbon future through the expansion of wind and solar power, as well as hydro from run-of-river turbines and tidal turbines.[80]

Investment in renewable energy in Canada (by both private and Crown corporations) reached a high point of $12 billion 2014, but dropped slightly in 2015 to $10 billion[81] (its second highest level) (Clean Energy Canada 2016). Solar and wind investments fell again in 2016 by 46%, leaving Canada out of the top ten largest renewable investing nations (Frankfurt School-UNEP Centre 2016).[82] Reflecting on the overall growth of green energy, recent work has cited the carbon extractive sector's prominent role as both producer and investor (Adkin 2017; Bakx 2016; Smith 2016; Wedding 2016). Considering only their Canada-based assets, Clean Energy Canada (2016) finds both Enbridge and Suncor to be among the five largest corporate renewable electricity operators and developers in Canada for 2015. However, the extent of carbon-capital's investments

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[80] Canada gets 17 percent of its *total* energy from hydro. As Laxer (2015) suggests, in so far as hydro has a role to play in low carbon transitions, we should focus on such smaller-scale developments rather than big dams, which are highly ecologically damaging in their initial construction.
[81] All figures in Canadian dollars, unless otherwise specified.
[82] This figure does not take into consideration new hydro developments.

in renewables and whether they reflect an emerging and core accumulation strategy, or a modest, yet profitable hedge, remains unclear. While the existing research on climate capitalism suggests that a process of 'transition capture' may be underway, this work is largely theoretical and informed by anecdotal evidence. It can be enriched through a more detailed empirical analysis.

CANADIAN CARBON CAPITAL AND RENEWABLES: AN EMERGING ACCUMULATION STRATEGY?

Of the top ten Canadian fossil fuel companies, six have invested in or hold significant renewable energy assets since 2012. As seen in Table 6.1, these companies are investing in and developing a range of renewables including hydro, solar, wind, geothermal and biofuels (ethanol).

Table 6.1: Top Ten Fossil Fuel Companies and Investments in Renewables

Company Name	Main Operations	Renewables Investment	Renewable Type
Enbridge	Oil/Gas Pipelines	Yes	Wind, Solar, Geothermal
Imperial	Integrated Oil	No	N/A
Suncor	Integrated Oil	Yes	Wind, Ethanol
Husky	Integrated Oil	Yes	Ethanol
TransCanada	Oil/Gas Pipelines	Yes	Wind, Solar, Hydro
Cenovus	Integrated Oil	No	N/A
CNRL	Integrated Oil	No	N/A
Teck	Divers. Mining	Yes	Wind, Hydro
Fortis	Electric Utilities	Yes	Solar Power, Hydro
Parkland Fuel	Fuel Supplier	No	N/A

Enbridge currently has assets in wind, solar and geothermal energy in Quebec, Ontario, Saskatchewan, Alberta, as well as in Colorado, Texas, the United Kingdom, France and Germany. TransCanada operates three wind farms in Canada and the US, and has interests in nine Ontario-based solar projects, and a hydro project. Fortis owns six hydroelectric generating facilities in Canada and three in the Caribbean, and has an interest in US-based solar power. As of 2016, Suncor's renewables business includes investments in five operating wind facilities throughout Canada, as well as an ethanol plant in Ontario. Husky is the largest ethanol producer in western Canada, with plants in both Saskatchewan and Manitoba. Before selling its shares in 2016, Teck was a partner in the Wintering Hills wind power facility in Alberta and continues to be a majority owner of Waneta hydroelectric dam.

Table 6.2 compiles power generation capacity from all renewables from these six companies from 2012-2016. With 2,500 Megawatts of power capacity, Enbridge is, based on the level of capacity, the largest player in renewable energy, followed by TransCanada.

Table 6.2: Power Generation/Net Capacity of all Renewable Energy Assets[83]

Company	**2012**	**2013**	**2014**	**2015**	**2016**
Enbridge	1,280 MW	1, 280 MW	1, 616 MW	1,997 MW	2, 500 MW
Suncor	N/A	255 MW	327 MW	287 MW	187 MW
TransCanada	1167 MW	1161 MW	1156 MW	1156 MW	1156 MW
Fortis	402 MW	402 MW	442 MW	612 MW	596 MW
Teck[84]	88 GWh	85 GWh	83 GWh	136 GWh	0
Ethanol					
Husky (thousand litres/day)	721.2	742.4	780.7	794.9	820.6
Teck (thousands of m3)	413	415	412	418	N/A

Analyzing the data in Tables 6.1 and 6.2, together with associated statements on climate change and renewable energy found in annual reports, we can place the majors into three categories. In the first category are Imperial, Cenovus, Canadian Natural (CNRL) and Parkland Fuel, which did not invest in renewable energy development or hold significant renewable energy assets during this

[83] Capacity is the maximum amount that a facility can produce, while generation refers to the amount actually produced. Reports of Megawatts (MW) reflect capacity, while gigawatt hours (GWh) reflect the amount of energy produced over the course of a year.

[84] Teck's share in the Waneta Dam (66.7%) is not considered in Table 6.2. Figures on the power generation capacity of the hydro project were not available.

period. Imperial explicitly recognizes a growing market for renewable power, but maintains its decision to focus on oil and gas. In its strategic discussion on renewables, it draws on its parent firm Exxon Mobil's *Long-Term Outlook for Energy*, which anticipates a growth in global energy demand (especially in the Global South), and expects that oil will continue to be the largest source of energy until at least 2040, with natural gas forecasted to grow precipitously and overtake coal in the same period (Imperial Oil 2017). Neither Parkland, Cenovus nor CNRL directly discuss the growth of renewable energy in their annual reports, while the latter two highlight the need to address emissions and other environmental concerns by "greening" the carbon extractive process. Cenovus is particularly forthright about the need for the industry to take responsibility for the challenge of climate change, but remains focused on becoming a leader in the areas of "energy efficiency, developing oil sands technology to reduce GHG emissions and carbon dioxide sequestration" (Cenovus Energy 2015: 54).

In a second category, we find significant investments in non-fossil fuel energy by Suncor, Teck, TransCanada and Husky. However, investments by these companies have either remained flat or declined from 2012 to 2016. In fact, at the end of 2016, companies tended towards shedding renewable assets. In 2016, Suncor announced the sale of one of its six wind farms (Cedar Point wind facility) for gross proceeds of $291 million. With declining revenues since 2014, the sale of the wind farm was cited as part of a decision to continue to "streamline our portfolio through a divestment program of non-core assets" (Suncor Energy 2017: 4). In January 2017, Teck also announced that it had entered into an agreement to sell its interest in its sole wind power facility – Wintering Hills – for $59 million. It made near simultaneous investments of $640 million in the Fort Hills oil sands project (Teck 2017). Among majors, TransCanada boasts the second largest generation capacity from renewables, but its large investments were made prior to 2012, and therefore the overall share of power generated from its solar, wind and hydro assets remained consistent at 9-10 percent from 2012 to 2016.[85] Moreover, in November of 2016, the company announced the sale of Ravenswood, Ironwood, Ocean State Power and Kibby Wind projects for US$2.2 billion and TC Hydro for US$1.07 billion (TransCanada 2017). This reduces TransCanada's renewable generation capacity to 441 Megawatts, less than half of its 2016 capacity displayed in Table 6.2. This divestment from renewables enabled TransCanada to acquire Columbia Pipeline Group for US$13 billion, expanding its natural gas business in the US market (ibid).

In a third category are Enbridge and Fortis, which as seen in Table 6.2 have steadily increased total renewable energy capacity since 2012. While Enbridge continues to grow its renewable stock, the company's rate of expenditure on renewables has remained relatively consistent over the last five years. Annual reports indicate that Enbridge has invested 2.8 billion since 2012, averaging just over half a billion per year, while its expenditure of 0.9 billion in 2013 was a high, followed by 0.7 billion in 2016. In addition to increasing renewable power generation capacity, Fortis increased the percentage of the power it generates from renewables from 11.53 percent in 2014 to 16.03 percent in 2016 (Fortis 2017).

Virtually all the majors recognize climate change as a growing problem and acknowledge the need to respond to public demands to reduce emissions. Overall, however, we find relatively little evidence of a move into renewables energy as an accumulation strategy. Four majors have not diversified their investments into renewables, focusing instead on enhancing energy efficiency and

[85] An additional 22-3% of TransCanada's power comes from nuclear generation. This remained consistent over the five-year period.

the use of new technologies to improve the carbon intensity and environmental footprint of the extractive process. While TransCanada and Suncor have made significant and sizeable investments into wind, solar and hydro production, as well as biofuels, their recent shedding of renewable assets marks a continuation of a fitful relationship between fossil fuel companies and renewables that reaches back almost two decades (Derber 2010; Switzer 2013).

Enbridge and Fortis, on the other hand, continue to grow renewable capacity and Enbridge is now a major player within the field. Notably, however, renewables remain a minor component of both companies' overall energy assets, earnings and expenditures. Fortis, for its part, still generates close to 84 percent of its power from gas, coal and oil (and power generation is a minor component of its business, which is mainly focused on transmission).[86] While Enbridge is an outlier in the sample in terms of the scale of its renewable investments, its $2.8 billion in spending amounts to approximately 7.6 percent of total capital expenditures from 2012 to 2016 and renewables represent 5.3 percent of the company's total before income tax earnings, from 2014 to 2016 (Enbridge Inc. 2017: 80). Such levels of investment may indicate an orientation towards climate capitalism in the very long-term. However, they can equally be interpreted as a (relatively low-cost) legitimation effort made by a company that has faced intense public scrutiny and social movement opposition, particularly surrounding its proposed Northern Gateway pipeline from the Alberta tar sands to the British Columbia coast. Without foreclosing the possibility of efforts at "transition capture" in the

[86] The fact that Enbridge, as well as Suncor and TransCanada are key renewable energy players in Canada and also fossil fuel majors, may partly reflect the export-oriented nature of their operations. Indeed, the majority of oil and gas produced in Canada is exported (Laxer, 2015). This points to how countries in the global North, such as Canada, may green their energy consumption first, while continuing to be fossil fuel exporters. Yet, this conclusion is premature: most of Canada's energy still comes from oil, natural gas and coal, and Canada is also a major importer of fossil fuels.

future, Enbridge's interest in positioning itself as a significant player in renewables compared to other fossil fuel majors may stem from a more immediate concern to improve its public image in an effort to legitimate its primary revenue stream – oil and gas production and transport.

So far, I have looked at investments in renewable energy by the ten largest Canadian fossil fuel corporations. I now examine directorate interlocking between the fossil fuel sector in Canada and Canadian renewable energy firms, as well as the sector's participation on the boards of renewable industry associations and climate-capitalist civil society organizations.

Interlocking Directorates

Using social network analysis sociologists have long mapped the social relations that link across corporations – in particular, the practice of two or more corporations sharing directors or top managers (see W. Carroll 2010; W. K. Carroll 2010; de Graaff 2012a; Mizruchi 1996; Porter 1965). These interlocking directorates serve many purposes. At an organizational level, they help put boards in contact, serving as information channels and providing corporate managers with a broad scan across sectors of the business community (Mizruchi 1996). They also allow for the coordination of economic activity and business strategy within an interlocked group, and at times enable the influence or control of one firm over another (Carroll and Sapinski 2011; Mizruchi 1996). As a system, interlocks form an extensive network linking large corporations, demonstrating the institutionalized relations between firms, and thereby between the different forms or fractions of capital – industrial, commercial, financial and so on (Carroll 1986; W. Carroll 2010). This provides evidence that corporations are embedded in and construct a network of social relations that reach beyond the firms themselves (de Graaff 2012a).

In an innovating and competitive emerging sector, such as renewable energy, interlocks at the firm level (and between carbon and renewable corporations) are likely to be relatively sparse (Mizruchi and Koenig 1988). The absence of extensive board interlocks with competitors would not necessarily point to the absence of a strategic orientation towards energy transition by fossil fuel firms. In contrast, the participation of carbon capital directors (especially senior executives) on the boards of renewable industry associations and also climate capitalist organizations, would both strengthen the strategic capacity of oil companies to shape and control the alternative energy field, and further represent 'signposts' of stakes in expanding the renewable sector and planning for energy transition, or "transition capture."

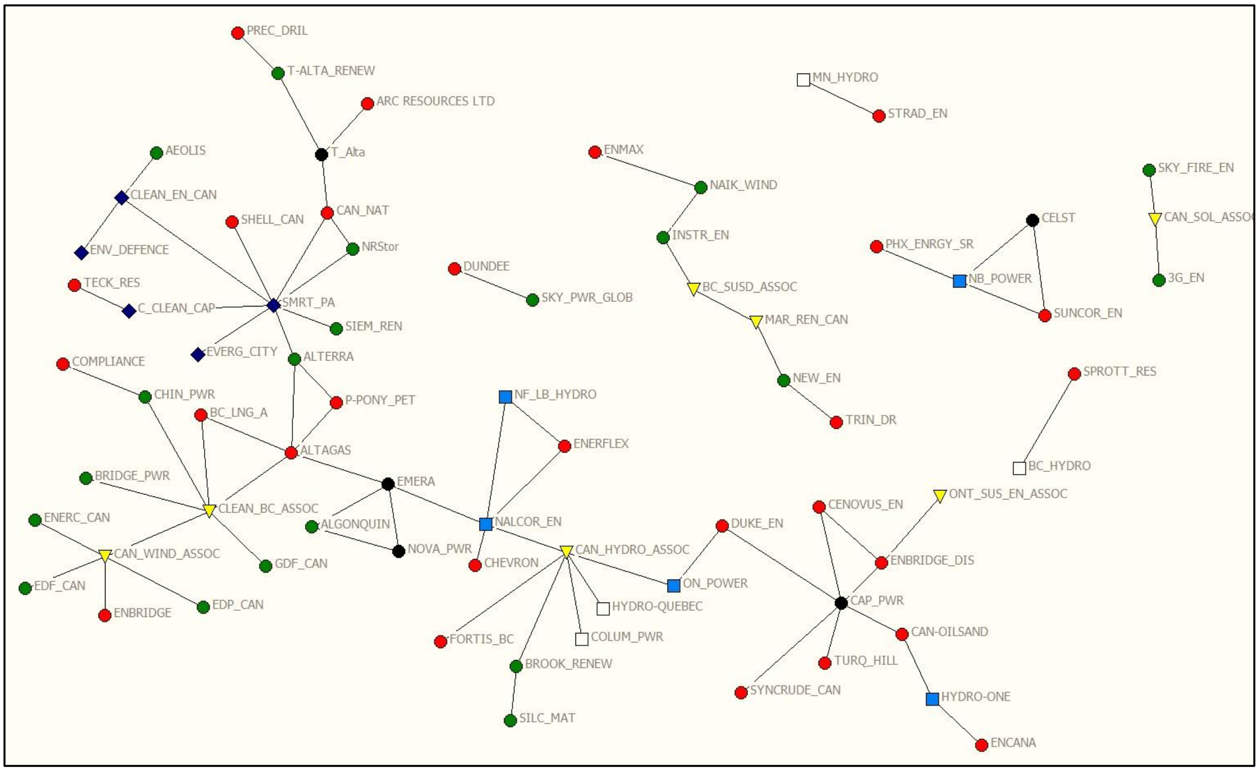
Table 6.3 presents our sample and displays overall levels of network participation (network participation indicates the number of organizations within each institutional category that have board interlocks with other firms in the sample).

Table 6.3: The Sample of Organizations and Network Participation

Sample Stratum	Overall sample	Network participant	Rate of Participation
1. Carbon-Capital Firms	238	27	0.11
2. a. Renewable Firms	51	20	0.39
2. b. Crown Renewable Firms	5	4	0.8
3. a. Hybrid Firms	7	5	0.71
3. b. Hybrid Crown Firms	8	5	0.63
4. Renewable Associations	9	7	0.77
5. Climate-Capitalist Orgs.	7	5	0.71

In all, we find 27 fossil fuel corporations in the network. This includes four 'majors' (Enbridge, Suncor, Teck, CNRL) as well as Fortis BC, a subsidiary of Fortis Inc. Figure 6.1 displays the network. For simplicity of presentation, the individuals carrying the ties are excluded and only organizational ties are displayed.

Figure 6.1: Directorate Interlocks Between Fossil Fuel and Renewable Energy Sectors



Key: red circle: fossil fuel firms, green circle: renewable firms, white square: Crown renewable firms, blue square: hybrid Crown, black circle: hybrid firm, yellow triangle: renewable industry association, blue diamond: climate-capitalist organization. See appendices 1-3 for a list of organizations included in the sample and the full names of organizations seen in all Figures.

As we see in Figure 6.1, direct corporate interlocks between the carbon sector and renewable companies are fairly sparse. In total, there are seven in this data set. Naikun Wind (NAIK_WIND), for example, is connected to Enmax, a natural gas and power utility, via Dave Rehn, who is sits on the board of directors at both companies. TransAlta renewables[87] (T-ALTA_RENEW) interlocks

[87] TransAlta renewables is a subsidiary of TransAlta(T_Alta) an electricity generation firm based in Calgary. As mentioned below, TransAlta is a 'hybrid' company whose power generation comes mainly from coal and gas, and secondarily from renewables. As seen in Figure 6.1, the two firms interlock.

with Precision Drilling (PREC_DRIL) via Allen Hagerman, while Don Seaman is on the boards of both New Energy (NEW_EN), a small-scale hydro power firm, and Trinidad Drilling (TRIN_DR). On the board of directors at Alterra, a diversified renewables company, is David Cornhill who is also Chairman of Altagas and a board member at Painted Pony Energy (P-PONY_PET). Annette Verschuren, who is Chair and CEO of NRstor, a renewable energy storage firm, also sits on the board of directors at CNRL (CAN_NAT). Sky Power Global (SKY_PWR_GLOB), a solar energy producer, is connected to oil and gas firm Dundee, which has 47 percent ownership stakes in Windiga, a solar and renewable energy producer in West Africa.[88] While solar firms Sky Power Global, SkyFire Energy (SKY_FIRE_EN) and the Canadian Solar Industries Association (CAN_SOL_ASSOC) are interlocked, this segment of the renewables sector is disconnected from the dominant component. (The segment is the set of nodes that link to all others in the set and form a complete sub-graph, running from the top left of Figure 6.1 to bottom right.)

Crown renewable corporations BC Hydro (BC_HYDRO) and Manitoba Hydro (MN_HYDRO) also interlock with Sprott Resources (SPROT_RES) and Strad Energy Services (STRAD-EN) respectively, while Hydro Quebec and Columbia Power (COLUM_PWR) do not have corporate interlocks, but are integrated into the larger network component through their representation on the board of Canadian Hydropower Association (CAN_HYDRO_ASSOC). Both Crown and private 'hybrids,' especially electricity power generators, are central to the network. Of the Crown corporations, electricity transmission firm Hydro-One and power producers Nalcor Energy (NALCOR_EN) and New Brunswick Power Corporation (NB_POWER) have multiple

[88] See: http://dundee-energy.com/windiga-energy/overview/index.php

interlocks with fossil fuel firms. Capital Power (CAP_PWR), a private power generation firm with coal, gas and wind assets, has a prolific six fossil fuel firms represented on its board.

By dint of their investments in renewables, fossil fuel firms are well represented on the boards of renewable energy associations. Mary Sye, program director at Enbridge Gas Distribution (ENBRIDGE_DIS), is on the board at Ontario Sustainable Energy Association (ONT_SUS_EN_ASSOC), while Rocco Vita, Director of business development at Enbridge Inc., sits on the board of Canadian Wind Association (CAN_WIND_ASSOC). Executive Director of Fortis BC, Doyle Sam, also sits on the board Canadian Hydro Association (CAN_HYDRO_ASSOC). Also intriguing is Clean Energy BC (CLEAN_BC_ASSOC), whose board of directors includes Dan Wosnow, director at both Altagas and at the BC LNG Alliance (BC_LNG_A). While Altagas has modest investments in wind power, Wosnow's directorship at Clean Energy BC may help explain the association's positioning of gas as a renewable fuel and its efforts to advocate for its development as part of the 'clean economy.'[89]

Three of seven climate-capitalist organizations participate in the network. Among them Smart Prosperity (SMRT_PA) plays a key role in integrating the network and bringing renewable and fossil fuel firms together. It links Alterra, Siemens Canada Renewables (SIEM_REN) and Nstor together with Shell Canada (SHELL_CAN) and CNRL. This is consistent with its mandate to bring together leaders in business and to forge a consensus around a green capitalist vision. Meanwhile, the representation of CNRL on its board (which, as noted above, does not have significant investments in renewables) is indicative of the organization's version of climate capitalism. Smart Prosperity makes 'energy transition' appealing to a wide number of corporations,

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[89] See: https://www.cleanenergybc.org/uncategorized/11625

including many fossil fuel firms, by emphasizing efforts aimed at reducing the carbon footprint of fossil fuels, while promoting a gradual, market-based approach to decarbonisation (McCartney 2018). This approach maintains the supply of fossil fuels in the medium term, while pricing carbon to incentivize and support a slow, 'stable' energy transition.

This vision for transitioning to a low-carbon economy is advanced through both public-facing reports, as well as via public appearances by high profile CEO's, such as Annette Verschuren, co-chair of Smart Prosperity.[90] It has gained national relevance, as similar policies are adopted by the current Trudeau Liberals, and who share a number of close connections with the organization.[91] Trudeau's Pan-Canadian Framework on Clean Growth offers a policy program of slow domestic and market-based energy transition, funded by the continued export of carbon intensive resources alongside the taxation of those same resources when used domestically. This is combined with the phasing out of traditional coal generated electricity and continued funding for clean tech solutions that are presented as reducing carbon emissions intensity (Hughes 2016; Canada Gazette, 2018).

The above interlocks signal the strategic capacity of carbon capital, or certain key firms and individuals within it, to exert political influence in shaping the field of alternative energy development. Given existing investments, fossil fuel firms have some stake in seeing these markets slowly expand and linkages with renewable firms and industry associations can help to advance that

[90] For example, see Smart Prosperity's 2016 report "New Thinking: Canada's Roadmap to Smart Prosperity" (<https://institute.smartprosperity.ca/sites/default/files/newthinking.pdf>).
Among other public appearances, Annette Verschuren's public discussions of energy transition can be seen via her appearance on 'The Agenda' with Steve Paikin (<https://tvo.org/video/programs/the-agenda-with-steve-paikin/annette-verschuren-on-leadership>)and BNNBloomberg (<https://business.financialpost.com/news/economy/we-need-to-push-harder-diversity-is-annette-verschurens-prescription-for-economic-growth>).

[91] As Gutstein (Gutstein 2018) reports much of Smart Prosperity's initial funding came from government, while several Smart Prosperity leaders at the time of the organization's launch in 2016 were also closely connected to Environment Canada and the Trudeau government.

line of business. By participating on the boards of industry associations and climate-capitalist organizations, carbon capital also gains information on the latest policy developments.

Extensive directorate interlocks between 'hybrid' electrical power generators and transmitters and 'core' fossil fuel firms speak, in part, to the fossil fuel industry's appetite for electrical power. In Alberta, this relation is especially pronounced. Electricity is an essential input to tar sands extraction, and the industrial sector accounts for over half of electricity consumption in the province (Weis, Thimbault, and Miller 2016). The province is also unique in that (unlike most other provinces), power generation and transmission are not owned or managed by Crown corporations. Through interlocks, carbon capital is able to influence electricity planning and development.

More generally, the presence of Alberta-based private hybrids in our sample speaks to the increasing share of electricity generated by renewable sources, following from policy frameworks aimed at the phase-out of coal-fired electricity in the province.[92] While it remains somewhat unclear who will provide the power, large predominantly coal firms such as Capital Power, Emera and TransAlta have steadily increased their share of non-fossil fuel assets (now producing between 25%-30% of their power from renewable sources) and have proposed several further large renewable electricity projects (Steward 2017).[93] This suggests that what little energy transition is taking place in Alberta is oriented primarily towards large-scale private electricity producers, rather than towards community and co-operative energy projects, or towards Crown corporations. In this context, the

[92] The Alberta government's Climate Leadership Action Plan aims at the phase-out of coal-fired electricity by 2030, with natural gas accounting for 70 percent of the province's electricity and generation by renewables making up the remaining 30 percent.

[93] Enmax, a power producer owned by the City of Calgary, is another interesting example. It now produces 14% of its power from renewables, just below our threshold of inclusion as a 'hybrid.'

aforementioned firms may be a harbinger of the fossil fuel sector's renewed efforts to move slowly "beyond carbon" once a clear sunsetting policy decision on oil and gas has been made.

However, it is important to recognize that the vast majority of electrical power previously generated by coal has been replaced by natural gas, rather than renewables (Hughes 2018; Witt 2018). Moreover, consistent with the petro-politics literature, the political viability of building a low-carbon electricity sector is linked to the small role electrical power plays in the economy and its relative insignificance as an export.[94] By contrast, phasing out tar sands and fracked gas development and moving away from reliance on exports are in combination a much more difficult task, one that carbon capital will not easily accommodate.

Broadly, the findings point to a certain level of coordination and cooperation between the renewable and carbon sectors, rather than opposition. However, as noted above, relatively few direct corporate interlocks join the carbon sector and renewable companies. Further, while carbon capital is represented on green energy associations, those tying the organizations together are overwhelmingly lower level managers (such as program directors or vice presidents of a corporate division) rather than CEO's or top executives. In fact, Dan Wosnow is the only director or executive on the board of renewable industry associations. This is consistent with findings that investment in renewables by Canada-based fossil fuel majors continues to constitute a minor component of their accumulation strategy. As we see in Figure 6.1, climate-capitalist organizations like Smart Prosperity play important integrative role, pulling the dominant component together, but overall, linkages

[94] Only 10 percent of power generation is exported – all to the US -- while close to 2/3 of oil and gas is exported. This is not meant to diminish the challenge and importance of decarbonizing electricity as the backbone of energy system transformation. Moreover, with close to 40% of electricity coming from fossil fuels and nuclear, there is still a long way to go in achieving it.

between carbon capital and the renewables sector are sparse, with a small number of individuals and firms carrying a thin network that could easily devolve into a set of dispersed groupings.

Conclusion

This chapter began by discussing research on the political economy and ecology of fossil capitalism, which has identified social and political barriers to a just energy transition. As observed, much of this resistance comes from fossil capital fractions, who are deeply invested in maintaining a carbon-powered social metabolism. However, while carbon capital is actively engaged in supressing a rapid process of decarbonization, recent literature considers how the sector's strategic attempts at self-preservation may be supported by a longer-term strategy of participating in a slow and "managed transition" towards a climate capitalist project built on green energy. As Lohmann (2011) suggests, such a strategy would allow for the short-term valorization of the large sums of capital invested in fossil fuel energy production, while simultaneously leaving business to establish control over energy substitutes (such as wind, solar, biofuels), as well as the land that is required to maintain them. Going further, Muller (2013) argues that fossil capital's tactic of delaying energy transitions can be understood as a short-term strategic move allowing oligopolistic energy companies and the finance industry to gain dominance in an emerging new energy system, subsuming renewables under their centralized control. Such an accumulation strategy, as Adkin notes (2017), runs counter to the vision shared by many on the green-left, for whom a largely decentralized energy system, based on a diversity of sources under collective control, is seen to provide the foundation for a wider transformation of patterns of production and consumption, gender relations, and relations with First Nations communities.[95]

[95] The Leap Manifesto nicely encapsulates this view. See: https://leapmanifesto.org/en/the-leap-manifesto/

We observe some 'signposts' of a strategic (re)orientation by large Canadian fossil fuel firms towards a future climate capitalism. Given existing investments, fossil fuel firms have some stake in seeing the slow expansion of renewables and their linkages with renewable firms and industry associations can help to advance that line of business. This development sits in some tension with the idea of fettering advances in forces of production. Overall, however, our findings are more tentative, pointing largely to a carbon extractive sector without plans for energy transition or transition capture. Of the ten largest fossil fuel firms in Canada, four have not diversified their investments into renewables, focusing instead on developing other features of productive forces, especially technology to achieve greater efficiency in carbon extraction and reduce the carbon footprint of fossil fuels. As I argue in the next chapter, development of reputedly "clean technologies" constitutes industry's dominant approach to reducing greenhouse gas emissions. While this development in the productive forces has practical benefit for the environment, the effectiveness of this approach is strictly limited: these initiatives are not intended to reduce, nor capable of reducing, hydrocarbon dependence. In the absence of parallel investments in renewable energy they signal the continuation of fossil capitalism as a project of 'business as usual.'

Suncor and TransCanada (and to lesser extend Teck and Husky) have made significant investments in renewables, but we observed a significant recent trend among these firms of shedding such assets. These findings help explain some of the year-to-year volatility and recent overall reductions in Canadian investments in renewable energy noted above. A likely reason for this recent shedding of assets, is that renewables struggle to compete (generate profits on par) with oil and gas investments (Wood Mackenzie 2018), while the short-term profit seeking of capitalist firms discourages investigation of alternative paths of development. Andreas Malm (2016, 368-373) argues that the qualities and 'spatio-temporal profile' of renewable energy 'flows' simply do not allow for the kind of profits generated by the primitive accumulation of fossil capital. In effect, he suggests that because such flow is not concentrated in underground stores and is instead more like a fruit that can be widely picked, there is much less profit attached to its appropriation. As sunshine and wind cannot be extracted and sold on the market, profit through surplus value is primarily found in the manufacturing of the technologies for capturing, converting and storing the energy of the fuel. This argument may help explain the curious situation whereby reductions in the price of solar panels and wind turbines, actually leads to divestment from them (see also Miller 2013). Therefore, as prices on solar panels or wind turbines plummet, profit from already installed solar or wind capacity is squeezed in a manner that is without equivalent in carbon-capital's 'core' business. Malm captures the contradiction succinctly, arguing that (carbon) capital is not investing in renewables at the rate that might be expected, "because energy flow lost so much of its exchange-value at the very same time as its social use-value – slowing down climate change – rose towards priceless heights" (2016, 371).

While increased investment in renewables by Fortis and especially Enbridge suggests the possibility of a more strategic (re)orientation towards a climate capitalist vision that could buck this trend, this can at present only be interpreted as a very long-term alignment, and one that is consistent with the notion of relative (developmental) fettering outlined in the introduction. Even among these firms, renewables account for only a small fraction of overall investments, as these 'majors' aim not only to protect vast sunk carbon investments, but are also simultaneously expanding oil and gas operations.[96] While fossil fuel corporations like Enbridge have made significant investments in renewables, the benefits of some green initiatives can be outweighed by misleading conclusions that these corporations are green saviours. Coupled with dubious yet increasingly common pronouncements that energy system transformation is now well underway,[97] these relatively minor investments can justify inaction.

Directorate interlocks show carbon capital's efforts to shape the field of alternative energy development and are further indicative of the sector's stake in expanding renewable energy markets. Meanwhile, the presence of several private 'hybrids' in our sample, especially in the electrical power sector in Alberta, speaks to the increasing share of electricity generated by renewable sources and to the prominent role played by large private fossil fuel firms in that development. This development suggests that transition capture may be carbon-capital's response, once a clear sunsetting decision (a policy aimed at declining, weaning off and retiring) has been made. For oil and gas, no such framework exists in Canada (or is in the works) and consequently the sun-setting of coal remains mostly a boon to natural gas. While the findings point to a degree of coordination and cooperation between the sectors, rather than outright opposition, carbon-renewable linkages are relatively sparse overall, with a small number of firms (represented mostly by lower-level managers and directors from carbon-capital firms) carrying a thin network. Evidence that oil and gas firms are orienting

[96] Beyond its extensive existing network, Enbridge is seeking to expand its oil and gas pipeline system, including via the $7.5 billion Line 3 replacement, the largest project in Enbridge's history. The project is positioned by Enbridge principally as a replacement and upgrading of existing pipes, yet Line 3 will also boost the capacity of its main export pipeline by 375,000 barrels per day, with the ability to expand it further in the future, and the expansion is also being used to justify a second new pipeline, Line 66, from Superior onward across Wisconsin.
[97] See Sweeney and Treat (2017) on the dubious yet increasingly commonplace assertion that energy system transformation is well underway and that fossil fuel companies have seen the "writing on the wall."

themselves towards a climate-capitalist vision is therefore only tentatively supported at the level of corporate networks.

As intimated above, current Canadian governments are (for the most part) leaving the development of renewable energy to market actors, while advancing policy frameworks that seek to create attractive conditions for private investment. Such an approach is likely to favour investments by large private energy firms and incumbent producers, laying some groundwork for a long-term shift to climate capitalism. What is clearer, however, is that such a market-based approach is unlikely to suffice to catalyze a green energy transition within our current carbon budget. While we have seen growing volumes of installed capacity, this development is fettered. As is the case globally (York and McGee 2017), non-fossil fuel sources have been added to Canada's 'energy mix' very slowly and incrementally and on top of a net expansion in the production/consumption of fossil fuels (Hughes 2018).

Along with the contradiction between the use and exchange-value of renewables noted by Malm, it is vital to recognize the contradiction between big carbon's quest to valorize massive fixed-capital investments, seen in Chapter 5, and the requirement to decarbonize energy in a rapid and socially just manner. Given the vast sunk infrastructural complexes that surround, process and move mined carbon in Canada and carbon capital's resistance to a stranding of sunk assets, rapid-transition advocates need policies that more significantly constrain and strategically shape energy development. Short-term and ameliorative measures (such as higher royalties on hydrocarbon extraction, taxes on carbon usage, and polluter-pays provisions) can raise funds to facilitate a planned transition to alternatives and are important component of climate change mitigation. Yet they do not challenge the actual basis of corporate power – the concentrated control and ownership of means of production and capital. Regulatory practices aimed at facilitating a rapid and just transition to alternative energies must be accompanied by measures that enhance the democratic control over production and economic decisions. In this manner, rapid green transition is intimately linked to the radical anti-capitalist question of the basis of corporate power, which is a problem not defined by or restricted to the carbon sector.

Chapter 7 – Fossil Knowledge Networks: Science, Ecology and Canadian Fossil Capitalism

Building from Marx and contemporary analyses of science as a productive force, this chapter explores the importance of scientific knowledge to fossil capitalism, with a focus on Canada. I begin by providing an overview of the nexus of science, fossil power and large-scale industry since the 18th century, followed by a discussion of technoscientific research and development (R&D) in unconventional oil and gas development more recently. In this development, I highlight the important enabling role played by the state and universities. Next, in the development of what can be called "green extractivism," I mark the recent incorporation of ecological science and knowledge into the carbon extractive process, in an effort to cope with the crisis of fossil capitalism. Through a social network analysis, I trace the social and institutional architecture behind this "green tech" knowledge, highlighting its production in a cluster of networked industry-university-state research institutes and centres.[98] The analysis demonstrates how the carbon-extractive sector has colonized ecologically oriented R&D and directed it towards its short-term needs and interests. This suggests a fettering in both the use and the development of ecological knowledge itself: the co-optation and harnessing of earth-science insights into the carbon extractive process speaks to the drastic underutilization of this knowledge in the context of the climate crisis, while extensive institutional support for knowledge tailored to the needs of extractive corporations, also displaces the further development of ecological knowledge critical to sustainability, including energy transition.

[98] See Appendix 4 for a list of institutes. The sample is derived in part from previous recent research (Adkin forthcoming; Adkin and Brittany Stares 2016; Canadian Association of University Teachers 2013; W. Carroll, Nicolas Graham, and Yunker 2018), as well as by researching industry, government and university websites.

<u>Marx and Science as a Force of Production</u>

As we saw in Chapter 4, Marx was among the first to analyze how capitalism systematically and routinely incorporates natural science as a force in the productive process. Science is harnessed to capitalism to transform the rest of nature to produce commodities and to cope with ecological problems insofar as the latter jeopardize the conditions for profitability and growth. In regard to the former, Marx noted that the development of large-scale industry (including the application of 'natural forces' (fossil fuels) to power production) and the creation of infrastructures for the circulation of commodities both required natural scientific knowledge. In Marx's time, this knowledge was appropriated as a 'free gift' (not typically produced as commodity under its own labour processes) and 'pressed into the service' of capital.

Moreover, Marx noted that capitalism's generation of an ever-greater mass of commodities, required an ever-larger quantity of 'inputs' to production, whether of wood, fiber, metals, water or energy. It follows from this that capitalists engage in an ever-widening pursuit of new sources of resources (and labour supply), working to ceaselessly to discover, develop and subject to capital all aspects of nature that are conducive to accumulation. In the process, it provokes steady developments in the extraction and processing of materials, as well improvements in the means and methods of search and discovery of 'inputs' to production, another form of technoscientific "progress."

While Marx saw capital promoting the general growth of sciences, he also saw it placing important constraints on that development. The constraints, as we saw in Chapter 4, inhibit both the development of ecological knowledge and its application (use) in production. Such knowledge is underdeveloped and not prioritized based on capital's narrow emphasis on insights that can be used for commercial purposes and on knowledge that can earn rents. At the same time, Marx argued that with its increasingly intensive appropriation of nature and environmental dysfunctions, capitalism cannot help producing new and also more universal forms of ecological consciousness, knowledge and science. With Engels, he showed enthusiasm for emerging forms of ecological understanding, which took account of the ecological interdependencies between different locations and of the unintended consequences of our metabolic interaction with nature. As Engels wrote: "…with every day that passes we are learning to understand these laws [of nature] more correctly, and getting to know both the more immediate and the more remote consequences of our interference with the traditional course of nature" (quoted in Burkett, 162).

In *Capital* III, Marx expressed particular enthusiasm for new forms of scientific knowledge in the field of agriculture, including the development of soil chemistry and agronomy, which emerged in response to severe crises of soil fertility wrought by capitalist agricultural techniques. He counted this potential as among "the great results of the capitalist mode of production" (Marx 1993a, 754). While expressing enthusiasm surrounding this development, he noted that such forms of knowledge could be applied to production in only a highly circumscribed fashion and "in so far as this is at all possible within the conditions of private property" (ibid). His excitement about the possibility of sustainable industrial agricultural enabled by the development of soil science thereby gave way to a critique of ecological degradation based on capitalist agricultural techniques. He subsequently came to the conclusion that "the entire spirit of capitalist production, which is oriented towards the most immediate monetary profit – stands in contradiction to agriculture, which has to concern itself with the whole gamut of permanent conditions of life required by the chain of human generation" (ibid).

We observe a related dialectic within contemporary fossil capitalism. As I show, capitalist science has been vital to the 'making' of fossil capitalism, including in the recent development of unconventional fossil fuels. The destructiveness of this development has encouraged the growth and deepening of ecological science and knowledge, including knowledge of the climate rift. While this knowledge forms a critical part of the radical critique of capitalism and is vital to the construction of alternatives, various branches of 'earth science' (conservation and restoration ecology, climatic and atmospheric science) are now harnessed (back) into the carbon extractive process in an effort to "green" the industry and help cope with its environmental impacts. In this process, which I refer to as 'green extractivism,' ecological thinking is colonized by the carbon extractive sector and subsumed into the accumulation process (or as side undertakings designed to demonstrate a commitment to impact abatement), while its role in construction of truly sustainable alternatives is obstructed and fettered.

To help illuminate this process, I first provide a broad overview of the growth of science as a productive force since Marx's writings, before focusing on its importance to the making of fossil capitalism.

Planned Capitalist Science

Monopoly Capital and the Scientific-Technical Revolution

As Harry Braverman suggests (1998), Marx's reflections on capitalism's application of science to production were mostly anticipatory – prescient observations of a process that had only just begun. While the routine integration of science within the production process begins with the advent of large-scale industry, it is under conditions of 'monopoly capitalism,' beginning in the last two decades of the 19th century, that science came to occupy a central place in the forces of production. Braverman refers to capital's increased organization, harnessing and funding of science beginning in the late 19th century and progressing through the 20th as the "scientific-technical revolution." As he documents, invention in North Atlantic capitalist states itself became big business in the early 20th century through the creation of network of corporate research laboratories and the extensive hiring of research scientists by large firms. While in 1920 in the U.S there were approximately 300 corporate laboratories, by 1940 there were over 2,200, enabling corporations to effectively 'invent on demand' (1998, 113).

Along with these research laboratories, and growing employment of scientists in private industry, in the inter-war period scientific and engineering education increased in new or expanded university departments, as well as a growth of government research institutes (Idid). While these institutions (especially the former) retained substantial autonomy from industry and often pursued 'pure' science, in the inter-war period, as Werskey (2007) argues, technical scientific knowledge, including occasionally the academic science establishment, became more effectively linked to needs of both private industry and empire,[99] while important networks and research projects spanning academic, industrial and state scientific bodies were established.[100]

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[99] Through the notion of a 'treadmill of destruction' Hooks and Smith (2005) show that the twentieth century has witnessed an unprecedented growth in the research, testing and employment of both conventional weaponry and weapons of mass destruction, which have profound environmental impacts. Drawing from C. Wright Mills, they argue that the treadmill of destruction, while not insulated from concerns surrounding the profitability of large corporations, is also a military and political phenomena, relating to national security and geopolitical competition among states. The treadmill therefore expresses or is bound up with a statist logic, which cannot be reduced to capitalism.

[100] Werskey (2007) examines the establishment of state-directed 'military industrial complexes' in numerous advanced capitalist states during the inter-war period, linking technical scientific knowledge to the production of scientific weaponry and other imperialist pursuits. In the process, important networks and research projects spanning academic, industrial and state scientific bodies were thereby established, while public funding of R&D became weighted towards military pursuits, especially in the U.S and Britain (Edgerton 2005). Carson (2015) analyzes the science-based weaponry of the Second World War, as well as the extensive R&D infrastructural networks that enabled the further 'scientization' of war. As she suggests, R&D systems that had been built up in

Science in the Golden Age

While these developments began in the late 19th century and progressed in the early 20th in the post War Era of 'state organized' monopoly capitalism, science became more thoroughly enmeshed in capitalist relations of production (Angus 2016). The R&D budgets of large corporations continued to rise, while post war affluence was linked to the commercialization of science (Werskey, 2007). Through the post war boom, General Electric for example worked to convince consumers that "in engineering, in research, in manufacturing skill, in the values that bring a better, more satisfying life, progress is our most important product," while Dupont aimed to produce "better things for better living through chemistry."

As O'Connor details (1974), beginning in the post-war era, the role of the state in supporting, funding and directing science also grew precipitously. Through funding of universities, especially in science, technology and medicine, along with corresponding increases in basic and applied scientific research, and the construction of new government research and development facilities, science was progressively converted into a more 'social' and 'organized' productive force (ibid). While government continued to fund 'basic research' and university scientists retained substantial autonomy from state and industry through their control of funding, growing state intervention effectively socialized production costs (especially the training of a scientific labour force), and created a vast pool of 'free' technical and scientific workers, whose knowledge and

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the early 20th century and through the First World War were extended and intensified during the Second World War, while linkages between large industrial firms, academia and centres of state power carried into the post-war context. An account of the militarization of scientific knowledge and policy is important to discussions of how science could be 're-made' in its organization, prioritization and application, yet unfortunately it is beyond the scope of this chapter.

inventiveness became available to capital to be appropriated and applied to production.[101] Meanwhile, as Werskey (2007) shows, 'big-science' projects based on private-public partnerships expanded, and a cadre class of scientifically minded policy and decision makers grew to direct 'mission-oriented' R&D and harness scientific knowledge towards perceived "national interests."

Neoliberalism and Corporatization

Since the 1980s there has been a concerted effort by industry to externalize the costs of research by appropriating public and university research infrastructures, resources, skills and knowledge (Brownlee 2015; Brownlee, Hurl, and Walby 2018a; Carroll and Beaton 2000; Noble 1998; Slaughter and Leslie 1997). Therefore, while corporations have for many years exercised influence within universities, in neoliberal times their influence has broadened and deepened, alongside trends in declining state funding.[102] Proponents of this shift justify university 'corporatization' as good business logic in an increasingly competitive economic environment, but critics point to how business's largely unchecked access to the academic arena places narrower and narrower limits to the relative autonomy of science from capital. Recent studies in North America have confirmed that corporate research funding and industry representation on academic governance boards profoundly influence the direction and scope of research undertaken within the academy (Canadian Association of University Teachers 2013; Washburn 2010). When industry

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[101] This is not to suggest that all or even a majority of education is based on or emerges from corporate capital's drive to socialize these costs. Theoretical, 'pure' and 'basic' research exceeds this dynamic, while here are many 'traditional' and social 'purposes' of education (the structuring of subjectivities, thoughts and behaviours, the creation and maintenance of social prestige and status) that accord with the establishment of social order more broadly. Furthermore, public and free higher education was won through social movement struggles.

[102] Industry's influence over university operations takes a number of forms, including the growing presence of corporate-affiliated board members, increased corporate funding of academic research, industry-supported academic chairs, and corporate funding for infrastructure.

directs scientific research within the university in pursuit of short-term interests, knowledge that may portend alternative futures is diminished (Polanyi 2011).

As suggested above, business interests have long had a powerful voice in setting the agenda of state agencies, including in scientific R&D. In the Canadian context, Nelles describes the prominence of a form of "state-enterprise capitalism" with government enterprises "run by businessmen and for businesses"(quoted in Brownlee, Hurl, and Walby 2018b, 7), while Leo Panitch identifies a longstanding 'confraternity' of power – an ideological hegemony emanating from the state and economic elites, cultivating the view that national interests and business interests are one and the same (Panitch 1977). Corporatization, as a component of neoliberalism, describes a deepening of this process of state-corporate symbiosis, an increased integration of public sector/university organizations with private/corporate firms and a thickening of ties between private and public agencies (Brownlee et al. 2018b). In contrast to privatization, which implies the outsourcing of state services to private capital, it signals a renewed role for the state as an indispensable tool for advancing capital accumulation.

Science and the 'Making' of Fossil Capitalism

The Nexus of Large-Scale Industry, Science and Fossil Fuels

In his reflections on the 'scientific-technical revolution,' Braverman points to the vital fusion of science, fossil fuels and large-industry. He writes:

> The old epoch gave way to the new during the last decade of the nineteenth century primarily as a result of advances in four fields: electricity, steel, coal-petroleum and the internal combustion engine. Scientific research along theoretical lines played enough of a role in these areas to demonstrate to the capitalist class, and especially to the giant corporate entities then coming into being as a result of the concentration and centralization of capital, its importance as a means of furthering the accumulation of capital. This was particularly true in the electrical industries, which were entirely the product of nineteenth-century science, and the chemistry of the synthetic products of coal and oil (1998, 111).

Indeed, new methods of organizing production and dramatic increases in labor productivity witnessed at the end of the nineteenth century and into the early twentieth, were made possible through the growing electrification of industrial operations. As Huber details (2013), this transformation ushered in a transition away from the heavy machinery of the early nineteenth century (e.g., steam engines powered by coal) to the compact power of electric motors and assembly-line production, most emblematically in the production of automobiles in Henry Ford's factories. As Huber reports, total electricity generation in the United States skyrocketed in the opening decades of the twentieth century, while fuel for the generation of electric power came from multiple sources – coal, oil, natural gas, hydroelectricity, and eventually nuclear fission.

As suggested by Braverman, the nexus of big business and science was pronounced in the field of industrial chemistry, which was developing entirely new products made from by-products of oil and coal refining, or that required the high levels of energy that only oil could provide. In the 1930s, chlorofluorocarbons for refrigeration, air conditioning, aerosol sprays and a host of electrical appliances for the home, were introduced by giant manufacturers like General Motors and General Electric (Angus 2016). U.S. chemical companies, such as DuPont and Dow Chemical, further developed artificial fibers such as nylon, rayon, as well as a host of industrial chemicals. In the decades following World War II, the production of synthetic substances – from plastics to fertilizers, to napalm, to pesticides – based on converting natural gas and the by-products of oil, accelerated our consumption of petroleum. Indeed, the whole 'petrochemical industry,' and the associated production of prodigious waste grew exponentially in the so-called "golden age" of capitalism (Angus, 2016).

As fossil fuels have been progressively incorporated into the production process throughout the last two centuries, the means and methods of search, discovery, and extraction have also simultaneously grown. Numerous innovations in geological exploration and engineering field development enabled the extraction and mining of coal in the mid eighteenth century, and oil and gas in the nineteenth. While scientific knowledge has been a vital component of the carbon extractive process, this relation has deepened with the advent of what some are calling a "new energy revolution," based on the production of 'unconventional' fossil fuels, such as fracked gas and oil, tar sands and deep off shore oil deposits. While the existence of these sources was known for a long time, they became "recoverable" due to the rise of oil and gas prices in the early 2000s and advances in extractive techniques.[103]

In the next section, I point to the extraordinary amounts of capital and scientific resources that have been mobilized in an effort to profitably develop 'unconventional' fossil fuels such as the tar sands, as well as shale gas development in Canada. We then turn to a consideration of how the crisis of fossil capitalism and growing resistance to carbon extractive development is forcing the industry to attempt to again harness science to the production process to cope with ecological degradation.

[103] For a helpful discussion see Pineault (2015). At the close of the 20th century much of the discussion of fossil capitalism centered on the problematic of 'peak oil,' pointing to growing shortages of conventional crude oil due to the depletion of known reserves. The suggestion was that the end of the fossil fuel era was fast approaching, and that reserves would run dry as consumption was growing more quickly that advances in extraction. As Pineault puts it, it has become clear that we will run out of 'sky' (atmospheric sinks) long before we run out of oil.

Tar Sands and Fossil Knowledge

Former Prime Minister Steven Harper indicated the huge amount resources required for tar sands development in clear terms:

> Digging the bitumen out of the ground, squeezing out the oil and converting into synthetic crude is a monumental challenge. It requires vast amounts of capital, Brobdingnagian technology and an army of skilled workers. In short, it is an enterprise of epic proportions, akin to the building of pyramids or China's Great Wall. Only bigger. (quoted in Carter 2014, 23)

While Harper describes the dynamics of today's extractive processes, the 'technics' of tar sands development reach back over a hundred years and involve dense ties to private and public agencies. The first full geological mapping of the region's potential for oil development, for example, was conducted in 1913 by an engineer from the Federal Department of Mines (Wilt 2018). Hot water separation, the process vital to the commercializing bitumen, was developed beginning in the late 1920s by research scientist Karl Clark when he worked for the provincial government. Following the perfection of the technique, the province of Alberta hosted a sizeable conference in Edmonton that attracted oil companies from around the world to hear about the region's prospects. The process was put into commercial production in 1967 by Great Canadian Oil Sands Limited, now Suncor Energy (ibid). While a contemporary version of this process has enabled the mining of bitumen just below the boreal forest floor, the vast majority of bitumen is buried much deeper below the earth's surface.

In the depths of the oil scarcity crisis in the 1970s, oil company R&D departments and university labs began investigating drilling methods and specialized techniques to extract bitumen located deeper in the ground. The government of Alberta established the Alberta Oil Sands Technology and Research Authority (AOSTRA) in 1974, with a $100 million budget (nearly half a billion dollars in today's money) to develop new technologies for extracting bitumen (Turner 2017). In the mid-1980s, AOSTRA began a pilot test project for the development of what came to be known as 'steam-assisted gravity drainage' (SAGD) – an oil recovery technology used to extract heavy crude oil and bitumen. AOSTRA's field tests of SAGD overlapped with advances in horizontal drilling developed by the oil industry, and was first tested commercially by Encana Corporation in 1996 at Foster Creek just southwest of Fort McMurray. The first commercial production facility was developed at this same site by Encana in 2001 (ibid). SAGD has since been widely adopted by industry players like Suncor and ConocoPhillips, and is reported to have unlocked over 170 billion barrels of previously inaccessible oil from the tar sands (ibid).

Engineering Shale Gas

Like bitumen, natural gas is a "gift of nature" produced by biophysical processes of decay, assisted by heat and pressure, over long periods of time. Yet producing gas as a *commodity* with exchange-value, takes tremendous amounts of capital, labour and scientific resources (Bridge 2004). This is particularly the case with shale gas, which accounts for the bulk of the remaining recoverable gas in Canada (Hughes 2015) and one third globally.[104] While it has long been recognized that shale rock basins, as well as low-permeability sandstone reservoirs (or 'tight gas' sands) contain gas, no feasible and profitable means of developing them were available. However, by combining hydraulic fracking (the injection of tonnes of sand, water and chemicals at high pressure to shatter rock) with horizontal drilling (drilling wellbores down vertically, as well as out in horizontal reaches to expose

[104] As of 2014, unconventional gas made up 18 percent of global gas production and is forecasted to make up 60 percent of the increase in global gas production over the period to 2040, see (International Energy Agency 2016). In North America, unconventional gas already accounts for about 48% of total production, and is projected to make up as much as 69% of North American production by 2040 (Energy Information Administration 2016).

more of a gas bearing formation), major technical barriers to exploiting vast unconventional shale and tight gas deposits have been removed.

A further limitation on natural gas usage is the difficulty of its transportation in gaseous form, particularly overseas and over long distances (Bridge 2004). The development of a global market in natural gas is therefore also heavily dependent on the growth of the liquefied natural gas (LNG) industry, which must be extensively 'engineered' via the production of a series of networked infrastructures and techno-scientific complexes that surround extracted gas and entail the further "reworking" of nature. LNG is natural gas (increasingly extracted in the Canadian case from unconventional sources) that has been liquefied for transport. In an LNG liquefaction plant, natural gas is cooled to approximately -162°C, which enables the natural gas to be shrunk to 1/600th of its original volume. The liquefied gas is then transported in specialised LNG carriers, designed to handle the low temperature of LNG under high pressure. Finally, LNG is received at ports, re-gasified and delivered via pipelines to natural gas customers.

The Greening of Fossil Capitalism

Climate change presents the most significant challenge to industry's claim that all of this represents progress and a reasonable use of capital, productive resources and capacities. While current trajectories in fossil capitalism threaten to breach key ecosystem tipping points within the next two decades (Hughes 2018; Le Quéré et al. 2013; Muttitt 2016), widespread evidence shows that unconventional fuels are yet more ecologically damaging that conventional sources. Given the energy intensive extraction process and extensive processing, upgrading and refining required to transform bitumen into commodified energy, recent studies have found that the lifecycle emissions (from extraction, upgrading, pipeline or tanker transport, refining and use) of bitumen from the tar sands ranges from eighteen to twenty-five per cent higher than conventional crude (Grant, Huot, et al. 2013).

As discussed in Chapter 5, corporations and industry associations along with intergovernmental organizations (such as the International Energy Agency (IEA) and the Intergovernmental Panel on Climate Change (IPCC)) have characterized natural gas as a 'bridge' fuel, capable in aiding in the transition to renewable sources of energy.[105] However, several recent studies on the greenhouse gas (GHG) emissions of shale gas and LNG have challenged the evidence for this characterization (Howarth 2014; Hughes 2015).

Facing a protracted crisis, industry R&D efforts are increasingly trained on the development of "environmental" or "clean technologies" which reduce the environmental impacts of fossil fuel development, lower costs and seek to maintain conditions for the accumulation of fossil capital. Examples include carbon capture and storage intended to capture emissions from coal-fired plants, fracked gas wells, and oil sands upgraders, the injection of CO2 for enhanced oil recovery (EOR), using solvents rather than steam to produce bitumen (cyclical solvent technology), along with improvements in remediation technologies. The greening of the industry is crucial in attempts to maintain business as usual in the short- to medium-term, while industry clings to the hope of discovering a technological "silver bullet" that is capable of achieving near-zero emissions across the carbon-extractive life-cycle at commercially viable price levels.[106]

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105 For their part, organizations like the IEA and IPCC have included caveats about both landscape level risks and climate impacts surrounding the development of unconventional sources, and indicate that further research is needed (Intergovernmental Panel on Climate Change 2007; International Energy Agency 2011).

106 The strategy also fits within Trudeau's Pan-Canadian Framework on Clean Growth. As Pineault notes (Pineault 2016), in this framework we are asked to accept pipelines and new extractive developments that are "greened" and held to the "highest environmental standards," as paradoxically, these will finance the needed transition to a low carbon economy.

Organizations such as the Canadian Oilsands Innovation Alliance (COSIA) illustrate this development. COSIA is a collaboration of thirteen of Canada's largest tar sands companies, which pools resources, collaborates on and funds research (primarily based in universities) to lessen the ecological impacts of tar sands development. Beyond COSIA, a significant cluster of interlinked corporate, government and university R&D institutes and centres focus on reducing industry's footprint and making fossil-fuel usage possible in a carbon-constrained world. I examine this network below, after further positioning this study in relation to existing literature on fossil knowledge networks in Canada.

Fossil Knowledge and the Corporate Colonization of R&D

Research on the production of fossil knowledge has emphasized the important role played by universities and public institutes and the progressive colonization of these public bodies by fossil fuel interests. In the Canadian context, especially in Alberta, the immense pressures put on higher education organizations by carbon capital has led to concerns about research and university "capture" by the fossil fuel industry (Gustafson 2012). Carbon capital, as intimated above, has much to gain from its relationship with academia. In a tangible sense, universities offer access to expert information tailored to corporate interests through funded and directed research projects. The University of Calgary, for example, played a key role in developing "steam-assisted gravity drainage" (Lowey 2004). Facing an uphill battle to maintain legitimacy amidst a rapidly changing climate, carbon capital is simultaneously able to draw on the veneer of academic prestige provided by its ties to higher education, polishing its reputation by employing the language of scientific validation, while cultivating a policy environment favourable to extractive interests (Gustafson 2012).

Sharing this concern, recent research (Carroll, et al. 2018; Carroll, Graham, and Yunker 2018) has used network analysis to examine the reach of the fossil fuel industry into universities and research institutes. Carroll, Graham and Yunker (ibid) reveal extensive linkages between carbon capital and Canadian (especially Alberta-based) university governance boards and policy and energy institutes within them, identifying sites of pervasive influence by carbon capital.

These findings complement recent political-ecological analyses of first world "petro-states" (see especially Adkin 2016). In such states, a carbon-intensive economic structure and heavy reliance on oil rents is shown to have far reaching implications for the production of knowledge, powerfully shaping state research infrastructures and funding priorities in accordance with interests of the carbon sector (Adkin forthcoming; Adkin and Brittany Stares 2016). Examining funding flows between major government innovation agencies (both federal and provincial) and the Universities of Calgary and of Alberta over a 15-year period from 2000 to 2016, Adkin (forthcoming) reveals the heavy public subsidization of fossil fuel-related research. She also examines the comparative failure to invest in the production of knowledge that is critical to advancing a transition to a post-carbon economy, such as that related to renewable energy development, low-carbon transport and sustainable agriculture.

In the following section, I provide a network analysis of the cluster of research institutes in Canada (and directors and researchers within them) producing, funding and coordinating fossil fuel related R&D, and their ties to carbon capital. Carbon-capital's representation on governing boards of university and public research institutes enables corporations to shape their research agendas in ways that mesh with corporate business strategies. More broadly, by mapping interlocks among these institutes and between them and carbon capital, I identify the formation of industry-university-state collaborations and networks – revealing a process of 'state-corporate symbiosis' – and the extensive social architecture through which R&D is directed towards and appropriated by the short and medium-term interests of fossil capital.

Networks of "Green" Fossil Knowledge in Canada

To represent the carbon-extractive corporate sector, I selected 238 corporations in this industry, each based in Canada with 2014 assets of at least $50 million as well as 21 industry associations. The sample of research institutes includes thirty-four research and technology organizations and institutes whose remit extends to fossil fuel related research.[107] Fifteen of these institutes are located in universities and receive funding from industry partners. Seven are housed at the University of Calgary (U of C), six at the University of Alberta (U of A), one at the University of Regina (U of R), and one at The Northern Alberta Institute of Technology, near Edmonton.

Twelve institutes are government research and technology organizations. While these organizations often conduct their own research, for the most part their function is to fund and 'facilitate,' science and technology research and innovation that is applied to industry (including, though in most cases not exclusively, fossil fuel production). They bring together industry, university researchers and state representatives and provide further structural support for corporate-university linkages, in the form of funding. The seven remaining institutes are industry-created innovation associations or collaborations (such as COSIA) that concentrate and coordinate R&D centered on 'clean technology,' while also including academics, state managers and corporate directors from

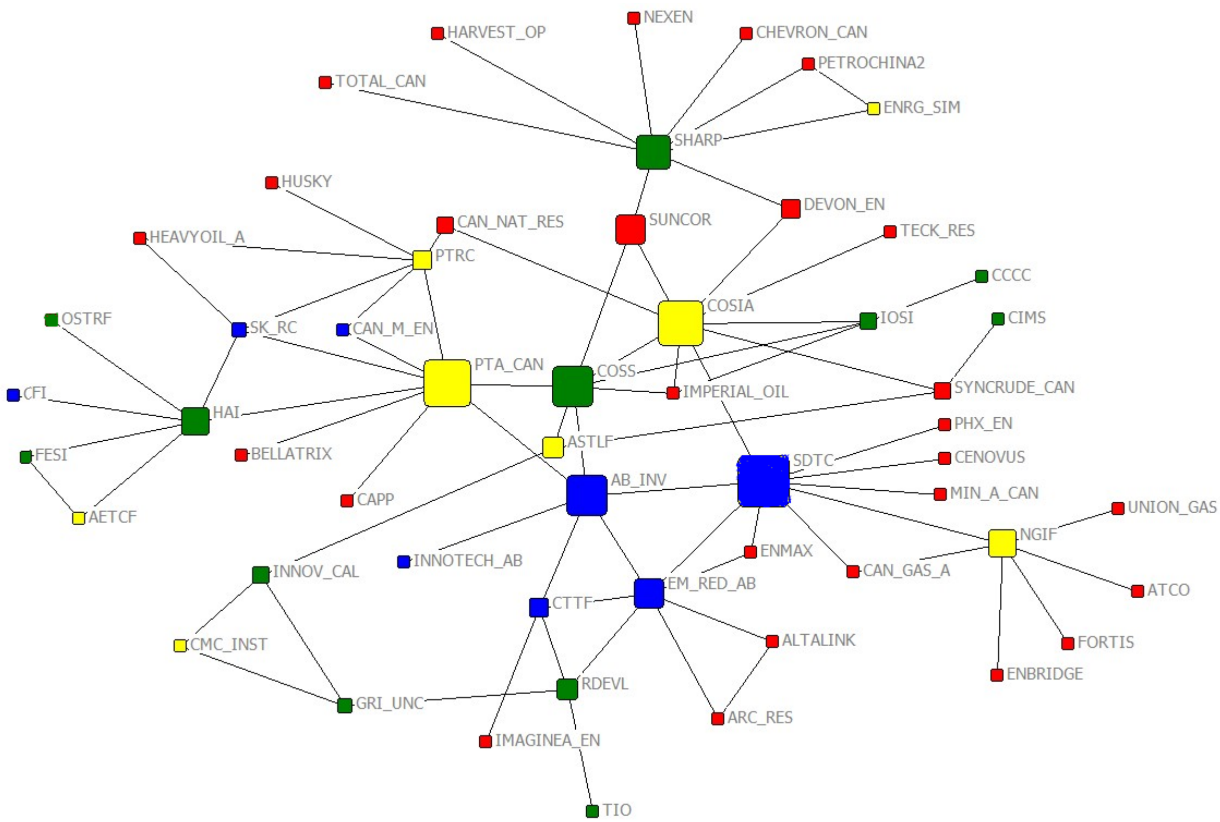
[107] See Appendix 4. These institutes were identified through a review of existing literature (Adkin and Stares 2016; Adkin forthcoming; Canadian Association of University Teachers 2013), and through searching university and government websites. I included state and university research centers that have an advisory board and which include corporate directors/officials and state managers (i.e. university-industry-state research collaborations). Research parks, now a corporatizing feature of many universities, were not included, although future research could beneficially trace these parks' linkages to corporate capital.

other industries on their governance boards.[108] To carry out the analysis, data was gathered on the names of the directors, or governors of these thirty-four research organizations and the directors, technical advisors and executives of the 238 carbon-extractive corporations, as of March 2018.[109]

Fully twenty-nine of the thirty-four research organizations/institutes belong to a single connected network that includes twenty-eight carbon-capital firms. This indicates that interlocks create a basis for elite cohesion among carbon capital leaders and others involved in university and state research-institute governance. On average, each research institute is linked to four other organizations, while some are far more integral to the network than others. Seven research institutes have only one interlock and five have two, while ten have at least six. This is seen in Figure 7.1 where node size is proportional to centrality within the network.

[108] Some organizations are "hybrid" private-public partnerships that could be categorized as either industry collaboration or state agencies. For example, the Petroleum Technology Research Centre, coded as an industry collaboration, is a non-profit founded by Natural Resources Canada, the Government of Saskatchewan, University of Regina and the Saskatchewan Research Council, as well as industry partners Nexen, Husky, and CNRL. Similarly, CMC Research Institutes, while also coded as an industry collaboration is founded through grants from the government of Alberta, as well as seven industry supporters and is housed at the University of Calgary. These organizations are a harbinger of what may come if the trend towards corporatization continues on its current path.
[109] Sources for the latter included online business databases (ORBIS and FP Infomart), as well as company websites. Information on top executives and directors was gathered by a team of researchers at Uvic as part of the Corporate Mapping Project. The database was expanded here by including senior research directors and other corporate technical advisors, officers and managers. Sources for research organizations were mainly organization websites and annual reports. Wherever there was ambiguity as to whether two name entries referred to the same person, the situation was investigated further to confirm the multiple affiliations. Unless otherwise indicated, all findings in this chapter refer to the situation at the beginning of 2018.

Figure 7.1: Interlocks between Green Tech Research Institutes and Carbon-Capital Firms (organizations only)



Key: Red square, fossil fuel corporations and industry groups; Green square, university institute; Blue square, state agency; Yellow square, non-profit/industry collaboration.

Particularly central is Ottawa-based Sustainable Development Technology Canada (SDTC), as well as the Canadian Oilsands Innovation Alliance (COSIA), each of which has 9 interlocks. The Petroleum Technology Alliance of Canada (PTA_CAN), a non-profit industry collaboration that facilitates research and technology development for the petroleum industry has eight interlocks, as does the Sharp Research Consortium at the University of Calgary. The Centre for Oil Sands

Sustainability (COSS), a university-industry collaboration at The Northern Alberta Institute of Technology, and the recently created Emissions Reductions Alberta (EM-RED_AB) each have seven. Alberta Innovates (AB_INV), Helmholtz-Alberta Initiative (HAI), Petroleum Technology Research Centre (PTRC) and the Natural Gas Innovation Fund (NGIF) have six interlocks.

Illustrating their integrative role, when five organizations at the centre of the network diagram – Alberta Innovates, Sustainable Development Technology Canada, The Centre for Oil Sands Sustainability, the Petroleum Technology Alliance of Canada and the Canadian Oilsands Innovation Alliance, are removed, the network breaks into six pieces, the largest of which contains 14 organizations (nine research institutes and five fossil fuel firms). Given that Alberta is far and away the heaviest emitter in Canada, it is not surprising that eight of nine institutes, which heavily network with carbon capital, are based there. In the context of the crisis of fossil capitalism, the latter's reach into focal sites of knowledge production indicates a strategic attempt at self-preservation.

Below, I investigate further by focusing on the elite individuals who carry the network and their affiliations with the three types of organizations (industry-state-university). I pay particular attention to organizations that are central to the network and bear numerous ties to the fossil fuel sector.

State Research Institutes and Carbon Cadres

The main function of state research institutes, which are created by government but operate at arms-length, is to fund and facilitate applied research and development. Several of these research institutes interlock with each other, as well as with the carbon-extractive sector, helping to form an elite governance and R&D network. As noted above, prominent in the network are Sustainable

Development Technology Canada (SDTC), Emissions Reductions Alberta (EM-RED_AB) and Alberta Innovates (AB_INV).

The SDTC is an Ottawa-based government institute established in 2001 to "demonstrate new technologies to promote sustainable development, including technologies to address issues related to climate change and the quality of air, water and soil" (Sustainable Development Technology Canada n.d.). These clean technologies are developed through public-private partnerships with SDTC acting as a public funder. It has funded numerous projects carried out by carbon corporations. These include

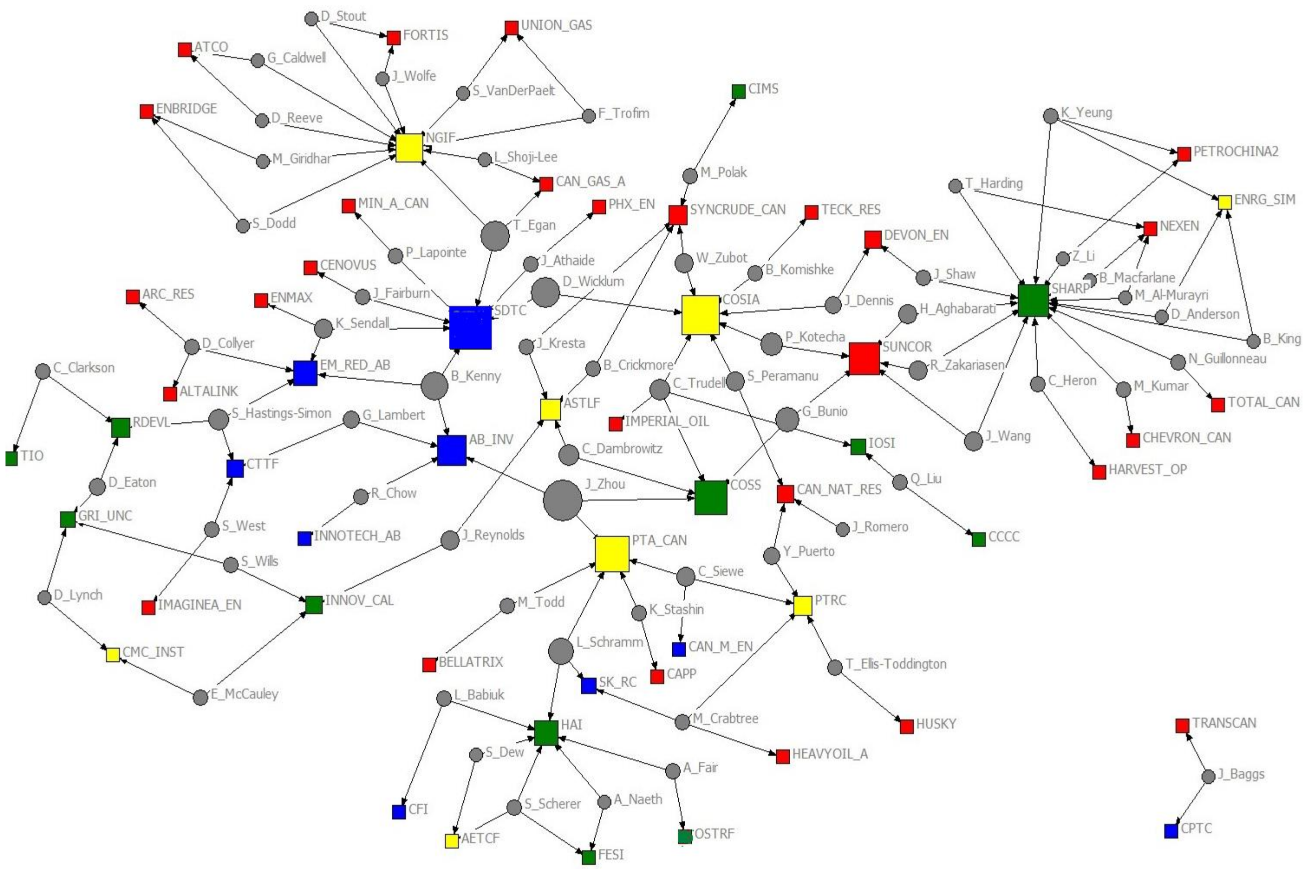
- a $1 million grant to Suncor in 2008 for research on carbon sequestration and enhanced methane production,
- $2, 673, 652 to Teck Resources for developing a "green approach" to copper and coal recovery in 2016, and
- $10 million to MEG Energy in 2018 for innovation to lower the costs and GHG emissions intensity of bitumen production that uses SAGD.

SDTC also contributed over 3 million in 2010 to the Petroleum Technology Research Centre research (a hydrocarbon industry association that facilitates collaborative R&D, seen in Figures 7.1 and 7.2), aimed at developing an environmentally sensitive and energy-efficient enhanced oil recovery (EOR) process for heavy oil reservoirs in Western Canada and $5 million to the organization in 2015, for research investigating the potential of CO2 capture and storage in deep saline aquifers (Sustainable Development Technology Canada n.d.).

Emissions Reductions Alberta (EM_RED_AB) is an Alberta-based government organization that works as a research funding steering committee directing funds to support the discovery, development and deployment of technology aimed at reducing emissions. Formerly Climate Change and Emissions Management Canada (CCEMC), the organization pools funds from carbon taxes levied on large-emitting companies. Under the Alberta government's "Specific Gas Emitters Regulation" emitters are required to pay carbon taxes if they fail to reduce their emissions intensity according to a given benchmark. Through a network of institutional arrangements, major tar sands companies and industry associations that represent them, such as COSIA, receive grants paid for by carbon taxes, for projects aimed at reducing emissions. They therefore effectively re-appropriate the taxes paid on carbon. For example, Emissions Reductions Alberta has recently funded Suncor to a tune of $1.6 million for its Oil Sands Energy Efficiency and Greenhouse Gas Mitigation Study, $5 million for a study by CNRL (in partnership with the Southern Alberta Institute of Technology) to improve detection, monitoring and quantification of methane emissions from mine faces and has supported a COSIA project that aims to draw on low-grade waste-heat to generate clean electricity (Emissions Reduction Alberta n.d.).

Both SDTC and EM-RED_AB are governed by boards of directors that participate in the allocation of funding and, as seen in Figure 7.2, are interlocked extensively with the fossil fuel sector.

Figure 7.2: Interlocking Between Clean Tech Institutes and Carbon-Capital Firms (including individuals)



Key: Grey circle, individual; Red square, fossil fuel firm; Green square, university institute; Blue square, state agency; Yellow square, non-profit/industry collaboration

Kathleen Sendall (K_Sendall), who is a corporate director at coal and gas firm Enmax and former board chair of the Canadian Association of Petroleum Producers, sits on the governance boards of both of SDTC and EM-RED_AB. Former president of CAPP, and current director at Arc Resources and AltaLink, David Collyer, (D_Collyer) is chair of Emissions Reductions Alberta.

Collyer also co-chaired the Oil Sands Advisory Group that helped inform Alberta's Climate Leadership Plan, and in 2016 was inducted into the 'Canadian Petroleum Hall of Fame.' In addition to Sendall, SDTC's board of directors and members council include four other carbon-capital elites. These are Judy Fairburn (J_Fairburn), executive vice president at Cenovus and past chair of Alberta Innovates, Pierre Lapointe (Lapointe_Pierre), director at the Mining Association of Canada, Judith Athaide (J_Athaide), director at Phoenix Energy and Timothy Egan. Egan is president and CEO of the Canadian Gas Association – an industry association representing Canada's natural gas distribution sector – and also director at the Natural Gas Innovation Fund (NGIF).

Also helping to stitch the network together is Alberta Innovates (AB_INV), an organization that was initially created in 2010 by the government of Alberta, with the aim of funding and facilitating applied research and development and to assist in commercializing research discoveries. While formerly composed of four separate Innovates corporations (Technology Futures, Bio Solutions, Energy and Environment Solutions, and Health Solutions) in 2017 it was consolidated into one corporation called Alberta Innovates, and is now managed by a single board of directors. The board does not include current carbon capitalists, but it is populated by prominent past players in the industry, acting as revolving door between industry and (quasi-)state institutions. For example, the current chair of AB_INV, Brenda Kenny (who replaced Judy Fairburn in 2018), is the past president and CEO of the Canadian Energy Pipeline Association – a group representing Canada's transmission pipeline companies – and also director of SDTC and EM-RED_AB. Also on the board at AB_INV, is Gordon Lambert, who is former vice president at Suncor and currently Suncor Sustainability Executive in Residence at the Ivey School of Business. Lambert also played an influential role in the creation of COSIA.

By participating in the governance of state research institutes, carbon capital is strategically positioned to direct public funds for research and innovation. In a process that is consistent with (and further entrenches) "petro-state" priorities and imperatives, prominent actors in the sector cultivate and maintain close relations with a cadre of scientifically minded policy and decision makers (themselves often past carbon elites) that help direct scientific discovery towards current needs of the extractive industry. This displaces institutional support of knowledge aimed at wider green transformation. As the process of scientific research discovery is harnessed towards the short and medium-term interests of the fossil fuel sector, the further *development* and growth of new ecological knowledge and insights critical to energy transition and sustainability more broadly (such knowledge related to sustainable agriculture, forestry, conservation) is fettered.

University Institutes and Corporate Elite

In comparison to state research agencies, university research centres bear less extensive directorate ties to carbon capital. Important exceptions to this are the Centre for Oil Sands Sustainability (COSS) and the Sharp Research Consortium (SHARP). COSS is a research centre at Edmonton's Northern Alberta Institute for Technology that carries out applied research "designed to meet the needs of Alberta's oil sands industry"(Centre for Oil Sands Sustainability n.d.). It was established through a $1.5 million endowment from Ledcor Group, as well as key additional funding from industry partners such as Suncor, along with both federal and provincial finding. It convenes university researchers with industry and government directors to conduct applied research on tailings management and water treatment, as well as developing technologies to reduce the emissions intensity of oil sands operations. Its 'management advisory board' includes Cheryl Trudell (C_Trudell), who is a Vice President at Imperial Oil. Trudell is a member of the steering committee at COSIA and the Institute for Oil Sands Innovation (IOSI), a research centre at the University of Alberta, also seeking to reduce the environmental footprint of tar sands operations. Meanwhile Dr. John Zhou (J_Zhou) who is a vice president of clean energy at Alberta Innovates, member of the advisory board at the Centre for Oil Sands Sustainability and board member of Petroleum Technology Alliance of Canada, is an example of a highly networked research scientist in the field of "clean" petroleum technologies.

The Sharp Research Consortium, as we see in Figure 7.2, has extensive ties to carbon capital. The Consortium was established in 2008 at the University of Calgary, with the aim of helping industry develop economically sustainable heavy oil and bitumen recovery processes that are less energy intensive and more environmentally friendly. Specifically, it is dedicated to developing solvent based bitumen extractive processes, such as vapour extraction and hybrid processes involving steam and solvents (solvent enhanced steam assisted gravity drainage), which hold the promise of reducing the energy intensity, water usage and treatment, and CO2 emissions of current practices. Its industry advisory committee contains representatives from numerous partnering corporations including Chevron Canada, Suncor, Nexen, PetroChina Canada, Devon Energy and Total Canada. Representatives on the advisory committee are senior advisors and directors of research at fossil fuel corporations, rather than members of boards of directors or top executives. For example, Bill Mcfarlane (Mcfarlane_B), is Senior Research Advisor at Nexen, Jerry Shaw (J_Shaw) is Senior Technical Advisor at Nexen, Hossein Aghabarati is Engineering Advisor at Suncor and Zhaowen Li is Director of Resources at PetroChina Canada. These organic intellectuals bring technical expertise and help direct research tailored to the needs of industry, but do not themselves have significant influence over the direction of the corporations they represent.

While we find less extensive interlocks among universities research centres and carbon capital, this is partly due to the lack of publicly available information pertaining to them. For example, the U of A's Canadian Centre for Clean Coal, is reported to be directed by a "Management Advisory Board" and a "Scientific Advisory Committee," with the former including industry representatives drawn from its partnering firms including Teck Resources, Nexen Energy, Glencore Canada, and Capital Power, but information on the individuals who make up these boards is not publicly available. Despite being a public institution, it refused formal requests for this information. Similarly, the U of C's 'Tight Oil Consortium' is reported to be governed by an external advisory committee, the details of which are not available.[110]

Other university research centres and institutes in the sample did not have oil representatives on their boards, but receive extensive funding from industry. This is seen, for example, at the U of C's Consortium for Heavy Oil Research by University Scientists. The consortium is an "oil industrial sponsored program," located in the Geology/Geophysics/ Petroleum Engineering Departments. It conducts research on the geological aspects of reservoir production, engineering, and simulation, and aims to develop technologies that simultaneously maximize the production and energy efficiency of extraction from heavy oil fields. Industry sponsors include ConocoPhillips, Nexen Energy, Shell Canada, British Petroleum, Japan Oil and Gas, Chevron Canada, and Kuwait Oil. Similarly – and also at the U of C – the Hydrocarbon Metagenomics Lab conducts exploratory research surrounding the potential to harness naturally occurring organisms and bioprocesses present in Canada's tar sands, oilfields, and coal beds in an effort to decrease the environmental impact of carbon

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110 The same goes for the U of A's Institute for Oil Sands Innovation, which is directed by an Executive Management Committee, whose composition is unknown and not publicly available. Trudell's position on the board of IOSI was only discovered through her online profile at the Centre for Oil Sands Sustainability.

extraction. While not governed by an advisory board, it also receives funding from a host of fossil fuel companies, including ConocoPhillips, EnCana, Nexen, ARC Resources, Quick Silver Resources, Shell Canada, Suncor, Syncrude, and Trident Exploration.

While some research funding for the development of reputedly "clean technologies" comes directly from industry, as noted above, it is also publicly subsidized. The Hydrocarbon Metagenomics Lab and The Centre for Oil Sands Sustainability, for example, receive funding from the Canada Foundation for Innovation – a research institute and funding body created by the government of Canada, but which operates as an independent, non-governmental entity. Alberta Innovates is also listed as a sponsor/funder for the Canadian Centre for Clean Coal and The Centre for Oil Sands Sustainability. Meanwhile, the Centre for Intelligent Mining Systems (CIMS) and the Helmholtz-Alberta Initiative (HAI) receive funding from the government of Alberta.

By funding and participating in the governance of university-based institutes, private corporations are able to direct and appropriate research and knowledge, while the public again helps foot the bill. The university has an important role to play in the production of knowledge that is critical to ecological transition, but this potential is obstructed as university-based resources and capacities are oriented towards serving the short-term interests of the carbon sector.

Industry Collaborations

Not surprisingly, industry-led green innovation institutes and collaborations are extensively governed by carbon-capital elites. They also interlock with state and university research institutes, helping to form a networked research infrastructure supporting carbon extraction, especially in Alberta, but also Canada more broadly. Below I focus on the three most central organizations in the network, the Natural Gas Innovation Fund, Canadian Oilsands Innovation Alliance and the Petroleum Technology Alliance of Canada.

The Natural Gas Innovation Fund (NGIF) was created in 2017 by the Canadian Gas Association to support clean technology development across the natural gas production chain. It works to bring the 'clean fuel' characterization of natural gas (at least in comparison to coal) closer to reality. As a result, the NGIF places significant emphasis on supporting research aimed at reducing methane emissions. Its focus on this front is currently on capture and storage of fugitive emissions (leaks in fracking and production) and in gas venting mitigation technologies (Natural Gas Innovation Fund n.d.). NGIF's investment advisory committee includes ten carbon-capital representatives, drawn from prominent natural gas producers and distributors. These include Doug Stout and Jason Wolfe who are respectively Vice President and the Director of Energy Solutions at Fortis BC, Dan Reeve, Senior Vice President at Atco, Scott Dodd, director at Enbridge and Leigh Shoji-Lee and Timothy Egan, who are respectively Vice Chair and President of the Canadian Gas Association. As mentioned, Egan is also director at Sustainable Development Technology Canada.

Formed in 2012, the Canadian Oilsands Innovation Alliance (COSIA) is a collaboration of thirteen of Canada's largest tar sands companies, which pools resources, shares new technologies and funds research to lessen the ecological impacts of tar sands development, while also working to cleanse the industry's public image. Its green technology efforts are focused in four 'Environmental Priority Areas' of land, water, tailings and greenhouse gases. COSIA members launch projects related to these priority areas, share and assess results and implement technology to improve environmental performance. Most projects are joint endeavours involving one or more producers, as well as 'third parties,' such as university research centres and state innovation agencies.

COSIA is formed under the recognition that energy that comes from fossil fuels like oil and natural gas "account for a majority of global carbon dioxide emissions," and that solutions are needed. Its public relations efforts subsequently seek to minimize the crisis of fossil capital and present tar sands producers as forward-thinking innovators who will play a key role in advancing solutions to climate change. Its brochure assures us that as "science and innovation have been constant companions of oil sands development for the last century" the COSIA 'idea' is but a "new a chapter in a history of innovation"… "enabling responsible and sustainable development of Canada's oils sands, while delivering accelerated improvement in environmental performance…"(COSIA 2012, 2-3).

The organization has a CEO and six directors (one director per each of four Environmental Priority Areas), as well as an advisory and steering committee. As seen in Figure 7.2, COSIA is governed by representatives from large capital firms, and also interlocks with government and university research centres. Dan Wicklum (D_Wicklum), who is president and CEO of COSIA is also director at SDTC. Wicklum has also previously held senior positions at Environment Canada and Natural Resources Canada. Meanwhile, COSIA's funding of projects at U of A's Institute for Oil Sands Innovation and NAIT's Centre for Oil Sands Sustainability (COSS), are accompanied and supported by the strategic direction of Cheryl Trudell (C_Trudell), who is a Vice President of the steering committee at COSIA, and an industry advisor at both University Centres.[111]

[111] COSIA is listed a corporate contributor and funder at IOSI (see https://www.ualberta.ca/engineering/research/groups/oil-sands-innovation/partners-and-contributors) and the organization funds projects at COSS, including a $200,000 donation in 2018 for tar sands water treatment (see https://www.cosia.ca/resources/news-releases/support-clean-water-technologies-benefit-oil-and-gas-industry_)

The Petroleum Technology Alliance of Canada (PTA_CAN) also plays an important role in stitching the network together and linking industry-state-university organizations in the development of fossil fuel R&D. The Alliance, which is headquartered in Calgary, was established in 1996, to promote collaborative research and technology development for the hydrocarbon energy industry, broadly defined. Its vision is to "help Canada become a global hydrocarbon energy technology leader," and its projects span a number of priority areas, including: managing industry's environmental footprint, improving oil and gas recovery, creating operating savings and finding ways to create value-added products (Petroleum Technology Alliance Canada n.d.).

While the organization pursues a broad mandate, beginning in 2010, it redefined its strategy and direction, so as to focus more closely on technology development and innovation related to unconventional oil and gas. In this area, it is focused on addressing what it views as the unique challenge facing the industry today: the effort to "recover increasingly challenging deposits while reducing costs" and at the same time meeting the demand "that hydrocarbon production have significantly less environmental impact… [and] significantly higher energy efficiency" (Petroleum Technology Alliance Canada 2010). In 2015, the organization launched 59 research and development projects (by far the most since its inception in 1996), 41 of which address "high-priority environmental and social issues" pertinent to Western Canada's oil and gas industry. A key priority area that it identified is to "create the lowest environmental footprint in multi-stage hydraulic fracturing"… "while establishing the best economic performance for Tight Oil and Shale Gas operations throughout Western Canada" (Petroleum Technology Alliance Canada 2015). In 2018, along with the Canadian Association of Petroleum Producers and the Explorers and Producers Association of Canada, it launched the Fugitive Emissions Management Program

Effectiveness Assessment (FEMP EA) project, focused on methane leak detection, quantification and repair. The project has funding support from over 400 oil and gas producers and is described as "immense in scope."[112]

The Alliance is governed by a twenty-person board that extensively links together carbon-capital elites and state and university officials. The former include Kevin Stashin (K_Stashin), who is chair of PTA_CAN and member of the board of directors at the Canadian Association of Petroleum Producers (as well as CEO of private oil and gas producer NAL Resources) and Murray Todd (M_Todd) director at Bellatrix Exploration (BELLATRIX). The latter include Laurier Schramm (L_Schramm), president and CEO of Saskatchewan Research Council (SK_RC) – a Crown corporation conducting applied research on behalf of the Saskatchewan provincial government – and Cecile Siewe (C_ Siewe), a director at CanMet energy (CAN_M_EN), a Government of Canada research laboratory focused on addressing the environmental impacts of fossil fuel extraction, processing and use. The board also includes high ranking environmental state regulators such as Paul Jenkins, Vice Chair of the Canadian Oil and Gas Commission; Jim Ellis, President & CEO of the Alberta Energy Regulator; Mike Ekelund, former assistant Deputy Minister in the Department of Natural Resources Canada and former CEO of the Canadian Gas Association; and the Dean of Engineering at the University of Calgary, William Rosehart.

The centrality of industry innovation organizations in the network reflects the sector's move towards green extractivism. Meanwhile, the thick ties between industry innovation organizations and carbon-capital firms and key university and state research bodies are indicative of the way that

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[112] JWN Energy (2018). Canadian oil and gas associations launch 'immense' joint methane program. See < https://www.jwnenergy.com/article/2018/11/canadian-oil-and-gas-associations-launch-immense-joint-methane-program/>

government and university R&D priorities in Alberta and Canada more broadly align closely with the current interests and needs of the industry. Playing a role in the strategic direction of these organizations are prominent carbon-capital elites, including CEO's and directors of firms that dominate much of the sector and the industry associations that represent them. The highly integrated character of the network contrasts with the carbon-renewable linkages seen in Chapter 6, which as we saw are overall relatively sparse, involving a small number of firms (represented mostly by lower-level managers from carbon-capital firms).

Conclusion

I began this chapter by noting with Marx that science is a crucial component of the productive forces, employed to both produce and cope with socio-ecological transformation. It has played a vital role in the 'making of fossil capitalism' since the 18th century and has enabled the development unconventional sources, into the 21st century. In the face of the current climate crisis, which is simultaneously a crisis of fossil capitalism, carbon capital is now engaged in a strategic effort to 'green' its operations, or at least the public perception of them, in order to maintain conditions for the accumulation of fossil capital. Development of reputedly "clean technologies" is a pillar of industry's efforts at strategic self-preservation.

Network analysis identified the social form of this knowledge – its production in and through a host of interlinked industry-government-university centres and organizations. It thereby revealed the architecture through which carbon capital exerts continuous pressure on and works together with higher education, state and civil society research organizations to appropriate scientific capacities and direct the process of scientific discovery itself. In the process, I argued that the short-term interests of carbon capital have become deeply entrenched within universities and state innovation agencies, in a manner consistent with (and which further entrenches) "petro-state" priorities and imperative.

While investment in technology to achieve greater efficiency in carbon extraction and reduce the carbon footprint of fossil fuels has a practical benefit for the environment, such initiatives are not intended to (or capable of) reducing hydrocarbon dependence. The continued public subsidization of such research suits the interests of carbon capital. Therefore, while green extractivism involves limited 'objectifications' of ecological knowledge, any application of this potential beyond profit-making is strategic and sharply constrained. Indeed, fossil fuel corporations themselves increasingly fund technological and scientific research aimed at lowering the costs of production *and* reducing the environmental impact of fossil fuel extraction and transport. In the development of "clean" fossil fuel technologies, ecological science is *underutilized* – employed only in half-hearted processes of ecological modernization that do not halt, but instead continuously measure, monitor, and mitigate some of the environmental impacts of ecological debasement.

In addition to the 'misuse' of this existing productive capacity, by focusing on carbon-capital's reach into universities and the state and the ensuing institutional architecture that supports green extractivism, the research points to how transforming scientific research in its organization and prioritization would encourage the further *development* of ecological knowledge. Ending the colonization and harnessing of the scientific research process itself to the interests of carbon capital, while increasing funding and institutional support for various forms of sustainable earth science, pursued on the basis of their broad ecological or metabolic use-value, would generate new knowledge vital for energy transition and for a sustainable economy more broadly. Yet so long as human production is fundamentally guided by exchange-value and capital, such knowledge would continue to find limited application.

Conclusion – Beyond Fossil Capitalism: The Future of Productive Forces

Marx argued that in capitalist social formations, a key contradiction surrounds the growth of forces of production within property forms that come to act as their fetters. He considered how certain productive forces, or capacities and powers to transform the rest of nature, were suppressed and non-optimally employed in a mode of production that singularly values exchange-value over use-value and profit over economic and ecological stability. Through narrow and un-dialectical interpretations of the development of productive forces, this argument has often been understood in purely technical and linear terms. In this perspective, powers and capacities are taken to refer almost exclusively to increases in labour productivity and material output, which are understood as cumulative historical advances, to be further unleashed and unshackled under socialism.

By contrast, a dialectical-green take on the productive forces leads us to consider other more qualitative dimensions of the productive forces, which possess ecological or metabolic use-value, and reflect the needs to restore, maintain and improve the ecosystems that sustain human life and flourishing. I have argued that it is in reference to ecological science and knowledge, renewable energy technology and human cooperation itself that is it most helpful to retain Marx's view of the emancipatory potential of developing productive forces that are potentiated by, but unfilled within capitalism.

In the 19th century, Marx did not yet broadly question the use-value of growing material output and maintained that in its propensity to advance technical productivity, capitalism continued to help lay the material conditions for socialism. From a perspective of relative scarcity, he suggested that socialism may yet be more productive than capitalism, while such productivity advances (especially reductions in labour time) would lead to qualitative changes, or enable new richer forms of human development. However, Marx did not blindly endorse the total development of the productive forces; through the notion of metabolic rift, he recognized the wastefulness and ecological destructiveness inherent to capitalism's development of the productive forces and viewed ecological sustainability as a central goal of socialism. His reflections lead us to consider how as productive forces are caught up in and have been forged around capital's growth imperative, they become entangled in its (ecological) contradictions and are marked in their very materiality by the socio-political conditions of the mode of production that produces them. From this perspective, they cannot be viewed as neutral or as an altogether positive acquisition; in an alternative paradigm devoted to human flourishing based on a rational sustainable metabolic interchange with nature, they will need to be significantly and substantially transformed, rather than simply inherited and put to new uses.

Building on this recognition, while reflecting on new ecological issues accompanying capitalism beginning in its monopoly phase (including through the 'scientific-technical revolution' of the late 19th and early 20th century) and into the post-war period, Ernest Mandel (1999) along with thinkers like Herbert Marcuse (1974, 1991), Barry Commoner (1971) and Rachel Carson (1962), point to the proliferation of environmentally destructive technologies and the role of planned (capitalist) science in these developments. For these thinkers, it has become clear that capitalist production no longer conformed to basic human needs and instead consisted largely of waste or negative use-values in the form of the growing output of wasteful and superfluous commodities. For Mandel, the 'objective material conditions' of socialism had long been established, while in the post-war era he argued that "growing productive forces, with growing commodity-relationships can in fact move a society farther from the socialist goal instead of bringing it closer" (quoted in Tanuro

2014, 146). Commoner (ibid), similarly critiqued the type of science and technology that was supporting economic growth based on toxics and synthetics and the elite power that benefitted from and stood in the way of a change of productive technique to eliminate pollution.

The anti-ecological deployment and materialization of science and technology, along with the recognition that developing material productive forces could move us away from the socialist goal, takes on new significance in the 21st century. Anthropogenic climate change represents the greatest existential peril of our time, threatening to erode the conditions that support friendly human life and flourishing. The scientific consensus on global warming and on the imperative of timely climate action is clear. To avoid catastrophic climate change, the world will have to decarbonize energy within the next two decades. By implication, most of the world's carbon (especially unconventional deposits) will need to stay in the ground, while large parts of existing fossil infrastructure will need to be dismantled and demolished before the end of its useful life.

However, as I showed through case studies on Canadian fossil capitalism, carbon capital and its allies are doubling down on the fossil fuel regime in the context of ecological overshoot, developing new methods to extract the dirtiest deposits and pushing hard to create vast new infrastructural complexes that would enable the heightened accumulation of fossil capital. Both the material lock-in of infrastructures and the power of carbon corporations and other 'enablers' of carbon extractive development are key blockages to a rapid and comprehensive transformation to a sustainable and low or post-carbon economy. Eroding power in and around this sector is therefore an urgent task.

Moreover, case studies considered not only the deepening of fossil-fuelled productive forces but carbon-capital's simultaneous colonization and 'fashioning' of green productive forces –

witnessed in its investments in renewable energy, and the application of ecological knowledge to industry in the pursuit of 'green extractivism.' In analyzing this process, the research advanced our understanding of the nature of fettering in renewable energy development and in the use of ecological knowledge itself in the context of the crisis of fossil capital. In both cases, the fettering we observed in the development of productive forces is relative rather than absolute.

In the case of renewable energy, existing research has documented slow, yet growing volumes of installed capacity. I subsequently investigated the carbon extractive sector's role in this development and considered whether we are witnessing signs of "transition capture" as some oil and gas producers invest in a gradual transition towards climate capitalism with an eye towards dominating the emerging sector. Existing investments by large players indicate that some fossil fuel firms may have a stake in seeing the slow expansion of renewable energy. This development sits in some tension with the idea of fettering advances in forces of production, pointing to how clean energy could develop under the control of big energy companies, especially fossil fuel corporations, who slowly subsume renewables under their centralized control. Overall, however, findings point largely to a carbon extractive sector without plans for energy transition or transition capture. Investments by large firms can at most be interpreted as a very long-term alignment, and one that is consistent with the notion of relative-developmental fettering.

In examining the relative lack of private sector investment in renewable energy, I pointed via Malm to a 'basic' contradiction between the use and exchange-value of renewables (as they possess tremendous metabolic worth but struggle to attract capital investment), as well as to the contradiction between big carbon's quest to valorize massive fixed-capital investments and the requirement to decarbonize energy in a rapid and socially just manner. The case study has several limitations. Further work could examine the investment strategies of large Canada-based firms beyond the top ten 'majors,' as well as those of non-Canada based corporations operating in its oil and gas sector (such as the subsidiaries of Shell, Total, Chevron, Nexen CNOOC and ConocoPhilips). This would enable comparisons between Canada-based, Europe-based, United States-based, and other (Asian and Middle-Eastern) carbon corporations in regard to their investment strategies, as well as a consideration of factors that help explain any differences. Additionally, it would be helpful to address the financial sector's role in both the ownership and funding of renewables – considering the extent to which major banks are shifting investments towards green energy – as well as the sector's interlocks with renewable energy firms and linkages into climate-capitalist organizations. This would help deepen the concrete-complex analysis of fettering within fossil capitalism, producing increasingly comprehensive and detailed explanations.

It remains an open question whether capitalism can decarbonize (however slowly, unevenly and unjustly), yet the case study makes it clear that a market-based approach will not suffice to catalyze a green energy transition within our current carbon budget. As is the case globally (York and McGee 2017), non-fossil fuel sources have been added to Canada's 'energy mix' incrementally and on top of a net expansion in the consumption of fossil fuels (Hughes 2018). The yearly ebb and flow of renewable energy development, along with the fact that clean energy capacity can continue to grow on top of an expanding bed of fossil fuels, points to fettering that follows when different feasible relations of production (unfettered to capital's profit and growth imperatives), would develop productive forces not only faster, but also systematically and comprehensively, on a prolonged basis (rather than temporarily, fleetingly and erratically) and according to a plan.

As explored in Chapter 7, science and ecological knowledge have long been appropriated and applied to the carbon extractive process. Undergirded by state and public research infrastructures, science has been vital to the 'making' of (Canadian) fossil capitalism. In the context of the climate crisis, which is simultaneously a crisis of fossil capitalism, scientific and ecological knowledge is increasingly co-opted and harnessed back into the extractive process, as a means of 'greening' the accumulation of fossil capital via the production of 'clean technologies.' The process enjoys extensive governmental and public institutional support. This partly because such projects have immediate and practical ecological benefits, while also being compatible with predominate and powerful corporate interests. Carbon capital is also highly active in seeking to direct the process of R&D by actively reaching into universities and cultivating and maintaining close relations with a cadre of scientifically minded policy and decision makers. Green extractivism, itself a contradiction in terms, is a vital case of the underutilization or 'relative-proportional' fettering of ecological knowledge under conditions of dangerous ecological overshoot.

Moreover, by showing how such knowledge is appropriated in service to the fossil fuel sector's accumulation strategy, the research points to how the 're-making' of scientific research and development in its organization and prioritization would enable the growth of new knowledge and insights critical to ecological sustainability, including energy transition. The situation in Canada is troubling but not exceptional. A recent study of carbon-capital's influence over leading American universities concludes: "Fossil fuel interests – oil, gas, and coal companies, fossil-fueled utilities, and fossil fuel investors – have colonized nearly every nook and cranny of energy and climate policy research in American universities, and much of energy science too" (Franta and Supran 2017).

In the remaining sections of this chapter, I develop the practical implications of a more dialectical, green-Marxist take on forces of production. I do not provide a 'blueprint,' but rather outline broad 'first measures' and strategies for building a democratic green socialist project centred on 'governing the human metabolism with nature in a rational way.' This involves bringing the process of production under collective control, enabling the creative/destructive transformation of productive forces and their 'unshackling' in the pursuit of just and sustainable alternatives. While I emphasize control over productive forces (and especially energy resources, infrastructures, technologies, and associated skills and knowledge), transformation necessarily extends to the sphere of reproduction and everyday life. The vision is tilted towards Canada, but maintains an eye towards the international, and the global.

Key Measures:

- Rapidly and comprehensively phasing out fossil fuels, while transitioning to a clean energy system based on sources such as wind, hydro, solar, wave and geothermal.
- Restructuring existing extraction, production and distribution systems, including eliminating the production of useless and harmful goods, reducing the length of commodity chains and the amount of transport where feasible and desirable.
- Halting the appropriation of knowledge by industry and "remaking" science in its organization, prioritization and application.
- Planning the transition at all levels in a democratic and participatory manner.

Taken in isolation, these measures appear somewhat compatible with a renovated capitalism. Uniting them into a coherent plan achievable within the next few decades is entirely inconceivable within the framework of today's neoliberal capitalism. The transition is not based on profit, but is necessitated in large part by the urgent threat of carbon-based fuels to the long-term viability of ecosystems that support human life. It will require new forms of planning, different forms of social property and the socialization and democratization of finance and investment, opening paths for deep and radical democratization (Candeias 2013b; Carroll 2017). This breaks from the logic of private accumulation and the reign of exchange-value, providing common ground for converging agendas across what Candeias (ibid) calls a 'mosaic' and transformative left.[113]

1) Rapidly and comprehensively phasing out fossil fuels, while transitioning to a clean energy system based on sources such as wind, hydro, solar, tidal, wave and geothermal.

Despite increasingly common pronouncements that energy system transformation is now underway, and that carbon corporations are helping lead the transition, there is little evidence that current market-led approaches can produce a timely energy transition, or that carbon capital will act as "green saviours." A climate capitalist model of energy transition portends ecological disaster. An enforced and managed wind-down of fossil fuel production is needed, alongside a democratically controlled and planned process of development in renewable energy.

As Carroll puts it, energy transition requires that we "shift power, in both senses of the term: from fossil-fuel power to renewables (decarbonization) and from corporate oligarchy to public, democratic control of economic decisions (democratization)" (2017, 256). Establishing democratic control requires public ownership of the energy sector. This can take different forms – state,

[113] While a mosaic of left agencies/movements can form the basis of such a fundamental transition, this does not preclude the role, indeed the likely imperative of, political parties struggling over the space of the state in conjunction with and alongside left movements. For discussion and debate on the form of such a party or political organization might take (see Harnecker 2007; Albo, Gindin and Panitch 2010, 89-121; Dean 2016).

community-based, worker-led operations and co-ops – which in different ways challenge private ownership and commodification. A combination of different forms of organization could be used, enabling the bottom-up development of alternative energy.

Public ownership does not merit blanket, uncritical endorsement. In terms of state ownership, much is wrong with traditional Crown corporations, which often function much like private corporations; they frequently operate with a profit-maximization mandate, encourage little public involvement in decision-making and maintain extensive ties to private industry. As Thompson and Newman (2009) suggest, it is therefore vital to provide such institutions with more robust social and ecological or 'public interest' mandates, while also democratizing their governance. From an ecological use-value perspective, a public-interest mandate should mean that renewable firms would induce consumers to buy less of what they sell, reducing energy demand and promoting conservation, while curtailing expanding production. Such strategies are incompatible with the private sector's growth and profit imperative.

Since the 1970s, many pioneering initiatives in renewables have taken the form of co-operative and community-ownership, with emphasis on local control (Abramsky 2010b). In the Canadian context, close to 60 percent of Canada's current renewable power comes from hydropower, most of it already constructed in the form of large 'legacy' dam projects, with Crown corporations playing an important role (Laxer 2015a). There is still a need for new large-scale development, but this provides a strong base from which to transition to a low carbon future through the expansion of small-to medium-scale renewable energy projects, including wind and solar power, as well as hydro from run of the river turbines and tidal turbines. First Nations, as well as other community groups and co-operatives have a key role to play in this development. Indeed, as research by Shaw et al. (2017) suggests First Nations in Canada are well positioned to help lead this, while other communities, especially in rural areas could also be encouraged on this path.

In addition to different form of public ownership and interest in renewable energy, which can facilitate a bottom-up process of development with built in social and ecological mandates, it is important to consider forms of planning aimed at comprehensive phase-out of fossil fuels. In the transition, as Abramsky (ibid) points out, there is a need for continued use of fossil fuels, but these must be used in a rational and collectively planned way, rather that through wasteful competitive market allocations. Muscular state policies can constrain and strategically shape development in a manner that assists in effecting a rapid transition to renewable energies. Higher royalties on hydrocarbon extraction, taxes on carbon usage, and controls on overall emissions (including through polluter-pays provisions) can raise funds to help facilitate a transition to alternatives, including the creation of "green jobs." In Alberta, the recent decision by the NDP government to impose a nearly 10 percent cut on the production of bitumen (in an effort to reduce excess supply and increase price per barrel, thereby maximizing profit across the sector), unwittingly points toward the clear feasibility of progressively downsizing and even sunsetting of the tar sands (See Acuña 2018).

Laxer's (2015) 'ecological security plan' for Canada combines a number of these measures. He advocates using existing conventional resources in the short-to medium term, with their planned phase out in a transition towards renewables. Moreover, as a component of the plan and drawing on Thompson and Newman (2009), Laxer points to the potential merits of transforming some segments of the existing oil and gas industry to public-interest ownership models. As he argues, some public interest ownership in this sector, along side a broader 'power down plan' would mandate non-profit entities to buy less of what they sell and could simultaneously wean users off carbon and onto renewables. His plan thereby helpfully combines strong regulatory measures with a shift away from private, for-profit ownership and control, as energy companies are converted to or displaced by such public-interest, not-for-profit entities.

Energy transition can begin nationally, but it must ultimately be achieved at the global level through cooperation and ideally based on collectively agreed pace and priorities.

Control over Finance

As we have seen, the financial sector maintains a very close relationship with the fossil fuel industry and has a strong vested interest in valorizing its massive investments in fixed fossil capital. Castree and Christophers (2015) point to the possibility of robust regulatory practices and reforms that can re-route private finance capital towards more ethical and ecological ends. Yet, as Zadek (2013) notes, various reforms and mechanisms aimed at provoking private, ecologically oriented financing are yet to come close to unlocking capital at the scale that that is required. Major institutional investors, he notes, continue to be resolutely “dirty and brown” and ‘short-termism’ continues to dominate institutional investment. Moreover, as much of the needed infrastructural development (transportation and built environment reconstruction for green energy) will not be revenue generative, it will not be pursued on capitalist criteria. Corporate allocative power, the control of the financing of energy is therefore a powerful obstacle to our dealing effectively with the ecological and economic challenges we face today.

As Carroll and Sapinski (2018) argue, a timely transition requires bringing banks and other sectors of allocative power under democratic control through public ownership. The socialization of banks has been long been an aim of the left, but as they make it clear, public ownership alone is not sufficient. As with energy Crowns, banks need to be thought of as a service delivered in the public interest (mandated to support socially and ecologically healthy investment), and also democratized in their governance. In contrast to the allocative power of today's financial institutions, Carroll and Sapinski point to a financial system organized as a network of public banks, whose governance is democratized through participatory budgeting. While participatory budgeting has been successfully practiced at the local and municipal level, the challenge is to scale it up and think of how it could apply to economic decision making broadly.

Worker Control

Workers currently employed either directly or indirectly in fossil and nuclear sectors and other energy intensive sectors have a key role to play in energy transition. Mobilizing and "redirecting" their skills and knowledge is vital to green transformation (while re-training may be needed in some cases). As Abramsky (2010b) suggests, in a drawn-out energy transition on the model of the market, every effort will be made to accomplish the shift on the back of workers. Having renewables 'out compete' fossil fuels in costs, does not only mean technology advancements, it means reducing labour costs across the (global) renewable commodity chain. Public ownership in the sector and across the chain (in manufacturing, installation, maintenance) provides an opportunity for not only good working conditions and wages, but also for worker participation in and democratization of workplaces in the establishment of these new industries. This is a vital part of collectively reclaiming and taking control over means of production. The combination of decarbonization and economic democratization has been endorsed by the international trade union movement, including Canada's largest unions and the Canadian Labour Congress, through Trade Unions for Energy Democracy.[114]

[114] See http://unionsforenergydemocracy.org/. TUED was formed through the roundtable of trade unionists in 2012, and currently includes 47 unions in 17 countries

Control of Land for Renewables

The process of energy transition could be an opportunity for re-claiming and asserting control of land by Indigenous communities. The primitive accumulation of fossil capital entails extensive land grabs, through which carbon-capital appropriates and controls huge swaths land for both carbon extractive exploration and production. In addition to land held for the process of 'search and discovery,' Jacobson et al. (2018) show that oil and gas development actually requires a much larger land footprint that renewables would. This counters the common claim that alternative energy systems require huge amounts of space and territory to generate the equivalent energy from buried sunshine (Huber 2015; Laxer 2015a). This is because fossil fuel energy production entails much more that extracting fuel from a single "hole." As we saw in Chapter 5, oil and gas production involves numerous wells and fields, as well as extensive networked infrastructures (associated roads and local storage facilities, vehicle fueling stations, large refineries, and processing plants, pipelines for import and export, long distribution networks and so on). This is dedicated fossil-fuel land and little of this land footprint can be used for other purposes. Giving substantial amounts of land back to Indigenous peoples currently held by carbon firms (and other large producers) and dedicated to fossil fuel use during the transition could contribute to decolonization and Indigenous resurgence.

Moreover, much of the land for renewable development (where much renewable energy development is likely to be located and where renewable energy resources are located) is in rural and (unceded) Indigenous territories. In Canada, as Shaw et al. (2017) suggest First Nations are themselves well positioned to help lead development, while securing or asserting control over land formerly held by or used in service to fossil fuel development can help ensure real decision-making power. Further to this, a largely publicly owned and democratically managed sector, built through organizations with strong social and ecological mandates, would help ensure free, prior, and informed consent for large-scale industrial projects.

Geographies of Reproduction and Everyday Life

Throughout the study, I have focused primarily on the process of industrial energy transformation, while energy system transition must include a transformation of the energy system as a whole – energy that powers production, as well as (public) transportation, communities and homes. Within this view, free and efficient public transport networks built on renewable electricity, along with urban planning schemes that increase walkability and reduce the need for private trucks and cars as well as the retrofitting homes and buildings for energy efficiency are important aspects of green transformation. Such a shift, as Huber (2013b) suggests, involves a radical transformation in the 'geographies of social reproduction' and everyday life. As he shows, the New Deal resurrected capitalism through not only the reorganization of production, but also the reproduction of material life built around private cars and suburban homes, dramatically reshaping the way people consumed oil and other forms of energy. Deep structures of feeling associated with regimes of energy consumption are a critical barrier to movements for a just transition. Yet, as he writes, "the cars, homes, roads and countless petroleum products that make up so much of American life are products not of atomized individuals but broader social relations, public investments and legacies of social and environmental injustice" (169, ibid). Within this understanding, an energy transition is viewed as a political struggle to "produce new spatialities of social life" (ibid, 168). It is situated within a broader struggle to control and remake various aspects of life and 'conditions of production' (patterns of housing, transport, leisure, education, health), bringing them under social and democratic control against the abstract forces of the market and the private appropriation of wealth.

Moreover, just as an energy transition implies a radical transformation in what Huber refers to as geographies of social reproduction and everyday life, it can form the basis for or be a component of broader process of democratic social transformation in the productive forces. Energy transition is a central component of green transformation, but it will not be enough to mend to the climate rift. A sustainable socialist alternative must go beyond replacing an industrial energy system built on fossil fuels with one based on cleaner and renewable fuels, grid for grid, pipe for pipe. As I have argued, fossil capital has enabled and facilitated the 'abstract space of accumulation,' while energy networks are geared around the underlying over-production of goods. A renewable energy system, organized in the long-term to mend and restore the metabolic relation with the rest of nature would need to look quite different. It would be constructed around sustainable production for use and would be much more decentralized.

2) Restructuring existing extraction, production, distribution systems, including eliminating the production of useless and harmful goods; reducing the length of commodity chains and amount of transport (and thereby relocating production)

Already in the 1970s Mandel ([1975]/1999), pointed to the overdevelopment of the productive forces in the Global North. Recent sharp outsourcing trends mean that large swaths of materialized productive forces that provision the "overdeveloped world" are now located in the Global South. This adds complexity to a recognition that the socialist alternative must involve in some respects a 'retreat' in material processing of goods (and in some cases a decline in the productivity of labour). Nevertheless, as this outsourcing remains heavily focused on Global North consumption (Malm 2012, 2016, 327-367; Minx et al. 2011), we can recognize that the productive forces dedicated to the output of goods both within and which service the Global North have been developed too far, such that along with decarbonization and the construction of a new energy system, green socialism requires substantially transforming and in some cases sunsetting high energy and polluting industries beyond the fossil fuel sector, such as in transport, automobiles, petrochemicals, mining construction, factory farms and monocrop agriculture.

In shutting down or substantially scaling back such industries there is an opportunity for the conversion of firms and workers in them to become 'green service' providers. Those in the automotive, steel and transport industry for example, possess vital skills and knowledge for developing and facilitating public transport and public mobility. The nationalization and democratization of these industries and the conversion of productive capacities to ecological ends again requires a broader national plan that creates the social demand for such a conversion. The short and medium-term interests of workers must be a priority in the transition and tangible jobs must be identified to win over unions and non-union workers suspicious of anything green after years of environmental scapegoating. There are difficulties and conflicts that cannot be glossed, however. As the energy transition cannot be joule for joule, it also would not, in the long-run, directly be job for job.

Supporting farmers to convert to ecological agriculture – more local food production on the basis of agroecology, while eliminating factory farms and high-polluting agribusiness – is also an important feature of green transformation. As Tanuro (2014) points out, this conversion provokes questions surrounding labour productivity. While growing the productivity of labour as a means of reducing work time has often been considered a central goal of socialism (and broad reductions of work time can have positive ecological effects), the need to move away from large-scale, one-crop farms to more integrated, organic agriculture and farming implies some decline in productivity. Marx's vision that we govern the human metabolism with nature rationally and with "the least expenditure of energy," is suggestive, yet he was almost surely referring to reducing the amount of human energy devoted to arduous human labour. In our times, it should be taken to refer firstly to a reduction in the use and squandering of "buried sunshine," to be largely replaced by solar flow, while the amount of human energy and work – that is, of people power – assigned to fields of production such as agriculture, may need to increase.

Reducing Transport and Shortening Commodity Chains

For Marx the metabolic rift is exacerbated and becomes irreparable due to the spatial disjuncture in production and in the antagonism between the city and the country. Already in the 19th century, he recognized that production chains were overstretched and wasting resources. While their predecessors were already staggering in Marx's time, today's continent spanning 'mega-corridors' (Hildyard 2017) that facilitate and structure the flow of goods and the associated re-engineering of ecologies and geographies they entail, dwarf those he could have possibly imagined. Today, lessening the spatial disjuncture between production and consumption must be a feature of sustainable transition. This is echoed in calls on the left for partial 'de-globalization,' including the shortening of commodity chains, the 're-municipalization' of infrastructure, and a re-focusing on domestic and local production (Candeias 2013b; Klein 2011). Such a shift could contribute towards ending the 'imperial mode of living,' enabling spaces for independent development in the global 'periphery' (Candeias, ibid). A move away from the export orientation of domestic corporations and focus on renationalization, could also allow firms to begin to develop their own strategies, moving away from whims of global market and choices taken by corporate controllers (Candeias 2013b).

While supporting perspectives advocating forms of localization and re-nationalization, and in some instances the replacement of 'dead' by 'living' labour, it is worth surrounding a cautious note around this shift. Such a transition would need to be complemented by extensive redistributions (including at the global level) addressing reproductive needs. A re-centering of activity upon the local and domestic economy would need to proceed simultaneously through an 'association of connected locales.' More generally, Marx considered there to be progressive features and potentialities associated with large-scale industrialization. He pointed to forms of human development and freedom enabled by the transformation of work away from human muscles and pointed to globalizing production networks as potentiating heightened forms of cooperation. An ecologically oriented left should not be quick to dismiss this. More pragmatically, to downplay the extent to which the material reproduction of much of humanity is supported by globalized and mechanized production, undergirded by high levels of energy consumption courts ecological disaster. To paraphrase Marx, we make history but under conditions set by the current mode of production.

Shift to a 'Caring Economy'

As we have seen, Marx's views surrounding reductions of work time have often been interpreted in anti-ecological fashion. By reading his arguments around free time through a productivist lens, critics here miss an opportunity to think of increased free time as a possible means of *reducing* the pressure of production on the environment (see Rosnick 2013). Indeed, reducing work time is an important means of reducing energy and matter throughput (and thereby emissions), while increases in free time could also help institutionalize subsistence practices and a "do it yourself" ethos, with positive environmental effects. Under conditions of present ecological overshoot, such a shift might reduce the quantities of objectified labour we surround ourselves with (leaving us poorer in terms of this capital-logic criterion) yet open up more free time for various social, political and cultural pursuits (including time to engage in effective political participation via time to read, think and learn, to attend meetings and events, to take part in strategizing) and also enable richer human relations.

In his reflections on the realm of freedom in Capital III, Marx problematically excluded friendly unalienated relations with other human beings from the sphere of labour and pointed to the goal of reducing all labour for the basic maintenance of one's life (see Mies, 1986, 212-13). However, today in reducing work dedicated to the production of "things," more time and energy could also be devoted to forms of labour that centre reproductive needs. This would mean substantially shifting from carbon intensive forms of labour, based on the production of commodities and goods, towards not only "clean-tech jobs," but also towards expanding sectors of the economy based on social provisioning and in areas such as caregiving, teaching, social work, the arts and public-interest media, which create small ecological footprints (Stanford 2008). These too are "green jobs," whose growth is critical to projects aimed at sustaining and rehabilitating the metabolism between humanity and the rest of nature. This would entail and provoke a re-definition of "socially necessary labour." Moreover, as most of this labour is performed by women, it points to their central role among the "associated producers," in sustainable transformation.[115]

[115] The need to shift from the production of ever-increasing quantities of things to an enhanced production of services in a 'caring economy' has resonances with ecofeminist work which points to the *regenerative* nature of reproductive work and social provisioning, and is also found in recent 'green left' alternative visions in Canada such as the 'Leap Manifesto': https://leapmanifesto.org/en/the-leap-manifesto/

Concomitantly and from a global perspective, we can point to the central role of women in peasant agriculture and subsistence farming practices, which meet the needs of much of the world's population (Bennholdt-Thomsen and Mies 2000; Rapsomanikis 2015). Indeed, as Shiva reports (2016, 16), the world's peasantry, mainly women, produce almost 70% of the world's food. As Salleh (2010) argues, peasant reproductive provisioning and subsistence farming (and the knowledge embedded in those practices) are critical to the maintenance and reproduction of natural environments. This form of production produces concrete use-values and is simultaneously 'rift-healing' and possesses 'metabolic-value,' denoting its contribution to sustaining and supporting ecological integrity. Valorizing these practices does not imply a romantic return to the past, but rather recovers knowledge and traditional practices and combines them with new technologies and new knowledge (Desmarais 2007). Peasant-based land reclamation and food sovereignty movements, such as Via Campesina,[116] for example, thereby encourage a rethinking of the global food system to encourage sustainable forms of food production and distribution and women's democratic control (McMichael 2007).

3) Halting the appropriation of knowledge by industry and "remaking" science in its organization, prioritization and application.

Ending the appropriation and colonization of ecological science and knowledge by the fossil fuel industry (and other corporate interests) is vital to the process of energy transition and to the development of a sustainable economy more broadly. Without political intervention, such knowledge will be progressively harnessed into the accumulation process and colonized by the

[116] See https://viacampesina.org/en/. Via Campesina is a coalition of 182 organisations in 81 countries across Europe, Latin America, Asia, North America, Central America and Africa.

interests of corporate capital (especially carbon capital), while governmental cadre will continue to direct research and development towards insipid reform efforts.

Concertedly, as universities and state innovation agencies continue to express a commitment to the production of knowledge and research for the public good, it is important to expose the limitations of current green technology development and the interests driving their development. While investment in technology to achieve greater efficiency in carbon extraction and reduce the carbon footprint of fossil fuels has a practical benefit for the environment, the limitations of this approach are clear: these initiatives are not intended to reduce, or capable of reducing hydrocarbon dependence.

The fossil fuel sector's colonization of scientific and ecological knowledge is but one (albeit an important) example of the appropriation of science and ecological insights by industry and one case of the drastic underutilization of such knowledge in the context of the ecological crisis. However, many ecological and climate scientists have come to acknowledge the momentous socio-economic implications of their findings and are increasingly frustrated by the inadequacy of such responses (Castree 2017; Foster 2010; Klein 2014). This situation offers a unique opportunity for Left coalition and alliance formation, based on a vision that ecological science, indeed science at large, needs to serve society in new and better ways. The crisis provokes politics aimed at, as Marx put it, "converting science from an instrument of class rule into a popular force" (Quoted in Perelman 1978, 868).

At the level of strategy, Werskey's (2007) recollection of earlier attempts (especially in the 1930s and 1960s) to radicalize science politically – to 're-make' science in its organization and prioritization – are helpful. While these efforts ended in failure, visions of a 'public interest science' model have merit and renewed purchase (see also Hamlin 2007). Such a model confronts, challenges and seeks to overturn the longstanding yet deepening processes of corporatization and 'state-corporate symbiosis,' surrounding R&D – that is, the increased integration between public sector organizations and private firms, and blurring of lines between public/academic and private/corporate spheres, regarding the goals of knowledge production. This involves challenging the way industry-state-university relations are organized and the various practices and programs witnessed in Chapter 7 (private funding to support industrially oriented research, university/industry partnerships, having corporate executives direct higher education and public bodies), through which control over these organizations is ceded to industry. By contrast, reorienting them to serve more public purposes, could begin by encouraging greater openness, consultation and partnerships with academics, students, community and public interest groups, in the development of a bottom-up mandate and vision (Atkinson-Grosjean 2006; Polster 2018).

A public interest model of science can be fruitfully combined with perspectives that point to the need for a greater diffusion of ecological knowledge and insights among producers or the possibilities of 'lay science' (See Saed 2011) and 'citizen science' (Riesch and Potter 2014). This more democratic approach to the practice of science, is perhaps especially relevant to the field of agriculture (and is a current feature of agroecology) and sharply contrasts with the big institutions of capitalist 'techno-science.' These approaches return us to Mao, as they encourage a more bottom up approach to science, which can help alleviate inevitable tensions between 'reds and experts.' A greater diffusion of ecological knowledge and insights and practices of 'lay science' also softens the distinction between formal ecological science and traditional and land-based knowledge, which has vital role to play in the construction of sustainable alternatives. Yet, as I have argued the fulsome development and expansive application of ecosystem knowledge to production is not possible within a paradigm centred on capital accumulation. It could only take place in a system devoted to human flourishing based on a rational and sustainable metabolic interaction with the rest of nature.

4) Planning the transition at all levels in a democratic and participatory manner.

Throughout *Capital* Marx places emphasis on the need for the "associated producers" to freely organize and plan production on a collective basis, according to their own plan.[117] The rolling back of capitalist discipline, the ending of the separation of thinking and doing (by introducing education into the workplace), the conscious organization of production on a democratic basis (through the councils tradition, of through cooperatives, for example) is the alternative at the level of the individual enterprise (See especially Lebowitz 2006). But this alternative has to be accompanied (possibly superseded) by some coordination and planning of production across the interrelated divisions of productive labour in society as a whole (Harvey 2010). Capital arrives at allocations largely through the "anarchy of the market," (particularly money flows and market processes), producing crises and a great irrationality in Marx's view. Where it does engage in limited and partial forms of planning, these are arrived at through corporate and state hierarchies (Van der Pijl 1998).

Planning extends to coordinating socialized labour in order to reproduce daily life at an acceptable level of material well being and in relation to conditions of ecological sustainability. It entails coordinated management or planning of associated labour with an eye to the functioning of the whole, including the restitution of the degraded of natural conditions that sustain life. I have

[117] Of course, the rational and democratic organization of production has to be the work not only of 'producers' but of the whole society, or of an 'association of free human beings,' working with common means of production (see Lowy 2007).

already considered how planning is vitally needed for energy transition, pointing to the need to developing renewables in not only a rapid but coordinated, rational and systematic fashion, in contrast to the prolonged and chaotic market.

More broadly, as I have intimated, the geographical proliferation of productive ties allows for resource allocations that meet reproductive needs and act as insurance against local calamities. Climate change in particular creates severe survival and livelihood challenges for many millions on a highly uneven basis. In a highly interdependent world, the reproductive needs of various communities require planned (global) resource flows. Marx helpfully encourages us to think of planning as a sharing of the skills and knowledge of the 'collective worker' that are required to address reproductive needs and eco-metabolic problems. This can be seen in the technology and knowledge transfer movement, including around renewable energy technologies (see for example the International Renewable Energy Agency).[118] As Abramsky (2010b) notes, technology transfer has echoes of modernization ideology, yet it takes on a very different meaning and dynamic when it is based on a non-commercial process. Such a global movement is part of defending control and common ownership of knowledge, devoting it to common use.

The contemporary left has largely avoided the issue of planning and all of the complexity of cooperation and expansive divisions of labour, likely in part because of the poor legacy and experience of communist and social democratic planning. Yet the issue cannot be ignored. As I have intimated, planning need not be hierarchical and centralized, or imply homogenization. Democratic global planning is part of process by which the capacities, capabilities and powers of the collective

[118] See https://www.irena.org/aboutirena. IRENA is an intergovernmental organisation founded in 2009 supporting countries in their transition to a sustainable energy future, including through knowledge sharing.

worker are developed and mobilized in service of the remaking of the world for justice and ecological restoration.

Conclusion

For much of today's green-left, forces of production are strictly associated with technological machinery aimed at increasing productivity and material output. Marx's focus on the development of productive forces is then taken as a symptom of an outmoded productivism. This (mis)understanding leads us to ignore the inevitable role of productive forces in a society beyond capital and forecloses the possibility of attaching political hopes to their development.

By reconceptualizing forces of production as that dimension of existence by which we are purposively linked to and transform the rest of nature, the struggle for control over them is readily placed at the centre of a socio-political response to the "Anthropocene." Such a conceptualization, understood dialectically (and thereby through a historical and geographical lens), encourages a careful consideration of their unfulfilled potentiality, as well as the need for their creative/destructive transformation in a society beyond capital. It enables us to better comprehend the challenges posed by (fossil) capital domination, as well as key vectors in a transition to green socialism in the 21st century.

The reconceptualization clarifies that the development of productive forces is not a linear process and that, at least in the Global North, the socialist alternative now implies a retreat in the aspect of their development dedicated to growth in the processing of natural resources and the production of things requiring matter and energy throughput. At the same time, a historical materialist standpoint recognizes that we cannot immediately shut down the vast productive networks, and infrastructural configurations that currently support and sustain huge swaths of human life, without courting humanitarian disaster. A socialist transformation may not necessarily be smooth, however, transforming and transitioning away from the productive forces inherited from capitalism entails some inevitable "compromise" with the forms of social organization and social relations that produced them.

While helping to specify facets of creative/destructive transformations that must accompany a worthy socialism, a green dialectical take on the forces of production and simultaneously points to capacities and powers necessary to maintain, restore and improve ecosystem health, but that are critically constrained by capitalism. Establishing democratic social control over green productive forces and unfettering them from capital's profit and growth imperatives is vital to creating a new paradigm based on human flourishing within sustainable and thriving ecosystems.

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Appendices

Appendix 1: Canadian Renewable Energy Firms

Name	Mnemonic	Catgeory
3G Energy Corp	3G Energy Corp	Renewable-Private
ACCIONA Energy Canada	ACCIONA_CAN	Renewable-Private
Aeolis Wind Power	AEOLIS	Renewable-Private
Algonquin Power and Utilities	ALGONQ	Renewable-Private
Alterra Power	ALTERRA	Renewable-Private
Ameresco Canada	AMER_CAN	Renewable-Private
AMP Solar Group	AMP_SOL	Renewable-Private
Aneargia	ANEARG	Renewable-Private
Avro Wind Energy	AVR_WND	Renewable-Private
Black Rock Tidal Power	BLACKROCK	Renewable-Private
Boralex INC	BORALEX	Renewable-Private
Bridge Power	BRIDGE_PWR	Renewable-Private
Brookfield Renewable Power	BR_FIELD	Renewable-Private
Bullfrog power	BULLFROG	Renewable-Private
Canadian Hydro Components	CAN_HYDRO	Renewable-Private
Canadian Solar Inc.	CAN_SOLAR	Renewable-Private
Cape Breton Explorations Ltd	CAPE_BR	Renewable-Private
Carmanah Technologies Corp	CARMA_TECH	Renewable-Private
Chinook Power	CHIN_PWR	Renewable-Private
EDF EN Canada	EDF_CAN	Renewable-Private
EDP Renewables Canada Ltd.	EDP_CAN	Renewable-Private
Endurance Wind Power Inc.	ENDUR_WIND	Renewable-Private
ENERCON Gmb	ENERC_CAN	Renewable-Private
Engie Canada	ENGIE_CAN	Renewable-Private
Fiera Axium Infrastructure	Fier_Ax	Renewable-Private
Fritzall	FRITZ	Renewable-Private
GDF SUEZ Canada Inc.	GDF_CAN	Renewable-Private
Innergex Renewable Energy Inc.	INNERGEX	Renewable-Private
Instream Energy Systems	INSTR_EN	Renewable-Private
Lakeland Power	LAKE_PWR	Renewable-Private
Naikun Wind Energy	NAIK_WIND	Renewable-Private
Natural Forces Technologies	NAT_F_TECH	Renewable-Private

New Energy	NEW_EN	Renewable-Private
Northland Power	NORTH_PWR	Renewable-Private
NRStor Inc.	NRStor	Renewable-Private
Pattern Energy	PATTERN	Renewable-Private
Potentia Renewables Inc.	POT_REN	Renewable-Private
Renewable Energy Systems Canada	REN_EN_CAN	Renewable-Private
Scotian WindFields Inc	SCOT_WIND	Renewable-Private
Sea Breeze Power	SEA_BR	Renewable-Private
Senvion Canada	Sevion_CAN	Renewable-Private
Sequoia Energy Inc.	SEQ_EN	Renewable-Private
Shear Wind Inc.	SHEAR_WIND	Renewable-Private
Silfab Ontario Inc.	SILFAB	Renewable-Private
Silicor Materials Canada Inc.	SILC_MAT	Renewable-Private
SkyFire Energy Inc	SKY_FIRE_EN	Renewable-Private
SkyPowerGlobal	SKY_PWR_GLOB	Renewable-Private
Synex International	SYNTEX	Renewable-Private
TransAlta Renewables	T_Alta	Renewable-Private
Vestas Canada	VEST_CAN	Renewable-Private
BC Hydro	BC_HYDRO	Renewable-Crown
Powerex	POWEREX	Renewable-Crown
Columbia Power	COLUM_PWR	Renewable-Crown
Manitoba Hydro	MN_HYDRO	Renewable-Crown
Nova Scotia Power	NS_POWER	Renewable-Crown
Hydro-Québec	HYDRO-QUEBEC	Renewable-Crown
Maritime Electric Company	MAR_ELEC	Renewable-Crown

Appendix 2: Hybrid Firms

Name	Mnemonic	Category
Nova Scotia Power	NOVA_PWR	Hybrid-Private
TransAlta Corp	T_ALTA	Hybrid-Private
5N Plus Inc.	5N_PLUS	Hybrid-Private
Emera	EMERA	Hybrid-Private
Celestica Inc	CELST	Hybrid-Private
Siemens Wind Power	SIEM_REN	Hybrid-Private
Capital Power	CAP_PWR	Hybrid-Private
Enmax Corporation	ENMAX	Hybrid-Private
Ontario Power Generation	ON_POWER	Hybrid-Crown
Hydro One	HYDRO_ONE	Hybrid-Crown
Newfoundland and Labrador Hydro	NF_LB_HYDRO	Hybrid-Crown
New Brunswick Power Corporation	NB_POWER	Hybrid-Crown
Nalcor Energy	NALCOR_EN	Hybrid-Crown
Yukon Energy Corporation	YUKON_EN	Hybrid-Crown
Northwest Territories Power Corporation	NWT_POWER	Hybrid-Crown
SaskPower	SAKSPOWER	Hybrid-Crown

Appendix 3: Climate-Capitalist Organzations and Renewable Associations

Name	Mnemonic	Category
Smart Prosperity Association	SMRT_PA	Climate-Capitalist Organization
Council for Clean Capitalism	C_CLEAN_CAP	Climate-Capitalist Organization
Clean 50	CLEAN_50	Climate-Capitalist Organization
Clean Economy Alliance	CLEN_ECON_AL	Climate-Capitalist Organization
The Climate Reality Project Canada	CLIMATE_REAL	Climate-Capitalist Organization
Clean Energy Canada	CLEAN_EN_CAN	Climate-Capitalist Organization
The Atmospheric Fund	ATMOS_FUND	Climate-Capitalist Organization
BC Sustainable Energy Association	BC_SUSD_ASSOC	Renewable Industry Association
Canadian Solar Industries Association	CAN_SOL_ASSOC	Renewable Industry Association
Canadian Wind Energy Association	CAN_WIND_ASSOC	Renewable Industry Association
Clean Energy Association of BC	CLEAN_BC_ASSOC	Renewable Industry Association
Renewables Industry Canada	RENEW_CAN	Renewable Industry Association
Ontario Sustainable Energy Association	ONT_SUS_EN_ASSOC	Renewable Industry Association
Canadian Hydropower Association	CAN_HYDRO_ASSOC	Renewable Industry Association
Marine Renewables Canada	MAR_REN_CAN	Renewable Industry Association
Canadian Biogas Association	CANBIO_ASSOC	Renewable Industry Association

Appendix 4: Green Technology Research Institutes and Centres

Mnemonic	Organization Name	Category
SK_RC	Saskatchewan Research Council	Government Agency/Crown Corp
AETCF	Alberta-Europe Technology Collaboration Fund	Government Agency
ALB_INV	Alberta Innovates	Government Agency
C_FER-TEC	C-FER Technologies	Government Agency
CAN_M_EN	CanmetENERGY	Government Agency
CFI	Canadian Foundation for Innovation	Government Agency
CPTC	Canadian Pipeline Technology Collaborative	Government Agency
EFI	Energy Innovation Fund	Government Agency
EM_RED_AB	Emissions Reductions Alberta	Government Agency
INOT_A	InnoTech Alberta -- Alberta Carbon Conversion Technology Centre	Government Agency
SRC	Sustainable Development Technology Canada	Government Agency
CTTF	Climate Technology Task Force	Governnment Agency
ASTLF	Alberta Science and Technology Leadership Foundation	Industry Collab/Assoc/Non-Profit
NGIF	Natural Gas Innovation Fund	Industry Collab/Assoc/Non-Profit
CMC_INST	CMC Research Institutes	Industry Collab/Assoc/Non-Profit
COSIA	Canadian Oilsands Innovations Alliance	Industry Collab/Assoc/Non-Profit
ENRG_STIM	Energi Simulation	Industry Collab/Assoc/Non-Profit
PTA_CAN	Petroleum Technology Alliance of Canada	Industry Collab/Assoc/Non-Profit
PTRC	Petroleum Technology Research Centre	Industry Collab/Assoc/Non-Profit
CCCC	Canadian Centre for Clean Coal	University Collaboration
CETRT	Clean Energy Technologies Research Institute	University Collaboration
CHORUS	Consortium for Heavy Oil Research by University Scientists	University Collaboration
CIMS	Centre for Intelligent Mining Systems	University Collaboration
COSS	Centre for Oil Sands Sustainability	University Collaboration
FESI	Future Energy Systems Initiative	University Collaboration
GRI_UNC	Global Research Initiative in Sustainable Low Carbon Unconventional Resources	University Collaboration
HAI	Helmholtz-Alberta Initiative	University Collaboration
HML	Hydrocarbon Metagenomics Lab	University Collaboration
INN_CAL	Innovate Calgary	University Collaboration
IOSI	Institute for Oil Sands Innovation	University Collaboration
OSTRF	Oil Sands Tailing Research Facility	University Collaboration
RDEVL	ReDeveLoP	University Collaboration
SHARP	Sharp Research Consortium	University Collaboration
TIO	Tight Oil Consortium	University Collaboration