Rethinking 'Drop-in' Biofuels:
On the Political Materialities of Bioenergy

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A sustainable transition is premised upon moving from a carbon energy regime to a renewable energy regime; a highly contested political-economic transformation, to say the least. In places like the United States and European Union the main form of renewable energy is bioenergy, especially biofuels. Recent policy and industry efforts are focusing on the development and implementation of what are known as 'drop-in' biofuels, so named because they can be incorporated into existing distribution infrastructure (e.g. pipelines) and conversion devices with relatively few, if any, technical modifications. As with carbon energy, bioenergy has particular materialities that are implicated in the political-economic possibilities and constraints facing societies around the world. These political materialities of bioenergy shape and are shaped by new energy regimes and therefore problematize the notion of a drop-in biofuel. Thus further examination of the political materialities of bioenergy, and of renewable energy more generally, is of critical importance for successful sustainable transitions.

Keywords: political materialities, drop-in biofuels, bioenergy, sustainable transitions, bio-economy

Introduction

Climate change is not only a major crisis facing the global community but also – and perhaps more crucially – a seemingly intractable political-economic problem for which governments, businesses and consumers are unwilling to accept responsibility through remedial action. These observations are made across the political, environmental and scholarly spectrum. For example, Lord Nicholas Stern, who authored the influential *Stern Review* (HM Treasury, 2006), increased his prediction regarding the likely rise of global average temperatures from two degrees to four degrees centigrade (The Observer, 2013). In *Rolling Stone* magazine, Bill McKibben (2012) pre-empted Stern by arguing that a four-degree rise is inevitable. Importantly for our paper, McKibben highlighted the ongoing enrolment (or complicity if we accept non-human agency) of political-economic technologies – notably resource and asset accounting and calculation criteria – in this process. Specifically, McKibben argues that a 2 degree centigrade increase in temperature will result from the release of another 565 gigatons of carbon dioxide. While a daunting observation on its own, he then points out that carbon reserves (e.g. oil, gas and coal) currently held by companies and states around the world represent approximately 2,795 gigatons of CO_2; or, five times what McKibben considers a tolerable threshold. The most frightening part of McKibben's assessment is that these reserves are "already economically aboveground – it's figured into share prices, companies are borrowing money against it, nations are basing their budgets on the presumed returns from their patrimony". In other words, in the absence of a willingness to write off "$20 trillion in assets" these 2,795 gigatons of CO_2 have already entered the atmosphere as a result of how we account for and calculate our (carbon-based) natural resources.

As environmentalists and scholars in this area are likely to point out (e.g. Lohmann, 2010), this carbon needs to stay in the ground if we are to have *any* chance of transitioning to a low-carbon future which will stabilize global temperature rises. However, we face significant obstacles to any social and economic transition. For example, Boykoff and Randalls (2009: 2299) argue that "carbon-based activities dominate [our] economies and societies in ways not seen before in human history"; thus it makes sense to talk about a *carbon economy* in which human action, institutions and infrastructures are entangled with the very materiality of natural and environmental processes relating to the discovery, extraction, processing, distribution and consumption of carbon resources. Moreover, as Timothy Mitchell (2011: 1) has argued we can also talk about a *carbon democracy* in which the materiality of "[f]ossil fuels helped to create both the possibility of modern democracy and its limits" (see also Mitchell, 2009, 2010). In particular, Mitchell (2011: 7) notes that one of the key limitations represented by carbon energy – especially oil – "is that the political machinery that emerged to govern the age of fossil fuels, partly as a product of those forms of energy, may be incapable of addressing the events that will end it".

It is clear that we need to de-carbonize our political-economies (see Jackson, 2008). The alternative is further 'carbon lock-in' (Unruh, 2000) and dramatic environmental and social impacts from rising temperatures. De-carbonization, however, entails more than the research, development and promotion of low-carbon innovation, including in the Global South (e.g. Tyfield & Urry, 2009). Indeed, a systemic shift in political-economic technologies (e.g. accounting) is needed as well in order to untangle our polities, societies and economies from the materialities of carbon as an energy regime (see Bradshaw, 2010). How we go about doing this is a critical issue and the subject of much heated debate (pun intended).

As this special issue attests, these concerns with energy politics and economics are not new to STS. In his research on the politics of combined heat and power back in the 1980s and 1990s, Stewart Russell's (1986, 1993) work prefigured much of the recent work on the politics of transitions and renewable energy. With regards to our own arguments, Russell highlighted several key issues that arise repeatedly, including: the problem of barriers to entry created by incumbent or prevailing energy producers (amongst others); the relationship between techno-scientific and political-economic knowledges (e.g. economics of energy); the politics of energy supply and use (e.g. energy decentralisation); and, especially, the decisions and choices that go into the shaping of energy pathways (e.g. techno-scientific exclusion).

Bioenergy represents one pathway towards a low- or zero-carbon future. Bioenergy is both an old form of energy (e.g. wood stoves) and new form of energy (e.g.

liquid biofuels). The idea of an emerging bio-energy regime has become popular over the last few years, and implies a transition to what is being called a *bio-based economy* or *bio-economy*; that is, an economic system in which societal needs and desires are met through institutions and infrastructures that enable the production and conversion of biological matter into various energy and non-energy products (see OECD, 2006; EU Presidency, 2007; CEC, 2012; White House, 2012).[1] It is not our intent to get into a discussion of this emerging bio-economy here; instead, our primary aim is to theorize the political materiality of bioenergy. We aim to highlight that this bio-economy, similar in process (though not in form) to a carbon-economy predicated on fossil energy, represents a political-economic project configured and conditioned by the particular biophysical and technoscientific materialities of bioenergy such as biofuels. Moreover, the bio-economy is likely to prove highly disruptive to the current carbon economy given the vastly different materialities between the two energy resources. It is hardly surprising, then, that more recently there has been greater emphasis placed on the development of technologies like 'drop-in' biofuels, so named because of their ability to be used in existing distribution infrastructure and conversion devices with relatively few, if any, technical modifications compared to conventional biofuels. We aim to question this notion of a drop-in biofuel, largely because it focuses only on downstream applications of bioenergy (i.e. conversion and consumption) and completely ignores the considerable upstream disruptions they will likely require for implementation.

We want to be clear at the start that our paper is programmatic in nature. Using empirical material from the Canadian province of Ontario to illustrate our claims, we are concerned with thinking about the problems that might surface during a transition from a carbon economy to a bio-economy, especially where the latter is predicated on disrupting the former as little as possible. This is the key research question and focus for our article. In order to build our arguments we first discuss the material politics of energy by drawing on the work by Timothy Mitchell (2009, 2010, 2011). We then discuss the relationship between renewable energy and systemic, sustainable transitions as they are currently conceptualized, before identifying a series of gaps and omissions in the promotion and development of bioenergy, especially biofuels, as an alternative energy to carbon within Ontario, Canada. We use Ontario as an illustrative case study because of its recent and continuing support for bioenergy and biofuels through several key policies including the *Ethanol Growth Fund* (enforced as of 2005), *Ethanol in Gasoline Regulation* (enforced as of 2007) and *Green Energy and Green Economy Act* (enforced as of 2009). We finish with a conclusion that outlines the implications of our arguments to the development of drop-in biofuels.

Political Materialities of Energy

We are concerned with the political materialities of energy in this paper, especially the role of bioenergy in any transition to a low- or zero-carbon energy regime. These sorts of concerns with the politics of material technologies are not new to science and technology studies (STS). In STS materiality has been used to reference the material agency of objects, technologies and even nature itself in shaping technoscience and technoscientific practices, and vice versa. This interactive process brings us to the work of Timothy Mitchell (2009, 2010, 2011), whose approach we use to examine the energy-politics nexus.

In Mitchell's (2009: 399) words, "fossil fuels helped to create the possibility of twentieth-century democracy and its limits" – or what he terms *carbon democracy* (also Mitchell 2011). As a starting point, Mitchell (2009, 2011) interrogates the claim that oil-producing countries tend to be less democratic because they suffer from a 'resource curse' – more specifically, an 'oil curse'. According to Mitchell, the claim that countries suffer from an oil curse largely ignores "the ways oil is extracted, processed, shipped and consumed, the forms of agency and control these processes involve or the power of oil as a concentrated source of energy" (Mitchell, 2009: 400). What Mitchell is getting at is that (democratic) politics is bound up with the very materialities of fossilized carbon itself, since these materialities shape the forms, participation and constraints of political engagement or dis-engagement. In addition to the simple physical characteristics of coal or oil, it is the material apparatus of energy production (e.g. mines), distribution (e.g. pipelines) and consumption (e.g. power stations) that shapes political power and, ultimately, the capacity for political and social change. Hence, it is critical to consider the materialities of bioenergy, as we do in this paper, since bioenergy is meant to represent a key alternative to the fossil fuel regime that Mitchell concentrates on in his work. Before we come to bioenergy, however, we want to properly outline Mitchell's broader argument.

The key to Mitchell's (2009) argument is that the materialities of carbon energy (e.g. coal, oil) create possibilities for and limits on political action, which have to do with the biophysical characteristics of hydrocarbons themselves as well as the material (e.g. transport) and epistemic (e.g. accounting) apparatus needed to bring them into use. According to Mitchell (2009), the existence and recovery of coal made it possible to transport and therefore centralize large quantities of energy and to generate motive power on a large scale (e.g. steam engines). These materialities were crucial for (re)distributing political power relations that were central to colonization, industrialization and urbanization. Mitchell argues that these political materialities of coal are evident in the rise of mass democratic movements driven by labour organizations during the 19th century and early 20th century (also Agustoni & Maretti, 2012). More specifically, Mitchell argues that the growing dependence on coal was accompanied by the rising power of the labour movement because workers could disrupt key junctures in the transport of coal (e.g. railway terminals, ports, coal mines) and therefore threaten the material basis of these political-economic pursuits. The power of workers was not limited to coal miners, moreover, since other workers could also blockade these key transit sites (e.g. railway workers, dockers, sailors). What this meant was that workers could shut down the flows of hydrocarbon energy on which industrial societies had become dependent and hence they were able to make political demands which had to be met, whether this was for higher wages or political franchise.

While coal represented one specific form of political materiality, oil represented another form according to Mitchell (2009, 2011). Mitchell argues that the pursuit of oil as an alternative energy source was partly a response to the growing power of labour. Indeed, the biophysical and energetic qualities of oil, as a liquid energy carrier that is of higher energy density than coal, meant that the man-power required in order to extract, refine and distribute energy was greatly reduced. In Mitchell's terms (2009: 407), the qualities of oil meant that:

> [I]t required a smaller workforce than coal in relation to the quantity of energy produced. Workers remained above ground, under continuous supervision of managers. Since the carbon occurs in liquid form, pumping stations and pipelines could replace railways as a means of transporting energy.

All of this entailed a different political materiality, involving a new technological and epistemic apparatus. First, Mitchell (2011: 46) points to the "development of technologies for transporting oil that took advantage of its liquid form and eliminated most manual labour from the movement of energy". Oil can be transported within buried pipelines and fractionated into useful products through automated processes. Workers therefore had fewer opportunities to disrupt the flows of energy so that the political power of labour was dramatically reduced (see also Huber, 2013), while the control of energy depended on control over "a comparatively small number of sites" including "major oilfields, pipelines and terminals, and the handful of bulk tanker fleets" (Mitchell, 2011: 67). Ultimately then, oil limited the development of democratic movements as it reduced the power of workers to back up their demands with acts of disruption.

Second, Mitchell highlights the necessary convergence of the materiality of oil with the epistemic practices and technologies of economics during the early years of the 20th century. In earlier work, Mitchell focuses on how 'the economy' has been constructed through epistemic practices in the discipline of economics (e.g. Mitchell, 2005). In relation to carbon democracy, Mitchell takes his argument further by examining not only the materiality of fossil fuels "but also the related networks, of international finance, for example, of technical knowledge, and of economic theory that different forms of energy depended upon and made possible" (Mitchell, 2010: 190). This *carbon economy* – or, perhaps more precisely, *carbon economics* – entailed a wholesale transformation of economics as a discipline, according to Mitchell (2011: chapter 5), from a focus on natural resource depletion (regarding coal in 19th century) to the treatment of oil (post World War II) as an 'inexhaustible resource' that reinforced the fiction of ever-rising national economic growth (also Boyer, 2011). Here epistemic practices are entangled with the different materialities of coal and oil; the latter became bound up with new forms of national accounting (e.g. GNP), Keynesian demand management and a focus on prices (i.e. "petroknowledge") which presaged new economic technologies of calculation, price-setting and so forth that "were built into the new financial institutions" (Mitchell, 2011: 135).

We will return to the importance of epistemic practices when we consider the implications of the political materialities of bioenergy since, and if we accept Mitchell's arguments, it is clear that an epistemic transition will be a necessity with any transition to a low- or zero-carbon economy. In coming back to how Mitchell relates to bioenergy, in general, it is crucial to consider his argument "that the political machinery that emerged to govern the age of fossil fuels, partly as a product of these forms of energy, may be incapable of addressing the events that will end it" (Mitchell, 2011: 7). Or, more simply, we cannot rely upon a political apparatus underpinned by fossil fuels to engender and drive a systemic transition to a new energy regime based on renewables, bioenergy included. New forms of energy entail new political machinery and new epistemic practices, which involve a completely different perspective to the carbon age. Any analysis of systemic energy transitions will necessarily involve an understanding of what Boyer (2011: 5) terms 'energopolitics'; this is more than the politics of access and control, it also concerns "interrogating the magnitude and methods of energy usage that carbon statecraft institutionalized".

Sustainable Transitions and Bioenergy

The reason that the political materialities of energy are important goes back to the discussion in the introduction about the emerging and growing policy, political and academic emphasis on low- or zero-carbon transitions (e.g. Jackson, 2008; Tyfield & Urry, 2009). One important technological pathway towards a sustainable transition is bioenergy; it is meant to offer a win-win solution in which transition can be allied to a new energy regime which will de-carbonize our economies (Frow et al., 2009; Birch et al., 2010). For the purpose of this paper, bioenergy refers to the conversion of biomass from plants and waste streams into various forms of energy (e.g. electricity, heat) or energy carriers (liquid, gaseous, or solid fuels)

The last decade has been characterized by a significant push behind bioenergy and specifically liquid biofuels (e.g. bioethanol, biodiesel) as a key sustainability solution to climate change. Moreover, bioenergy and biofuels are an important (and dominant) form of renewable energy in major world economies like the Unites States and European Union. In the US, for example, biofuels have a long history stretching back at least to the *Energy Tax Act* (1978), which was concerned with US energy security following the oil crises in the 1970s (Kedron & Bagchi-Sen 2011). More recently, and as a result of the *Energy Policy Act* (2005) and *Energy Independence and Security Act* (2007), the US overtook Brazil as the world's leading biofuels producer (Smith, 2010). Thus it is no surprise that bioenergy now represents nearly half of the USA's renewable energy production (Zimmerer, 2011). In the EU, bioenergy also represents a significant proportion of renewable energy production, over half in 2010 (ClientEarth, 2012). Again, in the EU bioenergy mainly relates to biofuels, primarily biodiesel, and support for biofuels has been integrated into the *Biofuels Directive* (enforced as of 2003) and *Renewable Energy Directive* (enforced as of 2009).

Bioenergy is a dominant renewable energy source in the USA and EU primarily because of policy support for biofuels in the transportation sector – a major greenhouse gas (GHG) emitter. As mentioned, this support dates back to the 1970s in some cases, largely as a response to the oil crises and fears about energy security (WorldWatch Institute, 2006). The rationale behind promoting biofuels has since evolved a number of times in both the US and EU; it has moved through several policy justifications including energy security, rural economic development, energy efficiency and, finally, GHG emission reductions following the *Kyoto Protocol* (1997) (e.g. Charles et al., 2007; Mol, 2007). It is no wonder that biofuel production quadrupled in the period between 2000 and 2006 (see Mol, 2007; also WorldWatch Institute, 2006), although this has largely been concentrated in the USA (ethanol) and EU (biodiesel) (Ponte, 2014).

Post-Kyoto, both the USA and EU began to articulate a sustainability rationale for promoting biofuels in legislation like the US *Biomass R&D Act* (2000) and the EC *Biofuels Directive* (2003) (Charriere 2009; ClientEarth 2012). There are plenty of analyses of the (positive and negative) impacts of these pieces of legislation and later policy decisions like the EU *Biofuels Strategy* (2006), US *Farm Bill* (2002), US *Energy Policy Act* (2005), and others (e.g.

Charles et al., 2007; Londo & Deurwaarder, 2007; McMichael, 2009, 2012; Gillon, 2010; Bailis & Baka, 2011; Kedron & Bagchi-Sen, 2011; Levidow et al., 2012b; Levidow & Papaioannou, 2014; Ponte, forthcoming); however, it is not our intent to go into these debates in any detail here. What we want to highlight is the importance of bioenergy and especially biofuels as a key renewable energy source for these major economies.

In the last few years, however, major media outlets have reported on the uncertainties surrounding biofuels, especially whether they will actually achieve their proposed environmental and socio-economic benefits (Smith, 2010). This uncertainty reflects growing criticism in the scientific literature about the ecological and social benefits of biofuels derived from primary agricultural products (e.g. corn, soy). Criticism from scientists in 2008, with several papers in *Science* (Fargione et al., 2008; Hill et al., 2006; Searchinger et al., 2008), spread quickly to mainstream media when policy concerns relating to the impact of biofuel production on food prices was highlighted in a World Bank report leaked to *The Guardian* newspaper (Mitchell, 2008). These criticisms largely focus on indirect land-use change (ILUC) as biofuels production in places like the US force changes in land-use in other parts of the world (cf. Harvey & Pilgrim, 2011). As a result there has been a policy push behind so-called 'second generation' or 'advanced' biofuels for which net energy returns are greater and which are derived from non-food crops (e.g. switchgrass, miscanthus) or biomass grown on non-agricultural land (e.g. forest residues) (Pimentel, 2009; Sims et al., 2010; Stephen et al., 2011), and hence can be considered as more ecologically and socially sustainable (Bailis & Baka, 2011; Levidow et al., 2012b). Given uncertainties surrounding, and impediments to, the development and commercialization of these second generation biofuels (O'Connell & Haritos, 2010; Tyner, 2010a, 2010b; Stephen et al., 2011), policy support is also increasing for research on new types of biofuels with higher energy contents (e.g. butanol). These third or fourth generation biofuels are derived from algae or synthetic biology (Ferry et al., 2012), and can be designed to 'drop-in' to prevailing infrastructures used by fossil fuels (Tyner, 2010c; Savage, 2011).[2]

What this brief discussion of bioenergy and biofuels is meant to illustrate is that these forms of energy are important alternatives in major national and regional economies to the carbon economy theorized by Mitchell (2009, 2011) and others (Boykoff & Randalls, 2009; Bridge, 2011). The prominence of bioenergy as a key renewable energy resource in both the USA and EU has been reinforced recently by the 'bio-economy' strategies produced by these states in early 2012 (e.g. CEC, 2012; White House, 2012). Whether or not bioenergy and biofuels will or can engender a sustainable transition to a low- or zero-carbon future is open to question. It is our argument that whether this is likely depends upon the political materialities of bioenergy and the constitution of a *de-carbonized democracy*. It is to this issue that we now turn.

Political Materialities of Bioenergy: The Case of Ontario

Our analysis in this section builds on Mitchell's (2009, 2010, 2011) arguments about the political materialities of carbon energy; what we do here is apply his insights to bioenergy, especially liquid biofuels. In order to help illustrate the political materialities of bioenergy and to contrast them against the political materialities of carbon energy, we focus, in particular, on the Canadian Province of Ontario. Our interest in Ontario stems from the

Provincial Government's recent and very active role in promoting sustainable energy transitions through various policies, which in many cases build on previous Federal Government policies. These include, but are not limited to, Ontario Provincial policies (e.g. *Ethanol Growth Fund*, 2005; *Ethanol in Gasoline Regulation*, 2007; *Ontario Green Energy Act*, 2009) and Canadian Federal policies (e.g. *Alternatives Fuels Act*, 1995; *Biomass for Energy Program*, 2000; *Action Plan on Climate Change*, 2000; *Ethanol Expansion Program*, 2003; *ecoENERGY for Renewable Power Initiative*, 2007; *NextGen Biofuels Fund*, 2007; *Federal Renewable Fuels Regulation*, 2011) (see Charriere, 2009; Puddister et al., 2011; Mabee, 2013). More recently, however, the Federal Government has all but halted the promotion of renewable energy; mostly for political reasons relating to the dominance of the Conservative Party and Alberta tar sand interests (Winfield, 2012). As a result, Ontario has taken a significant lead over other Canadian provinces when it comes to bioenergy and biofuels (CanBio, 2012).

Until recently, Ontario was heavily dependent upon fossil fuels for transport and electricity generation (Ontario Power Authority, 2010). The transition to renewable energy and especially bioenergy has been driven by several of the policies highlighted above. We focus here on three in particular. The first policy is the 2005 *Ethanol Growth Fund* (EGF) which was established to finance capital investment in ethanol production and assist producers in the face of market uncertainties, as well as fund R&D into biofuels. The EGF forms part of Ontario's plan to introduce a renewable fuel standard (RFS), which is the second policy and is represented by Ontario's 2007 *Ethanol in Gasoline Regulation* (EGR). This was originally announced in 2004 as a provincial RFS, reflecting moves in other countries to introduce RFS based on biofuels (see Bailis & Baka, 2011) and building on agreements with British Columbia and California to reduce GHG emissions (Charriere, 2009). The emphasis on volume mandates can be seen as part of a wider shift away from excise tax exemptions, which were highly variable between countries and even provinces (de Beer, 2011). The EGR stipulated a 5% minimum ethanol blend by volume for all gasoline sold in Ontario from 2007 – there is now a similar Federal RFS introduced by the *Renewable Fuels Regulation* (2011). The EGR has effectively created a market for over 880 million litres of ethanol for Ontario producers – a benefit of a RFS mandate over excise tax exemptions – most of which is produced from the conversion of starch from corn and wheat and is financially supported by the EGF. The investments through the EGF have resulted in the installation or construction of over 1000 Ml of ethanol production capacity in Ontario (Canadian Renewable Fuels Association, 2011). According to de Beer (2011: 21), Ontario's EGR policy was at the time of its enactment unique because it contains (albeit weak and so far ineffective) provisions to encourage advanced biofuels in Ontario, especially cellulosic biofuels from non-food plants (e.g. forestry), as part of this RFS mandate.[3] The provincial government has also financially and politically supported an increasing number of wood-pellet production facilities as well as commercial and pre-commercial advanced or drop-in biofuel production facilities through support for capital expenditures as well as licensing agreements on forest resources.

There are also moves to encourage bioenergy production in the electricity sector through the 2009 *Green Energy and Green Economy Act* (GEGEA). This legislation follows declarations and actions toward the closure of all coal power plants in Ontario by 2014 and investment in renewable energy sources like wind, solar and bioenergy; the latter is expected to reach 10,700 MW by 2018 (Ontario Power Authority, 2010). The main mechanism for promoting renewable electricity generation is through a feed-in-tariff, which guarantees a secure pricing structure for producers; the GEGEA also has a domestic context requirement meaning that a majority proportion of technology inputs need to be sourced from Ontario thereby linking sustainable innovation to the creation of new jobs in Ontario (Ritson-Bennett, 2010). The feed-in tariff rates for bioenergy are 13.8 cents per kWh for biomass-based electricity plants under 10 MW and 13.0 cents for those over 10 MW (Ontario, 2010).

These three policies in Ontario are representative of state interventions designed to promote sustainable transitions and the de-carbonization of the economy. They imply not only a significant rethinking of the organization and configuration of energy production, distribution and consumption, but also a rethinking of political formations and technologies. Changes could be undertaken within the current energy regime by integrating renewables and bioenergy into prevailing infrastructures and institutions, or they could be pursued by totally disrupting the current energy regime. As Mitchell (2011) points out, the latter is considerably less likely because the 'political machinery' associated with fossil fuels is biased against the introduction of new energy systems. The main reason for this is that any new energy regime (e.g. bioenergy) entails new political machinery which will necessarily contradict the political machinery of any prevailing energy regime (e.g. fossil fuels) – this new political machinery will be tied to the biophysical and energetic qualities and characteristics of bioenergy. This is especially the case if jurisdictions wish to achieve a scale of production that is able to replace entirely our existing fossil-based energy systems (Richard, 2010).

These political changes are frequently presented as socially, economically and politically positive because they are expected to encourage things like local control and autonomy, decentralized decision-making and cohesion, and localized economic benefits like new jobs, new investment etc. (e.g. Green New Deal Group, 2008). The positive impacts of bioenergy are more evident when we consider a range of possible bioenergy scenarios (see Upham et al., 2007 for examples). Deciding how biomass resources are best used is an inherently political choice with different political-economic implications in terms of end-users as well as patterns of production. If a given society chooses liquid biofuels or follows an export-oriented path for pellets, for instance, then production facilities will necessarily occur in large centralized facilities due to the need for economies of scale. If biomass is diverted instead toward combined heat and power or district heating systems, then it is more likely that a distributed pattern of development will occur because it is simply not possible to transfer heat over long distances. Such a bioenergy scenario would be more amenable to community-based ownership models similar to local cooperative models employed in the wind sector.

As Russell (1993) highlighted in his work, these questions of energy decentralization and distribution are tied up with political-economic decisions and not limited to technical issues. However, what we want to emphasize is that both of these bioenergy scenarios entail particular political materialities; unfortunately we cannot compare these different scenarios and materialities in this article for want of space, so instead we focus on the political materialities that will be important, regardless of the scenario considered. While we do not want to directly contradict the claims made about renewable energy regimes and especially bioenergy regimes, we do want to unpack the 'new political machinery' that will be necessary to facilitate a transition toward bioenergy while at the same time problematize the assumption that they necessarily entail positive political change. The emergence of bioenergy has significant material implications and impacts that necessitate an examination of the political materialities discussed by Mitchell (2009, 2011) in reference to oil and coal.

We are going to focus on three key issues in this regard, bringing together in our analysis a consideration of the physical materialities of bioenergy with the political machinery these materialities both enable and limit, and are, in turn, enabled and limited by. First, we discuss the implications of (bio-)energy flows in order to illustrate how they are different from fossil fuels. Second, we discuss the mobility of unprocessed bioenergy resources relative to fossil energy and whether this will have impacts on political machinery. Finally, we discuss the transboundary nature of bioenergy in relation to sustainability concerns and economic practices.

Mitchell's (2011: 12) concept of carbon democracy is based on "buried sunshine" in the form of coal, oil and gas. In stark contrast, bioenergy and biofuels can be considered "grown sunshine". This is the first crucial difference in the materiality of biomass as opposed to fossilized carbon. When it comes to differentiating between the materiality of bioenergy and carbon energy, it is evident that biomass has relatively low energy density (i.e. GJ/t) compared to fossil energy resources and it grows at relatively fixed rates. On average, approximately 1.5 tonnes of biomass, grown aboveground, are required in order to replace the energy equivalent of one tonne of coal, which is recovered from subterranean deposits. Replacement values can be as high as 2–4 tonnes where petroleum and natural gas is concerned. Further, the rate at which biomass can be extracted from any given area must be limited in order to maintain ecological integrity at the site, including soil quality and niche habitats.

These materialities are central to sustainable transitions involving bioenergy for two reasons. First, the low energy density of biomass indicates the need to reduce societal energy usage if bioenergy (and other renewables) are going to entirely displace fossilized hydrocarbons. In fact, biomass could not possibly be used to power all sectors (e.g. heat, motor fuels, electricity) under existing rates and trends of global energy consumption – i.e. almost all estimates suggest that there is just not enough solar energy being converted into biomass quickly enough, nor can biomass be extracted intensively enough, to allow that type of scenario to be sustainable (for a global-level perspective, see Berndes et al., 2003; for a local level perspective, see Mabee & Mirck, 2011). The shortfall grows larger when one accounts for the fact that biomass would also need to replace petroleum as an input into the production of chemicals and plastics. Second, even the most productive regions of the world will not produce enough biomass to support a bio-economy, so each society must greatly expand the land-footprint of its energy system in order to realize the full potential of bioenergy.[4]

Whether or not the land-intensive nature of bioenergy production entails specific blockage points along bioenergy flows – like coal in Mitchell's (2011) argument – is an open question, and depends on the political-economic conditions under which bioenergy systems are developed. On the one hand agriculture and forestry are sectors with low employment levels and traditionally low-levels of unionization, meaning that there is less likelihood of worker disruption. On the other hand, biomass has to be grown, cut down, moved, processed, refined, etc. in large quantities meaning that there will be plenty of blockage sites for disrupting these flows if workers so choose. The isolation of agriculture and forestry from urban centres is likely to limit the impact that workers can have at particular points of the bioenergy flow, which means that agricultural and forestry workers are less likely to be able to instigate political change by themselves as was the case for centralized and integrated coal workers. But there is also a shift from public to private resources that must be considered. Fossil energy resources in Ontario (and in most other states with the exception of a few notable countries such as the U.S.) are by constitutional law publicly owned. Much of the land from which biomass will be procured for bioenergy production however (e.g. agricultural land and privately owned woodlots) is privately owned. This not only requires new political technologies (e.g. contracts and agreements between hundreds or thousands of owners rather than a single owner) but might also add a new layer of complexity to the political relationship between suppliers and producers. We further reflect upon this relationship below.

The second and related material characteristic of bioenergy is that it is geographically distributed and relatively immobile. The low energy density (by weight and volume) of biomass means that it is not worthwhile in monetary or energetic returns to transport unprocessed biomass resources long distances from cultivation area to processing plant (Hamelinck et al., 2005). Bioenergy resource extraction and processing activities must therefore occur at the same site or in sites very close to one another in order to achieve viable and relevant production scales. Furthermore, the procurement radius for a given facility and therefore the land-based transport requirements are generally much greater (remembering that bioenergy production scales with land area). Biomass co-firing projects in the USA, for instance, "require supply chain managers to expand procurement from 2 to 3 coal suppliers supplying 16 million tonnes of coal to include 120 biomass suppliers supplying only 90,000 tonnes of biomass" (Wolf, 2012: 46, citing Johnson, 2012; see also Richard, 2010).

Three things matter here. First, the spread of bioenergy across a wide area and consequent spread of blockage points mean that the power of workers to affect political change may be significantly curtailed as there will be numerous sources of inputs (e.g. biomass); thus it will be relatively easy to shift from one sourcing site to another if bioenergy flows are disrupted. On the other hand, however, an existing bioenergy production facility might have less flexibility to switch suppliers because they cannot procure from a very long distance without incurring heavy economic costs. In other words, the friction of distance in bioenergy supply chains might bring some power balance between suppliers, producers and workers. This highlights the crux of the chicken-and-egg situation that is stalling many bioenergy investments: growers will not grow without a secure market and the market will not develop without a guarantee of a minimum supply at a fixed and acceptable price within a relatively small procurement radius. Second, and related to this point, a range of local upstream actors (e.g. growers, land managers, biomass aggregators) must be coordinated long before and long after project implementation in order to secure the resources that are necessary to keep a bioenergy system operational. This is in many ways different from all other renewable energy systems for which sustained human activity is not as crucial to maintaining resource flows (e.g. sunlight, wind). Third, oil can be moved by pipeline and coal from mine-to-facility by rail, while biomass must be collected from a wide geographical area and trucked to a rail terminal or shipping port prior to bulk transportation. This higher traffic activity associated with biomass transport and processing is a source of local resistance to project development (Sampson et al., 2012).

It is important to note that our discussion thus far has assumed that raw biomass will ultimately be consumed locally. This is not always the case. Processing biomass into a densified bioenergy carrier or biofuel (e.g. pellets, bio-oil, bio-gas) makes it possible to distribute bioenergy within international and global transportation networks, thereby extending the geographic reach of bioenergy supply chains. In all such cases, however, the upstream components of the supply-chain are distributed, land intensive, and require a significant new draw on local forest and agricultural resources. Furthermore, any such pre-processing incurs extra environmental and monetary costs that must be considered. Life-cycle analyses of long-distance transport of pellets between British Columbia and Europe, for example, reveal that ocean transport increases the energy costs of production and distribution by 54 per cent, raising the total energy costs to 40 per cent of the embodied energy of the biomass and lowering the net energy recovered well below that of locally consumed pellets (Magelli et al., 2009). Furthermore, these long-distance flows of bioenergy are entirely dependent on strong economic pulls or willed markets created by subsidies or carbon taxes in consumer jurisdictions.

Regardless of the development scenario – whether in many small or few large production facilities and whether focusing on heat, electricity, or fuels – bioenergy production systems are localized and land-intensive systems. What's more, the distribution of bioenergy products will operate at much smaller geographic scales than fossil energy products such as coal, especially if they are going to be cost effective and limit environmental impacts as much as possible. The impact that these bioenergy systems will have on local landscapes are, therefore, likely to be considerable; the extraction, distribution, and conversion of energy will be more visible to a greater proportion of the population than is currently the case under a fossil energy regime (Calvert & Simandan, 2010). In this sense, there is likely to be considerable resistance to the creation of new energy landscapes (Pasqualetti, 2011), not least because new energy regimes threaten existing livelihoods as well as lifestyles. As Mitchell (2011: 6) suggests:

> [C]itizens have developed ways of eating, travelling, housing themselves and consuming other goods and services that require very large amounts of energy from oil and other fossil fuels.

There is more to it than changing societal expectations and habits, however. While it might be possible to avoid some of these disruptions to lifestyles by importing biofuels, this would simply displace the problems onto other countries and defeat one key reason for promoting bioenergy in the first place (i.e. sustainability). Thus the political materialities of bioenergy are likely to be highly localized and distributed since they are entangled with different publics at and in many bioenergy sites.

The political capacities of these (largely rural) publics are as important when considering bioenergy as are the potential capacities of (largely rural) workers to affect social change (see earlier); in fact, the former could represent a significant (and possibly regressive) political force in contrast to the progressive political force presented by Mitchell (2009, 2011) when it came to coal and other workers.[5] For example, rural inhabitants have the capacity to block the installation of bioenergy facilities and thereby block bioenergy flows just like coal and other workers had the capacity to block carbon energy flows. Consequently it is important to acknowledge that the material immobility of bioenergy shapes and will continue to shape how different publics engage with bioenergy resources (Walker & Cass, 2007). Indeed, attempts to create new technologies of political governing in response to the move toward localized resources for energy production are already evident in the use of 'community energy plans' in Ontario (e.g. St. Denis & Parker, 2009). Such plans reflect broader moves in places like Denmark and Germany to enrol local communities in renewable energy developments throughout the decision-making process and within ownership models (Yappa, 2012).

New technologies of governance are especially critical where bioenergy processing, production and consumption are *not* localized with biomass cultivation precisely because the potential economic benefits of localized bioenergy processing and production will not accrue to the affected, local population. Thus the materiality of bioenergy and biofuels (i.e. land-based and relatively immobile) entails new technologies of political governance to enrol local publics in local decision-making and in the ownership of local production facilities, in order to enable public engagement in decisions that are likely to be highly disruptive as much as to forestall the highly disruptive capacity of local publics themselves.

Finally, we want to consider the transboundary nature of bioenergy and biofuels, not only in spatio-temporal terms (e.g. daily or seasonal variability) but also in socio-economic terms (e.g. price and commodification variability). Generally, the transboundary nature of bioenergy can be characterized as the *overflows* that happen between spatial and political jurisdictions (Giordano, 2003); these can constitute overflows of economies, energies and sustainability. Elsewhere ClientEarth (2012: 16) characterize such overflows as 'geographical' and 'sectoral' loopholes in accounting for carbon emissions and emissions reductions from biofuels.

Firstly, socio-economic transboundary issues are critical to bioenergy and to understanding the need for new technologies of governing (i.e. political machinery in Mitchell's terms). There are major differences, for instance, between excise tax exemptions and RFS mandates which make the latter more attractive as a policy mechanism to promote bioenergy. On one hand, RFS mandates are often supported by production incentives to develop local or 'home-grown' industries which are generally more acceptable to local citizens and associated with a higher 'willingness to pay' among the public (Upham et al., 2007). On the other hand, tax exemptions simply promote the redistribution of bioenergy products from low-cost producing areas toward areas where tax exemptions have created a market advantage for bio-based energy feedstock. This helps to explain why the Ontario Provincial Government removed the biofuels tax exemption and used the resultant tax revenue instead to fund local ethanol producers through the EGR, which meant that Ontario was no longer paying international producers.

Secondly, the producer receives the sustainability credit when it comes to accounting for the contribution of biofuels to GHG emissions reductions. Anyone producing biofuels, for example, could ship them to a country with an excise tax exemption and benefit from market advantage while any sustainability credit or economic development benefits would remain with the exporting country (ClientEarth, 2012).[6] Capturing these energy flows and sustainability credits necessitates new forms of accounting and calculation (i.e. political-economic technologies) which supersede those highlighted by Mitchell (2010, 2011) when it comes to the carbon economy, especially the oil economy. Thus, and like other energy regimes, bioenergy is bound up with particular political-economic practices and expertise to account for things like transboundary overflows of economic and sustainability benefits; this reflects how materialities are tied to political and epistemic machinery as argued by Mitchell (2011: 110) in reference to carbon.

When it comes to bioenergy there is a significant tension here. It is bound up with new political-economic technologies (e.g. sustainability accounting) that enable some countries to claim credit for the sustainable benefits of bioenergy. Such sustainability credit has to be determined as a political-economic consideration in global agreements because the sustainability benefits are global (i.e. declining emissions benefit everyone) and therefore countries have tried to find ways to integrate calculations of climate change mitigation or adaptation into bioenergy flows. However, this has not always been successful or sensible. In the Kyoto Protocol, for example, CO_2 emissions released by bioenergy are assigned to the country of origin (i.e. producers) rather than combustion (i.e. users) (ClientEarth, 2012). This makes a major difference in terms of who benefits from sustainability credit since user countries can simply discount these emissions by importing bioenergy, whether or not they have actually increased their emissions. This means that major economies like the USA and EU can increase their emissions as long as they import bioenergy from other places where any emissions reductions are assigned.

Overall, the political materialities of bioenergy necessitate a rethinking of economic practices that make “no distinction between beneficial and harmful costs” such as “the increased expenditure required to deal with the damage caused by fossil fuels” (Mitchell, 2011: 140). As highlighted in the introduction (e.g. McKibben, 2012), one prime example of what needs to be done is new ways to calculate the damage done by carbon energy and to assign responsibility (i.e. costs) for that damage to those who extract and use fossil fuels (e.g. oil companies, consumers). This is likely to entail significant struggle over knowledge claims, to say the least, especially in how to account for the costs associated with an increasingly bankrupt carbon democracy (Mitchell, 2009).

Conclusion

In examining the political materialities of bioenergy, we have hopefully pushed forward the work of Stewart Russell (1986, 1993) on the politics of energy and environmental sustainability. Our particular focus has been on the promotion of a green or sustainable transition in order to shift societies and economies away from dependence upon fossil fuels. These transitions are frequently represented as an almost entirely positive transformation of society towards low- or zero-carbon energy, jobs and economies. However, our discussion of the political materialities of bioenergy raise very troubling issues. While the notion of a bio-economy has clear benefits related to sustainability and in some cases stimulates new investments in forestry and agricultural regions, there are real and perceived negative impacts associated with its implementation that, as we have shown, are directly related to the materialities of biomass and how these materialities impact energy supply-chains as well as societal interaction with energy production, distribution and use.

Attempts to integrate bioenergy into prevailing infrastructures and institutions are likely to be problematic, not only because this will merely reinforce the carbon economy but also because the materialities of bioenergy will disrupt existing energy systems as well as regional economies, land-use systems, and transport infrastructure. The materiality of biomass/bioenergy, therefore, necessarily problematizes the notion of 'drop-in' biofuels. Although these fuels have been processed (e.g. de-oxygenated, reformed into long carbon chains) to mimic carbon fuels and therefore be compatible with existing infrastructure for fuel distribution (pipelines) and conversion (internal combustion engines), there are significant upstream changes that need to be made as well. These include: the way land is used and valued; where production facilities will be located; the sheer number and spatial distribution of resource (land) owners that must be considered; and increasing transportation requirements (i.e. for biomass). These things cannot be so easily 'dropped-in' to a carbon economy.

The reason this is important is that the carbon economy actually liberated most of our land and most of our transport infrastructure from supplying energy resources, since we could find them in relatively few sub-surface pools or deposits located great distances from population centres and distribute them in bulk via railways, pipelines and tankers. In contrast, bioenergy is dependent upon the collection of biomass from large areas of land compartmentalized into thousands of woodlots or farms, many of which are privately owned, and trucking that material to numerous, dispersed and relatively smaller processing or energy generating plants which makes energy production activities more visible to a greater proportion of the general public. Furthermore, bioenergy has socio-economic transboundary qualities that require a specific (rethinking of) policy mechanisms to capture energy and sustainability; for example, who gets to claim any GHG emissions reductions: producer or consumer?

These political materialities shape and are shaped by new energy regimes and are therefore of critical importance to sustainable transitions. We need to more closely examine these political materialities in order to understand the potential and limitations of any bio-economy or bio-based economy, and in order to fully grasp the ways in which the relations between society, technology, and environment will co-evolve in the process of a sustainable transition.

While we have found Mitchell's perspective useful as a starting point, we recognize there are limits to his analytical approach. Perhaps most importantly, the world Mitchell outlines is – not surprisingly – built on the notion of social groups pursuing their material interests (e.g. elites want control of energy while workers resist control for concessions). However, social mobilization is driven by more than material interests (e.g. nationalism, religion, culture, politics, etc.). In short, Mitchell's analysis is sometimes just too 'neat' – obviously he cannot cover everything, which means his arguments are often broader than perhaps merited.

Underpinning this flaw is a lack of clarity by Mitchell on how relations between society / social movements, technology, and environment are conceptualised: are these relations deterministic, contingent or co-productive? If the biophysical characteristics of fossil fuels determine particular forms of political mobilization and action, and limit others, it is not clear why the reverse cannot be true as well. For example, do particular forms of political mobilization and action determine access to certain types of energy?

These shortcomings aside, Mitchell's analytical lens has helped us to explore the possibilities and limits on social action, and anticipate the opportunities and challenges that might arise as efforts to transition toward a bio-economy proceed. Continuing this vein of research and thought will help to form the basis of new political technologies that might be required in order to expedite the transition toward sustainability, while at the same time ensuring that the costs as well as the benefits of technical innovations toward a sustainable energy future are considered.

Acknowledgements

We would like to thank the three anonymous referees and the special issue editors for their suggestions and comments on our paper. The usual disclaimers apply.

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Notes

1 There is increasing academic debate about the emergence of a bio-economy or bio-based economy as well; see, for example, Birch et al. (2010), Birch & Tyfield (2013), Levidow et al. (2012a, 2012b), McCormick & Kautto (2013), Ponte and Birch (2014) and Staffas et al. (2013).

2 Bioenergy production facilities could be fitted with carbon capture and storage technologies (CCS). Using IEA (2013) numbers, approximately 3.4 Gt CO_2/year would need to be sequestered which represents 1,804 bcm (assuming a density of 1.9kg/m^3), or 52 per cent of the total volume of gas that is currently produced in the world. In other words, it requires an addition of half of all pipelines that are currently in the ground to service the distribution of natural gas fuels. In the case CCS is deployed with biomass systems significant additions of infrastructure would need to be distributed over a wider geographic area, as our analysis has shown. The addition of CCS infrastructure on generating units lowers the efficiency of production, thereby requiring higher rates of resource extraction per unit of useful energy consumed. In other words, as a GHG-mitigation strategy, CCS is best considered independently from bioenergy production.

3 The provisions in the EGR related to cellulosics are a 'blending adder' for all ethanol derived from cellulosics so that 1L of cellulosic ethanol is equivalent to 2L of starch-based ethanol. To date, only a small (2Ml/yr) pre-commercial cellulosic ethanol plant has been developed in Ontario compared to more than 800 Ml/yr of starch-based ethanol.

4 We acknowledge that technical innovations will reduce the operational footprint of bioenergy systems where land-area is concerned (see Lynd et al., 2007). The fact remains, however, that even an advanced bioenergy regime will require a greater proportion of local land base than a fossil hydrocarbon based energy regime for an equivalent unit of power. This is a function of the aboveground and relatively immobile nature of bioenergy resources. We discuss the immobility of bioenergy resources later in the paper to further clarify this point.

5 It is possible that 'local' people will not necessarily be key actors in social mobilization and protest against rural-based energy infrastructure as evidenced in responses to the siting of nuclear waste in Germany (see Blowers & Lowry, 1997). Instead, it is possible that 'urban' dwellers will lead protest and mobilization efforts.

6 In many countries with a carbon tax, for example Finland, the tax is applied at the facility (e.g., the emissions leaving the smoke stack of a district heating system) and not to the fuels themselves. This means that the embodied carbon content of a fuel is not captured in the carbon accounting equation. As such, pellets shipped from Canada are considered equivalent as far as carbon content is concerned compared to pellets produced locally, even though they are clearly more energy intensive from a life-cycle perspective (Magelli et al., 2009).

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