Alternative Liquid Fuels: Governance, Security and Transitions in the Inter-War Period

Corresponding author: Peter J G Pearson

Victoria C A Johnson[a], Fionnguala Sherry-Brennan[b], Peter J G Pearson[b]

[a] Sustainable Consumption Institute, School of Social Sciences, Faculty of Humanities,188 Waterloo Place, Oxford Road, The University of Manchester, M13 9PL

[b] Low Carbon Research Institute, Welsh School of Architecture, Bute Building, King Edward VII Avenue, Cardiff University, Cardiff, CF10 3NB

Corresponding author telephone: +44(0)7917788990
Email: pearsonpj@cardiff.ac.uk

Abstract
In light of continuing interest in low-carbon alternatives to petroleum-derived liquid fuels, this paper explores earlier experiences of such alternatives. We investigate case-studies of two fuels produced in the UK during the inter-war period (1918-1938); power alcohol, from the Distillers Company Ltd. (DCL), and petrol-from-coal from Imperial Chemical Industries Ltd. (ICI). Our analysis explores the socio-technical context and underlying governance logics that formed the environment in which these fuels were developed. Both fuels received government support at a time of rapid motor industry growth, fluctuating economic circumstances, fears of oil shortages, and the desire to develop and restore the international position of the UK's chemical industry. Both fuels were considerably affected by changing political perspectives of energy security and oil major hegemony. Governance and regulatory approaches to fuel distribution in particular had significant effects on the economic feasibility of both fuels. The inter-war period was one of dynamic governance which saw a fluctuating hybrid of market- and state-led logics. The two case-studies offer an indirect historical analogue for current situations in which there is growing emphasis on the combined role of state and market, as in the UK's recent electricity market reform legislation.

Keywords
Alternative fuels, coal hydrogenation, energy policy, energy security, energy sources, energy transitions, fuel distribution, governance, power alcohol.

1: Introduction

The past decade has seen a rapid growth in research examining the dynamics of socio-technical transitions (Markard *et al.*, 2012). Understanding the complex dynamics of change can yield theoretical and practical insights to inform and help guide the transformation of extant socio-technical systems to a lower carbon, less resource intensive configuration (Rip and Kemp, 1998; Verbong and Loorbach, 2012).

Empirical case-studies of long-term historical transitions have enhanced understanding of transition dynamics and have been helpful in developing and testing theories of change and informing policy and practice (Garud and Gehman, 2012; Geels 2002; Grin *et al.*, 2010; Smith, 2013). Such case-studies can also illustrate the possibility of radical transformation and challenge naïve perspectives or received wisdom about past successes and failures of transitions, policy interventions and technology innovations (Bayly *et al*, 2011; Hirsch and Jones, 2014; Thane, 2009; Tilly, 2006).

Here, we present two empirical case-studies that explore the emergence of, and state support for, two liquid fuels developed in Britain during the inter-war period (1918-1938). Building on Bennett (2009) and Bennett and Pearson (2009), this paper focuses on power alcohol produced by the Distillers Company Ltd (DCL) and petrol derived from coal by Imperial Chemical Industries Ltd (ICI). We examine why and under what circumstances the British government agreed to support two alternative liquid fuels, and how changes in governance logics influenced decision-making and fuel development. We aim to provide a useful historical analogue for understanding the development and support of technological substitutes within socio-technical transitions.

Section 2 of the paper discusses the analytical approach; section 3 outlines the socio-technical context of the fuels' development; section 4 introduces the case-studies; section 5 presents the results and discussion around the themes of energy security, government and industry relationships, indirect state support, and oil major hegemony. Section 6 concludes and offers insights for sustainability transitions.

2: Analytical approach

Despite a growing body of literature, socio-technical transitions research is still at a formative stage. Scholars continue to use a variety of conceptual, theoretical, and heuristic tools to examine contemporary and historical socio-technical systems and their transformation (Garud and Gehman, 2012; Markard *et al*., 2012). Of these, the multi-level perspective (MLP) has been the most influential in empirical case-studies. The MLP is an analytical concept that views socio-technical transitions as arising from the interactions within and between three interrelated levels (niche, regime and landscape). Transitions come about through the multi-dimensional alignment between them (Geels, 2002). The approach adopted in this study, however, purposefully deviates from this valuable approach.

Responding to recent criticisms that MLP studies tend to underplay issues of governance, politics, agency, and power (Genus and Coles, 2008; Smith *et al*., 2005; Smith *et al*., 2010; Meadowcroft, 2011; Shove and Walker, 2010) we pay particular attention to the role of actors, their governance logics or 'framings' and agency, to better understand the drivers and rationales for state support.

First, we adopt a flat ontological, relational approach (Garud and Gehman, 2012; Jørgensen, 2012; Longhurst and Chilvers, 2013) to capture the active role of different actors in shaping decisions on alternative liquid fuels. The relational approach deviates from the MLP, and other approaches derived from evolutionary economics, where emphasis is placed on selection as a mechanism for transformation. Relational approaches, derived from constructivist theory, emphasise translation as a mechanism of transformation (Longhurst and Chilvers, 2013). Translation draws specific attention to how emerging issues are framed as interested stakeholders become implicated (Garud and Gehman, 2012).

Second, building on the idea of translation as a mechanism for change, we employ an 'action space' interpretive framework (Foxon 2013, Foxon *et al*., 2010) to examine the dynamics between competing governance logics, policy choices, and the agency of actors. The action space approach envisages the pathway of a transition arising through the dynamic interaction of technological and social factors, mediated by actors within the action space. Within the framework (Figure 1), three very broad actor types exert influence: government, market, and civil society. In the context of contemporary energy policy, Foxon (2013) explains how these actors have fundamentally different 'logics' or framings of key energy challenges. Through their interactions each actor attempts to enrol other actors, with the most successful enroller's logic defining the period's action-space. This dominant logic will then influence significantly the pathway to future energy systems through its approaches to policy challenges and responses and its visions of future societies and their technologies.

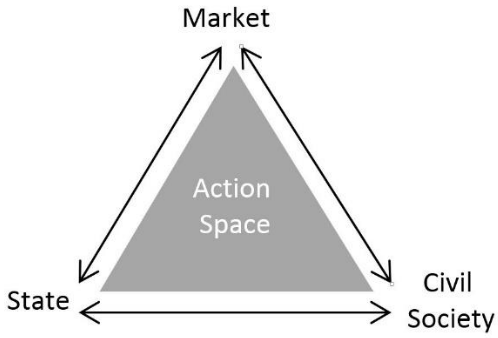

Figure 1 The action space framework (adapted from Foxon *et al*., 2010).

Several authors have identified that during periods of energy price instability, or other concerns about energy insecurity, a state logic tends to grow in influence. In contrast, at times of price stability or robust energy security, the governance logic tends to become more market orientated (Helm, 2005; Goldthau, 2012; Grimston, 2010).

Grimston (2010) describes a dynamic between state and market logics and its impact on energy policy. He argues that energy is framed either as a 'social service' (where socio-technical systems are dependent on energy services) or a market commodity. During periods of insecurity, dependence on energy services drives governments to intervene in energy supply and distribution. Energy then tends to be framed as a social service, a state logic persists and there is greater acceptance of intervention by other actors. In contrast, energy is perceived as a market commodity during periods of security and a market logic with minimal government intervention and regulation in the marketplace exists. (See also Helm, 2005; Fudge *et al.*, 2011; Goldthau, 2012; Rydin *et al*. 2013.) However, Grimston (2010) and Bolton and Foxon (2013) argue that this can be a false dichotomy and propose instead that hybrid governance logics comprising mixtures of market-mechanisms and state interventions often emerge and persist.

We argue that combining a relational approach with the action space framework enables us to better understand the tensions, choices, and decisions made by key actors involved in the development of alternative liquid fuels during a period of rapid macroeconomic, political, and social change. Using original archival material and secondary literature, we examine how the socio-technical context co-produced a policy environment that led to the ultimate demise of DCL's ventures into power alcohol and ICI's into petrol-from-coal.

3: Socio-technical context

Pressures to develop alternatives to crude oil derivatives reached a climax in the inter-war period, particularly among countries without indigenous petroleum resources, including Britain (Figure 2: Egloff, 1938). These alternatives were rarely economically competitive with petroleum-based fuels, and required state support (Committee on Industrial Alcohol, 1905; Falmouth Committee, 1938; San Román and Sudriá, 2003).

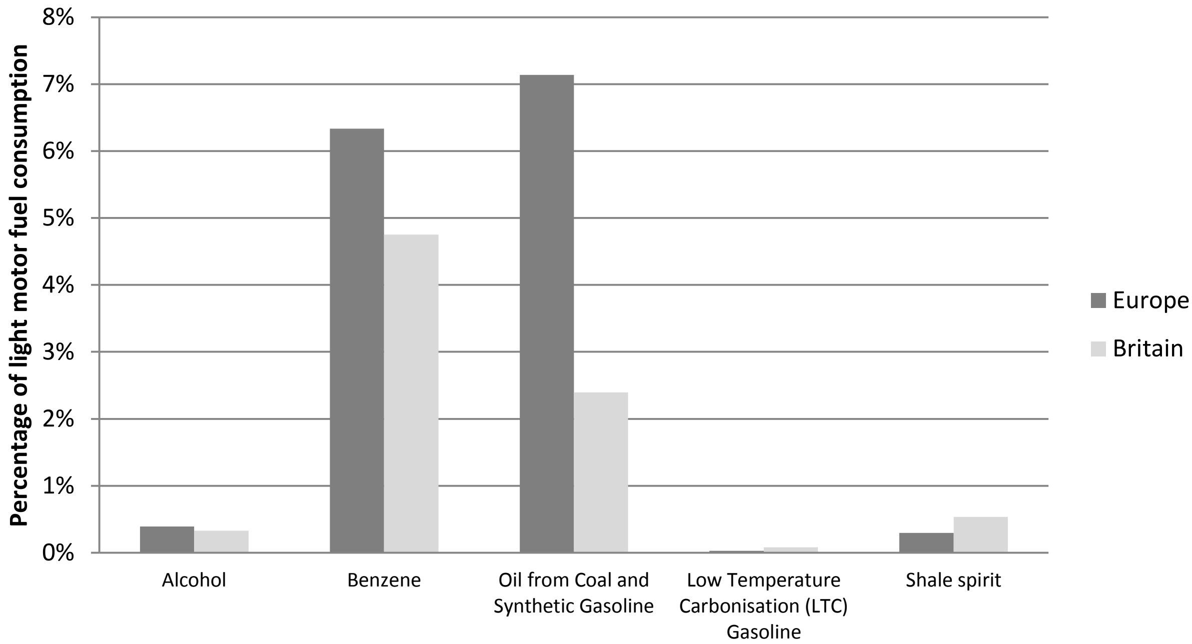

Figure 2 European and British synthetic fuel consumption as a percentage of total light motor fuel consumption, 1937. (Data source: Egloff (1938). Countries included: Germany, Estonia, Czechoslovakia, Lithuania, Hungary, Poland, Latvia, Yugoslavia, Belgium, France, United Kingdom, Austria, Sweden, Holland, Finland and Switzerland.)

While the economic and defence benefits of liquid fuels were increasingly recognised in Britain before World War I (WWI) (Royal Commission on Fuels and Engines, 1913), it was only after WWI, and from 1920, that imports of crude oil and other derivatives grew rapidly (Figure 3) and fuel distribution infrastructure developed considerably, contributing to reduced fuel costs (Dixon, 1963). These developments were responses to growing demand from the naval and marine mercantile sectors, and societal changes which saw rapid growth in motorcar ownership, road freight, and aviation (Figure 4; Johnson *et al*., 2014).

WWI had emphasised the strategic importance of liquid fuels and the consequences of heavy reliance on international supply chains. Severe economic instability during the inter-war period, including the depressions of 1919-21 and 1930-31 (Broadberry, 1986), rising demand for imported petroleum, widening trade deficits and a rising trend in economic nationalism across Europe, highlighted the potential for domestic production of alternative liquid fuels.

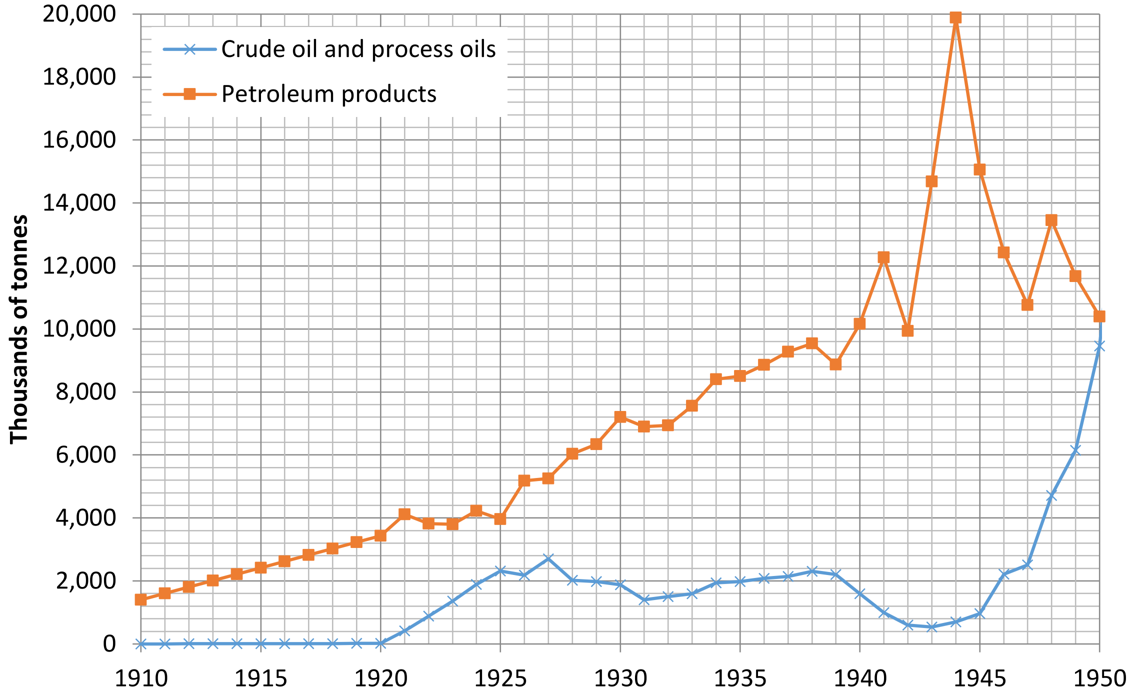

Figure 3 UK Imports of crude oil and petroleum products, 1910-1950, in thousands of tonnes. (Data source: DECC (2013).)

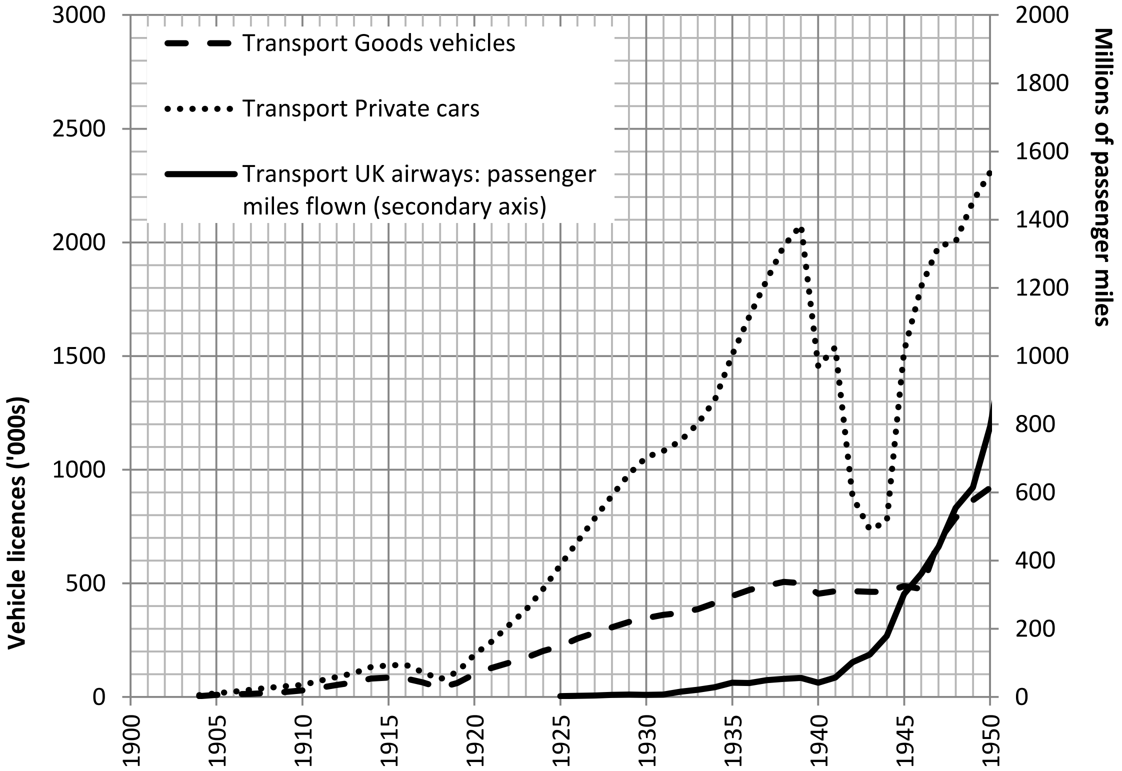

Figure 4 Growth in motor vehicle use for goods vehicles and private cars in thousands of vehicle licences (primary axis) and growth in civil aviation in millions of passenger miles

(secondary axis), 1897-1960. (Data sources: 1928-1960 from Society of Motor Manufacturers and Traders (1973) in Pugh (2008); 1914 from Pugh (2008); 1897-1905 from Wood (1996).)

4: Case-study selection and description

The case-studies discussed here were selected in an attempt to understand the processes and mechanisms which affected alternative fuels during the inter-war years. Although differences between the case-studies exist, both firms shared some similar features and experiences (summarised in Table 1). In particular, DCL and ICI played significant roles in WWI, especially in munitions, developing a close relationship with the state; both companies were combines; both were viewed as strategic industries and received direct and indirect support from government; and, during rearmament in the 1930s, both fuels were recognised for their strategic importance. ICI and DCL also shared a need to identify new markets in the inter-war years because of an excess of supply over demand. On the supply side, both had surplus capacity developed or planned during WWI, partly through aims to exploit economies of scale and anticipated exports to the British Empire. On the demand side, both experienced growing international competition, as well as falling demand during severe economic downturns.

In the next three sections, we outline the history of both fuels and the differences between the case-studies. More detailed information can be found in Johnson *et al*. (2014).

4.1: Power Alcohol and the Distillers Company Limited (DCL)

Power alcohol was used as motor fuel, either on its own or as part of a blend (Weir, 1995). It differed from petrol in that it possessed 'anti-knock' qualities due to its high octane level, making it suitable for high-compression engines (often found in commercial vehicles, sports, and motor-racing cars). It was said to offer improved engine power, increased mileage, and lower running costs than petrol (Commercial Motor Archive, 1923).

Power alcohol was produced from molasses by DCL. Formed in 1877, DCL was an amalgamation of several Scottish whisky distilleries. It grew to become one of the largest distilling companies in the UK, and with it a powerful force in the UK's distilling industry. The alcohol produced by DCL was also used extensively in the chemical industry and, although power alcohol was different to 'industrial alcohol', it was strongly influenced by decisions made by government on industrial alcohol. Domestic production of industrial alcohol was seen by many users as uncompetitive with imports from Germany and America (1905 Committee). The high cost of domestic industrial alcohol was attributed to the Excise restrictions (which prevented simultaneous brewing and distilling, and no brewing, fermentation, or distillation on Sundays) which were imposed originally on potable alcohol. It was argued that these restrictions limited output and contributed to the higher cost of industrial alcohol over imports. As government wanted to be seen supporting home industry, DCL received a subsidy for its industrial alcohol in 1906, enabling its use in the chemical industry to increase substantially (1905 Committee).

By 1913, with rapid increase in car ownership, and growing fuel security concerns, the government convened a Committee to discuss the potential for a home-produced fuel - power alcohol. Following the Committee's recommendations, and wanting to protect home industry from competition from the increasingly powerful international oil industry (Second Report on Motor Fuel, 1921), power alcohol benefitted from the same tax exemptions available to other domestically produced fuels available at the time (benzol from coal and shale-oil) and the subsidy on industrial alcohol was extended to power alcohol (1919 Committee). This resulted in power alcohol becoming cost competitive with high-grade petrol.

Consumption of power alcohol, and production of industrial alcohol, increased dramatically throughout the 1920s, leading the Treasury to question the cost of the subsidy (Marsden, 1943). No investigative steps were taken until 1944, however, when the May Committee was convened. The Committee found that domestic production of large quantities of alcohol for munitions during wartime had led to the removal of Excise restrictions. The conditions under which power and industrial alcohol were produced (which had justified the subsidy) were, therefore, no longer applicable (May Committee, 1944). This finding, combined with greater certainty over petrol supplies and price stability, led to the removal of the subsidy in 1945. Without the subsidy it became more difficult for power alcohol to compete with petrol, particularly as production and sales of power alcohol came under ownership of the oil companies (Weir, 1995).

4.2: Coal Hydrogenation and Imperial Chemical Industries (ICI)

Coal hydrogenation using the Bergius Process was developed alongside the Haber-Bosch process for ammonium production in Germany (Hughes, 1969; Smil, 2004). The process involved a reaction of hydrogen gas under high-pressure and temperature with creosote (coal-tar) or a creosote and a powdered coal mixture to yield synthetic crude oil. Further distillation of the synthetic oil resulted in a variety of different hydrocarbon oils, including petrol. This high quality fuel could be readily blended with petroleum-derived petrol (Oil Fuel Board, 1931) or with tetra-ethyl lead and iso-octane for a high-octane aviation spirit (Reader, 1977).

The Bergius process became a key method for producing this petroleum fuel substitute in Europe during the inter-war period (see Figure 2). Between 1927 and 1943, 12 coal hydrogenation plants were built in Germany, two in Britain, and one in Korea. The construction of commercial-scale coal hydrogenation plant occurred mostly during the late 1930s when Germany and Britain began rearming and during WWII in an attempt to secure supplies of liquid fuel for the military (National Academy of Sciences, 1977).

The British government played a central role in the early stages of coal hydrogenation development in Britain between 1920 and 1926 and, from 1927 to 1939 the state-owned Fuel Research Station in Greenwich continued to carry out basic research into the Bergius process. ICI proceeded with commercial development of the technology at the encouragement of the Oil Fuel Board of the Committee of Imperial Defence and the Treatment of Coal Sub-Committee, established in 1929.

ICI formed in late 1926 as an amalgamation of four of Britain's largest chemical firms - Nobel Industries Ltd., British Dyestuffs Corporation, Brunner, Mond & Co. Ltd. (Brunner) and United Alkali Company. ICI's formation was encouraged and brokered by Government officials, partly in response to chemical combines that had emerged in Germany (IG Farben) and the United States (du Pont). Government officials and industrialists held the view that if Britain was to regain its position as industry leader and influence international trade agreements in the strategically important chemical industry, Britain needed a firm that had similar scale and scope to IG Farben and du Pont (Pettigrew, 1985; Reader, 1977; US Tariff Commission, 1937).

The vision for ICI was that it would exploit growing and emerging markets within the Empire, particularly in the agricultural fertiliser sector. However, overcapacity of high capital ammonium production equipment at ICI's main industrial site in Billingham, Stockton-On-Tees , shortly after its formation, drove the firm to search for new markets. ICI's existing knowledge base in coal hydrogenation due to Brunner's early involvement in the process and the similarities to ammonium production meant that developing petrol-from-coal at Billingham offered ICI a new opportunity for their costly capital investment. With growing concerns about fuel security, declining markets for coal, and growing interest in the development of domestic fuel production, ICI built on its knowledge base and began to lobby for state support for a commercial-scale plant at Billingham.

ICI originally hoped that coal hydrogenation might be, with government support, a way forward for the stranded assets of the Billingham plant. In the event, however, the process proved to be cost-competitive with petroleum-derived fuels only when oil prices were high and commercially attractive only with a state-guaranteed preference for home-produced hydrocarbon fuels.

4.3: Differences between ICI and DCL case-studies

Whilst ICI and DCL shared experiences, differences did exist. First, a 'preference' (subsidy) for domestic production of hydrocarbon liquid fuels was orchestrated specifically to assist ICI in the commercial development of an experimental process whereas DCL received support for an existing product.

Second, the feedstock for ICI's fuel was a home-produced, non-renewable fossil fuel (coal), whereas DCL's imported feedstock was renewable (molasses). Whilst the 1919 Committee appointed to explore the potential of power alcohol recognised the advantages of a sustainable raw material, they were in the minority. Any rhetoric in support of the development of power alcohol put little emphasis on this property. Third, the petrol-from-coal developed by ICI did not receive any special marketing. A patent pool stipulation meant that petrol-from-coal was blended with petrol derived from oil and sold as petrol. For DCL, however, power alcohol was branded 'Discol' (later 'Cleveland-Discol') and was promoted as an alcohol fuel made in Britain with superior qualities over petrol. Nevertheless, as oil refining techniques advanced, and with increasing use of tetra-ethyl lead (a cheap fuel-enhancing petrol additive) during the 1920s, power alcohol's advantages over petrol were gradually eroded (Weir, 1995).

Table 1 Summary of case-studies (adapted from Johnson *et al*., 2014).

Feature	**DCL**	**ICI**
Fuel	• Alcohol produced by fermentation and blended with oil- and coal-based fuels (e.g. petrol and benzole) • High octane fuel, equivalent to No.1 grade petrol (a premium grade fuel) • Advertised as having superior qualities over petrol for starting in cold conditions • Branded as Discol, later Cleveland-Discol	• Identical to petroleum-derived petrol and easily blended with petrol • High octane fuel, equivalent to No. 1 grade petrol • Unbranded, blended with petrol and marketed by 'The Combine', BP Shell Mex Ltd
Raw materials and feedstocks	• Imported molasses	• British coal (pulverised coal or coal derived creosote)
Technology	• Alcohol produced using the Coffey still	• Petrol-from-coal produced using the Bergius process, similar to the Haber-Bosch process of ammonium production
Nature of business	• Market-led amalgamation • Business diversification led to power alcohol production • Influential industry voice exerted through market power	• Government supported amalgamation • Agricultural fertiliser production from Haber-Bosch process viewed as central for ICI's growth • Influential industry voice due to strategic importance of chemical industry
Drivers for new markets	• Falling whisky sales and overproduction prompted search for new products and markets, including power alcohol	• Overcapacity in the global nitrogen fertiliser market prompted search for new markets due to need to utilise capital-intensive ammonium production equipment at Billingham
Nature of new markets	• Alcohol for power alcohol produced by DCL (monopoly production) • Alcohol for power alcohol sold to Cleveland Petroleum for sales and distribution • Power alcohol subject to government Excise production restrictions, unlike oil-based fuels	• ICI held British Empire rights for hydrogenation patents (monopoly production) • ICI sold petrol to BP-Shell-Mex who were monopsony buyers • International Hydrogenation Patents (see Table 2) limited technology development in terms of imposed production quotas and unfavourable RD&D conditions

Civil society pressures	• Growing demand for fuel with growth in ownership of private motor vehicles • Power alcohol desirable in sports cars as a luxury fuel, relating to its use in motor racing	• Growing demand for fuel with growth in ownership of private motor vehicles; • Public and political support for the coal industry, particularly miners; specifically the Back-to-Coal Movement, a coalition of the National Union of Mineworkers, Coal Utilisation Council and local politicians from coal mining areas

Government support	• *Defence/ military*: DCL involved in acetone production (for munitions) during both World Wars
	• *State support:*
	  ○ Direct: Government subsidy received
	  ○ Indirect: Government alcohol fuel R&D and fuel testing
		• *Defence/ military*: Strong links to defence concerns: navy, aviation and land vehicles during wartime.
		• *State support*:
		  ○ Direct: Government subsidy received
		  ○ Indirect: Early government research and fuel testing

International context	• Molasses used in power alcohol production imported from British colonies • Power alcohol could be produced more cheaply abroad • Other European countries mandated the use of alcohol in motor fuels	• Germany's IG Farben demonstrated that petrol-from-coal not economically competitive with petroleum derived fuels several years before ICI • Spain, South Africa, and Japan developed large programmes post WWII

5: Results and Discussion

This section examines how state and industry actors affected the development of ICI and DCL's motor fuels. Here, we consider state support, government and industry relationships, indirect state support, and the effect of oil major hegemony. Through these themes, we illustrate how broader economic, social and technological change and relationships between actors co-produced the development, use, and distribution of power alcohol and petrol-from-coal. First, however, we examine the role of energy security as this emerged as a key underlying theme.

5.1: Energy security concerns

Concerns about energy security were voiced in the first decade of the 1900s when discussions about the transition of the Royal Navy fleet's fuel from coal to oil began (Jones, 1981). With few domestic crude oil resources, energy security in Britain before and during WWI was mainly framed in terms of securing military supplies at reasonable prices during wartime (Payton-Smith, 1971). A secondary concern, however, was the monopolistic organisation of the oil industry and the significant market power it held (Jones, 1981; Royal Commission on Fuels and Engines, 1913).

To guarantee supplies of fuel oil to the Admiralty, in 1914 the state negotiated an unprecedented controlling interest in the Anglo-Persian Oil Company (APOC). APOC would supply the Admiralty with oil below market price and, during war, the Admiralty would have rights over the entire output. The decision to take a controlling interest coincided with an official recognition of fuel oil by the state as a, '*special article*[s] *of warlike material*', exempt from market forces (Jones, 1981, p.24).

Disruption to Britain's oil supply chains during WWI shifted state perspectives on energy security during the inter-war period to focus on scarcity and sovereignty, framed in economic and militaristic terms. Fears of an absolute petroleum scarcity grew in the 1920s following a pessimistic report from the American Federal Oil Conservation Board (Federal Oil Conservation Board, 1926). As American oil then dominated the world market (United States Tariff Commission, 1931), the report reinforced the need for government support for domestic, non-petroleum motor fuels as a hedge against wartime scarcity. Although new oil was found in the US and elsewhere in the immediate years after the report, Britain experienced two 'oil price shocks' in the early 1930s which brought into relief Britain's dependence on foreign oil.

Both case-studies provide evidence that energy security played a significant role in the framing, shaping, and timing of state support for domestic production of motor spirits. Perceptions of fuel scarcity, dependence on non-domestic, non-colonial sources of fuel, and Britain's balance of payments, highlighted the economic and military potential of alternative liquid fuels to reduce Britain's import dependence. Consequently, a multi-faceted concept of energy security emerged, providing impetus for research into, and support for, the domestic production of motor fuel.

Both ICI and DCL framed their lobbying accordingly. ICI, negotiating with the Board of Trade for a state subsidy, highlighted the value of Britain's indigenous coal supply for energy independence, and its impact on Britain's trade deficit (Reader, 1977). DCL emphasised that the main raw material for power alcohol (molasses) was widely available within the Empire.

For DCL, post-WWI oil shortage fears provided the underlying rationale for government to extend the allowance on industrial alcohol to power alcohol (from 1921), to encourage production (Yergin, 2009). Even when oil became more readily available, scarcity of supply concerns, combined with the two 'oil price shocks' eventually led to the passing of the British

Hydrocarbon Oils Production Act in 1934, encouraging ICI to develop further its plans for an experimental industrial-scale coal hydrogenation plant based on its Billingham assets.

5.2: Government and industry interactions

Both World Wars had a significant influence on DCL's and ICI's relationships with government. Supply contracts with government established close relationships with state actors and institutions which also benefitted from the sharing of personnel during wartime.

Several government departments interacted with industry to address munitions concerns. In 1917, for example, the Advisory Committee on Alcohol Supplies, in search of alcohol and acetone supplies for munitions, established interactions between distillers and government over alcohol supplies that continued throughout the inter-war period and WWII (Weir, 1995). Similarly, during WWI chemical firm Brunner worked closely with the Ministry of Munitions through manufacture and research contracts (Reader, 1975). In the inter-war years, the Admiralty and the Air Ministry also played a considerable role in RD&D of alternative fuels, working closely with ICI and DCL.

Moreover, the wartime economy had changed perspectives on and enhanced government support for business amalgamation (Broadberry, 1986; Hannah, 1983). The size and scope of ICI's and DCL's businesses, born out of the second industrial revolution and intensified through the amalgamation movement, gave them the capacity to communicate with, and influence, government and industry. The movement transformed industrial organisation and required experienced managers, who were often recruited into industry from the civil service. This, combined with an established framework of co-operation developed during wartime, helped create a 'revolving door', giving DCL and ICI opportunities to influence government policy at the highest level (Reader, 1977; Weir, 1995).

5.3: Indirect state support

During WWI and the inter-war period, state engagement with, and support for, scientific research and strategic defence industries was seen as necessary and urgent, despite continuing interest in more laissez-faire approaches. Severe criticisms of Britain's flagging technological prowess were voiced by high profile political figures as received wisdom about the emerging chemical industry was that Britain was falling behind Germany and the US (Haber, 1971; MacLeod and Andrews, 1969; Reader, 1977). Consequently, ICI, with its experience for producing chemicals with military uses, and DCL, with its capacity for producing large quantities of alcohol for munitions, were considered strategic industries and both became a focus of government attention.

From 1914 the state took a central role in planning, financing, and directing the activities of strategically important manufacturing firms (Hannah, 1983). The Committee for Scientific and Industrial Research, charged with promoting research in industry and education, was formed in 1915, becoming the Department for Scientific Industrial Research (DSIR) in 1916. The DSIR played a key role in indirect state support for ICI's and DCL's motor spirits in two ways. First, its preferred method was to support industrialists to form research associations subsidised by government funds. For example, two DSIR grants to the British Colliery Owners' Research Association in the early 1920s funded academic research into coal hydrogenation (Stranges, 1984). Second, the DSIR itself undertook research considered to be of national importance and deemed unsuitable for private enterprise (Sayer, 1950). As power alcohol and petrol-from-coal were both deemed strategically important, the fuels received DSIR support. DSIR supported power alcohol by arranging funding for and initiating the testing of power alcohol in a fleet of London's Omnibuses[1] (The Times, 1920). DSIR also provided finance for a group of private investors to acquire patent licences for coal hydrogenation (Stranges, 1984). It also formed several departmental research stations, including the Fuel Research Station (FRS), established in 1919, which played a significant role in developing coal hydrogenation processes and testing of both fuels.

Establishment of the DSIR and FRS demonstrated governmental commitment to the exploration of alternative fuels, underpinned by the notion of their potential strategic importance. Both organisations worked closely with ICI and DCL.

5.4: Oil major hegemony: fuel distribution and patent pool agreements

Whilst government subsidies were provided to support DCL's and ICI's emerging fuels, oil major control of fuel distribution hindered the likelihood of their success. The Oil Fuel Board and other commentators recognised this inconsistency and the potential hostility of the oil majors to alternative fuels (Economist, 1927; Oil Fuel Board, 1930). Non-interference in fuel distribution was, however, implicitly endorsed by the government.

The origins and nature of the oil majors are important for the context in which power alcohol and petrol-from-coal emerged. The conditions under which the multi-national oil company developed are well documented and not repeated in detail here (see: Bamberg, 1994; Jones 1981; Macbeth, 1985; Nowell, 1994; Payton-Smith, 1971; Yergin, 2009). In summary, high capital costs of oil distribution and refining infrastructure led to the emergence of vertically integrated firms with global interests from exploration and drilling to production, distribution, and marketing and with capital intensive distribution networks operating loosely as a natural monopoly. Furthermore, the small number of firms controlling the majority of the world's oil resources was conducive to cartelisation and the exercise of market power.

DCL and ICI had similar experiences with the oil majors (Standard Oil, Royal Dutch Shell and Anglo-Persian) and their cartels. Two types of cartel affected ICI and DCL: market-sharing arrangements and patent pools (Table 2).

[1] In a modern equivalent, in 2003-05, 27 hydrogen-powered fuel cell buses were placed in the public transport fleets of nine European cities, including London (http://ec.europa.eu/energy/res/fp6_projects/doc/hydrogen/deliverables/summary.pdf, accessed 23/05/14).

Table 2 Summary of oil major cartels (adapted from Johnson *et al.*, 2014).

Cartel Type	Name	Description	References
Market-sharing arrangements	*Achnacarry Castle Agreement* (1928)	• Involved Anglo-Persian, Royal Dutch, and Standard Oil • Aimed to control supply and price at the international level • Agreement strengthened following the collapse of oil prices in the 1929-31 economic crisis	Bamberg, 1994; Nowell, 1994
	The Combine (early 1920s)	• Involved distribution units of the oil majors in Britain • Aimed to control wholesale and retail prices of motor spirit, prevent price cutting by independent firms, limit new market entrants, standardise motor spirit quality • Retailers restricted to selling members' motor spirit • Leased / provided finance for petrol pumps thus securing long-term contracts with retailers for sale of their fuels and gain control over emerging distribution infrastructure • By the mid-1920s, The Combine dominated 85% of the market	Brunner, 1930; Dixon, 1963; Fitzgerald, 1927
Patent pools	*International Hydrogenation Patent (IHP)*	• Developed by BASF (later IG Farben) and Standard Oil • Restricted the use of the coal hydrogenation process • Stipulated that all technological discoveries or modifications to the process by licensees had to be shared with the IHP • Only IG Farben permitted to use the technology for purposes other than petrol production	Nowell, 1994
	International Sugar and Alcohol Company (ISACo)	• Members committed to sharing power alcohol patents • Oil companies removed their support early on, focusing instead on alternative fuel enhancing processes e.g. lead additives	Ferrier, 1982

In 1920, an inquiry into high fuel prices argued that the oil industry and their market-sharing agreements operating at domestic and international levels had sufficient market power to threaten energy security. The report recommended that the newly established League of Nations act to regulate the international oil market and set maximum and minimum retail prices at the domestic level. It concluded that domestic production of motor spirits, specifically power alcohol, was the solution to motor fuel security (Report on Motor Fuel, 1920). Nevertheless, while the state was acutely aware of the restrictive market structure created by the oil cartels, the industry remained unregulated throughout the inter-war period (Bridgeman, 1920; Dixon, 1963). Although reasons for this remain somewhat unclear (for further discussion see Johnson *et al*., 2014), The Combine resisted government regulation by emphasising that they were making substantial infrastructure and oil exploration investments, unlike firms such as DCL's distributor, Cleveland, who were considered 'independents', unable or unwilling to make such investments (Board of Trade, 1929). This perspective was confirmed much later in a report by the Monopolies Commission which implied that, in the inter-war period, the state had been keen to attract private investment into the fuel distribution infrastructure (Monopolies Commission, 1965). We suggest that this attitude may have contributed to the state's reluctance to intervene.

Oil majors were also able to affect the economic prospects of power alcohol and petrol-from-coal through their involvement in patent pool agreements. These were cartels that developed around specific technologies or processes, often limiting their development. Patent pool agreements existed for coal hydrogenation (IHP) and power alcohol (ISACo) (Table 2). Little is known about the ISACo except that it was short-lived as oil companies soon removed their support, choosing instead to focus on fuel enhancing additives such as tetra-ethyl lead. The IHP placed strict restrictions on how coal hydrogenation technology could be used. Any technological discoveries or modifications to the process by licensees had to be shared with the IHP which contributed to reducing the economic attractiveness of large-scale production for ICI.

6: Conclusions

This paper examined the development of two alternative liquid fuels during the inter-war period, the circumstances in which the British government agreed to support them, and how changes in governance logics influenced state decision-making and fuel development. Government motives for supporting the fuels included the desire to develop the UK chemical industry, to modernise and identify new markets for a domestic coal industry, and to reduce trade deficits. Both fuels were considerably affected by changing political perspectives of energy security and oil major hegemony. Government expected the oil industry to invest in distribution infrastructure and continue with oil exploration, and implicitly accepted the market power of The Combine by an unwillingness to intervene through regulation. Oil company ownership and control over oil resources and distribution networks therefore reduced the state's agency to control oil prices and influence fuel distribution. The state instead legitimised the expense of supporting alternative fuels by means of a subsidy during periods of heightened energy insecurity.

Due to government requirement for secure fuel supplies, and the capacity of oil companies to provide it, liquid fuels were subject to a fluctuating, hybrid form of governance. DCL and ICI experienced a policy environment in which state subsidisation made both fuels cost-competitive with imported motor fuels, but which offered no support for access to distribution infrastructure and markets or protection from The Combine's drive to exclude alternative fuels from the market.

The inter-war period therefore was one of dynamic governance which saw a fluctuating hybrid of market- and state-led logic. Figure 5 illustrates how energy security dynamics, the framing of energy, and governance logics interrelated.

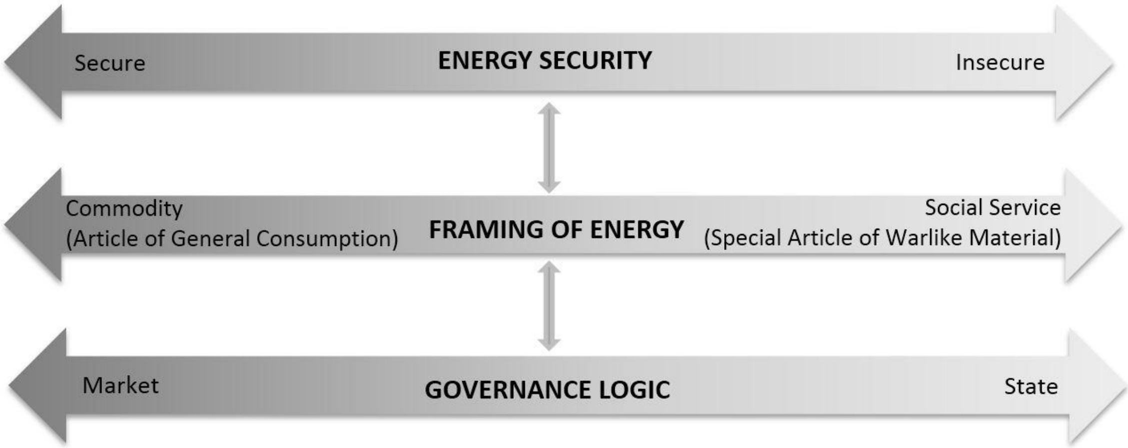

Figure 5 The relationship between energy security, framing of energy, and governance logics during the inter-war period.

These dynamics were revealed through applying a relational approach (Longhurst and Chilvers, 2013) within a historical context. This enabled us to observe not only how government and market logics co-evolved but also how shifting modes of governance affected energy decision-making, facilitating the capture of diverse characteristics of the failed-transition of both alternative fuels.

We suggest that these historical case-studies can help to understand and interpret the contemporary dynamics of energy policy and hybrid governance. They offer an indirect historical analogue for current situations which have seen growing emphasis on the combined role of state and market, as in the UK's recent electricity market reform legislation (Bolton and Foxon, 2013).

Finally, the histories of DCL's and ICI's ventures suggest that for alternative fuels to become successful and sustainable, they may require combinations of: initial entrepreneurial vision and investment, state support (direct or indirect), open access to distribution infrastructure, a conducive, stable regulatory environment that does not inappropriately favour incumbent fuels or actors, and last but not least the capacity eventually to reduce costs and become economically competitive with incumbent fuels.

Acknowledgements
The research for this paper was supported by funding from the UK Engineering and Physical Sciences Research Council (EPSRC) [Grant EP/K005316/1] under the 'Realising Transition Pathways' consortium project. The authors are solely responsible for all views expressed.

References

1905 Committee (1905) Industrial Alcohol Committee. *Report of the Departmental Committee on Industrial Alcohol*. HMSO: London. (Cd. 2472). The National Archives, Kew, London.

1919 Committee (1919) H.M. Petroleum Executive. *Report of the Inter-Departmental Committee on Various Matters concerning the Production and Utilization of Alcohol for Power and Traction Purposes.* Cmd. 218. The National Archives, Kew, London.

Bamberg, J.H. (1994) *The History of the British Petroleum Company: Volume 2, The Anglo-Iranian Years, 1928-1954*. Cambridge University Press, Cambridge.

Bayly, C.A., Rao, V., Szreter, S. and Woolcock, M. (2011) *History, Historians and Development: A necessary dialogue*. Manchester University Press, Manchester.

Bennett, S.J. (2009) *The Socio-technical Dynamics of Chemical Feedstock Transitions: The case of renewable raw materials in the UK*. PhD thesis, Imperial College London.

Bennett, S.J. and Pearson, P.J.G. (2009) From Petrochemical Complexes to Biorefineries? The past and prospective co-evolution of liquid fuels and chemicals production in the UK. *Chemical Engineering Research & Design*, **87**(9A), 1120-1139.

Board of Trade (1929) *Prices of Petroleum Products: Statements by the oil companies concerned*. Cmd. 3296. Command Papers; Accounts and Papers. Volume XVI.685. The National Archives, Kew, London.

Bolton, R. and Foxon, T. (2013) Negotiating the Energy Policy 'Trilemma' – An analysis of UK energy governance from a socio-technical systems perspective. In *Theorising Governance Change for a Sustainable Economy*. IGov Workshop, British Library, London 30th April, 2013.

Bridgeman, W. (1920) Written answers (Commons) of 22nd March, 1920. House of Commons Hansard, Volume 127, Columns 64 – 65.

Broadberry, S. (1986) *The British Economy between the Wars: A macroeconomic survey*. Basil Blackwell Ltd, Oxford.

Brunner, C. (1930) *The Problem of Oil*. Ernest Benn Limited, London.

Commercial Motor Archive (1923) *Alcohol as a Practical Fuel*. 24th April 1923. (accessed 13/02/14) http://archive.commercialmotor.com/article/24th-april-1923/12/alcohol-as-a-practical-fuel

Committee on Industrial Alcohol (1905) *Report of the Departmental Committee on Industrial Alcohol*. HMSO: London. (Cd. 2472). The National Archives, Kew, London.

Department of Energy and Climate Change (DECC) (2013) *Crude Oil and Petroleum: Production, imports and exports 1890 to 2012*. (accessed, 26/06/2014) https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/224640/oil_since_1890_historical_data.xls

Dixon, D. (1963) Petrol Distribution in the United Kingdom, 1900-1950. *Business History*. **6**, 1-19.

Economist (1927) Petrol from Coal. 8th January, p. 16.

Egloff, G. (1938) *Motor Fuel Economy of Europe*. Volume II of Committee on Motor Fuels. Motor Fuel Facts Series, American Petroleum Institute.

Falmouth Committee (1938) *Committee of Imperial Defence: Sub-committee on oil from coal: Report*. London: HMSO (Cmd. 5665).

Federal Oil Conservation Board (1926) *Report of the Federal Oil Conservation Board to the President of the United States*: Government Printing Office, Washington D.C.

Ferrier, R.W. (1982) *The History of the British Petroleum Company: Volume 1, The developing years, 1901-1932*. Cambridge University Press, Cambridge.

Fitzgerald, P. (1927) *Industrial Combination in England (European Business)*. Sir Isaac Pitman and Sons, London.
Foxon, T.J. (2013) Transition Pathways for a UK Low Carbon Electricity Future. *Energy Policy*, **52**, 10-24.
Foxon, T. J., Hammond, G. P. and Pearson, P. J. G. (2010) Developing Transition Pathways for a Low Carbon Electricity System in the UK. *Technological Forecasting and Social Change,* **77**, 1203-1213.
Fudge, S., Peters, M., Mulugetta, Y. and Jackson, T. (2011) Paradigms, Policy and Governance: The politics of energy regulation in the UK post-2000. *Environmental Policy and Governance*, **21**(4), 291-302.
Garud, R. and Gehman, J. (2012) Metatheoretical Perspectives on Sustainability Journeys: Evolutionary, relational and durational. *Research Policy,* **41**, 980-995.
Geels, F.W. (2002) Technological Transitions as Evolutionary Reconfiguration Processes: A multi-level perspective and a case-study. *Research Policy,* **31**(8-9), 1257-1274.
Genus, A. and Coles, A. M. (2008) Rethinking the Multi-Level Perspective of Technological Transitions. *Research Policy,* **37**, 1436-1445.
Grimston, M. (2010) *Electricity - Social Service or Market Commodity? The Importance of clarity for decision-making on nuclear build*. Chatham House, London.
Grin, J., Rotmans, J. and Schot, J. (2010) *Transitions to Sustainable Development: New directions in the study of long term transformation*. Routledge, Abingdon, Oxon.
Goldthau, A. (2012) From the State to the Market and back: Policy implications of changing energy paradigms. *Global Policy*. **3**, 198–210.
Haber, L.F. (1971) *The Chemical Industry 1900-1930: International growth and technological change*. Oxford University Press, London.
Hannah, L. (1983) *The Rise of the Corporate Economy*. Methuen & Co. Ltd, London.
Helm, D. (2005) The Assessment: The new energy paradigm. *Oxford Review of Economic Policy*. **21**, 1-18.
Hirsch, R.F. and Jones, C.F. (2014) History's Contributions to Energy Research and Policy. *Energy Research and Social Science*, **1**, 106-111.
Hughes, T.P. (1969) Technological Momentum in History: Hydrogenation in Germany 1898-1933. *Past and Present*. **44**, 106-132.
Johnson, V.C.A, Sherry-Brennan, F. and Pearson P.J. G. (2014) *Alternative Liquid Fuels in Britain during the Inter-War Period (1918-1938): Insights for future energy transitions*. Realising Transition Pathways Working Paper, 2014/01, March 2014.
Jones, G. (1981) *The State and the Emergence of the British Oil Industry*. Macmillan Press, London.
Jørgensen, U. (2012) Mapping and Navigating Transitions - The multi-level perspective compared with arenas of development. *Research Policy,* **41**, 996-1010.
Longhurst, N. and Chilvers, J. (2013) *Developing a Relational-coproductive Approach for Understanding Sociotechnical Transitions: A case study of hydraulic fracturing in the United Kingdom* Paper presented at an international workshop on 'Constructing and contesting spaces for low-carbon energy innovation', November 26-28, 2013, School of Innovation Sciences, Eindhoven University of Technology, the Netherlands.
Macbeth, B.S. (1985) *British Oil Policy 1919-1939*. Frank Cass Ltd, London.
Macleod, R. and Andrews, E. (1969) The Committee of Civil Research: Scientific advice for economic development, 1925-30. *Minerva,* **7**, 680-705.

Markard, J., Raven, R. and Truffer, B. (2012) Sustainability Transitions: An emerging field of research and its prospects. *Research Policy,* **41**, 955-967.
Marsden, C.A. (1943) *Verbatim oral evidence from Mr. C.A. Marsden given at a meeting of the Industrial Alcohol Committee on 21st September 1943. T161/1407*. The National Archives, Kew, London.
May Committee (1945) Industrial Alcohol Committee. *Removal of Certain Excise Restrictions on Distillation and of Allowances on Industrial Alcohol and Exported Spirits*. Cmd. 6622. The National Archives, Kew, London.
Meadowcroft, J. (2011) Engaging with the *Politics* of Sustainability Transitions. *Environmental Innovation and Societal Transitions*, **1**, 70-75.
Monopolies Commission (1965) *Petrol: A report on the supply of petrol to retailers in the United Kingdom*. HC 264, HMSO, London.
National Academy of Sciences (1977) Committee on Processing and Utilisation of Fossil Fuels, Commission on Sociotechnical Systems. *Assessment of Technology for the Liquefaction of Coal: Ad hoc panel on liquefaction of coal*. National Academy of Sciences, Washington D.C.
Nowell, G.P. (1994) *Mercantile State and the World Oil Cartel 1900-1939*. Cornell University Press, Ithaca.
Oil Fuel Board (1930) *Extraction of Oil from Coal*. CAB 50/30, 351-363. The National Archives, Kew, London.
Oil Fuel Board (1931) *Trials of Petrol Produced by Hydrogenation of Coal*. CAB 50/4 O.B. 64. British Library, London.
Payton-Smith, D.J. (1971) *Oil: A study of war-time policy and administration*. London: HMSO.
Pettigrew, A. (1985) *The Awakening Giant: Continuity and change in ICI*. Basil Blackwell Ltd, Oxford.
Pugh, M. (2008) *We Danced all Night: A social history of Britain between the wars*. Vintage Books, London.
Reader, W.J. (1975) *Imperial Chemical Industries. A History. Volume II. The first quarter-century 1926-1952*. Oxford University Press, London.
Reader, W.J. (1977) Imperial Chemical Industries and the State, 1926-1945. In Supple, B. (ed). *Essays in British Business History*. Oxford University Press, Oxford.
Report on Motor Fuel (1920) Profiteering Act, 1919. *Report on Motor Fuel Prepared by a Sub-Committee Appointed by the Standing Committee on the Investigation of Prices*. Cmd. 597. The National Archives, Kew, London.
Rip, A. and Kemp, R. (1998) Technological Change. In Rayner, S. and Malone E.L. (eds.) *Human Choice and Climate Change: Volume 2, Resources and technology*. Battelle Press, Columbus, Ohio.
Royal Commission on Fuels and Engines (1913) *Royal Commission on Fuels and Engines: Volume 1*. ADM 265/32. The National Archives, Kew, London.
Rydin, Y., Turcu, C., Guy, S. and Austin, P. (2013) Mapping the Coevolution of Urban Energy Systems: Pathways of change. *Environment and Planning A*. **45**(3), 634-649.
San Román, E. and Sudriá, C. (2003) Synthetic Fuels in Spain, 1942-66: The failure of Franco's autarkic dream. *Business History*, **45**, 73-88.
Sayer, R. (1950) The Springs of Technical Progress in Britain, 1919-1939. *The Economic Journal*. **60**, 275-291.
Second Report on Motor Fuel (1921) *Prepared by a Sub-Committee appointed by the Standing Committee on the Investigation of Prices. Profiteering Acts, 1919 and 1920. Second Report*

on Motor Fuel. Command papers; Reports of Commissioners. Cmd. 1119. The National Archives, Kew, London.
Shove, E. and Walker, G. (2010) Governing Transitions in the Sustainability of Everyday Life. *Research Policy,* **39**, 471-476.
Smil, V. (2004) *Enriching the Earth: Fritz Haber, Carl Bosch, and the transformation of world food production*. MIT Press, Cambridge, Massachusetts.
Smith, A. (2013) *Situating Pathways in Historical Contexts*. (accessed 26/06/14) http://steps-centre.org/wp-content/uploads/Situating-pathways-in-historical-contexts.pdf
Smith, A., Voß, J. P. and Grin, J. (2010) Innovation Studies and Sustainability Transitions: The allure of the multi-level perspective and its challenges. *Research Policy,* **39**, 435-448.
Smith, A., Stirling, A. and Berkhout, F. (2005) The Governance of Sustainable Socio-technical Transitions. *Research Policy,* **34**(10), 1491-1510.
Stranges, A. (1984) Fredrich Bergius and the Rise of the German Synthetic Fuel Industry. *Isis*. **75**, 642-667.
Thane, P. (2009) History and Policy. *History Workshop Journal*, **67**(1), 140-145.
Tilly, C. (2006) Why and How History Matters. In Goodin, R.E. and Tilly, C. (eds.) *Oxford Handbook of Contextual Political Analysis*. Oxford University Press, Oxford.
United States Tariff Commission (1931) *Report to the Congress on the Cost of Crude Petroleum*. Government Printing Office, Washington D.C.
United States Tariff Commission (1937) *Chemical Nitrogen: A survey of processes, organisation, and international trade, stressing factors essential to tariff consideration*. Government Printing Office, Washington D.C.
Verbong, G. and Loorbach, D. (2012) *Governing the Energy Transition: Reality, illusion, necessity*. Routledge, London.
Weir, R. (1995) *The History of the Distillers Company, 1877 - 1939: Diversification and growth in whisky and chemicals.* Oxford University Press, Oxford.
Wood, J. (1996) *The Motor Industry of Britain Centenary Book 1896-1990*. Eclat Initiatives Ltd, Wickford.
Yergin, D. (2009) *The Prize: The epic quest for oil, money and power*. Free Press, New York.