

THE ECONOMIC IMPACT OF HYDROGEN AND FUEL CELLS IN THE UK

A PRELIMINARY ASSESSMENT BASED ON ANALYSIS OF THE REPLACEMENT OF REFINED TRANSPORT FUELS AND VEHICLES

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March 2017

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Please cite this paper as:

M.J. Smith, K. Turner, J.T.S. Irvine (Eds.) (2017) *The Economic Impact of Hydrogen and Fuel Cells in the UK – A Preliminary Assessment based on Analysis of the replacement of Refined Transport Fuels and Vehicles*. H2FC SUPERGEN, London, UK.

Please cite individual chapters as:

Extended Summary: M.J. Smith and J.T.S. Irvine (2017) *Extended Summary*. In: M.J. Smith, K. Turner, J.T.S. Irvine (Eds.) (2017) *The Economic Impact of Hydrogen and Fuel Cells in the UK – A Preliminary Assessment based on Analysis of the replacement of Refined Transport Fuels and Vehicles*. H2FC SUPERGEN, London, UK.

Chapter 1: M.J. Smith and J.T.S. Irvine (2017) *Introduction*.

Chapter 2: M.J. Smith and J.T.S. Irvine (2017) *Existing UK Energy System Elements (including Transport)*

Chapter 3: O. Alabi and K. Turner (2017) *Introduction to Macroscale Scenario Switching – From Refined Fuels to Hydrogen in Personal Transport*

Chapter 4: O. Alabi, K. Turner and M.J. Smith (2017) *Supply Chain*.

Chapter 5: M.J. Smith (2017) *Development of a UK Manufacturing Base and industrial Cluster(s)*.

Chapter 6: O. Alabi and K. Turner (2017) *Employment*.

Chapter 7: N. Hughes and P.E. Dodds (2017) *Skills Requirement*.

Chapter 8: M.J. Smith and J.T.S. Irvine (2017) *Export and Retention of Intellectual Property*.

Chapter 9: O. Alabi and K. Turner (2017) *Modelling the Impact over Time – Consumer Transport*

Chapter 10: M.J. Smith and J.T.S. Irvine (2017) *The International Context*.

Chapter 11: M.J. Smith and J.T.S. Irvine (2017) *Conclusions and Recommendations*.

BACKGROUND

This White Paper has been commissioned by the UK Hydrogen and Fuel Cell (H2FC) SUPERGEN Hub to examine the potential economic impact of hydrogen and fuel cell technologies on the UK Economy – including early macroeconomic modelling of the impact of the replacement of refined fossil fuels with hydrogen in the UK transport sector.

The H2FC SUPERGEN Hub is an inclusive network encompassing the entire UK hydrogen and fuel cells research community, with around 100 UK-based academics supported by key stakeholders from industry and government. It is funded by the UK EPSRC research council as part of the RCUK Energy Programme. This paper is the fourth of four that were published over the lifetime of the Hub, with the others examining: (i) low-carbon heat; (ii) Energy security, and (iii) future energy systems.

ACKNOWLEDGEMENTS

Many people assisted in the preparation of this white paper. The authors are very grateful to all of them, including:

- Marcus Newborough (ITM Power)
- Doosan Babcock (Glasgow)
- Paul Ekins (UCL)
- Nigel Brandon (Imperial College London)
- Nigel Holmes (SHFCA)
- John Loughhead (BEIS)

The authors are indebted to Zeynep Kurban (Hydrogen and Fuel Cells Supergen Hub), who provided much invaluable assistance organising the launch event and producing this white paper.

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EXTENDED SUMMARY

1. RATIONALE FOR WHITE PAPER AND USING HYDROGEN FOR TRANSPORT TO DEMONSTRATE THE ECONOMIC POTENTIAL OF THE WIDER HYDROGEN AND FUEL CELL SECTOR

The emergence of both domestic and international hydrogen and fuel cell sectors presents a demonstrably significant economic opportunity to the UK. The White Paper is presented to provide a clearer picture on the importance of hydrogen and related technologies and its economy-wide benefits. Particularly in the light of the widely accepted view that; “historically, we [the UK] have not been as successful at commercialisation and development as we have been at basic research.” (DBEIS, 2017)¹

The white paper makes an assessment and limited early macro-economic analysis of the likely impact of an emergent hydrogen and fuel cell sector to support particularly private transport on the UK economy. Whilst many of the key industries are currently nascent and, hence difficult to quantify future impacts, a telling and indicative analysis of the likely impact can be achieved by considering the impacts of replacing refined road transport fuels by hydrogen.

Hydrogen is disruptive in that for the first time a single energy vector could be used and transferable across traditional energy markets which are currently distinct and separated by their need for different fuels or energy input types. Early markets will undoubtedly be driven by applicability and environmental considerations; however, our purpose here is to assess potential implications of mass market uptake, using hydrogen and road transport as an exemplar. This is because hydrogen as a road transport fuel may offer the greatest value proposition – hence it is a driver for large scale implementation which can lead the way for other hydrogen and fuel cell markets. Notwithstanding future policy intervention, and on the basis of a given price for hydrogen production and supply, early mass implementation will focus on the applications which offer the highest returns before seeking to supply lower margin mass applications and markets.

An approximation of the relative value hierarchy for energy in consumer mass markets for heat, electricity and road transport respectively is laid out. This was based on current, fully taxed, average UK prices paid by consumers for delivery of the energy/work per kWh. Subject to important qualifications, on a per kWh delivered basis and for heat, electricity and transport the relative values are given in the table below.

	Heat	Electricity	Transport
Current energy supply vector	1	3.3	9.8
Via Hydrogen	1	1.6	3.9

Relative consumer values for heat, electricity and transport per kWh using current energy supply vectors and hydrogen.

¹ Building Our Industrial Strategy, Green Paper, Department of Business, Energy and Industrial Strategy (BEIS), 2017.

The relative values for energy in the categories are significantly different and these relative values inform the (time-constrained) decision to focus the the paper's modelling work on the operational elements of hydrogen replacing fossil fuels in the UK consumer mass market for transport. The relative value ratios can be expected to inform rational market and investment behaviour.

It is extremely important to understand that although the production and domestic (UK household) use of transport fuel has formed the main focus of modelling work in this paper, essentially the same 'economic multiplier' effects will be relevant in respect of producing hydrogen for other applications also. **Transport is expressly not being recommended as the only UK market for hydrogen. The key point is more that its relative value in the transport market will act to drive economies of scale and the widespread availability of hydrogen – which can then be widely exploited in other applications.** It should also be noted that those ratios can also change markedly in respect of other countries which have different approaches to energy taxation (in particular) and thus there are potential export destinations for UK-made products which may be much more attractive value propositions there than they might be in the average UK situation.

2. HEADLINE FINDING: POTENTIAL FOR ECONOMY-WIDE GAINS THROUGH DOMESTIC UK SUPPLY CHAIN ACTIVITY

The paper's headline finding from modelling in respect of the private transport sector is that a significant move away from current UK use of refined fuels towards hydrogen can be expected to yield **a valuable increase in GDP and employment**. The likely gains will come not only from the production and distribution of hydrogen in the UK but also from the range of service sector activities, including finance, involved in a **potentially strong domestic supply chain**.

This finding derives mainly from the intrinsic increase in energy conversion efficiency in the change of vehicle type, in conjunction with the UK's current significant reliance on importing refined fuels (leakage to the UK economy) and the relative low amount of domestic UK economic activity per unit output associated with the UK's indigenous refined fuels sector. Specifically, the **current supply chain for petrol and diesel is highly import-intensive**. In contrast, where hydrogen could be produced using electrolysis and/or exploiting current gas supply networks, there is **potential for development of strong domestic hydrogen supply chain relationships within the UK**. The strength and impacts of supply chain activity on UK value-added (GDP) and employment are assessed in terms of economic 'multipliers'. In this paper potential multipliers for hydrogen are assessed using proxies defined by the existing UK gas and electricity supply sectors. In both cases the strength of the multipliers and impacts on GDP and employment throughout UK supply chains are much stronger than is the case for the UK refined fuels sector.

Rather than offering/suggesting actual economy-wide estimates and making predictions regarding key macroeconomic indicators, which would necessarily involve predictions on investment and other elements, figures produced in this paper give a general indication of the direction of travel and its approximate scaling only.

Qualifying assumptions include the extent of HFC vehicle uptake and it has been assumed that most of the UK private vehicle fleet switches over to HFC vehicles by 2050. A significant proportion of vehicles may become battery-electric, with this contingent on a marked increase in battery capacity which is difficult to assess. However, given that for battery-electric vehicles the primary energy source will be electricity generation, one of the proxies chosen in study will apply to some extent in either electric or hydrogen fuel cell cases, with a broadly similar direction of travel for the UK economy emerging.

Other qualifications include uncertainty regarding the net balance of import and export of HFC vehicles and of the potential need to import more gas and reduced import of refined fuels. It is assumed that investment in HFC infrastructure is at the same level that would otherwise be needed to replace existing refined fuels capacity. That is, the modelling is concerned with operational impact rather than impacts of required capital expenditure and investment activity. Potential vehicle (and other appliance) consumer price premiums are difficult to be definitive on and it is assumed that purchase prices are as current. Whilst that assumption is unrealistic today, HFC and other vehicle prices are expected to largely converge over the next two decades.

Variation of the qualifying assumptions would require a considerable amount of additional modelling work. *Undertaking this work would be very worthwhile.*

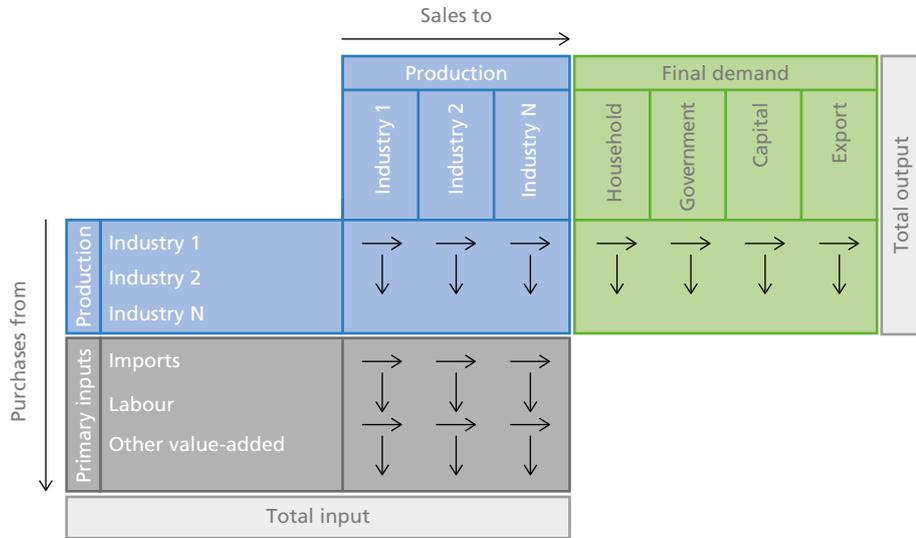
3. APPROACH AND WIDER INSIGHTS OF THE WHITE PAPER

Following a general introduction to the hydrogen and fuel cell sector and a survey of the existing UK energy, the paper notes that hydrogen and HFC technologies are not a *silver-bullet*, but one of a suite of existing and emerging technologies likely to form the UK's energy future.

The paper indirectly questions the likelihood that hydrogen will be used in the near term as a heat vector on the basis of additional cost implied and simple market economics – whereby higher value transport and energy storage applications are likely to have to be fully sated before hydrogen becomes cheap enough for use in heating. Carbon capture and storage cost will narrow the currently understood cost advantage of natural gas-derived hydrogen over electrolysis.

The input-output macroeconomic technique used for supply chain multiplier analysis, employing standard industrial classifications to define individual and interacting sectors, and using input-output accounting tables, is described before going on to model and assess the impact of switching from refined transport fuels to hydrogen (as above).

Figure ES1 Schematic input-output table.



Both a general description of and modelled supply chain assessment finds that the UK is well placed to benefit significantly from a switch from refined fuels to hydrogen in private transport. Whilst the UK is not world-leading in terms of having many successful core HFC companies, it is strong internationally in both its existing innovation and supply chain interest and would obtain significant domestic value from a large service sector deployment element (which cannot be readily off-shored). The UK's existing gas and electricity sectors provide the best proxies for an HFC sector but their use is likely **to understate the amount of economic impact** an actual HFC sector would have due to the requirement of additional innovation and technological development (for example, with respect the intrinsic role of CCS – which will bring its own supply chain requirements – in a hydrogen economy). Moreover, in terms of the research and development requirement to bring 'game changing' technologies to economic and practical reality, it must be noted that **Scientific research and development (including academic research) is seen to have among the highest of all economic multipliers** and is key to maintaining the development of high value innovation.

However, there is a **strong foundation already existing in the UK economy**. The bulk of the HFC supply chain comprises of components already common to the existing electricity and gas sectors. Thus, **the UK already possesses a significant element of the HFC supply chain in terms of both manufacturing and services activity**.

Similarly, what will be the UK's core HFC companies are likely to employ many of the same components, skills and fabrication techniques already present in other extant UK manufacturing, including automotive, industries. It is reasonable, therefore, to expect that the development of core HFC will generate significant GDP and employment value in much the same way that was demonstrated in transport fuel supply and automotive manufacture.

Multiplier (activity per £1million final consumption demand)					
SIC	Sector/industry name	Output (£million)	Value-added (£million)	Employment (FTE jobs)	Wage income (GDP) (£million)
29	Manufacture of motor vehicles, trailers and semi-trailers	2.35	0.80	13.61	0.54
19	Manufacture of coke and refined petroleum products (refined fuels supply)	1.47	0.33	2.93	0.19
35.1	Electric power generation, transmission and distribution (hydrogen supply proxy 1)	2.56	0.78	8.05	0.32
35.2	Manufacture of gas; distribution of gaseous fuels (hydrogen supply proxy 2)	2.25	0.81	8.04	0.32
41–43	Construction	2.31	1.01	19.20	0.57
45	Wholesale and retail trade and repair of motor vehicles and motorcycles	2.10	1.07	20.38	0.72
72	Scientific research and development	2.39	1.29	25.31	1.00

Table showing weak Value-Added (GDP) and Employment (full-time equivalent jobs) multipliers in the refined fuels sector compared to others relevant to a Hydrogen and Fuel cells sector (based on 2010 UK input-output accounting data).

4. UK AUTOMOTIVE SECTOR

The UK would be wise to strongly build up its HFC automotive and transport sector to take advantage the potential for wider economic expansion through strong UK supply chain opportunities. This recommendation is consistent with proposals outlined in the January 2017 UK Government Green Paper on ‘Building Our Industrial Strategy’ (BEIS, 2017).

It is also crucial to avoid being left behind by other vehicle manufacturing countries in developing a strategy that builds on a basis of ‘make not buy’ in the introduction of new technologies. Nonetheless, this must involve caution in not ignoring and supporting other options for hydrogen that transport will draw in its wake. For example, if the UK promotes and pursues the role of hydrogen in transport, it is likely that the emerging market will begin to pull other applications – particularly regarding provision of heat – along with it. Of course, the UK also needs to be ready and able to take advantage of the follow on applications and hence should adequately support the development and early deployment of those applications also.

5. ENERGY STORAGE

Energy storage is the subject of increasing attention in the context of electricity generation. However, the paper considers how hydrogen is arguably a key enabler for energy storage thanks to its ability to time-shift when renewables (in particular) are available to when there is demand for electricity. The value proposition for hydrogen and fuel cell re-generation would be much stronger **if energy storage in the UK was better valued generally**. Energy storage will become increasingly important as more and more intermittent/variable primary generation facilities come on line and indeed will enable further renewables. The UK should act to support energy storage in a much stronger way and perhaps especially on scales which are smaller and better distributed than large scale pumped hydro facilities. **Meeting demand locally reduces the need for long distance transmission and for expensive grid reinforcement**. It also results in increased local energy security. The issue around a lack of concrete UK support for energy storage equally impacts battery and other means of storage.

6. SKILLS

The type of jobs and skills required to develop a widespread UK HFC sector were considered. The UK is well placed in terms of skills and the ability to train for a vibrant HFC sector – it is very much a matter of **‘evolution rather than revolution’**.

The UK already has a solid compliment of the required skills deriving from its existing energy sectors, e.g. oil and gas and electricity generation; from the UK chemical processing sector and from its automotive sector (manufacturing and service). The new modelling work in the paper shows that, in shifting from petrol and diesel to hydrogen for private transport we can expect numbers of those with such skills employed in HFC (and related supply chain work) to increase. This is mainly as a result of supply chain jobs being repatriated due to reduction of import of refined fuels. On the other hand, vehicle service jobs will probably change rather than see a net gain or loss. The number of vehicle manufacturing jobs will probably remain similar if the UK captures ‘its proportion’ of the new HFC component (and/or supply chain) production assuming that the UK vehicle import/export balance remains similar to that currently. However, any growth and increased exports in this sector would of course change that positively.

The formal skills provision requirement will see a mixture of commercial in-house training and retraining (including CPD), a relatively small number of new college NVQ/SVQ modules and some extension/modification of existing graduate and post-graduate programmes.

7. COORDINATION AND CLUSTERING

Consideration of the formation of one or more UK HFC industrial cluster(s) believes that successful clustering would mainly be concerned with proximity to local concentration of knowledge and skills – rather than an ease of access to traditional heavy engineering resources type model. **Visibility of clustering provides a strong focus for investors and financial services interest and provides the type of ‘anchor’ business**

activity for domestic UK supply chain development promoted in the January 2017 Green Paper on ‘Building our industrial strategy’.

Geographically the UK offers a number of relatively obvious areas in which clustering may be successful and employed to nucleated the growth of a widespread UK HFC sector. Specific areas are identified in all four of the home nations. The paper introduces the idea is of developing two types of hubs. One is aimed at dealing with heavily urbanised areas which will, at least initially, mainly employ natural gas as its primary energy source. The second focusses on developing renewables (and electrolysis) capacity in areas rich in renewable resources which are liable to be less heavily populated.

UK coordination and support for an emergent HFC sector is somewhat scattered between a number of relevant agencies, including transport, business, energy and academia. Germany chose to form a single national agency – Nationale Organisation Wasserstoff und Brennstoffzelle [NOW] – to coordinate and support its emerging HFC sector, drawing on expertise and ring-fenced funding from each of the main relevant agencies. Such a body is better suited for dealing with the type of cross-cutting issues that HFC presents to any country, including the UK. The formation of a UK agency similar to that in Germany is strongly recommended.

8. THE UK’S PLACE IN THE WORLD

Due to HFC emerging as a largely globalised sector from its beginnings, **the UK already has a number of key supply chain players** as well as a number of companies producing/supplying core HFC and related equipment. **There is already evidence of export.**

How the UK might fair in a fully developed global HFC sector is difficult to assess so early in its emergence, but there clearly will be value obtained for the UK. As noted above, it is important that the UK incentivises the capture of as much core HFC business as possible if it is to maximise eventual export value. **The UK automotive manufacturing sector is probably the key** to that in terms of generating economies of scale. Service sector aside, the generation and retention of IP will play a very significant role in maximising economic benefit to the UK. Whilst legally protectable IP will play a role, **in overall IP retention the largest factor will be the education, training and retention of highly mobile and highly skilled persons** who will provide the main fuel for innovative UK-domiciled businesses.

The UK’s international context in respect of an emergent HFC sector has altered radically since this paper was planned on account of the result of the Summer 2016 referendum on EU membership. Europe, including the UK, has been developing its HFC sector as a shared/joint exercise and the UK has had a great deal of success in acquiring EU support for both fundamental research/innovation and demonstration projects. Such success can be found from the London hydrogen bus projects in the South to the current Big-Hit project in the Orkneys to the North. Government and public support has not simply been in the form of funding: development projects in the UK have been delivered in collaboration with many EU states just as the UK has had participants in many homed in other

member states. It is difficult to understate the importance of the collaborative approach to UK companies, academia and public/3rd sectors. The UK's continuance in EU HFC development programmes after some fashion, perhaps in the manner of Norway or Switzerland, should be given very serious consideration as the Brexit situation develops. As a nascent sector, patterns of production and wealth creation are currently being established and the UK could suffer if its indigenous players are at a disadvantage to their EU counterparts who will retain the ease of collaboration and market access.

No longer being an EU member does offer some potential advantages. For instance, if the UK government can develop its own incentive and support schemes, the elimination of the need to comply with EU State-Aid requirements offers significant potential to direct and invest heavily in the establishment of strong a domestic market(s).

Irrespective of the UK's EU membership status, it should be noted that many UK HFC companies have strong links with Japanese, SE Asian and US and whilst Europe has been very important in terms of R&D and is an extremely valuable potential market for potential UK exports that there are wider opportunities.

9. LIST OF RECOMMENDATIONS OF THIS WHITE PAPER

1. Other than 'procurement' the development of a strong domestic HFC sector and market (including export) aligns well with 9 of the 10 strategic pillars of the UK Government's January 2017 Green Paper on 'Building our industrial strategy'. This is most, but not exclusively, apparent in this white paper's insights on the potential for economic expansion through the development of stronger UK supply chain activity in our energy supply particularly in the context of replacing petrol and diesel fuelling of private transportation with hydrogen sources.
2. The UK Government should consider very carefully the idea of setting up a UK Hydrogen (and Fuel cells) Agency charged with coordinating support for a UK HFC sector. The role of such an agency may involve dealing with relevant regulation, formal training and similar administrative aspects. Funding could be ring-fenced from relevant UK departments (transport, energy, environment, industry *et sim.*). The German NOW agency makes a good example to follow.
3. The UK Government must be aware that the public sector, 3rd sector and academia has been significantly reliant on EU support in respect of HFC and may want to consider seriously the option of 'buying into' the relevant EU programmes following Brexit. Norway and Switzerland serves as potential examples of how this could be done, whereby their national governments agree to cover the public support element of the costs of participation by their own nationals. Equally, any UK-EU arrangement would also wisely allow UK companies to participate in and access EU early-deployment markets/programmes.
4. The UK Government should recognise that 'UK HFC' offers strong potential export earnings. Relationships already exist between UK HFC businesses and companies/organisations in North America, Asia and Japan, strengthening these and the development of others would be wise. Further inwards investment could

and should be sought. UK HFC businesses would benefit from joining trade missions in particular.

5. As and when EU-State Aid regulations cease to apply, the UK Government is advised to consider boosting support to UK HFC businesses to levels the regulations would have otherwise prevented. The sector is facing strongly entrenched incumbency in the existing energy markets and often extremely high development costs. UK core HFC companies are largely still SMEs and they will struggle in the face of competition from Japanese and other SE Asian conglomerates which have immense market power, exceptional internal R&D capabilities and a capacity to raise R&D finance which few UK SMEs can match. Many are also closely linked to state-funded research facilities. Such action would level the playing field to some extent.
6. In relation also to Recommendation 5, additional tax and investment instruments would also help to bolster the probability of UK HFC businesses growing beyond SME scale.
7. The UK automotive sector should be strongly encouraged to ensure that it stays abreast of developments in HFC vehicle manufacture and does not become left behind by Japanese and German manufacturers in particular. The UK has invested heavily in the automotive manufacturing sector and it is essential that this public investment is protected by the speedy evolution of the UK sector into HFC vehicles. The UK Government, via its Automotive Council (Government-Industry body), can drive this by means of its input to that existing investment and support structure. There could be substantial merit in linking an HFC Industrial cluster directly to that state investment. Potential partnership deals could be pursued, possibly involving additional inwards investment.
8. Domestically the establishment of one (or more) HFC cluster(s) should be given priority. This will accelerate the UK's ability to develop a valuable domestic HFC market which cannot readily be relocated off-shore. The idea of two such (linked) clusters has merit, with one focussing on densely populated urban deployment and a natural gas energy base, with the other focussing on exploiting renewables opportunities (usually) in less densely populated areas. Potential for the devolved governments on partnering with the UK Government on the latter in particular should be explored.
9. The UK is not homogenous in terms of its energy production or markets. The UK Government should give serious consideration to developing nuanced regional support programmes capable of incentivising local investment based on their particular energy circumstances. This is subtle and would require work, but it is about supporting appropriate levels of local supply and demand and preventing costly imbalance in the form of new grid capacity investment. Potential for the devolved governments on partnering with the UK Government on the latter in particular should be explored.

10. The UK Government should move swiftly to properly incentivise investment in energy storage generally. All forms of energy conversion suffer physical losses and those physical losses can result in actual financial loss upon regeneration. Very few significant scale storage facilities (of any kind) have been built for decades and it is evident that the market, as is, is incapable of driving such investment. Arbitrage can work for larger scale facilities, but small local storage has very little chance of repaying its investment within acceptable periods currently. Incentivising storage should focus mainly on smaller local scale storage as sufficient quantities of this on grid will reduce the need for costly grid reinforcement. The incentivising of storage should probably be technology neutral.
11. The UK national and devolved Governments should ensure that their further education sectors are aware of an emergent HFC sector and are ready to work with trade, industry and relevant official bodies to develop appropriate NVQ/SVQ HFC training modules for college students and retraining/CPD offerings for those tradespeople and professionals who may need to adapt.
12. The Higher Education sector, from which much UK HFC development has emerged, is better aware, but not all institutions have been involved and where appropriate encouragement could be given by state agencies for them to keep abreast of developments/requirements.

CHAPTER 1

INTRODUCTION

The UK Hydrogen and Fuel Cells SUPERGEN Hub is producing a series of evidence-based White Papers aimed at informing key stakeholders, especially policy makers, of the roles and potential benefits of hydrogen and fuel cell technologies. The first of these White Papers on “The role of hydrogen and fuel cells in providing affordable, secure low-carbon heat” was published in May 2014. Two further White Papers on “The role of hydrogen and of fuel cells in delivering energy security for the UK” and “The role of hydrogen, and of fuel cells, in the future energy system” are being published concurrently with this White Paper, addressing the topic: **“The Economic Impact of Hydrogen and Fuel Cells in the UK”**. This paper examines how hydrogen and fuel cell technologies can generate opportunities for wealth and job creation in the UK. More specifically, the analysis should include impact assessment on i) Supply Chain Development, ii) Employment (Skills Requirement), iii) Development of a UK Manufacturing Base, iv) Exports, v) Intellectual Property and vi) The Formation of an Industrial Cluster. This analysis considers the existing energy systems in the UK, as well as the additional infrastructure requirements, and identifies pathways for innovation with minimal investment costs.

1.1 BACKGROUND

The production and use of hydrogen goes largely unseen by the public, but it is already produced in colossal quantities across the globe as it is a lynchpin of the Chemicals Sector. For example, the production of hydrogen is the first element in making all synthetic agricultural fertilisers. As such, its production underpins the bulk of the food system which sustains the human race at modern population levels. It is estimated that about a half of the nitrogen in our bodies is derived from the Haber-Bosch ammonia production process.² Hydrogen also has a long history in providing humans with local energy and power, a history which began in the United Kingdom. In the 1790s, William Murdoch who was working with James Watt in Cornwall developing improved steam engines for mining, experimented with boiling coal in the absence of air. This produced a colourless flammable gas which gave a good light when burned. Murdoch invented the world’s first gas engine using his new fuel gas shortly afterwards. His gas engine didn’t take off as a technology, but his simultaneous invention of gas-lighting changed the world.³ Town gas plant spread all over the UK very rapidly indeed following its discovery. And it would go on to become one of the UK’s principle sources of light, heating, cooking and commercial power right through to the discovery of natural gas in the North Sea and its UK-wide provision around 1969/70. Importantly Town gas is ca.50% hydrogen. Clearly the historical role of town gas and hydrogen’s use in underpinning global agriculture ask serious questions of those who contend that hydrogen is too new, strange and dangerous to be produced, distributed and employed in substantial quantities.

Evidently, when hydrogen is produced from natural gas the carbon present in the natural gas has to go somewhere. It becomes carbon dioxide during the hydrogen production process and therefore ***hydrogen derived from natural gas is not carbon-free.***

2 The Haber-Bosch process fixes nitrogen as ammonia, its main precursor is hydrogen – this makes prior hydrogen production one of the planet’s most important industrial processes as without it, it would be difficult to produce sufficient food to sustain the human population.

3 The Scot Who Lit the World, Janet Thomson, ISBN 0-9530013-2-6, 2003.

1.2 TODAY

Hydrogen and fuel cell technology have seen billions of dollars, euros and pounds poured into their development in the last few decades and growth continues apace, the US DoE reporting that the fuel cell industry grew from a value of around \$1.3B in 2013 to around \$2.2B in 2014.⁴ Despite investment of this scale and the basis of the technology dating back to the 1840s, it is only now that a hydrogen and fuel cell industry is close to emerging. Investment has switched from mainly research and development into customer products recognisable as such, some markets such as for power plant for forklift trucks are quite well established, and some of the early-mover commercial investments are beginning to move into profitability.

Hydrogen and fuel cell technology is not a single product with any clearly defined market or scale parameters. Both hydrogen and fuel cell technology are capable of playing a number of roles across a wide range of existing and potentially new technology areas. To illustrate the potential extremes of this:

It is a simple matter to make hydrogen in a thimble containing some water, with no more than a couple of wires and a small battery; but equally we can note that prior to the advent of cheap North Sea gas, the Norwegians built large hydro-power facilities to make hydrogen on an industrial scale – for use in fertiliser manufacture and a range of other products. [Most of the world's current hydrogen is produced by processing natural gas.]

Existing commercial fuel cell product offerings, some of which use hydrogen as their fuel, others can use hydrocarbon fuels, can generate power on scales from below 1kW to above 1MW. The technology is highly modular and hence multi-MW capacity can also be obtained by chaining MW-class modules. The scalability and flexibility of hydrogen and fuel cell technology is immense and this can be regarded as one of its core strengths and advantages, however this versatility can make the assessment of their economic potential difficult – as the value proposition(s) in each of the possible sectors can and will be very different.

Broadly speaking hydrogen and fuel cell technology can be assigned to four broad use categories, these are usually given as: Energy conversion and storage, Transport, Heat and 'Early Market' applications.

1.3 STORAGE AND APPLICATIONS

Energy conversion and storage is nothing new, pumped hydro facilities have been used for more than a century in the UK and elsewhere to store energy and to assist in matching immediate demand. Its flexibility makes it amongst the most market valuable forms of electricity generation. There is a great deal of UK research interest in storage including that being undertaken across the Supergen Energy Storage Hub which published its own White Paper in 2016 looking at grid-scale storage requirements.⁵

⁴ Fuel Cell Technologies Market Report 2014, US Dept of Energy, 2014.

⁵ http://energysuperstore.org/wp-content/uploads/2016/04/IMPJ4129_White_Paper_UK-Research-Needs-in-Grid-Scale-Energy-Storage-Technologies_WEB.pdf.

What is new and changing the prospect for energy storage is the UK's increasing reliance on intermittent renewable forms of primary generation. These are extremely reliable and predictable generation sources statistically, but not at any given moment in time. They will tend to result in both gluts of potential electricity production, which have to be constrained off to protect the grid/network, or at other times they generate insufficient power or no power at all. The former representing waste of a potential resource, the latter requires back-up generation assets which cannot be 'sweated' implying additional cost and frequently additional carbon.

The inherent inability to sweat energy storage assets of any kind can present an obvious potential barrier to investment, however the ability to store intermittent excesses of intermittent generation changes the value proposition for primary renewables investment. It has become generally accepted that energy conversion and storage will become increasingly necessary and important in managing security of electricity supply.

Energy storage implies wider energy system impact and is liable to lead to a more distributed overall energy and road fuel system rather than the current highly centralised UK system. This increases overall energy security and importantly also reduces transmission volumes over distance on the electricity grid in particular. That will have impact in terms of reducing the need for grid reinforcement and its associated investment. That there are potential overall system benefits is clear enough, but it is unclear how those system level cost savings might be used to partially off-set parties investing in such a more distributed energy provision model.

DBEIS have recognised the need for substantive change in which energy storage must and will play a role,⁶ to date however policy and market structure regulation in this area is yet to be developed and the consequential uncertainty in regards to those elements causes investment to be delayed.

There are several potential forms of energy conversion and storage liable to be deployed, **but none has the characteristics of a 'silver-bullet'**. Pumped storage is likely to remain the preferred choice for low operating-cost massive storage, but its potential expansion is strictly limited by its geographical requirements. Flywheel and compressed gas energy storage have existed for some time. Flywheel applications tend to have remained restricted to short term rapid storage on a small scale, often employed in transport applications. Compressed gas (usually air) storage has been employed since the 1800s(!), however modern utility scale requires specific geology (underground salt caverns) restricting their geographical spread. Smaller compressed air systems (non-geological pressure vessel) have tended to burn natural gas and have not been not carbon neutral or positive (to date) – to deal with extreme temperature changes involved in energy release and the rapid expansion of the pressurised gas which can cause extreme cooling. Flywheel and compressed gas storage may be good options in specific circumstances/applications, but it remains to be seen whether or not they can find widespread usage.

⁶ Towards a Smart Energy System, DECC, Dec 2015.

Existing and emerging battery technologies look set to offer local to medium energy scale and short-to-medium term storage capacity. Hydrogen and fuel cell technology offer local to larger scale energy storage, but also the additional benefit of being able to directly divert storage of excess electricity into higher value road transport fuel. Given their characteristics, reasoned thought suggests that both battery and HFC options will find valuable slots in a more diverse energy future.

In raw conversion efficiency terms, battery technologies will readily out-compete hydrogen and fuel cell options in small-to-medium scale local storage, however the provision of hydrogen as a higher value (than electricity) road fuel plus local regeneration of electricity as an additional revenue stream offers a clear economic route whereby hydrogen can be competitive overall in local energy conversion and storage. Hydrogen's other key advantage in energy storage is that it's capacity to store – in terms of MWhrs of eventual output – is potentially unlimited at relatively low additional unit cost. Each additional unit of battery storage requires another full-cost battery unit at its full volume/space requirement. Each additional unit of hydrogen storage requires a little more pressure in the existing tank (at negligible cost) or more tank volume at very low relative cost. At some scale, the battery/hydrogen storage cost efficiency comparison reverses and thereafter increasing scale sees progressively more value in hydrogen.

Where the value advantage cross-over for energy storage between battery and hydrogen technologies lies is a complex question and is very specific to both local and wider circumstances. It is complicated further where hydrogen is diverted into its higher value road transport fuel application – the proportion diverted being an obvious parameter in itself. Each potential investment case must be carefully considered in its own specific circumstances and the alternative options compared directly.

Geological scale hydrogen storage is an option, underground salt caverns and depleted gas fields can and have been employed. The use of depleted gas fields around the UK for hydrogen storage would offer essentially infinite energy storage capability and the model is little different from that used currently for strategic reserves of natural gas. Hydrogen for energy storage on that scale would require new pipeline infrastructure and/or the repurposing of current natural gas capability, but the key storage assets themselves – the geology – already exist.

The discovery of natural gas in the North Sea drove the construction of an almost UK-wide natural gas pipe network in little more than a decade. Admittedly that was building on and connecting existing local town gas networks, but it offers an indication of how rapidly core infrastructure can be put into place where the will and motivations are present – with the economic case playing the dominant major role in 'motivation'. As per natural gas, the transport of hydrogen, for any application purpose, via pipes will be far more cost effective in the medium and long term than some of the road and water-borne suggestions with present currency.

1.4 TRANSPORT

Around a third of all energy consumed in developed nations is expended on transport and the UK is typical in that respect. With the exception of electrified rail and

an extremely small proportion (to date) of battery electric cars, virtually all of that transport is powered directly by liquid fossil fuels. With around 80% of UK grid electricity also being carbon-derived, to all intents UK transport is presently entirely fossil powered.

The UK's fossil-powered transport system presents a significant decarbonisation challenge and opportunity. A number of studies, including a synopsis of existing work prepared for the House of Commons Office of Science and Technology [OST], indicate that the market for battery-electric vehicles [BEV] is liable to remain quite limited.⁷ This is mainly on account of consumers being unwilling to replace larger long range vehicles with smaller very short-range ones. The OST paper reports that the proportion of the UK fleet susceptible to replacement by BEVs at anywhere between 1 and 10%. Conventional commercial Li-ion battery technology is around 40 years old and whilst it has been continuously improved, it can be regarded as mature.

The current situation of battery technologies places emerging hydrogen fuel cell vehicles (HFCV) in a strong position, as these offer travel range and refuelling times commensurate with that of conventional fossil-powered transport. Replacing extremely inefficient (<20%) tank-to-wheel small petrol and diesel engines with fuel cell units offering 50–60% tank-to-wheel efficiency gives hydrogen a potentially competitive position as a road fuel. The carbon and financial case for burning hydrogen in internal combustion engines [ICE] is less attractive as using any form of ICE necessarily imports the intrinsic inefficiency of small heat engines. The efficiency difference between HFC and ICE technologies acts to offer a net carbon benefit even where the hydrogen employed is directly derived from fossil fuels. Where hydrogen is produced from water and renewable electricity it becomes possible to realise a transport energy chain which is operationally free of carbon.

HFC vehicle technology is at an early stage in respect of being able to power HGV-class vehicles, however bus scale deployment is proven and ramping up, while passenger car vehicle development is currently seeing its first stage of mass manufacture. Rail applications are being explored in Germany, whilst Scotland and Norway have marine transport programmes.⁸

With much of the UK's transport energy requirement potentially available to HFC technology and with the potential for both major financial and carbon gains, transport represents the most significant opportunity to the UK.

1.5 HEAT

Heat is a major element in the UK energy portfolio, and one that is difficult decarbonise. Possible scenarios whereby hydrogen and fuel cells can assist in the

⁷ UK Parliamentary Office of Science & Technology; POSTNOTE, Electric Vehicles, Number 365, 2010.

⁸ Scottish HySeas programme supported by Scottish Enterprise, Scottish and Canadian Governments and private funding [www.gov.scot/Publications/2017/01/2768/11]. Norwegian: www.sjofartsdir.no/en/news/news-from-the-nma/breaking-new-ground-in-hydrogen-ferry-project/.

decarbonisation of heat have been described in detail before in an earlier white paper,⁹ so it will not be described in detail here. The bulk of current natural gas usage sees it burned for heat. The use of hydrogen to directly replace natural gas, as we currently use it, is almost implied above in the context of geological storage and that would tend to suggest the use of **hydrogen for the generation of heat**. Whilst there are no major technical impediments to that thinking, there are significant cost issues and some carbon emissions questions concerning the conversion of natural gas to hydrogen for subsequent storage and eventually combustion to produce heat. In utilising natural gas-derived hydrogen for heat, there are further issues to be addressed:

- This requires rather more (+30–40%) of the natural gas precursor to produce hydrogen with the same net heating value¹⁰
- Would require comprehensive carbon capture and storage to offer a net emissions benefit, adds to the required energy and cost¹¹
- Would also require investment in the plant to convert the natural gas to hydrogen and replacement of consumer and commercial appliances¹²

Each of these elements carries its own costs and therefore **natural gas-derived hydrogen for heating must be significantly more expensive to the consumer than current natural gas heating is**.

That model simultaneously decreases energy security thanks to increased gas imports/reliance, whilst increasing costs; however, if avoiding carbon emissions is paramount it could be a path worth following.

In their ‘Gone Green’ scenario National Grid’s Future Energy Scenarios 2016 notes that:

“Air source heat pumps (ASHPs) are more efficient than gas boilers and therefore less energy is required for the same heat demand. This ensures that running costs can be similar or lower than alternative gas appliances. By 2040, 3.6 GW of heat pumps are installed, requiring 11 TWh per year of electricity demand but offsetting 50 TWh per year of gas demand. This is due in part to reduced capital costs and government incentives to keep ASHPs economical. The RHI is funded by the Treasury which has committed to increasing funding to £1.15 billion in 2021.”¹³

With serious financial competition already existing between air source heat pumps (ASHPs) and current natural gas heating, and a net reduction in emissions and energy usage delivered by ASHPs in any case (-39 TWhrs gas net as per the above

9 www.h2fcsupergen.com/wp-content/uploads/2014/05/H2FC-SUPERGEN-White-Paper-on-Heat-May-2014.pdf.

10 A.P. Simpson, A.E. Lutz / International Journal of Hydrogen Energy 32 (2007) 4811–4820.

11 [IPCC, 2005] *IPCC special report on Carbon Dioxide Capture and Storage*. Prepared by working group III of the Intergovernmental Panel on Climate Change. Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L.A. Meyer (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp.

12 H21 <http://services.kiwa.co.uk/energy-carbon-advice/hydrogen/hydrogen-leeds-h21>.

13 Future Energy Scenarios 2016, National Grid, page 43.

NG scenario example), a compelling business case for widespread natural gas-derived hydrogen for heating is not clear, unless sufficient cost benefits may arise in carbon offsetting and capture is not partially implemented.

A case for natural gas-derived hydrogen CHP can potentially be constructed thanks to the relative user values of electricity and heat – where the case is made on the basis of the electricity value rather than that of the heat. There may also be local circumstances, possibly in isolated communities, where a financial case for renewables-derived hydrogen for heat can be constructed.

1.6 EARLY MARKET APPLICATIONS

Early Market applications for hydrogen and fuel cells covers an immense number of possibilities that typically offer disruptive market opportunities. Attempting to model or quantify that is difficult as there is no obvious means of discerning which might emerge as popular consumer products or understand/predict their potential market share. Applications range from small battery-like fuel cell units fuelled with liquid methanol which can be used to recharge any number of small consumer appliances like mobile phones, tablet computers and so on; to providing compact lightweight power systems for long range unmanned aerial vehicles. Multinationals like Boeing as well as UK SMEs like Intelligent Energy already have development programmes and pre-commercial products in both of these areas.

In essence, anywhere that we currently use batteries which can benefit from having more on-board energy than batteries can provide a potential market for smaller scale HFC technology. For those which do become popular commercial products, the individual HFC or FC unit value will tend to be low in comparison with transport or energy system scale products, but they could potentially be sold in immense numbers. This potential HFC market space is perhaps intrinsically riskier than motive power and system scale energy applications, but it should not be ignored in policy thinking as the rewards in exploiting potential success here could be substantial.

1.7 THIS PAPER

This paper sets out a relatively early attempt to assess the potential macroeconomic impact(s) of the deployment of hydrogen and fuel cell technology on the UK economy.

As noted above, it is not possible to understand, predict and assess either the scale of the potential deployment or all of the areas of the economy it might impact in. HFC as a sector is not recognised in the SIC categorisations and the multipliers acting on its supply chains are not formally defined or widely agreed. That said, within the larger and more obvious application areas, HFC draws the great bulk of its supply chain from conventional sectors which are well understood and it also acts into markets and areas which are equally well understood at the macro level. In this context, conventional economic modelling can be undertaken on the basis of what is understood and agreed and since that will generate the bulk of the output in any case, overall uncertainty is at least somewhat limited and the modelling output can be taken as being reasonably accurate interpretation of the general direction of travel.

In due course accurate up and downstream multipliers can be established to provide greater output accuracy, but that work is involved and is beyond the scope of work being undertaken here. The approach taken here is to lay out potential deployment scenarios in some of the larger and more significant potential application areas into the medium term and to then assess how that change impacts on economic activity compared to the present-day situation. The assumptions made in scenario building will be laid out. In some cases deployment will involve replacement of some current economic activity – loss of current activity as well as new activity will be accounted for in the determination of net change.

In many supply chain cases there will be no net change, it's reasonable to assume that each road vehicle will still employ at least 4 wheels and 4 tyres – irrespective of its power plant being changed. Those no-change elements are not discounted as economically meaningless however, as continued production of vehicles, albeit with new power train, will continue to sustain economic activity and employment in the production of wheels and tyres (to follow the example through). Modelling will account for the import and export of both supply chain components and complete HFC products themselves.

CHAPTER 2 EXISTING UK ENERGY SYSTEM ELEMENTS

(including transport)

2.1 HEADLINE FIGURES

In 2014, the UK was estimated to have used around 2.25 PWhrs of energy, which translates into each of us using around 35 MWhrs per year. The table below is taken from DBEIS' Energy Trends September 2016 and details both energy production and usage quarterly from 2nd Quarter 2014 to 2nd quarter 2016.¹⁴ As seen from the table the UK is using around 200 million tonnes of oil equivalent per year.

Table 2.1 Total energy.

Supply and use of fuels

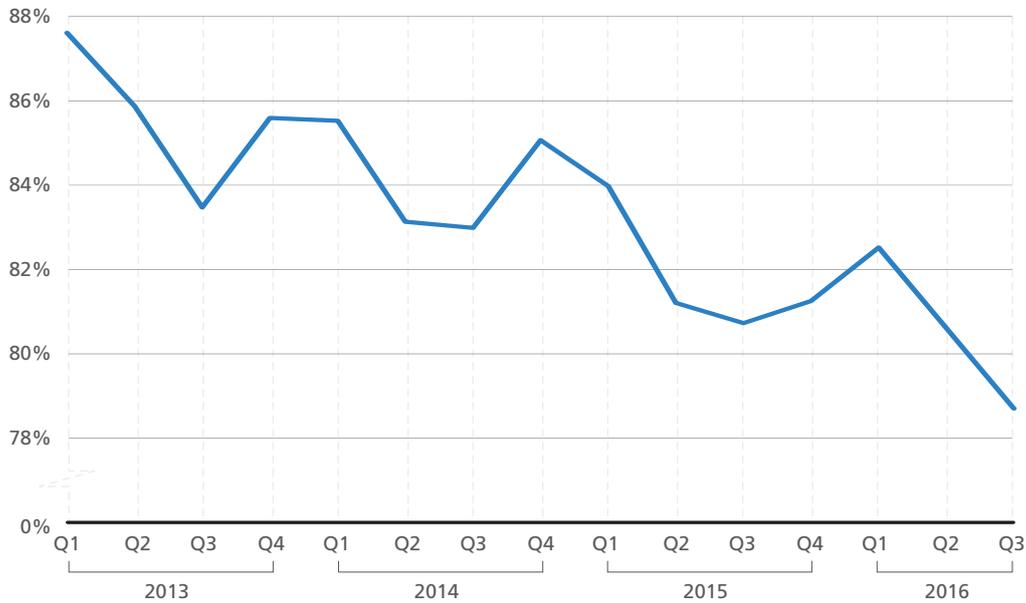
Thousand tonnes of oil equivalent

	2014	2015	% change	2014 2nd quarter	2014 3rd quarter	2014 4th quarter	2015 1st quarter	2015 2nd quarter	2015 3rd quarter	2015 4th quarter	2016 1st quarter	2016 2nd quarter	% change ¹
SUPPLY													
Indigenous production	113,620	121,517	+9.6	28,784	24,695	29,251	31,852	32,157	27,636	32,903	33,296r	31,902	-3.6
Imports	164,965	151,840	-6.1	39,179	38,650	43,407	43,766	35,233	36,170	39,676	39,572r	35,097	-0.4
Exports	-70,629	-76,667	+8.5	-18,258	-16,948	-17,471	-16,955	-19,532	-20,270	-19,910	-19,452r	-18,256	-6.5
Marine bunkers	-3,034	-2,593	-13.7	-711	-740	-812	-564	-720	-725	-584	-553r	-821	+14.0
Stock change ²	-3,935	+2,868		-2,998	-2,763	+72	+2,507	-960	+479	+841	+6,741r	-739	(+)
Primary supply	201,013	203,001	+1.0	45,996	42,893	54,448	60,606	46,176	43,291	52,926	58,605r	46,263	+0.2
Statistical difference ³	-374	523		-54	-218	-96	258	32	25	213	-74r	10	
Primary demand	201,387	2132,478	+0.5	48,050	43,111	54,544	60,346	46,146	43,271	52,713	58,687r	46,274	+0.3
Transfers⁴	-3	21		-5	6	-2	19	2	3	-3	-4r	1	
TRANSFORMATION													
Electricity generation	-39,578	-37,603	-5.0	-9,397	-8,902	-10,286	-10,984	-8,629	-8,346	-9,644	-9,93r	-8,110	-6.0
Heat generation	-1,105	-1,084	-1.9	-240	-210	-312	-350	-240	-207	-287	-351	-240	0.0
Petroleum Refineries	-505	-40	-92.2	-145	-196	-111	-80	-6	12	34	-74r	-35	(+)
Coke manufacture	-334	-176	-47.2	-77	-85	-86	-48	-46	-38	-44	-20	-20	-56.9
Blast furnaces	-2,379	-2,201	-7.5	-573	-626	-537	-665	-647	-485	-404	-407	-425	-34.3
Patent fuel manufacture	-66	-64	-2.4	-17	-18	-15	-10	-18	-17	-20	-21	-11	-39.4
Other ⁵	-44	-44	+0.7	-8	-11	-11	-10	-9	-12	-12	-13	-11	+20.1
Energy industry use	11,873	12,485	+5.2	2,987	2,808	2,975	3,197	3,115	3,056	3,118	3,080r	3,126	+0.4
Losses	3,270	3,147	-3.7	714	705	915	982	649	658	858	859r	657	+1.1
FINAL CONSUMPTION													
Iron and steel	1,359	1,263	-7.1	345	338	317	369	343	291	260	249r	236	-31.3
Other end users	22,359	22,332	-0.1	5,149	5,015	5,952	6,593	5,127	4,986	5,626	6,252r	5,219	+1.8
Transport	54,126	54,810	+1.3	13,623	14,169	13,658	12,791	13,894	14,325	13,800	13,141r	14,223	+2.4
Domestic	38,232	39,623	+3.6	6,648	4,537	12,361	16,265	7,247	4,814	11,297	15,921r	7,364	+1.6
Other Final Users	19,063	19,403	+1.8	4,259	3,781	5,232	6,069	4,238	3,969	5,127	6,094r	4,347	+2.6
Non energy use	7,093	8,223	+15.9	1,868	1,723	1,769	1,944	1,942	2,090	2,247	2,254r	2,254	+16.1
DEPENDENCY⁶													
Net import dependency	46.2%	38.0%		44.8%	49.7%	46.9%	43.8%	33.5%	36.1%	36.9%	34.0%r	35.8%	
Fossil fuel dependency	84.3%	82.0%		83.1%	83.0%	85.1%	84.0%	81.2%	80.7%	81.3%	82.5%	80.5%	
Low carbon share	14.3%	16.5%		15.4%	15.4%	13.7%	14.8%	17.1%	17.3%	17.4%	16.1%	17.8%	

1. Percentage change between the most recent quarter and the same quarter a year earlier, (+) represents a positive percentage change greater than 100%.
2. Stock change * = stock draw – = stock build.
3. Primary supply minus primary demand.
4. Annual transfers should ideally be zero. For manufactured fuels differences occur in the rescreening of coke to breeze. For oil and petroleum products differences arise due to small variations in the calorific values used.
5. Back-Rows horn the petrochemical industry – see article in the June 2018 edition of Energy Trends.
6. See article in the December 2010 edition of Energy Trends.

Whilst all of the UK's energy is obviously not derived from oil itself, the UK's high degree of dependence on oil, natural gas and coal is shown in the figure below from the same source.

Figure 2.1 UK fossil fuel dependency 2013–2016. Source: DBEIS.



As noted in the above DBEIS graphic, the second quarter of 2016 saw the UK at record low dependency on fossil fuels of only 80.5%. The UK's current carbon dependency is perhaps much higher than most people realise – possibly due to the tendency of the media to focus on renewables and nuclear power which are controversial and hence more newsworthy in the minds of some at least.

In 2016 the UK's dependency on energy imports was at 35.8% down from peaks of around 50% in the first quarter of 2013 and third quarter of 2014. These levels of import dependency and the outflows of revenue implied are of serious security concern both economically and physically. The UK is extremely vulnerable to international fossil energy price variance. Quite aside from specific defence assets and manning, the potential loss of those fossil energy imports in any local conflict situation asks serious questions as to the UK's ability to physically defend itself under all circumstances.

National Grid reported that without the purchase of additional electricity reserves over the winter of 2015/2016, the UK's de-rated capacity margin would have fallen to only 1.2%. At that level of margin, any major power station outage would almost certainly have resulted in interrupted supplies.¹⁵

¹⁵ Ofgem, Electricity Security of Supply Report, July 2015 can be obtained from: www.ofgem.gov.uk/publications-and-updates/electricity-security-supply-report.

The Royal Academy of Engineering note that there are: 3 cycles of car replacement; 2 cycles of boiler replacement and $1 < 1$ cycle of power plant replacement before the UK reaches 2050 and the deadline to meet the 85% carbon emissions reduction target.¹⁶ In 2016/17, 2050 may seem like a long way off, however in terms of investment and strategy decisions 2050 is much closer than it might appear. With planned decommissioning of further fossil-fuelled electricity generation plant still to come and the timescales for new generation plant to come online, it is clear that UK is at a critical point in terms of energy decision-making.

2.1.1 Establishing an approximate energy applications value hierarchy for hydrogen

Hydrogen represents a disruptive change to energy models because for the first time it will become possible to serve consumer transport, electricity and heat mass markets using exactly the same energy vector. This raises economic questions as to the relative value of energy in each of these application types and automatically generates different potential values for hydrogen in each of the three areas. Relative energy values were established in terms of existing energy technology and fuel markets on the basis of current UK consumer prices for energy in those markets. Transport fuel is clearly of greater value with consumers paying significantly more on a per kWh basis for private transport than they pay for electricity and gas. This suggests that hydrogen is likely to be drawn into the UK transport mass market more readily than it will be into other energy sectors. The latter statement must be strongly qualified however, recognising that there are widespread circumstances where the value of electricity and heat can be greater than average UK prices. For instance some areas of the UK have no access to mains gas and are long since reliant on forms of electric-derived heat. The relative values point only to the general/average UK case.

It is instructive to determine an approximate value hierarchy for these three types in order to determine the most attractive economic use of a unit of hydrogen.

In terms of assessing consumer and political acceptability, prices directly impacting the public are of most value suggesting that the use of actual consumer prices paid per kWh makes for establishing the best relative value ratios. A very accurate ratio set would require the use of specific tariffs, specific appliances and specific vehicles, whilst those might be extremely important in a consumer choosing to purchase a particular appliance or to make domestic supply arrangements, the use of UK average figures gives a useful general understanding of the hierarchy.

NB In establishing a perceived/acceptable value/cost hierarchy, the cost of hydrogen is not relevant of itself – this is about what consumers expect to pay for the delivered services and ultimately what they will find acceptable. Consumers provide the demand side of the market to which suppliers can be expected to respond rationally to. Where consumers are prepared to pay significantly more for one application type than they are for another on a similar per kWh basis, it is reasonable to expect that

¹⁶ A Critical Time for UK Energy policy, a report of the PM's Council for Science and Technology, Royal Academy of Engineering, October 2015.

rational suppliers, seeking higher margins, will concentrate on satisfying demand for the former before addressing the latter. Policy interventions, including taxation, which impact consumer pricing, can be expected to modify such natural market behaviour.

The reference UK fuelling cost of heat is taken to be the consumer price of gas on account of gas being dominant in the UK heat market and the reference other forms of heating are compared to.

The understood UK gas:electricity (per kWh) value ratio is generally taken to be around 1:3. More specifically, the Energy Savings Trust quotes the average 2015–2016 UK gas and electricity prices at 4.18p and 13.86p respectively per kWh,¹⁷ (ratio 1:3.3).

[Strictly, account should be made of electricity and gas standing charges but these are fixed costs which must be borne for supply generally and hence are not cost variables as per the kWh unit prices. The reader could assume a standing charge contribution of c. +10% to each on average UK household consumption basis, but this will only have a small impact on the relative value ratio].

Transport value is seldom expressed on a per kWh work delivered basis and doing so requires a number of conversions:

The absolute energy content of road diesel¹⁸ (c.110% of petrol) varies source by source (data and actual diesel energy content) but is generally taken to be around 36MJ/L which translates to 9.94kWh/L.¹⁹ However the internal combustion engine and conventional vehicles are particularly poor at converting the fossil fuel's absolute energy content into delivered work. The US DoE and EPA estimate that 14–30% of the fuel's energy content is converted to useful work.²⁰ Newer European vehicles are towards the higher side of that conversion range and so the 30% conversion value is chosen here. (c.20% is probably more typical, but the use of 30% usefully accounts for a good measure of the hybrid vehicles now appearing in the mix.) The 30% conversion applied to the absolute energy content yields a delivered energy of 2.98kWh/l-1. The UK average price for diesel at the time of writing [Feb 2016] is 122p/l.²¹

And hence UK consumers are on average paying around 40.9p per kWh for private transport [122p/l-1/2.98kWhl-1].

So on a **conventional technology basis**, the consumer heat to electricity to transport value ratios are approximately: 4.2p : 13.8p : 41p.

Normalising those to the heat basis gives approximately: **1 : 3.3 : 9.8**.

The hydrogen case is somewhat different recognising that fuel cell and electric drivetrain losses must be accounted for in its usage to put transport and electrical generation onto the same kWh delivered to the consumer basis.

17 www.energysavingtrust.org.uk/about-us/our-calculations . NB these vary frequently with market fluctuations.

18 www.afdc.energy.gov/fuels/fuel_comparison_chart.pdf.

19 https://en.wikipedia.org/wiki/Energy_density.

20 www.fueleconomy.gov/feg/atv.shtml.

21 www.theaa.com/driving-advice/driving-costs/fuel-prices.

Warning – whilst the above is easy to understand and mainly from our everyday knowledge of UK prices, the following ‘conversion to hydrogen’ switches to a less well understood basis where exactly the same energy vector can serve all 3 application types. It is very important to stress that this says nothing whatsoever about the cost of producing hydrogen or about the retail cost a consumer might pay. It seeks only to understand the relative values that hydrogen might have in each of the application types. It only uses the above conventional technology prices as a basis on which to establish the approximate relative values of hydrogen.

At a consumer level it is convention to use the natural gas HHV value and the same hydrogen HHV energy content is assumed for the combustion of hydrogen in broadly similar appliances (reasonably valid where condensing boilers are employed). And so the perceived consumer (reference) value of heat will remain much the same on a kWh gas delivered basis, e.g. c.4.2p/kWh.

Fuel cell electrical conversion efficiencies vary by FC type but systems designed specifically for high electrical efficiency can be taken to offer 40–60%.²² Overall energy conversion efficiency can be higher – particularly for high temperature fuel cells in CHP configuration which can generate a 2nd value stream in the form of high quality heat, but this is not considered here.

In transport the (Canadian) Ballard HD7 transport module²³ are claiming to offer a c.60% FC electrical conversion, reducing to around 55% in accounting for non-stack FC system requirements. That figure reduces further to c.40% as delivered work via the vehicle’s electric drive train.

A drive-train is not required for stationery power generation, its losses do not apply and hence a system figure of 50% electrical conversion is probably reasonable for generation.

Applying the above FC system conversion factors (losses) to FC electric generation and transport components respectively of the above conventional technology consumer heat to electricity to transport value ratios/hierarchy yields: **1 : 1.6 : 3.9**

It must be stressed that these values are approximate and that any individual case must be examined in more detail accounting for its specific components and circumstances. Inclusion of the standing charge cost component for gas and electricity would narrow the gap between those and transport somewhat, but not such as to significantly impact either the order or general scaling of the ratio set. The general shape of the ratio set is largely pre-determined in any case by consumer/market understanding and acceptance of current technology delivery of those goods.

Based on regular UK consumer prices, the ratio set will not account for particularly high value electrical generation such as backup power for data centres, or grid-balancing arbitrage – where additional revenue streams and other value factors become

²² www.hydrogen.energy.gov/pdfs/doe_fuelcell_factsheet.pdf.

²³ <http://ballard.com/power-products/motive-modules/bus/>.

extremely important – as noted above the value of heat is of importance in the consideration of CHP FC applications.

Energy taxation regimes vary country by country and so the relative values do not necessarily apply out-with the UK. This type of national variation may strongly influence how markets might develop in different countries and must be taken into account when making international comparisons.

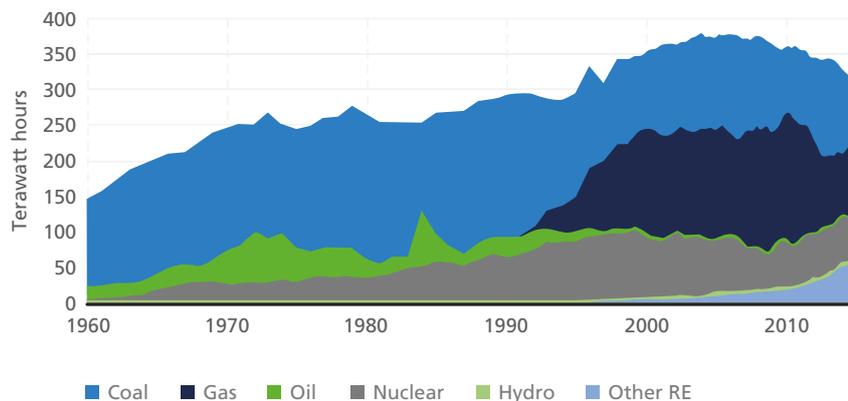
Importantly however, it does however give a general sense of the relative potential values for hydrogen in the UK mass consumer markets as we currently understand those markets. Notwithstanding the potential for policy intervention(s), the difference in relative values is marked and can be reasonably expected to direct market behaviour.

It is on this relative-value basis that modelling in this work has mainly concentrated on approximating the UK economic impact of the operational elements for hydrogen in mass consumer market transport.

2.2 TRANSPORT

From the DBEIS figures referenced above it is seen that around a third of the UK's total energy consumption goes into transport of some form and virtually all of that is currently carbon-derived. The 2014 UK grid mix (shown in the figure below) indicated that around 62% of electricity is carbon-derived, meaning that even the very limited number (around 1%, DoT) of battery-electric vehicles currently in the UK are still substantially reliant on carbon-derived energy sources. With current battery technology seeming unlikely to offer 1:1 performance replacement meeting customer needs, hydrogen vehicle fuelling, which can offer both speed of refuelling and vehicle range, looks set to play a major role in transport decarbonisation.

Fig 2.2 UK electricity generation.



In 2014, the UK electricity mix was 31% coal, 31% gas, 19% renewable and 18% nuclear. Chart by Carbon Brief using DECC data.²⁴

²⁴ www.carbonbrief.org/mapped-how-the-uk-generates-its-electricity.

2.3 ENERGY STORAGE

The UK currently employs 2.8GW of pumped hydro storage at:

- Dinorwig (Wales, 1.8GW, 1984),
- Cruachan (Scotland, 440MW, 1965),
- Ffestiniog (Wales, 360MW, 1963), and
- Foyers (Scotland, 300MW, 1969).

These facilities have not generally been employed for term storage of power and have instead been used as short term operating reserve (SRO) to meet rapid changes in demand and to offer *Blackstart* capability if needed. The youngest of those facilities at Dinorwig is now 32 years old and there has been no strategic grid-scale UK investment in SRO or term storage since its opening in 1984.

In 2015 UK peak demand for electricity was 52.7GW having fallen about 8GW across the preceding 8 or so years. The UK average electricity demand is currently around 34GW.²⁵ Those figures put the UK's total pumped storage power capacity (2.8GW) into stark focus in terms of resilience – aside of fossil reserves, the UK's total non-carbon energy storage facility adds up to a few minutes only worth of UK electricity consumption.

As noted in the introduction, increasing reliance on intermittent renewable forms of primary generation necessarily increases the requirement for and investment in energy storage. With bulk of the UK population living in areas which do not lend themselves geographically towards local pumped storage solutions, medium-grid and local scale hydrogen and battery storage solutions must be considered.

The UK has around 14 grid-connected battery storage systems currently in operation,²⁶ their power ranges from 5kW on a very small Scottish Island to a 6MW/10MWhr system in Bedford. More are in planning. Systems employed in urban locations are frequently predicated on supplying local voltage support and frequency regulation rather than offering term storage, whereas for island and other more remote systems term storage and demand matching are more important objectives.

The UK currently has no substantive (grid scale) hydrogen-as-electricity-storage facilities with most of her non-industrial hydrogen facilities being used to provide early transport fuel. A number of small (sub 100kW re-generation scale) hydrogen-as-electricity-storage demonstration facilities such as the Hydrogen Office in Methil, Fife²⁷ and facilities belonging to the University of Glamorgan near Port Talbot have been operational for a number of years whilst additional facilities are currently being constructed on Orkney.²⁸

²⁵ Ofgem, Electricity Security of Supply Report, July 2015 can be obtained from: www.ofgem.gov.uk/publications-and-updates/electricity-security-supply-report.

²⁶ Energy Storage in the UK, REA, 2015/16.

²⁷ <http://brightgreenhydrogen.org.uk/>.

²⁸ www.shfca.org.uk/news/big-hit.

CHAPTER 3

INTRODUCTION OF MACROSCALE SCENARIO SWITCHING

From refined fuels to
hydrogen in personal
transportation

3.1 INTRODUCTION

This chapter introduces the core scenario for which potential economic impacts of hydrogen and fuel cells in the UK are considered in this White Paper. This focuses on the replacement of petrol and diesel in cars with hydrogen, with some attention to the manufacture and uptake of hydrogen-ready cars and short-term investment in activities such as Research and Development and construction required to enable such as switch.

In economic terms, the transition to a hydrogen-based economy of shifting from a carbon intensive economy to a low-carbon economy, where hydrogen is used to change the way energy is produced, consumed, distributed and stored, may require three key phases. Here these phases are identified as:

1. Contraction in expenditure on traditional refined fossil fuels, mainly petrol and diesel;
2. Gradual reallocation of spending toward hydrogen-based energy (which may involve changes in vehicle spending);
3. Investment to support and maintain increased uptake of hydrogen-based technologies and fuels both in transport and beyond.

These ‘economic phases’ provide an important framework for considering the transition to a hydrogen economy. This is because the deployment, and uptake, of hydrogen will be a gradual process. It is assumed here that commences first in transport activities, where conventional automotive fuel use must change if hydrogen is to become a competitive and widespread option in the wider UK energy mix.

The overarching transition process will still involve significant reliance on conventional fossil fuels. This is because, unlike coal or gas, hydrogen is not a primary natural resource. Rather it is a vector/carrier of energy. This then raises the question of how much conventional fossil fuel activity needs to be retained to support the move to a hydrogen economy.

This chapter also provides the context for introducing the multi-sector economy-wide input-output multiplier tool that is used later in the paper to model conceivable impacts on output, wage income, employment and value added (GDP) throughout UK supply chains in scaled scenario analyses. The use of the input-output tool facilitates policy understanding of the supply chain impacts of HFC scenarios. It also and permits a preliminary assessment of how well-positioned UK supply chain capacity currently is to capture a share of global activity for hydrogen and fuel cell activity. Here, the focus is particularly on transport (under a near term ‘small hydrogen’ scenario).

3.2 THE TRANSITION SCENARIO

In Chapter 9 we consider the macroscale scenario in detail, specifically in terms of trying to scale potential shifts in spending activity. The current chapter focuses attention on the nature of the transition phases and the type of economic activities that are likely to be impacted.

The first phase is that expenditure on traditional fossil fuels will contract. In the context of transport, the greatest potential impact is likely to be in the use of petrol and diesel in cars. This means that expenditure on these fuels at service stations will decrease, which means a contraction that will have ripple effects up the refined fuel supply chain. In the UK, this means negative impacts on the domestic fossil fuel extraction sector and a number of industries supplying feedstocks and other goods and services. However, as highlighted below, the refined supply fuel supply chain also involves a relatively high level of imports, this will limit negative multiplier effects at a domestic (UK economy level).

The second phase is that spending will gradually be reallocated towards hydrogen based fuels. Again, the main near term focus is likely to be in terms of fuel used in cars. At the current time a hydrogen industry does not yet exist at scale in the UK economy (or more specifically, given the current exercise, within the UK economic input-output accounts). However, this may be similar in nature, partly depending on the hydrogen source, to (a) the current gas production and distribution sector (though, where this would involve introduction of carbon capture and storage (CCS), the input structure would change to some extent), or (b) the current electricity production and distribution sector. A key point may be that in the case of (b), electricity is similar to hydrogen in that it is a secondary energy carrier/vector rather than an energy resource.

There could also be a potential boost to UK manufacturing at this stage. The Automotive Council UK roadmap 2013,²⁹ highlights 11 core areas where the UK vehicles manufacturing industry could make advancement in automotive technology during the transition to a hydrogen economy. If the UK vehicle manufacturing industry develops specialism in producing hydrogen-ready cars, routine replacement and upgrade of domestic vehicles this could involve domestic rather than import spending. Indeed, the availability of a good quality UK branded vehicle may help incentivise individuals to engage in the transition towards hydrogen cars (though a similar argument could be made for electric cars).

The third phase will involve fuller investment to support increased uptake and maintenance of hydrogen-based technologies. If the deployment of hydrogen is ultimately to be sufficient to meet current/projected demand for fuels/energy, not only to run cars, but also potentially heating systems, there are opportunities for a range of UK industries. In particular, if technologies are ‘made in the UK’ rather than designed, developed and ‘bought in’ from overseas, investment in research and development (R&D) activity could offer a significant contribution to the wider economic impacts of HFC. However, at least in the shorter term positive impacts in the construction sector and its supply chain may be important.

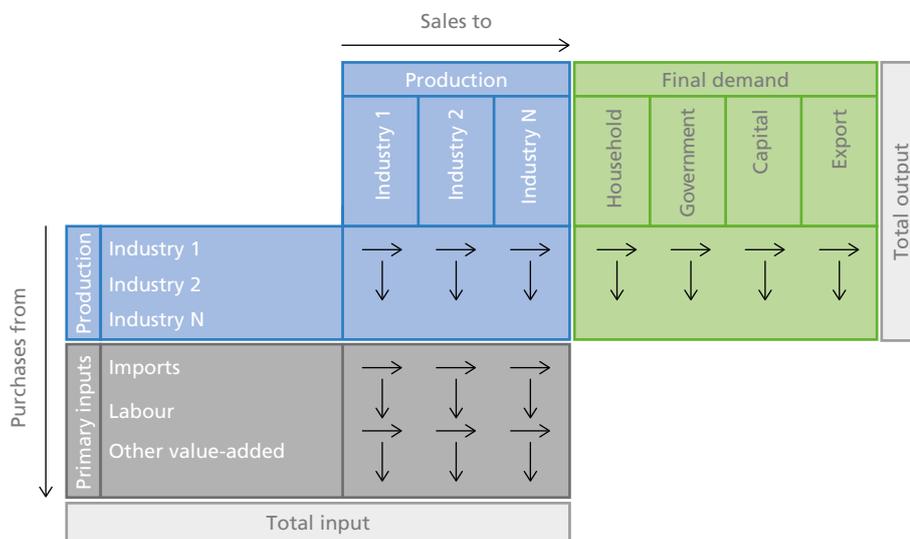
3.3 THE INPUT-OUTPUT MODEL – THE ECONOMIC MULTIPLIER TOOL

The most straightforward and transparent way to get a clear and simple picture of the likely nature and extent of potential contractions and expansions in activity to

²⁹ Automotive Council UK: Power Electronics Roadmap 2013: www.automotive-council.co.uk/2013/09/automotive-technology-roadmaps.

support the emergence of a hydrogen economy is to draw on input-output accounting data. Input-output data are produced as part of the UK National Accounts by the Office of National Statistics (ONS),³⁰ under the United Nations System of National Accounts (SNA 1993).³¹ The UK input-output tables describe the structure of the economy in a given year in terms of what 103 industries (identified by the Standard Industrial Classification, SIC, 2007³²) sell to one another, to domestic consumers (UK households, government and capital formation) and to exports, and how much they pay for employment and other value-added.³³ See Figure 3.1 for a simple illustration of an input-output table. This paper uses input-output data reported for 2010, the most recent year for which the required analytical form data have been produced.³⁴

Figure 3.1 Schematic input-output table.



In their 'analytical' form input-output accounts are reported in producer/factory gate prices and are symmetric so that total input balances to total output in any one industry and as a whole in the tables. The key feature of analytical input-output data is that they can be used to derive multipliers, which are a useful tool in telling us how much output, employment, wage income, other value-added etc. in the wider economy is

30 UK Input-output supply and use tables for 1994 to 2014, Available at: www.ons.gov.uk/economy/nationalaccounts/supplyandusetables/datasets/inputoutputsupplyandusetables.

31 System of National Accounts 1993, Available at: <http://unstats.un.org/unsd/nationalaccount/sna1993.asp>.

32 Standard Industrial Classification 2007, Available at: www.gov.uk/government/uploads/system/uploads/attachment_data/file/455263/SIC_codes_V2.pdf.

33 Income to primary inputs is identified as value-added and this is consistent with the income measure of GDP. Components of value-added are usually distinguished as labour (where the return is the wage paid) and 'other value-added' or gross operating surplus. The latter is often considered to be returns to capital in general, though land may also be distinguished. Primary, or non-produced inputs generally include the components of value-added and any production taxes and subsidies. Imports are also generally included within the primary input block of a national input-output table as, while they are produced, they are not produced within the domestic economy.

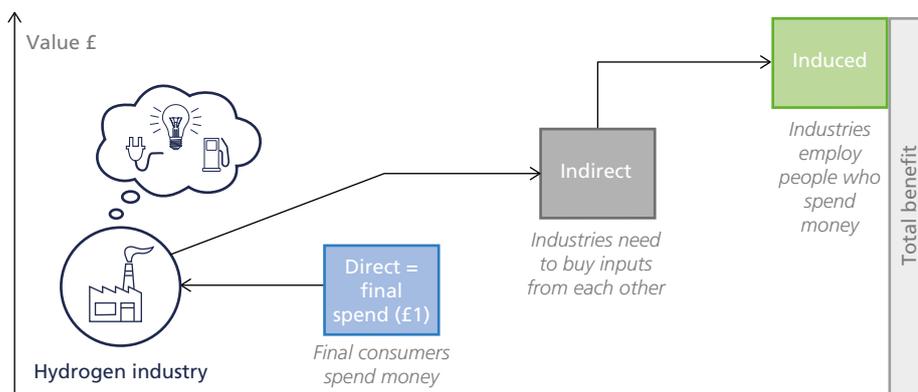
34 Note that this study uses a variant of these data that are reported in industry-by-industry format (as opposed to the product-by-product data reported by ONS, produced by the Fraser of Allander Institute at the University of Strathclyde, in order to provide an industrial level focus on key variables such as employment (see www.strath.ac.uk/business/economics/fraserofallanderinstitute/research/economicmodelling/).

required to support one unit of output produced to meet end use or final demand in any one industry. Caution must be exerted in using multipliers to make projections in term of what might happen if there is economic expansion as supply chains can change, due to changes in prices, technology and other factors. This is discussed in Chapter 9 where impacts of scaled scenarios are modelled.

Similarly, if attention is on the creation of new activity (i.e. that does not currently exist in the economy), such as the supply of hydrogen, use of multiplier tools initially requires identification of a similar or proxy industry. The next step is then to consider how the input structure of the new activity may differ from that of the proxy. For example, below the existing ‘Manufacture of gas; distribution of gaseous fuels through mains; steam and aircon supply’ industry (SIC 35.2 – see SIC, 2007, p.38) is identified as proxy for hydrogen supply. It is then considered (see Chapter 4) how the supply chain of hydrogen manufacture and distribution may differ from that of gas. For example, this may be through use of a different chemical mix and/or the reforming of natural gas. However, while this may be important from a technical standpoint, it will not necessarily be the case that there will be much of an impact on the nature and strength of supply chain linkages in the UK economy.

The central multiplier measure is the output multiplier for any given industry, X, which tells us the amount of output (generally reported in £million) that is generated throughout the economy (across all industries) per £1million of final consumption demand for industry X’s output. What is known as the Type I variant of this multiplier captures (a) the direct effect of the £1million of final demand plus (b) indirect effects in the industry’s up-stream supply chain. The Type II variant also incorporates (c) the additional, induced, impacts of household consumption financed through wage income from employment in industrial production. Figure 3.2 gives a basic illustration of the multiplier concept.

Figure 3.2 Basic mechanics of the input-output multiplier.



The key thing to understand in applying multipliers in scenario analysis is that any multiplier is basically a ratio: how much return does the economy as a whole get per unit of direct final demand requirement? For example, for every £1million spent by UK households on gas, how much output, employment, wage income and other

value-added is generated throughout all 103 UK industries? The Type II output multiplier for the UK gas industry is 2.25 meaning that for every £1million of, for example, household spending on gas a further £1.25million in UK output is generated in indirect and induced effects. **One of the main factors limiting the size of a multiplier is leakage through imports rather use of domestically produced inputs.**

3.4 QUALIFICATION ON THE USE OF THE INPUT-OUTPUT MODEL

The simplicity and transparency of the input-output model has made it popular with policy communities throughout the world, providing a simple metric, using the common language of ‘multiplier effects’ to consider what are often very complex direct, indirect and induced supply chain impacts. However, the simplicity is also a result of quite restrictive assumptions as to how the economy actually functions and these become more important when scaled scenario analyses are attempted (as in Chapter 9) rather than simple marginal analyses (as in Chapters 4 and 6).

The most fundamental of the restrictive assumptions is that the conventional input-output model is driven by change on the final or end user demand side of the economy. The supply side is assumed to be entirely passive and able to fully respond to any change in demand without technology or prices having to adjust, and indeed these two variables are fixed and cannot adjust in the input-output model. The basic implication is that the user must accept the assumption that economy (and individual industries, providers of labour and capital services therein) has sufficient capacity to be able to respond in this way. This be more realistic over some timeframes and/or for relatively small scale changes in activity.

Other assumptions of the input-output model are generally more restrictive. For example, taxes, subsidies and other forms of government transfers are very important in the functioning of the economy. However, the underlying input-output data only include information on taxes on commodities, and only at the level of the total paid by any industry or user, and not relating to individual goods and services purchased and sold. Distribution margins are also only included at an aggregate level. Thus, in the current context, for example, in considering expenditure on fuels only the actual fuel cost element is and can be included. In the absence of other elements of government income and expenditure, such as income or corporate taxes, the simulation of any expansion (or contraction) excludes impacts via increased (or decreased) tax revenues.

Ultimately, if there is a need to conduct a more in-depth and sophisticated analysis, it is advisable to consider use of an alternative multi-sector economy-wide model. The most common approach in this respect is the type of computable general equilibrium (CGE) model used widely in the research community and by policy agencies, such as HM Treasury,³⁵ particularly commonly for fiscal analysis.

³⁵ HM Treasury and HM Revenue & Customs (2014), A report applying HMRC’s peer reviewed Computable General Equilibrium (CGE) model to the fuel duty reductions announced since 2010. Available at: www.gov.uk/government/publications/analysis-of-the-dynamic-effects-of-fuel-duty-reductions.

Nonetheless, the IO model does provide a useful starting point for economy-wide analysis of additional and new potential activity, focussing as it does on the composition and nature of supply chains supporting different goods and services. For this reason, it has been selected for the supply chain analysis in Chapters 4, 6 and 9.

3.5 IDENTIFICATION OF KEY MULTIPLIERS FOR THE NEAR TERM SMALL HYDROGEN SCENARIO

In this section the 2010 UK industry-by-industry input-output accounts are used to identify key multiplier values that are likely to be relevant in the near term or small hydrogen scenario. Attention focuses on the basic output multiplier, along with related multipliers reporting the amount of value-added (total, and focussing on the wage income component) and employment are generated per £1million final spending.

3.5.1 Phase 1: Contraction in expenditure on refined fuels use in vehicles

The industry that supplies petrol, diesel and other refined fossil fuels is ‘Manufacture of coke and refined petroleum products’ (Standard Industrial Classification, SIC, code 19). This is the industry that would likely be directly negatively impacted if there is a shift in the personal (and/or freight/commercial) transport fleet in favour of hydrogen fuel cell (or electric) vehicles. The total (Type II) UK multiplier values calculated for this industry using the 2010 input-output accounts are 1.47 for output, 0.33 for GDP 2.93 for employment (where employment is the only variable not reported in £million, instead considering full-time equivalent, FTE, jobs required or supported throughout the economy per £1million spending) and 0.19 for wage income.

This means that for every £1million contraction in demand for refined fuels (in 2010 UK households spent £6,556million on the industry’s outputs), a total of £1.47million of UK output will be lost, £0.33million of GDP (at producer prices), 2.93 FTE jobs and £0.19 million in wage income. Table 3.1 summarises multiplier values for several UK industries discussed in the text throughout this chapter and in chapters 4 and 6.

A crucial point to note is the UK ‘Manufacture of coke and refined petroleum products’ (or, more simply, the ‘Refined fuel’ sector) has a relatively high import intensity. The use of produced goods and services as ‘intermediate’ inputs (generally the driver of multiplier values) is high, at almost 83% of the total input requirement of the industry. However, 75% of this is imported from overseas, thereby reducing the extent of multiplier effects in the UK (which are driven only by domestic intermediate and labour inputs). In fact, **the ‘Refined fuel’ sector is the lowest ranking of all 103 UK industries in terms of the size of its output, employment, value-added and wage income multipliers.**

The implication of this last point is that **any reallocation of spending away from refined fuels towards any other UK produced good or service will result in a net positive impact on goods and services production in the UK economy.** There will, however, be ‘losers’ at the industrial level, particularly in the extraction of oil/crude petroleum, though this may be offset if hydrogen is sourced from a fossil fuel source (see below). In Chapters 4 and 6 the industrial composition of the supply chain impacts of decreased demand for refined fuels will be considered in more detail.

Table 3.1 Output multiplier values for selected UK industries.

Multiplier (activity per £1million final consumption demand)					
SIC	Sector/industry name	Output (£million)	Value-added (£million)	Employment (FTE jobs)	Wage income (GDP) (£million)
29	Manufacture of motor vehicles, trailers and semi-trailers	2.35	0.80	13.61	0.54
19	Manufacture of coke and refined petroleum products (refined fuels supply)	1.47	0.33	2.93	0.19
35.1	Electric power generation, transmission and distribution (hydrogen supply proxy 1)	2.56	0.78	8.05	0.32
35.2	Manufacture of gas; distribution of gaseous fuels (hydrogen supply proxy 2)	2.25	0.81	8.04	0.32
41–43	Construction	2.31	1.01	19.20	0.57
45	Wholesale and retail trade and repair of motor vehicles and motorcycles	2.10	1.07	20.38	0.72
72	Scientific research and development	2.39	1.29	25.31	1.00

Source: Author's calculations based on UK input-output data produced by the Fraser of Allander Institute.³⁶

3.5.2 Phase 2: Reallocation towards hydrogen-based fuels

Hydrogen can be sourced from diverse resources, either from renewable sources (e.g. hydro, biomass and geothermal) or non-renewable sources (e.g. coal, natural gas and nuclear) or a combination of both. Each potential source would involve different cost estimates and social cost benefits analysis to capture the potential production capacity, processing and technological requirement to support hydrogen. This would be crucial to determine what hydrogen source(s) is most cost effective, accessible and less carbon intensive for the UK economy to support hydrogen uptake.

Such a social cost benefit analysis exercise is beyond the scope of the current paper. Rather, in the absence of a current hydrogen supply industry in the UK economy (or at least one large enough to be identified in UK input-output accounts), the focus is on identifying a 'proxy industry' to consider the potential nature of hydrogen supply chain requirements. Indeed, a key output of the input-output multiplier modelling exercise using proxies in this paper may be to focus attention on how the greatest net impacts across the UK economy could be achieved by, where possible, replicating key characteristics of the proxies identified.

36 Download at www.strath.ac.uk/media/1newwebsite/departmentsubject/economics/fraser/UK_analytical_Table.xlsx/.

3.6 IDENTIFICATION OF HYDROGEN SUPPLY PROXIES

Whilst there are potential bio-sources of hydrogen, it seems most likely that the greatest bulk of hydrogen produced in the UK will derive from the processing of natural gas or the electrolysis of water. As such, the provision of natural gas and electricity form the majority of the operating economic inputs of a future UK hydrogen supply system. For that reason, the existing UK electricity and gas supply sectors (SIC industries 35.1 and 35.2 respectively) would seem to offer the best economic proxies in make a first assessment of the likely macro-economic impacts of a shift from current refined fossil road fuels towards hydrogen. The impact of change in demand for the outputs of these two sectors can be understood using the type of basic input-output models that are familiar to many policy analysts.

Simple inspection of the economic and employment multipliers associated with the electricity and gas sectors compared to that for refined fuel immediately indicates (e.g. based on Table 3.1 above) that there will be a boost to activity across the economy. This is likely to translate to sustained net economic benefits to the UK from a switch away from refined road fuels to natural gas or electricity-derived hydrogen. On the other hand, the choice of the gas and/or electricity proxies also limit attention at this time on use of hydrogen in heating rather than transport options as the substitution in fuel source would involve replacing spend in the same/very similar activity.

However, one issue in this respect and more generally, is that the production of hydrogen from either natural gas or electrolysis of water will require an additional layer of processing. This implies additional labour and other inputs, which may in turn generate additional direct and supply chain jobs, investment and value-added if hydrogen becomes a replacement for transport fossil fuels or gas/electricity in providing heat. Nonetheless, as an emergent sector, no definitive data on macro-level implications or economy-wide (indirect and/or induced) supply chain requirements exist from which to be able to reliably assess the impact of that additional layer. Similarly, any CCS requirement is likely to add an additional layer(s) of activity, but data to inform assessment of economy-wide implications are not yet available.

At this stage, the main point that can be made is that it is very clear that the potential for additional economic activity implied by additional layer(s) associated with processing of hydrogen fuel and/or associated emissions means that modelling outcomes based purely on the electricity and gas proxies is likely understate any benefits to the UK macro-economy. However, as discussed in Chapter 4, this must be set against the negative economic impacts of any reduced reliance on hydrocarbons extracted in the UK off-shore oil and gas industry.

Thus, rather than attempt to use speculative predictions, in the economy-wide analyses reported here it seems appropriately conservative to rely on the results obtained from the gas and electricity proxies alone, abstracting from consideration of the additional layer(s). However, this is done with the qualification that (particularly in combination with the qualifications – see Section 4.2.1 below – on what may be overstated negative multiplier effects associated with decreasing reliance on fossil fuels for transport) results reported here may understate the overall benefits.

3.6.1 Existing UK gas supply

The existing gas supply ('Manufacture of gas; distribution of gaseous fuels through mains; steam and aircon supply', SIC 35.2) industry may be taken as a proxy for a future hydrogen supply industry. This may be motivated by the fact that hydrogen supply could potentially utilise the existing gas distribution infrastructure. If gas supply is taken as a proxy, the multiplier impacts in the UK economy of £1million of expenditure on a hydrogen supply industry with a similar supply chain composition are considerably higher than what is discussed above for 'Refined fuel' supply of petrol and diesel. For gas supply in 2010, the key headline multipliers for gas supply are 2.25 for output, 0.81 for value-added, 8.04 for employment (FTE jobs) and 0.32 for wage income. **The key characteristic underlying the higher multiplier values is that 75% of intermediate or produced inputs to the gas supply industry are produced within the UK** (compared to only 25% in refined fuel supply above). Gas supply is also more capital-intensive than refined fuel supply, which boosts the value-added (GDP) multiplier.

A crucial point is that the input-output accounts reveal that (in the base accounting year of 2010) 43.5% of goods and services produced in the UK and used in gas supply are directly sourced from the UK off-shore extraction industry. **Therefore, one important issue is that if extraction in the UK oil and gas extraction industry continues to decline more of this will be imported, reducing the size of the UK multiplier values for the gas supply proxy.** Moreover, as noted above, a core motivation for taking gas supply as a proxy may be **the nature of the existing distribution infrastructure rather than the energy resource itself.** If hydrogen is produced using a resource that is not extracted by the UK oil and gas extraction industry, while the gas supply industry may remain a useful proxy (due to the distribution infrastructure), **again the multiplier values may be overstated.**

The key point to take from this is that there will be impacts on the proxy multiplier values if the requirement on the UK oil and gas extraction industry no longer exists or is relevant. As long as other supply chain patterns for a new hydrogen supply industry are similar to those reflected in the 2010 multipliers for gas supply, **replacement with hydrogen may be expected to more than compensate for losses in the UK off-shore industry as demand for petrol and diesel falls.** Nonetheless the role of the oil and gas extraction sector does remain important though. In Chapter 4, examination of the supply chain composition of the current output multiplier values for refined fuels (1.47) and gas supply (2.25) shows that these involve, per £1million reallocated, respectively £56k (decrease) and £248k (increase) of output in the UK oil and gas extraction industry.

3.6.2 Existing UK electricity supply

On the other hand, **electricity may be considered to be a better proxy for hydrogen** in that the two share a similar key characteristic in that both are secondary energy carriers or vectors. That is, they are both produced using energy from a natural resource to realise a delivered energy service. If electricity supply is selected as a proxy, the UK 'Electric power generation, transmission and distribution' industry (SIC 35.1)

has **similar overall multiplier values to the gas industry**: notably higher for output at 2.56, while slightly lower for value added at 0.78, but almost the same for employment, 8.05 (FTE jobs). Again this is due to a relatively high dependence on a domestic supply chain. Again, changing reliance on the extraction of fossil fuels will impact the size of these multipliers, but to a lesser extent given that (in 2010) only 20% of the domestic goods and services input requirement was sourced from the UK fossil fuel extraction sector (though, this still equates to £230k per £1million of spending on electricity).

However, hydrogen can also be sourced *from* electricity. If this is the case, it presents another reason for potentially taking the multipliers for the existing electricity industry as an initial proxy for hydrogen supply. However, strictly speaking, in an input-output context, if hydrogen is sourced from electricity then electricity should appear as an intermediate input (perhaps a dominant one) rather than as a proxy.

Generally, in terms of shifting between refined fossil fuel and hydrogen energy sources for transportation, **the basic conclusion that can be drawn from considering the first two phases of the transition is that the net impact on the UK from switching from petrol/diesel to hydrogen as a whole, has the potential to be positive** (though there will be industrial ‘losers’). In the analysis presented here, this is because the output, employment, value-added and wage income multipliers are stronger for supply of gas or electricity (as proxies for hydrogen) than those for refined fuels such as petrol or diesel. However, this is only true as long as the reliance on UK supply chains is sustained in a cost-effective way and to a similar extent as can be observed for the current UK electricity and gas supply industries.

Moreover, one other factor identified above is that there could be a potential boost to UK-based manufacturing (whether UK or foreign owned) at this stage through a market for UK-produced hydrogen-ready cars. The UK ‘Manufacture of motor vehicles, trailers and semi-trailers’ industry (SIC 29) is another industry (see Table 3.1) with relatively high multiplier values: 2.35 for output, 0.80 for value added, 13.6 (FTE jobs) for employment and 0.54 for wage income. The headline output and value-added multiplier values are not greatly different from those of gas and electricity. However, both the vehicle manufacturing industry itself (in particular) and its supply chain (less so) are relatively more labour-intensive, which accounts for the markedly higher output-employment multiplier of 13.6 FTE jobs per £1million of final spending on vehicles produced. In Chapters 6 and 7 the nature of the employment embedded in these supply chains, and the related wage-intensity and skills profile will be examined.

3.6.3 Phase 3: Potential expansion through investment to support increased uptake and maintenance of hydrogen-based technologies

Under Phases 1 and 2, the main consideration is of changes in **household final demand spending when different fuel types are used to run new/replacement cars**. However, as noted above, if the deployment of hydrogen is ultimately to be sufficient to meet current/projected demand for fuels/energy, **investment will be required**. That is, within and beyond the case of hydrogen replacing refined fuels in running cars (i.e. potentially extending to heating and cooling systems), in order to increase capacity to serve

a hydrogen economy, there will be opportunities for a range of UK industries. This will be partly through **government or private investment spending to support any required increase in capacity**. Multiplier findings under Phases 1 and 2 (extended and decomposed in Chapters 4 and 6) provide information on how investment may be directed in order to enable the hydrogen fuel supply chain itself. However, there will be a wider set of opportunities to create wealth and job creation in the UK, through multiplier effects being triggered in other areas of the economy in different time frames.

A crucial central point is a ‘make or buy’ question. In terms of UK industrial value-added (GDP at basic prices) multipliers, with £1.29million in value-added generated throughout the UK economy per £1million final demand (including export of services), ‘Scientific Research and Development’ (SIC 72) ranks second out of all 103 UK industries (only ‘Education’ is higher). The corresponding output and employment multipliers are 2.39 and 25.31. In terms of wage income from employment, £0.99million is generated across the economy per £1million spend on R&D (again, second highest only to ‘Education’). Therefore, **there are opportunities for significant economy-wide returns if technological discoveries and developments are conducted ‘at home’**.

In terms of other industries that may be targets for government or private investment spending in order to increase capacity to support the roll-out of a UK hydrogen industry, these will fall under one of three broad categories.

1. Industries where output is required to enable people to use hydrogen as a fuel.

The obvious example is one given above, the UK car manufacturing industry. **People must buy a hydrogen-ready car if they are to use hydrogen as a fuel.** Therefore industries in the supply chain of car manufacturing or distribution may have opportunities to expand to service this demand. The main multiplier values for the UK ‘Manufacture of motor vehicles, trailers and semi-trailers’ industry (SIC 29) have already been reported in Section 3.4.2 (and Table 3.1) as 2.35 for output, 0.80 for value added, 13.6 (FTE jobs) for employment and 0.54 for wage income.

However, people may alternatively purchase imported cars. The manufacture of these may have some UK supply chain elements (if UK industries export into foreign car manufacturing supply chains) but there is no direct way to determine these impacts from the UK national input-output framework. However, it is possible to **examine the supply chain of the industry that provides wholesale and retail services in the UK to both domestic and foreign car manufacturers**. This is the ‘Wholesale and retail trade and repair of motor vehicles and motorcycles’ (SIC 45) sector, which appears in the domestic supply chain of the UK manufacturing sector but also exports output (distribution services) to the rest of the EU and the rest of the world. The main multiplier values for this industry are 2.10 for output, 1.07 for value added, 20.4 (FTE jobs) for employment and 0.72 for wage income

2. Industries where short-term but potentially large investment spending may be required to enable the supply and distribution of hydrogen.

For example, as with the sale/distribution of cars, there must be distribution points for fuels. Where development of these is required to create or convert to hydrogen

refuelling stations, it is not the retail distribution point itself that we consider multiplier values for. Rather it is the **construction industry** that undertakes the work required. The UK ‘Construction’ sector reported in the IO accounts covers SIC codes 41–43, which covers construction of buildings, civil engineering and specialised construction services (with the latter including demolition, site preparation, electrical and plumbing, plastering etc.). The main multiplier values for this industry are 2.30 for output, 1.01 for value added, 19.2 (FTE jobs) for employment and 0.57 for wage income.

3. Industries where capacity requirements may be indirectly impacted rather than being targets for direct spending changes or investment.

That is, industries that service the supply chains of electricity or gas supply as proxies for hydrogen supply (from Section 3.4.2) and/or the industries identified under (1) and (2) above. For example, in both the existing electricity and gas supply industries, the off-shore oil and gas extraction industry has already been identified as an important provider of inputs. This may also be the case for hydrogen supply depending on how the hydrogen is sourced, and whether it uses **imported or domestically extracted fossil fuel supplies**. In terms of other supply chain industries, one issue is that the current UK electricity and gas industries both service each other (i.e. figure prominently in one another’s supply chains in the 2010 IO tables) and the nature of this relationship will need to be considered if either (or some combination of both) is taken as a proxy for hydrogen supply.

Other UK industries also feature in the electricity and gas supply chains and may play similar roles in hydrogen supply. Thus they may, require investment to enable an increase in capacity to enable this new supply chain role. For example, **financial services** (‘Financial service activities, except insurance and pension funding’, SIC 64) features in the supply chains of both electricity and gas so is likely to play a role in a hydrogen supply industry. On the other hand, **‘Manufacture of electrical equipment’** (SIC 27) features more prominently in electricity supply, so would be important if hydrogen is sourced from electricity but perhaps less so if it is sourced from other fossil fuels (e.g. coal).

In the case of industries directly impacted as described under (1) above – e.g. **the manufacture of cars to enable the use of hydrogen as a fuel** – one question is whether there would need to be any expansion in the *UK-based industry* and its supply chain. A second is whether the input mix would change in producing cars that run on hydrogen rather than petrol/diesel. For example, would the manufacture of electrical equipment industry be important here also?

It should be noted that any expansion in activity or adjustment in input mix would only be required **if the UK car manufacturing industry were able to exploit opportunities from the move to hydrogen** (e.g. the point made above about a ‘UK brand’ potentially helping to induce the move). If it were, there may be **export opportunities as well as domestic supply ones**, if the UK-based industry can take a leading role in producing hydrogen-ready cars). If so, industries in the supply chain of UK car manufacturing, including any adjustment in input mix to produce hydrogen – rather

than petrol/diesel ready cars, would need to be able to expand capacity. One key issue is distribution. It is already noted above, that one of these is the wholesale and retail sector that provides distribution services to both UK and foreign manufacturers. However, this industry may not necessarily need to expand its capacity if the issue is simply one of a redistribution of demand for cars between UK and foreign manufacturers.

Other UK manufacturing sectors also play a role in the car manufacturing sector, most notably 'Manufacture of fabricated metal products' (SIC 25) and these may benefit from expansion through increased domestic and/or export demands. Again, electricity supply and construction also play a role (as they do in many UK supply chains). In summary, if there are opportunities for the UK car manufacturing industry to expand, all of these industries and others would need to be able to respond.

In the case of industries directly impacted under (2) – i.e. **short-term but potentially large scale investment activity** – the main target is likely to be the UK 'Construction' sector. In terms of the industries that will be indirectly impacted, a wide range of UK industries appear in the 'Construction' industry supply chain (where 88% of the goods and services or intermediate input requirement is sourced within the UK). Activity throughout the supply chain would need to be able to respond to any expansion in demand, though this may only be temporary. **The UK construction supply chain includes obvious industries such as cement manufacturing, glass and fabricated metals, as well as architectural and engineering services. However, once again, financial services play an important role.**

Issues relating to the composition of supply chains of directly impacted industries, is explored in more detail in Chapters 4 (output and value added) and 6 (employment and wage income) below. The main point to make here is that the multiplier values of industries that are indirectly affected remain relevant in that they bring their own supply chains to that of the industry they are servicing (e.g. see entries in Table 3.1 for the UK oil and gas extraction industry (SIC 6). However, multiplier values should strictly only be applied when considering the impacts of potential changes in a final demand in the form of household, government, investment or export demand.

3.7 CONCLUSIONS

This chapter has identified 3 key economic phases that the UK economy will potentially undergo towards the actualisation of a hydrogen-economy. **These are (i) contraction in expenditure on refined fuels use in vehicles, (ii) reallocation towards hydrogen-based fuels, and (iii) potential expansion of some industries through investment to support a hydrogen-economy.**

The chapter also provides an overview of the economic multiplier tool that will be applied overall to quantify/measure the marginal effect/impacts (per £1m) of output, employment, wage income and value-added under each transition phase in Chapters 4 and 6 and selected scaled scenarios in Chapter 9. The main pathways and opportunities for investment in terms of household, government and private investment

spending to support the uptake and maintenance of hydrogen enabling technologies in the short-term and potentially long-term have been highlighted.

The main issue identified has been the **importance of domestic supply chain linkages in delivering economic expansion through multiplier effect**. A key conclusion drawn is that, **where hydrogen supply can replicate the strong domestic supply linkages of the current UK gas and electricity supply sectors, opportunities for economic expansion (through a hydrogen transport economy at least), are significant**. This is because hydrogen for transport purposes would replace a petrol and diesel supply chain that has relatively weak domestic supply chain linkages. **Much will depend on the continued role of fossil fuel extraction from the UK oil and gas extraction industry** as this plays an important role in the current electricity and gas supply chains that are taken as proxies for hydrogen supply in this paper.

In the next chapter existing UK supply chain activity to support the headline multiplier values reported here is examined in more detail to consider its robustness/strength to adjust, adapt and respond to the transition to a hydrogen-economy. The objective of Chapter 4 is to identify the key drivers likely to facilitate the emergence of hydrogen as a replacement or new fuel/energy source within the UK supply chain. This will provide insights on the likely composition of the wider H2FC supply chain, including its links to pre-established industry and expertise.

CHAPTER 4

SUPPLY CHAIN

4.1 INTRODUCTION

The Supply Chain is critical to the establishment of a hydrogen fuel cell economy and indeed offers immense benefit to the economy. A range of Lifecycle Analysis studies conducted in EU FC Framework and EU FCH Joint Undertaking projects³⁷ detailing HFC system inventories readily explains the widespread extent of potential interest showing that the physical bulk of any fuel cell system or application does not involve a great deal of new technology. Although the core fuel cell (or electrolysis) stack is fundamental to the technology – the physical bulk of any system or application is made up of regular engineering and fabricated components. And the greatest proportion of cost and value in such systems is entrained in their overall design and integration content (IP). For example in scoping out the prospects for a hydrogen ferry being built and operated in Scotland, around 200 local supply chain companies were identified which could have an interest in such a development.³⁸

It should be noted that different HFC companies have different commercial strategies. Some may choose to develop and manufacture core HFC components, such as fuel cell or electrolysis stacks, only. In that case the relative proportion of in-house fabricated core HFC product content will be much higher than for those producing complete systems. At some point however those core HFC elements will have to be integrated into some form of complete system for the end user and this will necessarily result in the purchase and use of non-core system elements. From a wider macro-economic impact perspective therefore, it is valid to consider systems as a whole and the type of overall systems' bills of materials referred to above.

Non-core components are on the whole the same or very similar to those widely employed in the electricity generation and gas supply industries – and hence the electricity generation and gas supply industries make for the best economic proxies of the impact that the deployment of HFC technology might have on the macro economy. Both electricity generation and gas supply industries have relatively high economic multipliers – meaning that additional investment in either of those, as proxies to an emergent HFC technology industry, can be expected to have a relatively large and positive impact on the UK macro economy. (Subject to the import/export qualifications mentioned elsewhere.)

HFC specific additional supplies add additional value, an 'HFC layer', into the electricity generation and gas supply proxy supply chain and it is a reasonable assumption that an overall multiplier for an HFC industry will be at least a little higher still than the proxy employed in this paper's modelling work. No attempt is made herein to assess how much higher such an HFC multiplier might be as this would involve a much more extensive piece of work than can be covered here – essentially creating an SIC classification from scratch. Insufficient historical evidence exists at this time to do that reliably in any case. For now, it is sufficient to recognise that modelling outcomes of this work are liable to be conservative.

³⁷ www.fch.europa.eu/fchju-projects.

³⁸ HySeas I Final Report (2014), updated in HySeas II (2016), not public, but can be made available on appropriate request from www.cmassets.co.uk/.

The non-core element supply chain is made up of a range of components and services obtained from both the UK and overseas. Given that supply chains are already mature and pre-established for components such as pumps, pipes, wiring, power-electronics, generic controllers and so on, it seems unlikely that the deployment of HFC technologies will create any substantial number of new UK (or overseas) businesses to supply that type of system element. In the worst case economic scenario, where a conventional power generation solution is replaced with a like-for-like HFC based one, there will be little or no direct net micro or macro-economic effect over and above the additional 'HFC layer' of HFC deployment. The impact in that case is essentially to retain jobs and current levels of economic activity.

To exemplify that in the transport sector, we could imagine those currently employed in internal combustion engine making being redeployed to the construction of FC systems or their component parts. In other applications, because HFC systems and applications are likely to be smaller and more distributed than conventionally centralised power stations (for example), it is almost certain that the deployment of HFC technologies will generate more manufacturing work for those existing component supply businesses. This must result in either higher productivity, increased employment or some measure of both, in and around those types of supply chain business in the UK.

As the European capital of oil and gas, indeed as the inventor of much of the world's fossil energy extraction industry, and also from her other industrial history, the UK has retained a perhaps surprising (to some) amount of industrial manufacturing and IP which is very relevant to an emergent HFC sector supply chain. In general this paper seeks to avoid mentioning specific companies as inclusion of all businesses with a potential HFC interest is difficult, however for example Rolls Royce, Johnson Matthey, The Wood Group, Aggreko and The Weir Group are known as major suppliers of the Global energy and energy extraction and processing sector. Multinational extraction and refinery specialists such as BP, Ineos, Exxon, Technip and Shell are very well represented in the UK and are employers of very large numbers of UK residents. All of these companies already have HFC activity or the potential to supply components and/or expertise into an emergent HFC sector. And in the wake of giants such as those, comes their UK and overseas supply chains.

In addition to the multinational giants, the UK has a good number of smaller specialist and HFC specific companies – some manufacturing core HFC components and/or systems, others supplying related services. The UK has particular strengths in electrolysis, high-temperature fuel cell based technologies and systems, niche applications, hydrogen storage and systems integration. Virtually all of that UK interest is IP rich and hence is potentially value rich. It is worth noting that a great deal of macro-economic value derives from the service activities required to support HFC activities. The greatest bulk of service sector activity will necessarily be local to the UK, is of relatively high value and cannot be readily outsourced from the UK.

In this context the **UK Motor Industry** deserves special mention as it is likely to be amongst the most extensive integrators of HFC technologies. Although largely foreign-owned, the UK has a very significant and currently thriving vehicle

manufacturing sector. As fossil-derived fuels become less acceptable, it is essential that the UK's vehicle manufacturing sector adapts and evolves towards zero emissions vehicles.

Although battery vehicle technology is improving, and specialist vehicle successes such as Tesla, there are many obstacles to whole scale replacement of the internal combustion engine by battery systems, such as limited range, grid capacity and cost. Li-battery improvement can be expected but will probably be gradual rather than offering the step-change (and increased vehicles ranges) so frequently promised in the past. Wittingham lays out a good overview of historical, current and probably future of battery development and notes 8 specific fundamental technical issues that would need to be overcome were the Li-air batteries often referred to as potentially offering conventional vehicle range ever to become commercial.³⁹ The first generation of HFC road vehicles have ranges of 200–300 miles and beyond and can be refilled in much the same time as refilling with liquid fossil fuels does.

The Battery Vs Hydrogen vehicle competition/conflict idea is misplaced. In reality, the technologies are complimentary. All HFC vehicles have and will continue to have a good-sized Li-ion battery – to get them started, to allow the most efficient use of the HFC technology (load levelling) and to benefit from regenerative-braking. HFC vehicles are smart hybrids from day one! And from that smart-hybrid observation, it is a short step to realise what the inevitable passenger vehicle of the future will look like – at least in terms of its power provision. That vehicle will have sufficient battery capacity to allow battery-only usage in and around towns, on short commutes, school runs and such. But that local battery range will be backed up with significant additional range-extension from HFC technology.

Nissan/Renault seem to have been among the first of the major automotives to realise this and Renault's HFC range-extended electric 'HyKangoo' vans can already be found in the UK.⁴⁰ Nissan have recently announced their hybrid e-NV200 – which is essentially the same electric vehicle platform as the e-Kangoo, with the NV200 HFC variant employing a different fuel cell type.

Nissan already make electric vehicles in Sunderland and hence they already have the electric platform and virtually all of the required supply chain established for Hy-Leafs (if we can name them that). Others will surely follow as the model provides for zero tail pipe emissions, low-cost battery charging for local transport needs alongside the familiar consumer convenience of fast-filling (of H2) for range.

In order to maintain the UK's current healthy vehicle manufacturing sector, the development of a vehicle HFC supply chain seems to be essential. Failure to do so seems likely to have the effect of eventually losing current UK engine manufacture such as Land Rover Jaguar's plant at Wolverhampton in favour of importing fuel cell units – which equates to financial leakage from the UK economy.

³⁹ Whittingham, M Stanley : History, Evolution and Future Status of Energy storage, Proceedings of the IEEE | P1518, Vol. 100, May 13th, 2012.

⁴⁰ <http://brightgreenhydrogen.org.uk/>.

Whether UK automotive FC manufacturing capability would or should amount to 100% of FC sub-assembly construction or local integration of both locally made and imported components would be a matter for specific investors. However, given the UK Government's existing vehicle power train investments and commitments to invest, some thought should be given in that context to ensuring a significant continuity of vehicle power plant production in the UK – by encouraging and incentivising substantive private investment in vehicle FC production.

Core-HFC and supply-chain should arguably be a key sector element within the UK's recently announced proposals and consultation on developing a modern Industrial Strategy⁴¹ as HFC aligns well with 9 of its 10 announced 'Strategic Pillars'.

4.2 HYDROGEN SUPPLY CHAIN

This chapter now explores the nature of the hydrogen supply chain activity implied by the headline input-output 'multiplier' values introduced in Chapter 3. It focuses on the composition of these multipliers in terms of output in different UK industries required or supported by key industries that are identified as direct players in the 'hydrogen economy', in terms of the value added (GDP at sectoral level) content of indirect and induced supply chain activity.⁴² It also highlights whether any boost to activity in a given sector is likely to be temporary (start-up investment activity) or on-going (operation of the hydrogen economy).

In Chapter 6 the analysis is extended to consider the employment and wage income content of supply chain activity. The supply chain analysis here and in Chapter 6 continues to focus 'at the margin'. That is, impacts are initially considered in terms of supply chain activity required per £1million of activity generated by the shift to a hydrogen economy. This helps inform analysis of the nature of the industrial base required to respond to opportunities and challenge presented by this shift (in Chapter 5) and of the nature of the skills requirement (Chapter 7). It also helps inform consideration of issues around export opportunities set in the context of the retention of intellectual property (Chapter 8). Chapter 9 then introduces consideration of potential scale of making even a limited shift to a hydrogen economy. It does so by applying information on projected demand shifts that may drive new activity via the multipliers identified and analysed in the earlier chapters.⁴³

However, a crucial issue that must be highlighted up front, and one which frames the analysis in this chapter, is that any transition to hydrogen as a fuel vector will require **a reallocation of spending and related supply chain activity away from traditional fossil fuels, rather than a pure economic expansion**. This issue has been introduced

41 UK Govt. announcement and press releases to date available at: www.gov.uk/government/news/pm-unveils-plans-for-a-modern-industrial-strategy-fit-for-global-britain.

42 In considering results reported, the reader is reminded that input-output multiplier analysis must be approached with caution given that it can only be based on the most recently available 'analytical' input-output accounts for the UK economy, here (as explained in Chapter 3) for the year 2010.

43 As will be explained in Chapter 9, use of input-output multipliers for scaled 'what if' scenario analysis involves additional modelling assumptions that must be considered in drawing policy implications from results reported.

in Chapter 3, where it was explained that, in economic terms, the transition to a hydrogen-based economy is likely to require three key phases to achieve the replacement of traditional refined fossil fuels with hydrogen-based energy source(s).

The first of these mainly involves a change in how personal transportation services are delivered, and is characterised by a contraction in expenditure on traditional refined fossil fuels, mainly petrol and diesel. This is the focus of Section 4.2 below. It is only in the second and third phases – respectively involving uptake of hydrogen as a fuel and investment to support/enable this shift – that potential expansion in activity across the economy becomes relevant. The remainder of the chapter considers the output and value added (GDP by the income measure at basic prices) composition of supply chains that are likely to be relevant in each of these phases, starting with the net multiplier impact of £1million reallocated from conventional fossil fuel to hydrogen in transportation activity.

4.3 REFINED FUEL SECTOR: SUPPLY CHAIN STRUCTURE AFFECTED BY CONTRACTION IN DEMAND FOR PETROL AND DIESEL TO RUN VEHICLES

This section provides an overview of the UK supply chain structure for the ‘Manufacture of coke and refined petroleum products’ (Standard Industrial Classification, SIC, code 19) or ‘Refined fuel’ industry. This is the industrial sector that currently supplies the petrol and diesel used to run vehicles. The headline multiplier values identified in Chapter 3 are £1.47million output required throughout the UK economy per £1million of household or other final consumption spending, with a value added component of £0.33million reflected by the 0.33 output-GDP multiplier. Again, it is important to note that these relate to 2010 analytical input-output data for the UK. In Section 4.2.1 below the nature and potential implication of real world developments (e.g. the closure of the refinery at Milford Haven in 2015) are considered, before the composition of the output and value added multipliers is considered in Section 4.2.2.

4.3.1 Practical qualifications: some real world developments pre- and post-2010

According to the UK input-output data, in 2010 the ‘refined fuel’ sector had a total output of £26,007million (2010 prices). Around 41% of this was produced to meet export demand and 25% to meet UK household domestic demand. A minimal (0.1%) of output went to other forms of final demand (e.g. capital formation). The remaining 34% of sector output was produced to meet UK industrial (or intermediate) demand, about a fifth of which is ‘own sector’ (implying some over-aggregation of activity in the input-output industry and/or notable levels of the use of some refined fuels in the production of others).

The 2010 input-output information has to be put in context. It will incorporate pre-2010 shifts in activity, such as the closure of the Petro Plus refinery in Teeside in 2009. However, two other refineries have closed since 2010: Petro Plus in Coryton in 2012 and Murco in Milford Haven in 2014. This will have impacted the scale of activity in the ‘refined fuel’ sector.

However, in terms of using 2010 multipliers, the key question is whether the input structure (per £1million total input) has changed. A 2015 UK Oil and Gas Industry⁴⁴ shows that exports of refined fuels have fallen lately. If the contraction in the industry is mainly in terms of delivery and destination of output, it is possible to retain confidence in the level and composition of the output multipliers (with the 1.47 core value for output). The 2015 industry data do show an increase in imports around UK refined fuel use. However, the crucial test for the multipliers is the importance of imported inputs to the UK refining industry relative to use of domestic intermediate inputs (although imported refined fuels may still be distributed via UK refineries).

As discussed, the 2010 input-output data already reflect a high import content in the refined fuel industry's input structure (75% of intermediate – i.e. excluding payments to capital, labour and net production taxes – inputs are imported). This high import intensity is what causes the refined fuel industry to have the lowest multipliers of all 103 UK input-output industries. However, if import intensity has increased (e.g. more crude oil raw inputs being imported rather than sourced from the UK offshore industry), the true multiplier values may in practice now be lower than those reported for 2010.

Given that the scenario examined here involves a projected contraction in refined fuel industry activity, this means that the 2010 multipliers may over-estimate the extent of contraction. Given that this will thereby render estimates of the resulting net expansion from transition to a hydrogen (transport) economy as being conservative, the decision has been taken to work with the 2010 multipliers as they stand. It is important to note that any pound, or £1million spend in this sector excludes distribution margins and taxes on fuels, which have to be neglected in an input-output study of the type commissioned here.

4.3.2 The nature of supply chain contraction linked to reduced demand for UK 'refined fuel'

The basic input-output tables (i.e. before the multipliers are derived) tell us that, according to patterns reflected in the 2010 data, the main UK industries that the 'Refined fuel' sector purchases buys inputs from are 'Extraction of crude petroleum and natural gas & mining or metal ores' (SIC 06) and 'own sector' (see above). However, while other more technical relationships are reflected, such as a relatively high importance of purchases from the electricity sector, it is important to note that service industries are also important in the 'Refined fuel' direct supply chain, particularly 'Financial service activities' (SIC 64).

When multipliers are derived to extend to indirect and induced supply chain relationships, the role of UK resource extraction and energy supply industries remains apparent. Moreover, the importance of manufacturing and service activities is enhanced through indirect and induced supply chain links. This is shown in Figure 4.1 where the 0.47 (£470k per £1million) indirect and induced component of the 1.47 'Refined

⁴⁴ DBEIS (2016) Petroleum: Chapter 3, Digest of United Kingdom Energy Statistics (DUKES) – see www.gov.uk/government/collections/oil-statistics.

fuel’ industry multiplier is decomposed by industry type, with the 103 UK input-output industries reported in aggregate groupings (see Table A1 and A2).

Figure 4.1 Composition of indirect and induced supply chain output requirements for the UK Refined Fuel sector.

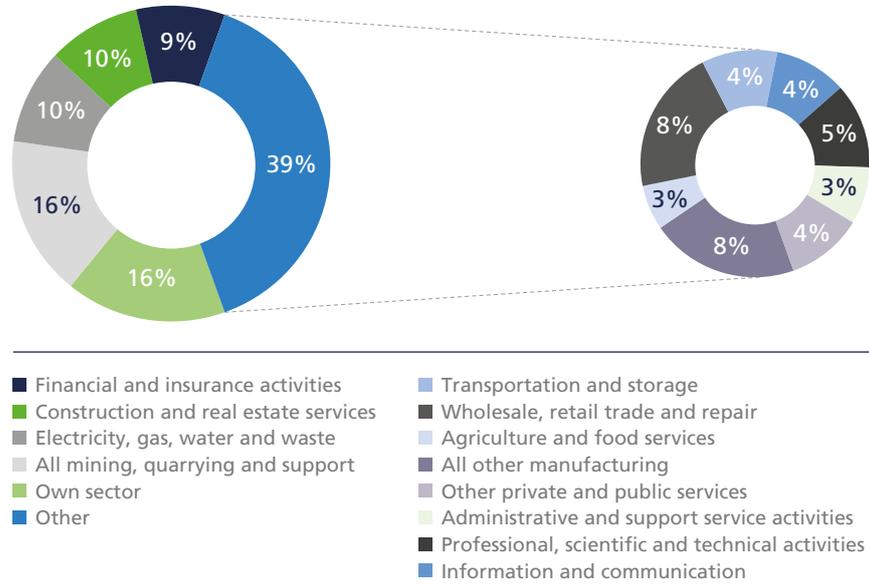
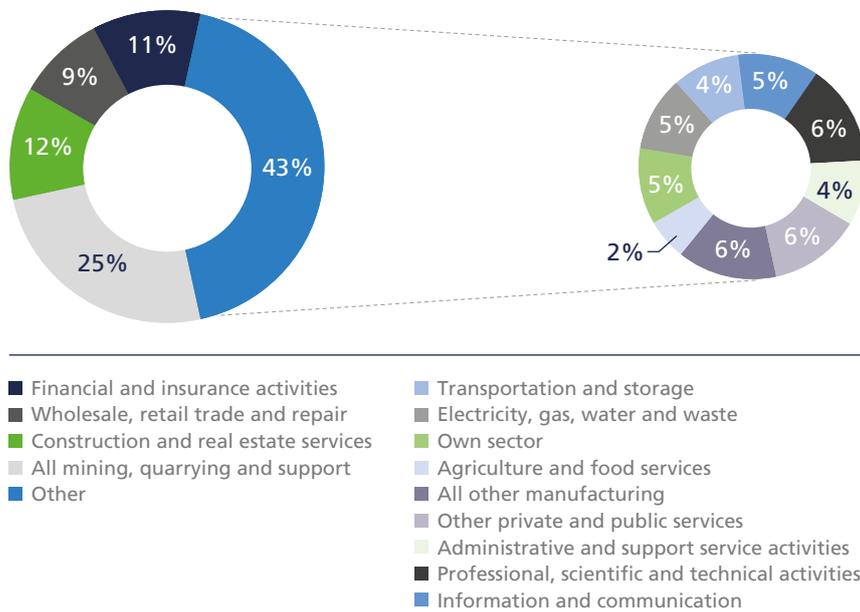


Figure 4.1 shows that 42% of the indirect and induced supply chain linkages within the UK for ‘Refined fuel’ are own sector, extraction ‘All mining, quarrying & support’ and utilities (‘Electricity, gas, water & waste’) industries. A further 8% are located in UK manufacturing.⁴⁵ The key point to note from Figure 4.1 is the wide spread of supply chain linkages in particular, spanning a range of service activities. Throughout this chapter, and Chapter 6 (employment and wage income) this is a common and important finding. That is, **the supply chain activity impacted by a shift to a hydrogen economy is not limited to manufacturing, utilities, construction etc.** However, given that Figure 4.1 focuses on ‘Refined fuel’ as a contracting industry this indicates that **a wide range of UK industries will be negatively affected by a shift away from the use of petrol and diesel to run vehicles.**

If focus is on the value-added (GDP at sectoral level) content of output, the picture changes given that different sectors in the indirect and induced output supply chain have different direct GDP content. Figure 4.2 shows the indirect and induced supply chain composition for value-added/GDP required or supported by demand for ‘Refined Fuel’. The direct value added component of the total 0.33 value-added multiplier (i.e. GDP directly related to the £1million direct final demand) is 0.13 (or 13 pence in the pound) so that the composition of the remaining 0.2 is illustrated in Figure 4.2.

⁴⁵ Labelled as ‘all other manufacturing’ given that ‘refined fuel’ is classed as a manufacturing industry.

Figure 4.2 Composition of indirect and induced supply chain value-added (GDP) requirements for the UK Refined Fuel sector.



There are two important features to note from Figure 4.2. First the identity of the UK industries where most value-added would be lost from reduced demand for petrol and diesel (shown in the larger pie chart) shifts relative to output in Figure 4.1, with the **service industries that provide financial and distributional services having higher GDP content than utilities or manufacturing** (both of which shift to the smaller pie chart). However, the impact on extraction/mining and mining support industries is markedly greater due to the high value-added content particularly of off-shore oil and gas extraction in the UK: the UK 'Extraction of crude petroleum and natural gas & mining of metal ores' industry (SIC 6) has a relatively high direct value-added intensity (68 pence in the pound in 2010). However, this is a result that must be qualified. If the UK oil and gas industry continues to decline, the supply chain multipliers of 'Refined fuel' (positive or negative) will also decline, particularly in terms of GDP content.

The second important feature of Figure 4.2 (value-added content of output) relative to Figure 4.1 (output) is that the spread of industries affected is greater, with the share in the 'other' part of the larger pie chart (broken out in the smaller one) growing in Figure 4.2. Again, the key point is that the UK industries with the strongest shares in Figures 4.1 and 4.2 join the 'Refined fuel' industry itself (which loses the direct impacts of the £1million spend, and its own £130k value-added component within this) as **'losers' in the shift to a hydrogen (transport) economy**. Moreover, this extends to a variety of service industries.

The point made in Chapter 3 – that a pound for pound reallocation of spending away from the UK 'Refined fuel' sector, with its relatively weak domestic upstream supply chain linkages and low marginal multiplier values – is likely to have net positive impacts extends to the sectoral level here. This is discussed in more detail in Section 4.4 below. First, in Section 4.3 the supply chain composition of the existing (2010)

gas and electricity production and distribution industries – identified in Chapter 3 as proxies for hydrogen supply – is examined. Sufficient common elements with the ‘Refined fuel’ supply industry are found such that (in Section 4.4) a key finding is that there are likely to be net contractions in activity in only three or four of the 103 UK industries identified in the input-output framework, most notably ‘Refined fuel’ itself.

As highlighted below, this depends crucially on the assumption of a pound for pound reallocation. On the other hand, given that ‘Refined fuel’ has the lowest multipliers of any of the 103 UK industries, it may be expected that, **as long as any spend withdrawn from petrol/diesel supply is spent within the UK (rather than on imported goods and services), there will be a net overall positive impact.** The question then is one of ‘winners and losers’ at the sectoral level. This can be more fully considered by moving to what has been identified in Chapter 3 as Phase 2 of the transition scenario, where reduced spending on petrol/diesel is reallocated, in whole or in part, to hydrogen.

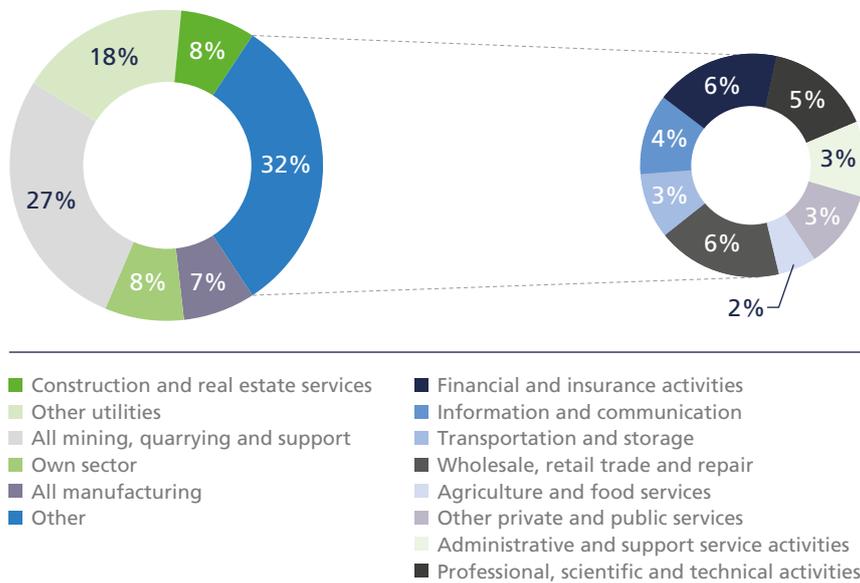
At a high level of analysis, **in 2010 UK households spent just under £6556million on the outputs of the ‘Refined fuel’ sector.** Applying this figure to the overall multipliers, this equates to £9,646million in UK output, £2,187million of which is value-added or GDP content, and supporting 19,225 full-time equivalent jobs. On the other hand, **the same spend directed at an activity similar to UK gas supply would translate to £14,741million in output (net increase of £7,131million), £5,279million in GDP (a net increase of £2,920million, or 0.24% additional total UK GDP in 2010) and 52,689 FTE jobs (a net increase of 33,464).** The next section considers how output and GDP multiplier impacts in the gas and electricity supply proxies are spread across all UK industries, with similar analysis for employment carried out in Chapter 6.

4.4 PROXY HYDROGEN SUPPLY SECTORS: SUPPLY CHAIN STRUCTURES FOR CURRENT UK GAS AND/OR ELECTRICITY SUPPLY

This section is concerned with the need to consider the supply chain implications of compensation of reduced demand for the UK ‘Refined fuel’ industry as spending to run vehicles shifts from petrol/diesel to hydrogen. The first question is how much can be absorbed by spending on hydrogen fuel. In Chapter 3, in the absence of an existing hydrogen supply industry, the existing (again based on 2010 data) UK gas and/or electricity production and distribution industries are identified as potential proxies, albeit in the absence of consideration of any additional layers of activity likely to be required in processing hydrogen and removing emissions via CCS. As discussed in Chapter 3, gas supply may be considered as an appropriate proxy industry given that existing gas industry infrastructure may be used in distributing hydrogen. On the other hand, there may be similarities with electricity supply given that hydrogen and electricity share the characteristic of being a secondary energy carrier/vector rather than a raw energy resource.

Figure 4.3 illustrates the sectoral composition of the indirect and induced (1.25 or £1.25million) component of the 2.25 ‘Gas supply’ industry output multiplier. Here the ‘Electricity, gas, water and waste’ utility composite from Figure 4.1 is split to identify gas supply as ‘own sector’ distinguished from ‘other utilities’, while ‘refined fuels’ falls back into ‘All manufacturing’.

Figure 4.3 Composition of indirect and induced supply chain output requirements for the UK Gas sector.



A key point to note is that the main supply chain sectors where output is supported by demand for gas supply (larger pie chart in Figure 4.3) are resource extraction, utility, construction and manufacturing industries. On the other hand, the 32% of supply chain requirements broken out in the smaller pie chart are mainly service industries. This reinforces the point already made that **the service industry requirement of a hydrogen economy must be carefully considered.**

Another crucial point to be made is that marginal multiplier values reflect the operating costs of the proxy hydrogen supply industry. However, this assumes that sufficient investment will be made up-front to permit the industry to operate in a similar way to that reflected in Figure 4.3 for gas supply as the proxy. That is, on-going service links to, for example, the construction and finance industries assume that sufficient initial investment to enable these supply links is made. The input-output model could be used to separately model impacts of up-front investment activity and this point is revisited in the context of construction below.

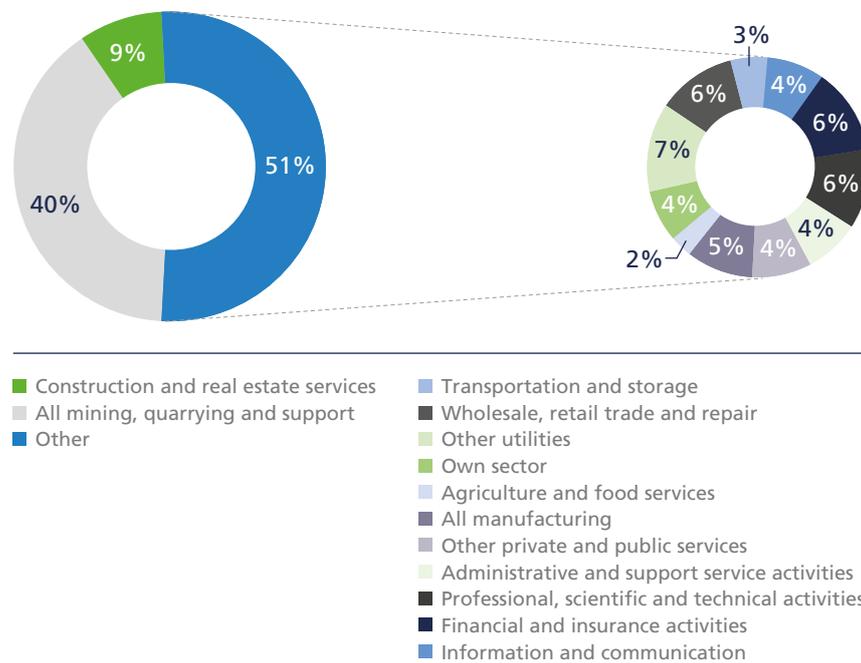
A note on CCS

If carbon capture and storage (CCS) would be introduced in hydrogen supply, this would be likely to increase the direct dependence of the gas supply proxy on manufacturing (e.g. through chemicals required) and on the construction sector. Production may also become more capital and/or labour-intensive, with the latter in turn increasing the strength of induced effects in all of the multipliers identified for (here) the gas supply proxy. Thus, the input structure may change to some extent. However, as discussed in Chapter 3 (Section 3.4.2), the impact of this on multiplier values cannot be assessed without an in-depth study to develop the input-output framework to incorporate CCS activity. Such a study is beyond the scope of the current paper. However, as with additional processing involved in creating hydrogen, it is important to note

that any additional layers of activity, while adding to costs, will also add to supply chain requirements and, therefore, activity supported throughout the UK economy.

Returning to the gas supply proxy as it stands, Figure 4.4 illustrates the indirect and induced supply chain composition for value-added/GDP required or supported by demand for the current (2010) UK gas supply industry. The direct value added component of the total 0.81 value-added multiplier (i.e. GDP directly related to the £1million direct final demand) is 0.22 (or 22 pence in the pound) so that the composition of the remaining 0.59 is illustrated in Figure 4.4.

Figure 4.4 Composition of indirect and induced supply chain value-added (GDP) requirements for the UK Gas sector.



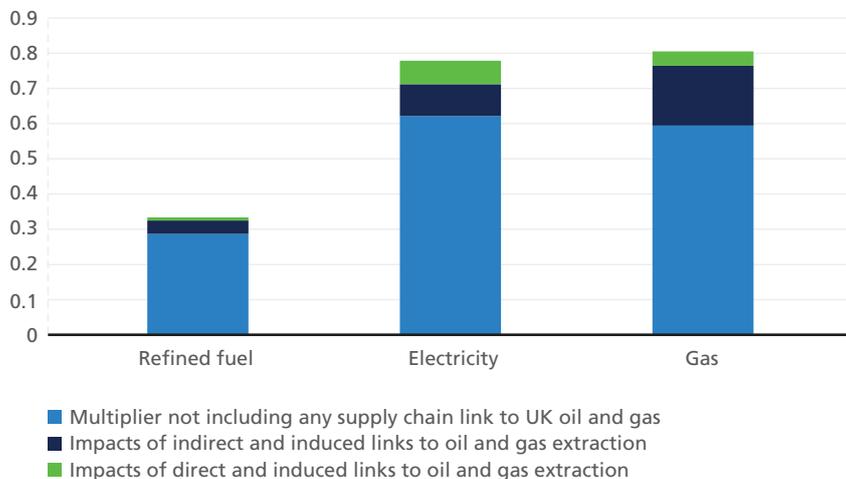
Two key results are apparent in Figure 4.4. The first is, once again **the relative importance of service industries**. The second is the **dominating impact of value-added required or supported by spending on gas in the UK mining and mining support composite group**. Again, as with refined fuel supply but to a greater extent here, the key element of this is the value-added content of the UK off-shore oil and gas extraction industry (noted above as 68 pence in the pound).

This is an important issue in considering the nature of the gas supply proxy. As discussed in Chapter 3 (Section 3.4.2), if extraction in the UK oil and gas extraction industry continues to decline, more of the gas resource would be imported, thereby reducing the values of the UK multiplier values for gas as a proxy for hydrogen. There is also the issue that the gas proxy is largely motivated by the existing infrastructure, rather than the gas resource itself. **If the resource used to produce hydrogen is not one that would be extracted by the UK off-shore industry (SIC 6) then the output and value-added component of the gas proxy multiplier located in the mining and mining support industries will be reduced.**

A note on the impact of the UK oil and gas extraction industry on proxy multipliers

As indicated by Figure 4.4, the existing dependence of the UK gas supply industry on the particularly the UK oil and gas extraction industry (SIC 6) has a marked impact on the nature of the supply chain multiplier relationships that are mapped to the hydrogen supply proxy in this paper. Figure 4.5 shows the impact on the gas supply output-GDP multiplier (which also includes the direct component of 22p in the pound that is excluded from Figure 4.4) of removing the indirect and induced impacts located in the SIC 6 extraction industry. However, given that this is also driven by the use of UK oil and gas in other industries in the supply chain, the multiplier is also shown excluding only the impact of the gas supply industry's own purchases. The results of the same analysis are also reported for the electricity industry (where indirect and induced relevance on UK oil and gas extraction, and the mining and mining support industry as a whole, is shown in Figure 4.6 below). In both the gas and electricity proxy cases, while the impact of discounting these elements is relatively large, inclusion of the same results for 'Refined fuel' in Figure 4.5 demonstrates that other domestic supply chain impacts remain sufficiently strong that either proxy has a larger overall multiplier impact.

Figure 4.5 Impacts on UK gas, electricity and refined fuel output-value added (GDP) multiplier of the remaining impacts of upstream supply chain reliance on UK oil and gas extraction.



	Refined fuel	Electricity	Gas
Total multiplier effect	0.33	0.78	0.81
Excluding impacts of direct purchases from oil and gas extraction	0.30	0.69	0.64
	11.55%	11.60%	21.04%
Excluding any supply chain link to UK oil and gas	0.29	0.62	0.59
	14.11%	20.14%	26.12%

Turning to the alternative proxy of electricity supply, Figure 4.6 shows the composition of the indirect and induced (1.56 or £1.56million) component of the 2.56 ‘Electricity supply’ industry output multiplier. As noted in Chapter 3, the total electricity supply output multiplier is notably larger than that for gas supply (2.25). Figure 4.6 demonstrates that there are, however, similarities in the industrial composition of indirect and induced impacts across other UK industries (though the ‘own sector’ electricity impact is large relative to that for gas).

The main area of divergence between the gas and electricity supply proxies is in the more limited contribution of the mining and mining support industries under the latter. This is emphasised when attention turns to the composition of the indirect and induced component of the electricity supply output-GDP multiplier in Figure 4.7, and has already been demonstrated in Figure 4.5. Again, particularly due to the relatively high value-added intensity of the oil and gas extraction industry, the contribution of mining and mining support industries is larger in the output-GDP relative to the overall output multiplier. However, remember the total multiplier is slightly smaller, (0.79), than that of gas supply, (0.81). In comparing gas and electricity as proxies, note from Figure 4.5 that when the impact of SIC 6 oil and gas extraction components (own sector purchases and fuller supply chain dependence) is removed the output-GVA multiplier for electricity is actually larger than for the gas supply proxy.

Figure 4.6 Composition of indirect and induced supply chain output requirements for the UK Electricity sector.

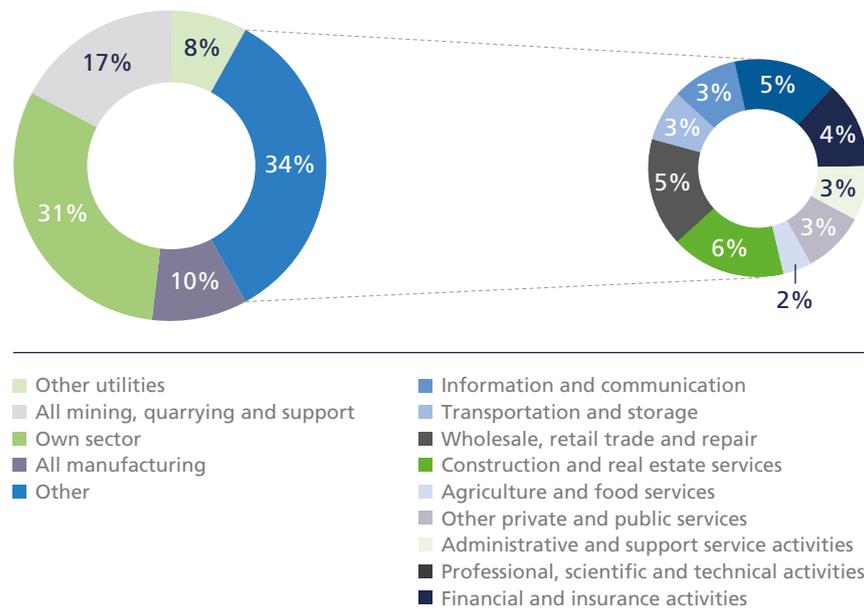
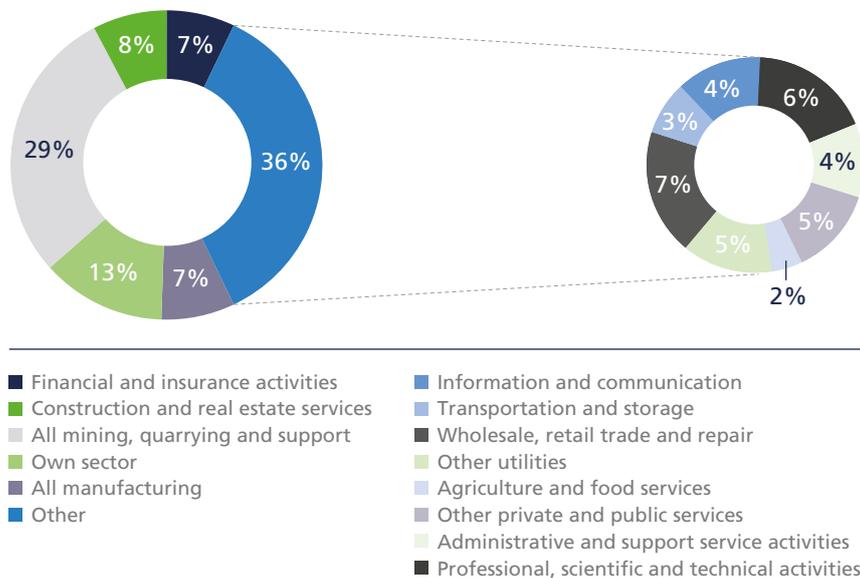


Figure 4.7 Composition of indirect and induced supply chain value-added (GDP) requirements for the UK Electricity sector.



Comparing Figures 4.6 and 4.7, the other key point to note is that the contribution of own sector and other utilities contracts (given a relative low value-added intensity) while the contribution of service industries, particularly finance/insurance and ‘professional, scientific and technical activities’ grows. Thus, again, a key finding is that **the role of service sectors must be carefully analysed in considering the industrial base underlying a potential hydrogen economy**. That is, attention must not be limited to the manufacturing base for equipment to enable hydrogen uptake.

4.5 NET MULTIPLIER EFFECTS OF A SHIFT IN FUEL SOURCE FOR TRANSPORTATION (OUTPUT AND VALUE ADDED)

A key issue that has been emphasised earlier in Chapters 3 and 4 is that it is crucial to consider the net impacts of shifting from the use of petrol and diesel to hydrogen in running vehicles, rather than focus on the gross impacts of spending on hydrogen as a fuel. For illustrative purposes, this section considers the net economy-wide impacts of a pound for pound (£1million/or £1million) shift between petrol/diesel and hydrogen fuels to run vehicles. For various reasons (including but not limited to what relative prices of petrol diesel vs. hydrogen may actual prove to be) a pound for pound reallocation may not be a realistic assumption. But, as noted in Chapter 3, ‘Refined fuel’ has the lowest multiplier values of all UK industries suggest that the total net impact of any reallocation of spending away from refined fuels towards any other *UK produced good or service* (i.e. as opposed to imports) will be positive impact for goods and services production in the UK economy. One other example considered below is the possibility of using some savings from reduced fuel spend on expenditure on vehicles. However, the question of how spending may be reallocated is largely reserved for the fuller scenario analysis in Chapter 9.

Taking the simple example of a pound for pound reallocation of fuel spending, the net total impacts on the UK economy can be derived using the headline multipliers

for refined fuel versus the hydrogen proxy industries. As noted in Chapter 3, the overall output multipliers for gas and electricity supply (respectively £2.56million and £2.25million per £1million demand) are higher than that for refined fuel supply (£1.47million per £1million demand). Thus, a positive overall impact on UK output may be expected for every pound (or £million) reallocated of spending between refined fuel and either proxy. The headline results are generated simply by taking the differences in the total multiplier values: for a £1million reallocation the net impact would be £0.78million (£777,225) for refined fuel to the gas supply proxy and £1.09million (£1,087,705) for the electricity supply proxy.

Similarly for value-added (GDP at industry level), differences in the headline multipliers of £0.33million, £0.81million and £0.78million for refined fuel, gas and electricity supply respectively allow us to calculate the total impact of a £1million reallocation. In this context, given the greater value-added content of UK gas supply, the ranking between reallocation to the gas or electricity proxies is reversed. The net impacts on total UK GDP would be £0.472million (£471,666) for refined fuel to the gas supply proxy and £0.445million (£445,429) for refined fuel to the electricity supply proxy. The main lesson from this headline finding is that **the economy-wide impacts of shifting from traditional fossil fuel to hydrogen to run vehicles will be maximised if hydrogen supply can replicate the same or similar strength of domestic supply linkages as existing gas or electricity supply.**

These net positive overall impacts would, of course, be reduced if the role of the UK oil and gas extraction industry is reduced in line with the analysis in Section 4.3 above. However, retaining focus on the unadjusted proxy multipliers, a key focus in analysing the net impacts of a reallocation of spend from one fuel source to another is to identify if there are any net 'losers'. Of all 103 UK industries as classified in the input-output accounts, application of the multiplier predicts that 3 or 4 sectors (depending on whether the electricity or gas proxy is applied) will suffer net losses. These are identified in Table 4.1. Of these, the sizeable loss is to the 'Refined fuel' sector itself and this is mainly due to the £1million direct loss of demand.

Table 4.1 Identification of industry location and magnitude of potential gross losses from the shift from petrol/diesel to hydrogen.

		Output		Value added (GDP)	
SIC	Sector name	Refined fuel to electricity proxy	Refined fuel to gas proxy	Refined fuel to electricity proxy	Refined fuel to gas proxy
10.4	Manufacture of vegetable, animal oils and fats	-£6	-£27	-£2	-£10
19	Manufacture of refined petroleum products	-£1,060,251	-£1,066,289	-£134,412	-£135,177
20.3	Manufacture of industrial gases	-£629	-£973	-£142	-£220
20.4	Manufacture of petrochemicals	£480	-£925	£78	-£1,495

Source: Author's calculations based on UK input-output data produced by the Fraser of Allander Institute.

In terms of the distribution of potential gains from a reallocation, the results reflect the discussion of the composition of the output and output-GDP multipliers in the previous section. At the level of the aggregate industry groupings reported in the pie charts in Section 4.3 (but with ‘refined fuel’ separated from other manufacturing), Table 4.2 shows that all (except ‘refined fuel’) are net ‘winners’. The net impacts for the industry groupings (which incorporate the gross losses reported in Table 4.1) sum to the totals derived from the headline multipliers above. Note that the mining and mining support industries in particular gain most if gas supply is used as a proxy for hydrogen supply, while manufacturing and service industries (particularly professional, scientific and technical services) gain more under the electricity supply proxy. However, a crucial point to note, once again, is the **importance of considering the potential expansion in various service activities**, and, thus, **the need not to limit attention to manufacturing and/or technical requirements in a shift to a hydrogen economy**.

Table 4.2 Net impacts on UK industry groupings of a £1million reallocation of final spending from petrol/diesel to hydrogen.

SIC	Sector name	Output		Value added	
		Refined fuel to electricity proxy	Refined fuel to gas proxy	Refined fuel to electricity proxy	Refined fuel to gas proxy
01–03, 67,68	Agriculture and food services	£11,086	£10,083	£4,956	£4,500
04–07	All mining, quarrying and support	£194,109	£266,425	£125,589	£178,867
19	Manufacture of refined petroleum products	-£1,060,251	-£1,066,289	-£134,412	-£135,177
08–48	All other Manufacturing	£98,838	£43,935	£32,059	£15,280
52–57	Other utilities	£1,558,506	£1,276,346	£264,261	£275,982
58,77, 78	Construction and real estate services	£44,822	£52,035	£23,176	£26,275
49–51, 59,60	Wholesale, retail trade and repair	£47,225	£32,673	£22,811	£15,992
61–66	Transportation and storage	£20,777	£17,614	£9,064	£7,548
69–73	Information and communication	£32,143	£26,977	£17,736	£14,883
74–76	Financial and insurance activities	£38,151	£28,053	£20,515	£14,872
79–85	Professional, scientific and technical activities	£46,011	£37,505	£26,703	£22,239
86–92	Administrative and support service activities	£27,997	£27,903	£16,009	£16,119
93–103	Other private and public services	£28,291	£23,965	£16,961	£14,286
	Total	£1,087,705	£777,225	£445,429	£471,666

Source: Author’s calculations based on UK input-output data produced by the Fraser of Allander Institute.

4.6 ENABLING THE USE OF HYDROGEN AS A FUEL: POTENTIAL FOR OUTPUT AND VALUE-ADDED EXPANSION IN THE UK VEHICLE MANUFACTURING INDUSTRY

As argued in Chapter 3, there could also be a potential boost to UK manufacturing at the second transition phase if funds saved from spending on petrol/diesel are directed towards UK manufactured hydrogen-ready cars. More generally, **if the UK vehicle manufacturing industry could develop specialism in producing hydrogen-ready cars, routine replacement and upgrade of domestic vehicles during the transition towards hydrogen could involve domestic rather than import spending.** Indeed, one issue for consideration identified in Chapter 3 is whether the availability of a good quality UK branded vehicle may help incentivise individuals to engage in the transition towards hydrogen cars.

Moreover, if the UK industry could develop such a specialism in producing hydrogen-ready vehicles, there is also the **potential to expand current vehicle production for export:** in 2020 the UK vehicle manufacturing industry (SIC 29) exported just under 60% of its output, while only 13% went to UK household demand. That is, **the UK vehicle manufacturing industry is already an export orientated one and could potentially extend its role via developing specialism in producing hydrogen ready vehicles.**

Again, in Chapter 3 the headline output and output-GDP multipliers for the UK vehicle manufacturing industry have been identified (based on the 2010 input-output data) as 2.35 for output (£2.35million required/supported throughout the UK economy per £1million spend on vehicles produced) and 0.80 for GDP (£0.8million per £1million spend). Figure 4.8 shows the results of decomposing the indirect and induced components (1.35) of the output multiplier while Figure 4.9 considers the related GDP content (only 0.31, given a high direct, 0.49, component of the output-GDP multiplier).

One key observation is similar to what has been noted already for fuel supply industries. This is **the importance of impacts on some of the service industries of demand for UK vehicle manufacturing is greater when focus is on GDP content rather than gross output.** The opposite is true of impacts via other (i.e. non-vehicle) manufacturing and utilities where output gains are less value-added intensive. A key industry area to highlight here is the ‘wholesale, retail trade and repair’ grouping. Even where cars are imported, distribution services within the UK will be used. This has two important implications. First, even if hydrogen-ready vehicles are imported, if this involves additional spending on cars by UK consumers, **there may still be positive multiplier effects on the UK economy as firms involved in distribution services within the UK will export their services to foreign manufacturers.** Where there is a direct boost to distribution activity via export demand in this way (as opposed to an indirect boost via demand for UK vehicle manufacturing) the multipliers for the relevant distribution industry (identified as SIC 45 in Table 3.1 in Chapter 3) are relevant: these are 1.94 for output and 1.07 for value added (i.e. £1.94million and £1.05million in UK-wide output and GDP respectively per £1million export

demand for UK distribution services). If relevant, these multipliers can be decomposed in a similar manner to that demonstrated here for vehicle manufacturing and other industries.

Figure 4.8 Composition of indirect and induced supply chain output requirements for the UK Motor Vehicles sector.

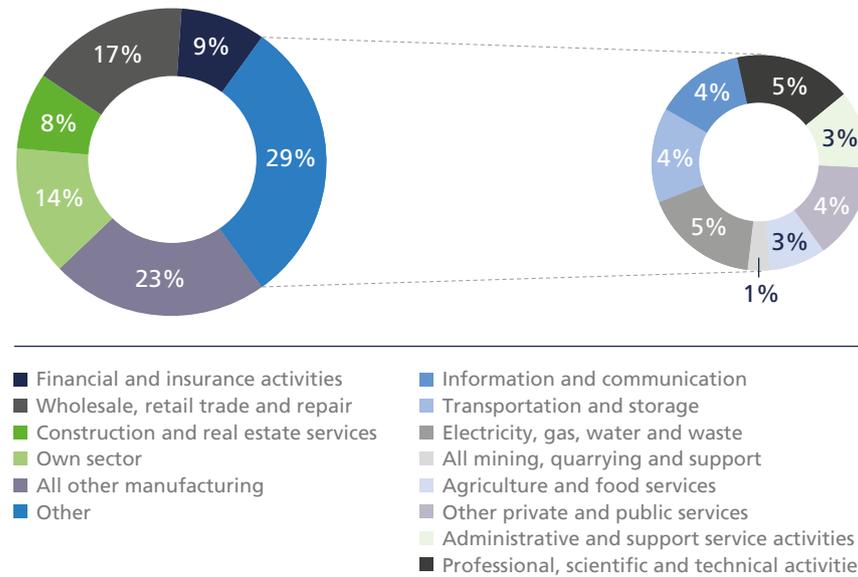
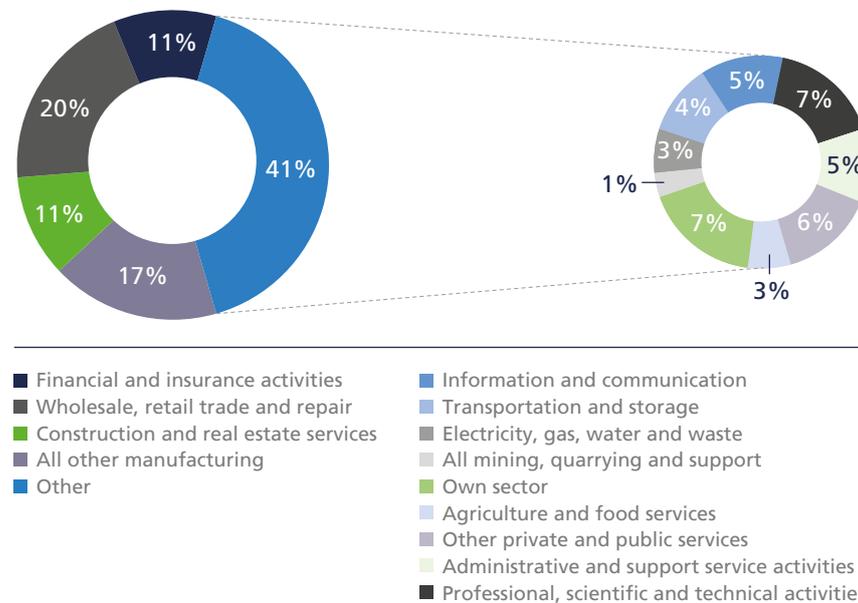


Figure 4.9 Composition of indirect and induced supply chain value-added (GDP) requirements for the UK Motor Vehicles sector.



Second, and related to the first point, in the context of using input-output multipliers (which assume that if demand for output rises the requirement all input requirements expand) **if there is substitution in favour of UK manufactured vehicles away from imports rather than an overall increase in demand for cars, there may not be much**

of a net expansion in distribution activity. That is, the 17% contribution of distribution services to the output multiplier in Figure 4.8 and 20% for value-added in Figure 4.9 may reflect a potential over-statement of the total marginal multiplier impacts of any increased demand for the UK vehicle manufacturing sector. On the other hand, **if there is a net boost to export demand for the UK industry and/or a net increase in UK household demand for UK-made vehicles, an increase in distribution activity may be more likely.**

Within the aggregate manufacturing industry in Figure 4.8 and 4.9, the greatest supply chain impacts of demand for UK vehicle manufacturing are found in industries such as manufacturing of fabricated metals, rubber and plastic, iron and steel, all of which would remain important in the context of hydrogen-ready vehicles. On the other hand, other types of manufacturing such as electrical equipment to support fuel cell (manufacture of batteries and accumulators) may become more important in the context of shifting to hydrogen-ready vehicles. However, in considering economy-wide multiplier effects, as with the consideration of CCS in the context of the gas supply proxy above, the results in Figures 4.8 and 4.9 would only be substantially affected if such a development had sufficient impact on the input structure (and UK supply-chain dependence) of the industry.

4.7 OUTPUT AND VALUE-ADDED LINKED TO UK INDUSTRIES THAT MAY BE 'INVESTMENT' TARGETS IN FACILITATING THE SHIFT TO A HYDROGEN ECONOMY

Chapter 3 identified a third transition phase wherein there may be potential for economic expansion through investment in activity to support increased uptake and maintenance of hydrogen-based technologies. Within this, three broad categories for the types of industries affected/targeted were highlighted (in Section 3.4.3). The first is industries where output is required to enable people to actually use hydrogen as a fuel and, in the case of transport, the vehicle manufacturing industry discussed in the previous section would be the key focus. But, if focus broadens to areas such as heating, then the manufacture of heating systems would become relevant. This is not an area considered at this stage but to do so would involve identifying the UK input-output classified industry that produces the product(s) used by consumers and studying the up-stream supply chain as is done here for vehicle manufacturing.

Another dimension of the crucial 'make or buy' question was also identified in chapter 3 in the context of enabling people to use hydrogen as a fuel. That is, R&D activity may be required to enable UK manufacturers to produce hydrogen-ready equipment to enable people to switch to hydrogen as a fuel. Indeed, R&D activity may be required in order to make the switch in the fuel supply (the potential multiplier impacts of this switch have been considered in Sections 4.2–4.4 above). For this reason in Section 4.6.1, multiplier impacts for R&D spending in the UK are decomposed. Within this, the crucial question of the timeframe over which boosted R&D activity may be required and sustained and the implications for the use of multiplier analysis is considered.

The question of relevant timeframe for additional activity and impact is also relevant in the context of the second type of industry identified at the investment stage under Phase 3. This is where short-term but potentially large scale investment spending may be required to enable supply and distribution of hydrogen. In Section 3.4.3 focus was placed in this context on the UK construction industry, which would be involved, for example, in developing service station capacity for hydrogen refuelling for vehicles; however, it would be relevant in a wider hydrogen economy context where, for example, pipeline infrastructure needs to be laid, heating systems need to be installed etc. Accordingly, the headline multipliers for the UK construction industry are also decomposed in Section 4.6.1.

Finally, a third type of industry where increased capacity requirements may be required was identified in Chapter 3 (Section 3.4.3) as those indirectly rather than directly impacted by spending changes. This falls into a more general consideration of considering increased capacity requirements in those industries that play a prominent role in the supply chain decompositions carried out throughout this chapter. Consideration of commonly identified industries in this respect is the focus of Section 4.6.2.

4.7.1 Direct investment targets – examples of R&D and construction

In terms areas of the UK economy that may deliver the greatest opportunities for a ‘high quality’ impact through the shift to a hydrogen economy, research and development (R&D) is a key candidate. That is, there is a **crucial ‘make or buy’ question**, where **there are important opportunities if the UK can become a known specialised player in designing and delivering hydrogen-based technologies and delivery capacity (outlined in Section 1.6, (Chapter 1)**. Moreover, if the UK can become a ‘maker’ of hydrogen-related technologies, **opportunities may extend to exploiting hydrogen economy developments in other countries**. If so, there is potential for **sustained economic expansion in the UK though continued R&D activity at least over the medium term as a hydrogen transition takes place**. As previously, the UK would begin such a shift into HFC vehicle manufacturing from a position of existing strength in design and manufacture of analogous conventional vehicles and supply chain components and services suggesting that the UK is well placed to make such a shift from that existing *brand-strength*.

Chapter 3 has identified how, in terms of UK industrial value-added multipliers, with £1.29million in value-added generated throughout the UK economy per £1million final demand (including export of services), ‘Scientific Research and Development’ (SIC 72) ranks second out of all 103 UK industries in terms of the GDP impacts required/supported in its supply chain (only ‘Education’ is higher). It also ranks highly on employment and wage income multipliers, as will be explored in Chapter 6.

A crucial point to note, however, is that the impacts of R&D spending will be incorporated in the multipliers of other industries. That is, where industries such as the UK vehicle manufacturing or energy supply sectors and/or their up-stream supply chain partners commit part of their **operational spending to on-going R&D activity within the UK**, impacts in the UK R&D sector will already be captured within the ‘Professional, scientific and technical activities’ grouping in the Figures in Sections

4.2–4.5. However, **if a boost to R&D activity is required to enable a major step-up in capability and/or capacity in the context of the shift to a hydrogen economy – which would include any R&D required to make CCS a reality – additional spending in the form of government and/or non-profit sector final spending may be required.** If this is the case, it is appropriate to directly apply that spending to multiplier values for the R&D industry.

Figure 4.10 Composition of indirect and induced supply chain output requirements for the UK Scientific Research and Development sector.

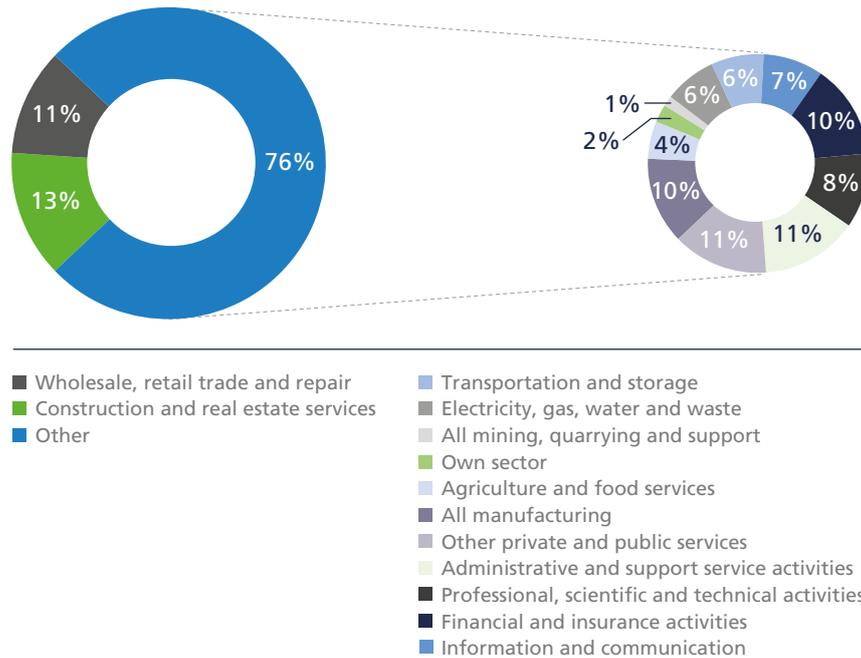
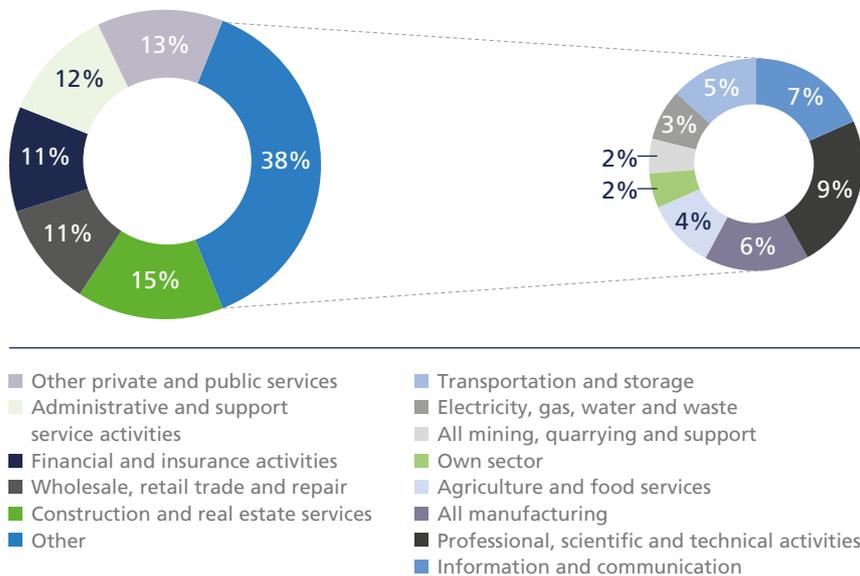


Figure 4.10 shows the results of decomposing the indirect and induced components (1.39 of a total 2.39) of the UK R&D industry output multiplier (it is separated from ‘other professional scientific and technical activities’). Figure 4.11 (below) then considers the related GDP content. As noted above, R&D has a relatively high output-GDP multiplier of (1.29), and it is one with both relatively high direct value added content (59 pence in the pound) but also strong indirect and induced GDP embedded in the UK supply chain. Thus, Figure 4.11 illustrates the industry sources of only the indirect and induced £0.7million in value-added per £1million final spending on R&D.

The key observation that can be made in comparing Figures 4.10 and 4.11 is that, while output is supported across a wide range of UK industries, **if attention is focussed on value-added or GDP generated the impacts are more concentrated in service activities with higher value-added intensities.** On the other hand, as has been found above for other industries, the relative importance of impacts in manufacturing and utility industries decreases when attention is on value-added rather than gross output.

Figure 4.11 Composition of indirect and induced supply chain value-added requirements for the UK Scientific Research and Development sector.



From Figure 4.11, the biggest share of indirect/induced value-added required/supported by R&D spending is in the ‘Other private and public services’ grouping. Just over half of this is located in the **UK Education sector**, where academic departments in universities are located and there is both high direct value-added and strong supply chain linkages involving GDP generation. As will be explored in Chapter 6, this type of supply chain activity is particularly strong in the wage income element of value-added.

Note that, as in the case of other industries where multiplier impacts are decomposed in this chapter, that an important area for impact in the R&D supply chain is in the UK construction industry (combined in the figures with the renting/leasing of property/land through real estate services). In moving to consider the **UK construction industry as a potential investment target to enable a step-change in the shift to a hydrogen economy**, this result emphasises a point already made for R&D above. That is, the impacts of construction spending will be incorporated in the multipliers of other industries where they and/or their up-stream supply chain partners commit part of their **operational spending to on-going construction activity (including routine maintenance etc.)**.

Again though, if a boost to construction activity is required to enable a major step-up in capability and/or capacity, for example, in **building hydrogen re-fuelling stations and/or installing pipelines for hydrogen supply and/or carbon sequestration**, additional spending in the form of government and/or private investment to enable capital formation may be required. If this is the case, it is appropriate to directly apply that spending to multiplier values for the construction industry. However, this must be done in the context that the boost from any investment in construction may be short-term in nature, relating only to the additional investment required with multiplier

impacts in other industries potentially not lasting much longer than the construction project in question. On the other hand, where major infrastructure development is required, project periods could last a number of years.

Figure 4.12 shows the results of decomposing the indirect and induced components (1.31 of a total 2.31) of the UK construction industry output multiplier. Figure 4.11 then considers the related indirect and induced GDP content, or the 0.6 component of the 1.01 output-GDP multiplier that is not directly generated in the construction sector itself.

In contrast to the case of R&D, comparison of Figures 4.12 and 4.13 illustrates a similar spread of output and GDP impacts across UK industry groupings in the UK construction industry supply chain. **Again, the core finding is that the relative importance of impacts in some service orientated industries tends to grow when focus is on value-added while the opposite is true of manufacturing and utility industries.**

Another key observation is the importance of ‘own sector’ indirect and induced impacts in the construction industry, which implies some **over-aggregation of activities in the ‘construction’ industry in the UK input-output accounts**. The input-output sector incorporates all of SIC grouping 41–43, which encompasses construction of buildings (SIC 41), civil engineering (SIC 42) and specialised construction services (SIC 43), where the latter includes plumbing, glazing, roofing etc.

Figure 4.12 Composition of indirect and induced supply chain output requirements for the UK Construction sector.

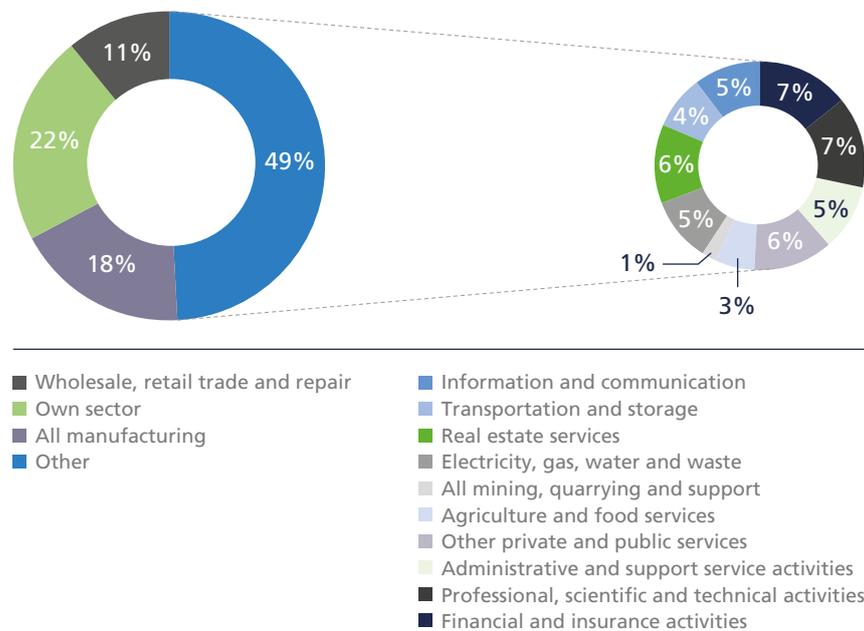
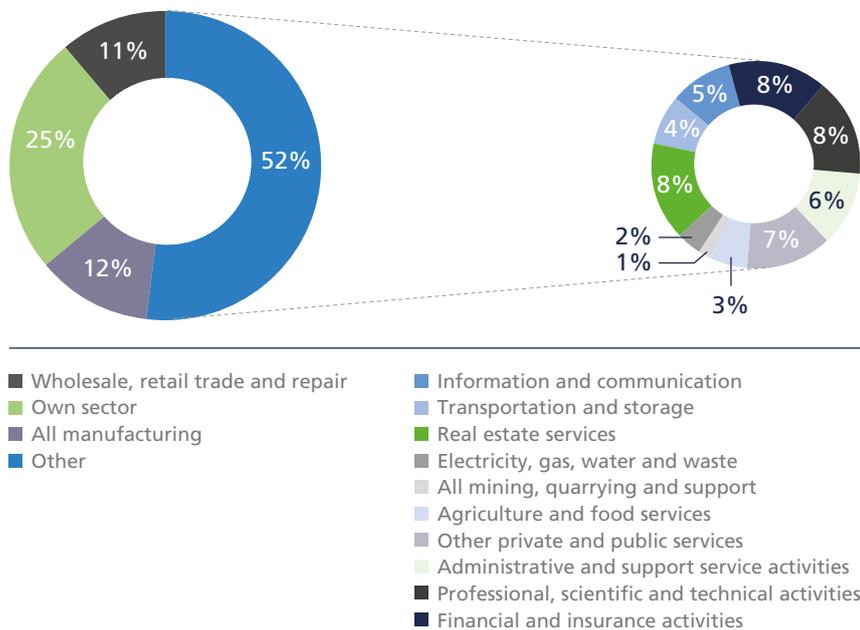


Figure 4.13 Composition of indirect and induced supply chain value-added (GDP) requirements for the UK Construction sector.



4.7.2 Enabling expansion in upstream supply chains of directly impacted industries

As in the cases of R&D and construction, the supply chain decomposition for key industries that are likely to be directly affected by a shift to a hydrogen economy has identified a range of upstream industries within these supply chains where capacity may ultimately need to expand. This is partly reflected through the multipliers themselves, where indirect and induced impacts reflect additional input requirements of supply chain industries. However, there may in practice be **constraints on the capacity and capability of supply industries that will require investment in physical and/or human capital to enable them to expand** as predicted via the application of simple input-output multipliers. In the context of using input-output multiplier modelling for scaled scenario analysis, Chapter 9 will highlight the potential need for more sophisticated economic modelling to consider the need for, and further impacts of investment requirements on economic adjustment processes.

However, the results of the multiplier decomposition carried out here, and in Chapter 6 for employment, do enable initial consideration of the type of industrial and skills base that is likely to be required in making the move to a hydrogen economy. This is the focus of Chapters 5 and 7, and some key observations can be drawn from findings reported in this chapter (and from Chapter 6 for skills analysis in Chapter 7).

The first key observation that can be made is in the context of shifting from refined (petrol and diesel) to hydrogen fuels in a transport context. This chapter has shown that if either existing gas or electricity supply is taken as a proxy for hydrogen supply, **the UK oil and gas extraction industry is likely to continue to play an important role.**

The multiplier analysis demonstrates that particularly domestic gas extraction is crucial contributor to the strong UK GDP impacts of a potential shift from refined fuels (where the import content is high and multiplier impacts thus relatively weak) to hydrogen produced using a gas resource.

If imported gas were used instead, the benefits to the UK economy would be likely to remain positive but much more limited. This in turn raises the issue of the **need for investment in CCS to limit the climate change impacts of continued economic reliance on hydrogen carbons**. The introduction of CCS may or may not significantly impact the operational multiplier impacts of spending on a hydrogen fuel (proxied here by gas or electricity supply). However, as noted in the previous section, investment first in R&D and then construction activity to enable large scale CCS may have significant economy-wide impacts, even if over a shorter time frame.

The second key observation is the **importance of service activities** across the different industries for which multiplier impacts have been decomposed in this chapter. In particular, a common finding has been **the importance of the UK finance and insurance industries in terms of both output and (particularly) GDP impacts of potential expansion and on-going operation of a hydrogen economy**. Consideration of any increased capacity implications for the UK finance industry must be taken in the context of net impacts (i.e. given that the hydrogen economy involves replacement of a traditional fossil fuel economy). However, at least in the transition stages, where new and additional investment activity must be financed, this is likely to be positive. **However, assessment of what capacity expansion is possible in practice in the UK finance industry must of course be subject to uncertainty presented by the current Brexit transition.**

4.8 CONCLUSIONS

This chapter has focussed on examining the composition of the supply chains of UK industries that are likely to be directly impacted through the three key economic phases identified in Chapter 3 as likely for the UK economy to move through in realising the actualisation of a hydrogen-economy. It has begun to explore the nature of the hydrogen supply chain activity underlying the headline input-output ‘multiplier’ values introduced in Chapter 3. It has done so by examining the composition of these multipliers in terms of gross output and value-added (GDP) content therein in different UK industries required or supported by key industries that are identified as direct players in the ‘hydrogen economy’. It also highlights whether any boost to activity in a given sector is likely to be temporary (investment activity) or on-going (operation of the hydrogen economy).

In terms of fuel supply, a key argument of the analysis is **the need to consider the net impacts of moving away from petrol and diesel in transport activity** (and thereby triggering a contraction in the relevant supply industry) and towards hydrogen based fuel (with proxy industries identified to consider the nature of expansion. The key finding was that, provided actual hydrogen supply shares the type of relatively strong UK supply chain linkages of current gas and electricity supply, **net impacts on the**

UK economy are likely to be positive. However, a large share of the potential positive GDP impacts on the UK economy originate in the off-shore oil and gas industry. While this presents dual challenges in the context of (a) the maturing (and currently declining) off-shore industry, and (b) the low carbon motivations for shifting to a hydrogen economy, it may also present an opportunity if expansion through knowledge and physical infrastructure development involves a combination of hydrogen and CCS.

The other key argument emerging from the multiplier analysis in this chapter is the need to ensure that attention to development of the UK industrial base to enable a hydrogen economy includes attention to required service sector provision. Particularly where attention is on value-added (GDP) rather than broader activity levels, services play potentially as important a role as manufacturing in enabling and operating a hydrogen economy in the UK. How these arguments extend in the context of the employment and jobs of supply chain activity to support a hydrogen economy is the focus of Chapter 6. First, Chapter 5 considers how the findings reported here impact the potential development of the UK industrial base, including potential scale and other economies that may be realised through development of industrial clusters.

A final point to make in concluding this chapter is that the proxies employed probably do not adequately reflect that hydrogen production is liable to be a far more distributed activity than the UK's current highly centralised refinery and refined fuels activity. Hydrogen can be made anywhere that a gas or electricity supply can be found and even simply for reasons of increased local and national resilience there is great merit in having such a far more distributed activity. Hydrogen is a relatively awkward gas to transport other than by pipe on account of its low volumetric density – and if and when the UK develops a substantive piped hydrogen network there will be areas where it will not be practical to pipe hydrogen in from distant larger production facilities. A more distributed activity will almost certainly require a larger measure of capital investment than a centralised model would, however it also implies more employment and more economic activity generally. And for that 'more distributed' reason alone, the economic figures developed within the model used certainly and probably quite significantly **underestimate** the amount of economic activity implied in such a transition.

CHAPTER 5

DEVELOPMENT OF A UK MANUFACTURING BASE AND INDUSTRIAL CLUSTER(S)

A business or industrial cluster seeks to concentrate related businesses, supply chain and other associated organisations geographically in order to increase their collective competitiveness. The idea was formalised for the modern era by Michael Porter in *The Competitive Advantage of Nations* (1990)⁴⁶ and by subsequent authors such as Paul Krugman,⁴⁷ but having evolved naturally in many places as the industrial revolution progressed it has been discussed and considered by economists such as Alfred Marshall since the late 19th century.

Historically clusters tended to evolve in and around geographies which had competitive advantages of their own in respect of specific industries and trades. Most obvious is heavy industry where for instance steel-making would tend to arise in areas adjacent to extraction of the raw materials required for steel manufacture (mainly coal and iron ore).

The siting of steel-making fairly close to the source of the main input raw materials reduces supply transportation costs significantly offering a local competitive advantage. That local advantage would then draw in labour (increasing local population) and attract downstream users of the steel product and other manufacturing and service providers.

Similar historic models can be observed all across the UK, even from before the industrial revolution where a great deal of the UK's historical weaving and cloth manufacture developed around water-mill sites relatively close to agriculture or agricultural market towns providing the input wool and flax.

The traditional geographical industrial cluster has tended to rely heavily on raw material supply advantages and arguably still does in respect of a number of heavy industries – but this is of little relevance to modern high-tech industries where raw material transportation costs tend to be low or non-existent (for IP-dominated industries such as IT).

In the modern era social activities and networks are of more direct relevance in clustering, whereby human capital and hence local capability is the greatest determinant factor in successful clustering (Porter⁴⁸).

5.1 HFC CLUSTERING

The production of fuel cells themselves and as opposed to systems is a highly specialised activity and one on which the sector will be largely based. It is not practical to go into the details of this here, not least on account of the fact that there are many fuel cell type variants, however it is important to stress that this activity will underpin a great deal of value creation. Whether fuel cell manufacture itself as an activity would wish to cluster directly or benefit from it, is difficult to assess. IP is often closely guarded and the easy exchange of personnel that clustering would facilitate might be a serious concern to some UK fuel cell manufacturing businesses. Clustering of these

⁴⁶ Porter, M.E. (1990). *The Competitive Advantage of Nations*. New York: The Free Press.

⁴⁷ Krugman, P. (1991). *Geography and Trade*. MIT Press. 1–142pp.

⁴⁸ Porter, M. E. 1998, Clusters and the new economics of competition, *Harvard Business Review*, Nov/Dec98, Vol. 76 Issue 6, p77.

core-HFC technology companies might be more concerned with clustering alongside some of their supply chain partners and downstream customers/integrators rather than clustering among themselves.

Hydrogen and fuel cell technologies more generally however draw heavily on existing gas and electricity supply chains and so if there is a will to develop a UK HFC cluster or clusters, areas with existing strength in those areas make obvious target locations. This will build naturally on the reasons as to why those areas have already built up strength thereabouts.

One of those reasons will certainly be relative proximity to early-markets on scale. Whilst major power stations and other energy supplies are generally outside cities and towns, and with the exception of UK nuclear generation plant perhaps, they are seldom too far from them and the expertise required to build and maintain them is similarly close by. Raw materials for generating power are generally piped in or have been extracted from the local areas (gas and coal mainly). The expertise in delivering that raw-energy supply is local or can be cost-effectively remote in the form of piped or other relatively low-cost bulk deliveries (often marine transport).

Unsurprisingly then the bulk of the UK's existing energy expertise and capability is to be found in and around urban areas including ports.

Given the traditional reliance of UK industry on significant energy supplies and delivery expertise, HFC clustering would fit naturally into one or more of the UK's existing industrial or commercial areas. An interesting alternative possibility is of course that such industry may also follow the availability of new forms of energy generation, i.e. renewables which often are not so available in present urban centres.

5.2 KNOWLEDGE

A second clustering factor to consider is that with HFC technologies being a new entrant to the energy space, existing industry has a growing interest but relatively little awareness of them. Exemplifying that, 40–50 years after the UK abandoned coal-derived town gas which was 50% hydrogen, almost no one is left with the UK gas supply sector who remembers town gas or that a great deal of the UK's historical energy supply (1790s onwards) was in fact hydrogen. That lack of knowledge/memory feeds into a number of misunderstandings, the main one being that hydrogen is somehow too dangerous to be used as a regular fuel gas – a curious misconception given that it formed about 50% of UK's entire gas supply for more than a century and a half.

The establishment of a successful cluster or clusters will require some degree of new-blood already trained in and knowledgeable of HFC technologies along with locally pre-established flexible skills and knowledge base. This plays into *knowledge services cluster*-thinking which has fuelled the development and growth of areas such as Bangalore, Shanghai and Silicon Valley.

In such areas companies tend to develop close relationships with local universities and research facilities. These can train and provide new labour market entrants with

the required knowledge and also provide innovation capabilities and facilities which SMEs (in particular) would not be able to provide of themselves.

5.3 FUNDING

Successful cluster locations are also usually marked out by the interest financial markets pay to them. The Cambridge IT, biotech and electronics cluster – sometimes referred to as Silicon Fen – being a good example of this, whereby venture capital funding for new businesses is more easily obtained by new-start IT companies in that area. The relative ease of obtaining investment funding relates strongly to the funders recognising that start-ups in such an area are more likely to find the calibre of people required to deliver a successful IT company than in other areas, and that the locality already has an extensive range of other support mechanisms and supplies conducive to success.

5.4 Potential UK HFC cluster locations

On the basis of the above factors it is relatively easy to locate obvious potential UK locations for an HFC cluster or clusters.

Given HFC technologies' limited reliance on high transport cost supplies, almost any location in the **South East of England** offers the required proximity to market, knowledge, skills and financial basis which would be required to deliver an effective HFC cluster. A number of HFC companies are already based in the South East.

The Midlands offers essentially the same potential for success as the South East – with Birmingham, Sheffield, Coventry and others already having a good level of existing HFC activity and considerable strength in automotive and its supply chain, much of which is world-class.

Moving further North, population and hence market density thins out markedly, however there are obvious potential HFC cluster locations in the **Merseyside-Manchester-Leeds-Bradford area, Teeside and Newcastle /Gateshead** areas.

These areas of Northern England are interesting from a strategic UK Government investment perspective, their relative distance from London's financial markets makes it more difficult for them to attract venture funding (see above) than is the case for the South East and Midlands. As such, deliberate national investment in clustering in the North may draw such attention from the financial markets – and hence act as a useful balance against increasing UK reliance on population growth and wealth creation in the South East.

Beyond England, there are obvious potential areas for HFC clusters in Scotland, Wales and Northern Ireland.

In **Scotland**, the M8 corridor between Glasgow and Edinburgh and the larger area formed between those, Fife and Stirling encompasses many specific locations where successful clustering could be envisaged – this area has extensive general industrial capability including world-class refinery and gas processing/handling operations and support.

The Scottish North-East A90 corridor is home to most of the UK's physical world-class oil and gas extraction capability and hence has similar potential to the Edinburgh-Glasgow-Fife-Stirling area.

Scotland's current HFC activity is probably equal to the scale of the rest of the UK combined with major investment projects in Fife, Aberdeen and Orkney and with others in planning.

Scotland is liable to take a different route from the densely populated parts of South and Midlands however – with the bulk of Scotland's hydrogen supply being derived from otherwise-constrained renewables rather than from natural gas. The significant opportunity in using that otherwise wasted potential generation to green transport (in particular) in Scotland is liable to be the main driver in Scottish HFC development.

Whilst constrained renewables as a specific driver of HFC development is very strong in Scotland, it should be noted that there are areas in the North of England, Wales and Northern Ireland with a similar potential constrained-renewables HFC driver.

The UK is not homogenous in terms of its renewables potential – a *one-size fits all* UK policy as per UK Government renewables incentives schemes would not be wise. There may be very good reasons for developing and supporting HFC clusters (plural) based on different local economic drivers – possibly of different types.

In Wales, the M4 Newport/Cardiff to Swansea/Port Talbot corridor and further West over toward Milford Haven provides the type of pre-existing local capability and knowledge basis on which to develop HFC clustering. [The Wrexham area would fall within the auspices of any Merseyside HFC development.] However and as per Scotland, much of the rest of Wales, mainly central and West Wales, has excellent renewables (and/or renewables potential) giving rise to the likelihood of constrained/wasted renewables and there may be a good argument for supporting role out of the use of HFC technology in those parts.

Northern Ireland is quite similar to Wales in that it has an obvious existing industrial corridor stretching from around Lisburn through Belfast and along the M2 to Ballymena. This would be suitable for HFC clustering of a similar nature to the more populated parts of England, though it lacks the same scale of population/local market. However and as per Scotland and Wales, the North, Western and central parts of Northern Ireland have excellent renewables (and/or potential), especially in conjunction with cross-border capabilities to the West. In these areas, one would expect constrained renewables to be an issue and to provide an economic driver for the deployment of HFC technologies.

The Scottish Government, Welsh and Northern Irish Assemblies have responsibility for economic development in those areas. All of these devolved governments have proven keen to partner with UK Government in the delivery of investment programmes – such as the currently topical City-Region Deals – and so devolution is not seen as a barrier to a good degree of holistic UK HFC strategic planning and partnership.

5.5 SUGGESTED CLUSTER TYPES

Rather than thinking in terms of a single *historic heavy industry-type cluster*, the above consideration draws attention towards a more *hub and spoke-type* model. This would see an innovation and manufacturing cluster (or clusters) in and around an area (or areas) of existing relevant significant industrial strength and a range of deployment (service and support) clusters in areas where there are specific local economic drivers advantaging deployment of HFC technologies.

This might take the form of 2 innovation and manufacturing clusters, one based in the South East, Midlands or the Merseyside to Leeds area of England, another based in Central or on the East Coast of Scotland.

These would naturally support HFC technology deployment in their immediate vicinities.

Out-with their immediate vicinities, these innovation and manufacturing clusters would serve as hubs for *deployment clusters* (or spokes). Deployment clusters elsewhere would specialise in deployment specific to local geographical and economic circumstances.

Close working and a measure of cross-over would be expected from the hubs but some clear lines of demarcation/specialisation are easily conceivable.

An English Cluster/hub would concentrate mainly on innovation and manufacturing and on the deployment of HFC technologies in densely populated areas – which will rely much more heavily on natural gas derived hydrogen (at least initially).

Just as it is suggested that a Scottish hub would support renewables based hydrogen production all across the UK below, an English based hub would be expected to support hydrogen role out in densely populated parts of Scotland such as Glasgow – which more resembles Manchester or Birmingham than it does Perth, Powys, Penrith or Coleraine.

The A1M, M4, M5 and M6 transport corridors would give any likely hub/cluster location relative ease of access to most of England, Wales and the West of Scotland to directly support *deployment clusters* as necessary.

An English cluster/hub would draw on resources such as the University of Birmingham's doctoral training college and spread of HFC research expertise, Imperial College London's significant HFC R&D capability along with specialist HFC expertise from the universities of Bath, Oxbridge, Cardiff, Newcastle, UCL, Cardiff and Glamorgan. It could also draw on relevant TICs such as that for advanced manufacturing at Warwick. Fundamental UK R&D facilities such as those at RAL in Oxfordshire are unlikely to be far away from its location.

All of the likely English locations possess a surplus of general manufacturing capability and an excellent supply of skilled labour and trainees from the likes of the universities mentioned and a wide range of craft-level skills training in nearby further education colleges.

Since transport is likely to be the earliest and *best hit* in terms of using hydrogen to decarbonise with or without carbon sequestration, there would be significant merit in strongly linking an English HFC cluster/hub to the existing English car manufacturing sector.

A Scottish hub would be driven mainly by the need to maximise the use of otherwise wasted renewables generation and hence its main concentration would be on means to deploy electrolysis-based hydrogen production.

Within reasonable proximity to Northern Ireland and the North of England where similar geographic and climatic conditions are found, such a Scottish hub would be heavily involved in supporting those areas from a shared common perspective. Support should also be provided to deployment clusters anywhere in the UK or Ireland with similar local circumstances.

Such a Scottish hub would be expected to draw on Scotland's world-class refinery and gas handling expertise and also on existing manufacturing and service capability which currently feeds (mainly) into the Scottish oil and gas and chemical sectors.

In terms of innovation, Scotland's universities are already united via the (Scottish Government supported) Energy Technology Partnership banner and would readily feed into any such structure.⁴⁹ Scottish Enterprise has previously and is currently looking at means of supporting HFC innovation and deployment in Scotland.

Scotland has no significant mass road vehicle manufacture, but does have a diverse range of specialist transport supply chain manufacturers making amongst other things refuse vehicles and is home to the UK's largest bus and coach manufacturing operation. Also the UK's most extensive range of high tech maritime transport manufacturing companies and many specialist SMEs feeding directly into the UK and EU transport manufacturing sectors. As such Scotland's HFC manufacturing and innovation interest is likely to be in niche low-volume high-value applications rather than in mass vehicle manufacture. That interest is less dependent on having immediate geographical proximity to the relevant mass manufacturing sectors.

It is assumed that likely locations for both English and Scottish hub clusters will have good proximity to factors liable to facilitate the growth of locally cohesive HFC communities. These include the obvious transport and higher education linkages, but also important human factors such as reasonable cost housing, schooling, commerce, entertainment and other such elements likely to attract and retain high quality personnel.

Deployment Clusters would focus on optimising the early roll out of HFC technologies in areas best suited for that early roll out. Whilst these could conceivably involve some local innovation and manufacturing, they would mainly provide a measure of clustering support for local installation and service capabilities.

⁴⁹ Prof Irvine, one of this paper's authors is one of the ETP's directors.

They would probably cluster a mixture of existing and new local energy supply SMEs and provide relatively low cost bases for larger suppliers (including inwards investors). Ideally they would have some connection to local higher or further education institutions.

It is suggested that UK and Scottish Governments directly support the *Hub Clusters* whilst *Deployment Hubs* are supported (to some extent at least) by the relevant local authorities and regional economic development agencies.

Clusters should have some form of corporate existence to allow them to apply for national and international grant funding.

In addition to some measure of direct funding from national and regional authorities, both types of hub would benefit strongly from business rates relief and other investment tax incentives. The latter may prove particularly attractive to potential inwards investors.

5.6 MODELS AND ECONOMIC/POLICY QUESTIONS

The economic models underpinning renewables and natural gas-derived hydrogen deployment and usage are quite different – given the different alternative values of the energy input feedstock and different application values. Feedstock and application costs and values can vary substantially depending on where in the UK an activity is proposed.

Renewables-derived hydrogen will have to deal with intermittent production, whereas natural gas (or nuclear-derived electrolysis) production can be more *base-load*. Intermittent production results in less production *asset-sweating* and hence to greater apparent capital costs, but intermittent production is *time-shifting* the availability of renewables enabling better demand matching and that time-shifting/storage element has a financial value in its own right. Also we might expect the assets to have longer life-span.

Hydrogen derived from otherwise constrained renewables is making use of a resource that would otherwise be lost/wasted which has no market value at all if it is not used, but what value/cost does it have if it is used for hydrogen production?

The proposed figures costs and energy efficiency surrounding hydrogen production from SMR employing *carbon capture and storage* should be considered as preliminary as there is no clear consensus on CCS costs and efficiencies at this time, and these may be significant.

Evidently renewables which could be used for general grid supply, could also be used for hydrogen production shifting from electrical energy to the more urgent areas for impact, chemicals, fuels and transport. This can not only avoid intermittency problems but could also provide grounds for increased renewables implementation.⁵⁰

50 H. Lund, *Renewable Energy Systems – A Smart Energy Systems Approach to Choice and Modelling of 100% Renewable Solutions*. 2nd Ed, Academic Press 2014.

Albeit qualified and as per 2.1.1, the potential value of hydrogen in transport applications is significantly higher than it is for its use in electricity storage, with hydrogen for heat offering least value for money (natural gas being a commodity consumers expect to pay relatively little for).⁵¹ That value hierarchy tends to suggest that commercial organisations producing hydrogen will focus strongly on transport as their initial market. How will it be possible to encourage them to target lower value applications – what type of tax and/or incentive regime might do that? Is that something that we would want to do even? Should simple market economics be allowed to saturate the potential transport market before hydrogen makes a significant impact in other energy applications?

High temperature fuel cell systems can operate on natural gas and other hydrocarbon fuels as discussed in the sister White Paper on Energy Systems – but still deliver good net carbon reductions. Also outputting high quality heat, they have far greater potential in domestic and medium-scale stationery applications in combined heat and power mode (than do low temperature fuel cell types). Not employing hydrogen at all, (although they can be set up to run on hydrogen), and producing both heat and electricity results in a much more complicated and quite different business proposition to that of low temperature FC technology, although the potential can also be assessed in relation to replacement of refined fuels, as is the main approach in this paper.

Since economics will ultimately determine the success (or otherwise) of hydrogen deployment, it is essential that appropriate real-world operational economic models are derived and fully understood – these will underpin market decisions to invest, or not. This should not be forgotten when planning/delivering HFC clusters.

Strong provision should be made for the establishment of accepted and fully understood micro-economic models (plural) and more extensive macro-economic impact models covering the range of likely HFC deployment types. As seen in this paper's early stage modelling work – the most positive overall economic impact of HFC deployment is as likely as not to derive from HFC supply chain and service sectors as it is from HFC specific manufacturing. Hub Clusters would seem to be the natural home for such work.

⁵¹ The relative UK consumer values for electricity, gas and transport derived from consumer prices are laid out in section 2.1.1.

CHAPTER 6

EMPLOYMENT

6.1 INTRODUCTION

This chapter focuses on the employment embodied in the hydrogen supply chain activity implied by the headline input-output ‘multiplier’ values introduced in Chapter 3 and decomposed for output and total value-added (GDP) in Chapter 4. Here attention is on considering the composition of hydrogen supply chain multipliers in terms of the sectoral location of jobs and the associated generation of wage income. The latter gives some indication of the ‘quality of jobs’ associated with particular areas of the hydrogen economy. This is in so far as wage income is an element of value-added at the economy-wide level (GDP by an income measure) and to the individuals who receive earnings from paid employment. Given that jobs in the input-output framework are reported in full-time equivalent (FTE) units (for reasons of aggregation across sectors) it is not possible to consider the quality of jobs from a part-time vs. full-time perspective. However, Chapter 7 does go on to consider skills requirements, which is another important indicator of the quality of jobs/employment (and one that may, to some extent correlate with wage incomes)

As in Chapter 4, the focus is on decomposing multipliers (here, employment and wage income) for different UK industries that are directly impacted, to identify ones where activity is indirectly required or supported by direct players in different stages of the transition to a hydrogen economy. In doing so, it highlights whether any boost to activity in a given sector is likely to be temporary (investment activity) or on-going (operation of the hydrogen economy). The analysis continues (at this stage) to focus ‘at the margin’, with impacts considered in terms of supply chain activity required per £1million of production to serve final demand activity generated by the shift to a hydrogen economy, with scaled scenario simulations reserved for Chapter 9. However, again, the marginal analysis in the current chapter helps inform analysis of the nature of the industrial and employment base required to respond to opportunities and challenge presented by the shift to a hydrogen economy. In particular, the focus on employment and wage income will help inform analysis of the shorter and longer terms skills requirement in Chapter 7.

Similar also to Chapter 4, a crucial issue that must be highlighted up front, and one which again frames the analysis at this stage, is that **any transition to hydrogen as a fuel vector will require a reallocation of spending and related supply chain activity away from traditional fossil fuels, and associated employment, rather than an outright boost to employment and wage income across the UK economy.** In Chapter 3 three key phases to achieve the replacement of traditional refined fossil fuels with a hydrogen based energy source(s) were identified.

Again, the first task in the current chapter is to consider the employment and wage income impacts of the first of these phases, which is characterised by a contraction in expenditure on traditional refined fossil fuels, mainly petrol and diesel. This is the focus of Section 6.2 below. Then, from Section 6.3, the impacts of potential expansion through the second and third phases – respectively involving uptake of hydrogen as a fuel and investment to support/enable this shift – on employment and wage incomes are considered. Again, this begins with consideration of how

employment and wage income in a hydrogen supply industry – proxied by a sector that is similar in its input structure to current (2010) UK gas or electricity supply – may offset job and wage losses in the supply of traditional refined fuels.

6.2 EMPLOYMENT AND WAGE INCOME ASSOCIATED WITH SUPPLY CHAIN CONTRACTION LINKED TO REDUCED DEMAND FOR UK ‘REFINED FUEL’

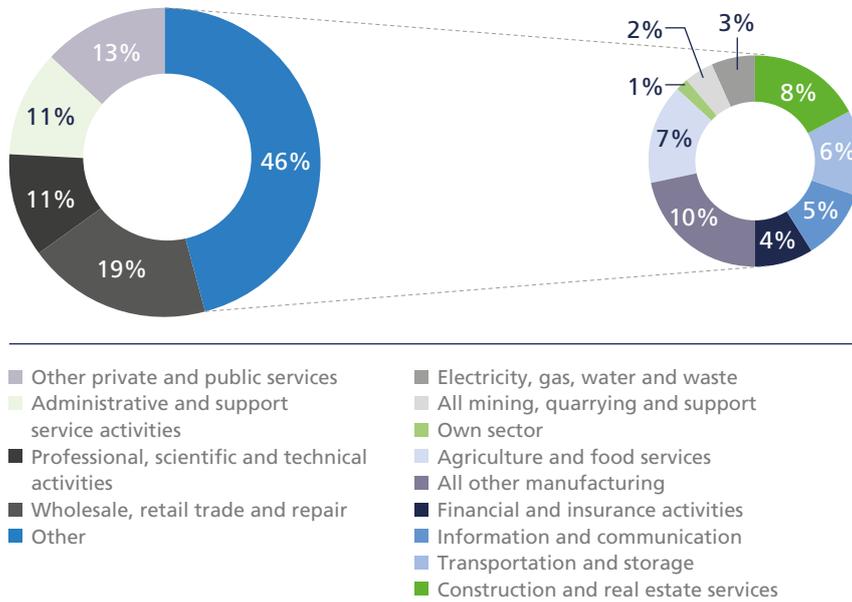
In relation to Section 4.2 (Chapter 4), this section provides an overview of the employment and wage income embodied in the supply chain of ‘Manufacture of coke and refined petroleum products’ (SIC 19).⁵² The focus here is to show where there may be potential gross losses in employment and wage income if spending is reallocated from refined fuels to hydrogen fuels. In chapter 9, the number of FTE jobs losses in the ‘Refined Fuel’ industry and the potential FTE jobs created from reallocating fuel spend to hydrogen (using electricity and gas proxies) are considered in more details.

In terms of employment, the ‘Refined Fuel’ industry’s direct output-employment multiplier is 2.93 FTE jobs per £1million of final demand spending on petrol or diesel. As noted in Chapter 3, and similarly to output and value-added in Chapter 4, this ranks as the smallest output-employment multiplier across all 103 UK industries. Therefore, any £1 million reallocation of household spending away from petrol or diesel to hydrogen will result in 2.93 gross FTE job losses in the UK supply chain.

The direct employment component of the total 2.93 FTE multiplier (i.e. FTE employment related to the £1million direct final demand) is 0.38 so that the composition of the remaining 2.55 is illustrated in Figure 6.1. The larger pie chart in Figure 6.1 shows that wholesale/retail, professional/technical, administrative/support and other public/private service industries contribute the largest shares of the indirect and induced FTE employment requirements for the UK ‘Refined fuel’ sector. **These service industries are, therefore, the industries that will be most impacted (alongside the ‘Refined fuel’ sector itself) by the gross contraction in employment associated with reduced spending on petrol and diesel.** However, note that this pattern of sectoral impacts **contrasts with the findings reported in Chapter 4 for output and value-added** (Figures 4.1 and 4.2 respectively), where the negative impacts of reduction in demand for petrol and diesel were found to be more on (less labour intensive) resource extraction (mining and mining support), construction and financial services industry groupings.

52 “The reader is reminded of the qualifications discussed in Section 4.2.1 regarding how the structure of the sector may have shifted since 2010, the input-output base accounting year used to identify multipliers.”

Figure 6.1 Composition of indirect and induced supply chain employment requirements for the UK Refined Fuel sector.

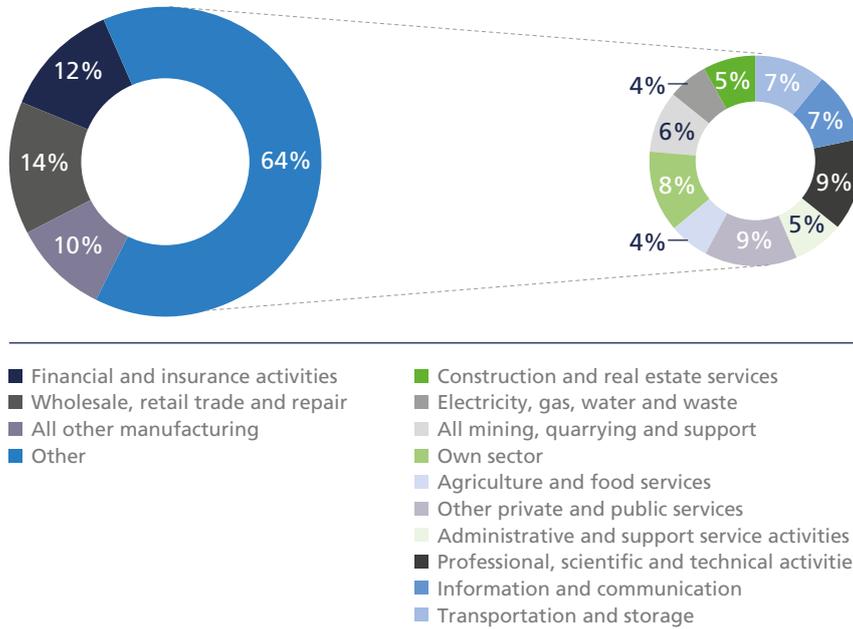


Alternatively, if attention focusses on wage income, as an indicator of quality of jobs, the picture is somewhat different. Figure 6.2 shows the 0.09 (9p in the £, or £90k per £1million) indirect and induced component of the 0.19 'Refined Fuel' industry output-wage income multiplier across the UK 103 industries.⁵³ As with the employment (and other) multiplier(s), the 'Refined fuel' industry ranks lowest of all the UK industries, primarily reflects the weakness of its backward supply linkages in the UK economy. Figure 6.2 shows that in terms of the quality of jobs – as indicated by average wage rates – in the 'Refined fuel' industry supply chain, there is more of mix across a range of industries than with employment. The key point to note is that higher average wage sectors, such as the 'Finance and insurance activities' industry gain more importance, as does mining/mining support activities, when attention is on wage income effect rather than absolute employment levels.

However, a key point to note is that the strength of 'own sector' indirect and induced supply chain impacts increases markedly when attention is on wage income rather than employment levels. Added to the fact that direct component of the wage income multiplier is much more important than that for employment emphasises that **the quality of jobs impacted by contraction in demand for petrol and diesel may be of more concern than the number of jobs lost. This is particularly in the 'Refined fuel' sector itself, where job and wage income losses are less likely to be compensated by a shift to hydrogen fuels.**

⁵³ The direct component of the wage income multiplier is proportionately larger than for the employment multiplier reflects relatively high wage intensity per worker within 'Refined Fuels' itself.

Figure 6.2 Composition of indirect and induced supply chain wage-income requirements for the UK Refined Fuel sector.



Overall, the same point as made in Chapter 4 with regard to output and value-added should be made here. This is that, given the relatively weak employment and wage income multipliers for ‘Refined fuels’, outside of the own sector employment and wage income losses, it is likely that a reallocation of spending will have net positive impacts across the UK as a whole. However, again, this is dependent on any spend withdrawn from petrol and diesel is spent within the UK (rather than on imported goods and services).

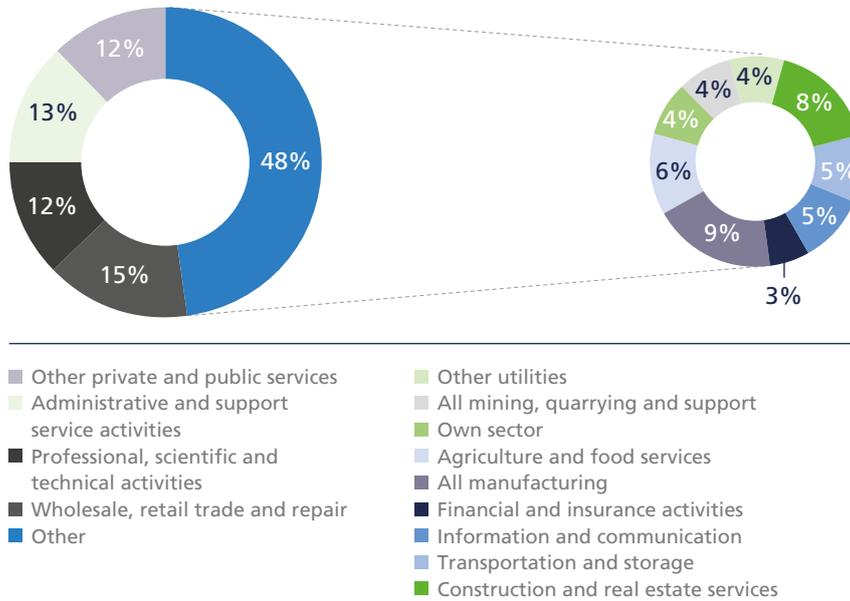
6.3 PROXY HYDROGEN SUPPLY SECTORS: EMPLOYMENT AND WAGE INCOME EMBEDDED IN SUPPLY CHAIN STRUCTURES FOR THE GAS AND/OR ELECTRICITY PROXIES

This section examines implications and impacts on employment and wage income within the supply chain of the gas and electricity industries as candidate proxies for hydrogen supply. As discussed in Chapters 3 and 4, these industries may be considered as appropriate proxies for the uptake of hydrogen on the basis of similar infrastructure in the case of gas and the sharing of secondary energy supply characteristics in the case of electricity.

Thus, focus is on which industries within the supply chains of the current UK gas and/or electricity supply sectors may absorb the skill-content, quantity and/or quality of jobs shifted away from the ‘Refined fuels’ supply chain. For the case of the gas supply proxy, Figure 6.3 shows a breakdown of indirect and induced (6.02 FTE job

per £1million) components of the overall current 8.04FTE UK gas sector output-employment multiplier.⁵⁴

Figure 6.3 Composition of indirect and induced supply chain employment requirements for the UK Gas sector.



The crucial point to note from the results in the larger pie chart in Figure 6.3 is the similarity compared to Figure 6.1 for ‘Refined fuels’ in terms of the types of industries with the largest indirect and induced employment impacts of a switch in demand.

That is, there is potential for compensation and absorption of the employment impacts of reallocated demand and spending from petrol/diesel to hydrogen, where the supply chain for the latter is similar its domestic supply chain to the current gas supply proxy. Figure 6.3 implies that there will be retention of FTE jobs in the same services industries as will be negatively impacted through contraction of the refined fuel supply chain. Moreover, with a higher overall output-employment multiplier (8.04 FTE jobs per £1m spend on the gas proxy compared to 2.93 in ‘Refined fuels’) there is a higher employment intensity spread across the gas supply chain so that net positive impacts are more likely.

The potential for compensation of reduced supply chain employment when demand for petrol/diesel contracts is not limited to services. For example, the trade-off in jobs in extraction (mining and mining support) linked to contraction in the ‘Refined fuels’ supply chain (smaller pie chart in Figure 6.1) is likely to be compensated by jobs supported in this sector in the gas supply proxy supply chain. The same is true in the case of utilities (split to identify gas as ‘own sector’ in Figure 6.3). The shares of gas supply chain jobs in the wholesale, other private and public services and

⁵⁴ In contrast to the findings for output and value-added in Chapter 4, the contribution of the UK off-shore oil and gas industry to the output-employment multipliers for either the gas or electricity proxies is relatively small. This is due to the relatively low labour intensity of this and other mining and mining support industries. However, when attention turns to wage income this issue becomes more important again, though still less so than was found for value-added (given the capital intensity of UK extraction industries).

professional scientific & technical industry groupings are smaller than for 'Refined fuels'. However, again, the overall multiplier for which these shares are reported is larger in the case of gas supply so that below it is found that there will still be a net positive impact if there is a pound for pound (£1m for £1m) reallocation of spending.

Figure 6.4 Composition of indirect and induced supply chain wage-income requirements for the UK Gas sector.

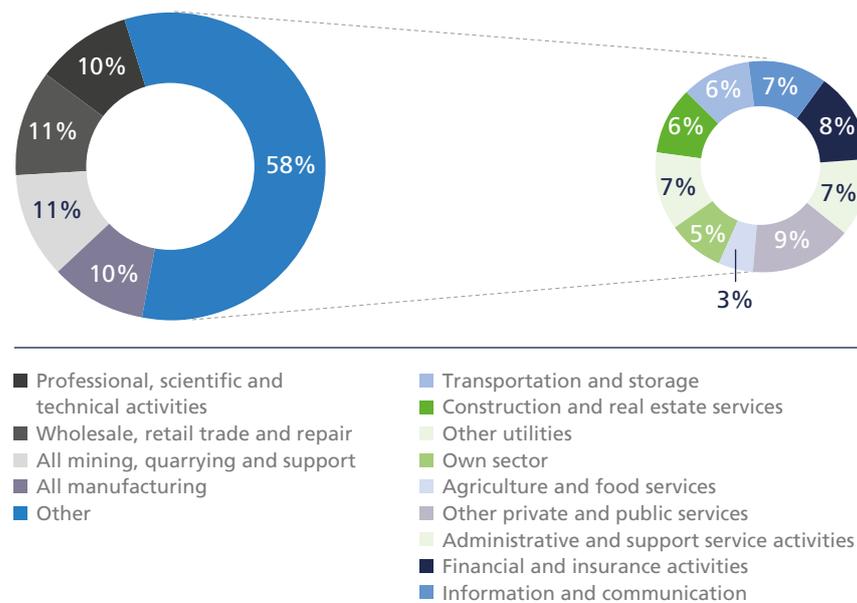
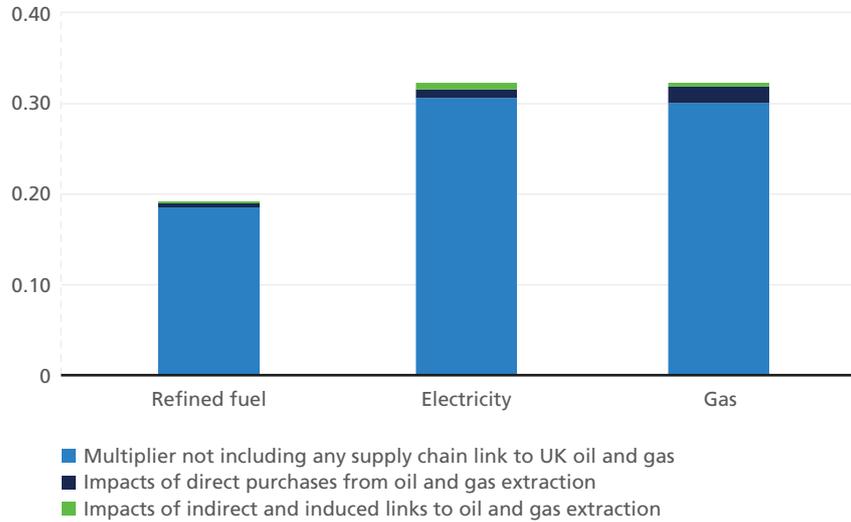


Figure 6.4 shows the distribution of the 0.22 (220k per £1million) indirect and induced component of the 0.32 output-wage income of UK 'Gas supply' industry. Again, (as with 'Refined fuels'), the higher value jobs (as judged by average wage rates) are located in services, extraction and manufacturing industries with the UK gas supply chain proxy. This again provides the potential that, outside of the 'Refined fuels' industry itself, there is potential to absorb both the quality and quantity of jobs following a reduction in spend on refine petrol and diesel. This is despite the fact that the share of jobs and wage income sectors such as finance and insurance are smaller in Figure 6.4 relative to Figure 6.2; again this is because Figure 6.4 shows shares for a larger overall output-wage income multiplier (0.32 relative to 0.19).

Note on the declining importance of impacts in the UK oil and gas extraction industry when considering employment and wage income.

Figure 6.5 shows the impacts on the gas supply output- wage income multiplier (which here includes the direct component of 10p in the pound that is excluded from Figure 6.4) of removing the indirect and induced impacts located in SIC 6 extraction industry. It gives a comparison with 'Refined fuel' and the alternative proxy of 'Electricity supply'. Moreover, given that income generation in the off-shore oil and gas extraction industry is also driven by the use of UK oil and gas in other industries in each of the supply chains, the multiplier is also shown excluding only the impact of the target industry's own purchases.

Figure 6.5 Impacts on UK gas, electricity and refined fuel output-income multiplier of the remaining impacts of upstream supply chain reliance on UK oil and gas extraction.



	Refined Fuel	Electricity	Gas
Total multiplier effect	0.19	0.32	0.32
Excluding impacts of indirect and induced links to oil and gas extraction	0.187	0.313	0.305
	2%	3%	6%
Excluding any supply chain link to UK oil and gas	0.19	0.31	0.30
	3%	5%	7%

Albeit to a lesser extent than output or value added in Chapter 4, for both electricity and gas supplies, particularly the latter, the impact of discounting these elements is noteworthy. Nonetheless, the multipliers are still larger than that for refined fuel, with or without these elements included (and the impact of removing them is less). **If focus is on number of FTE employment, given the low labour (but relatively high wage) intensity of the off-shore industry, the impact on the multipliers of removing off-shore elements from the multipliers falls to less than 1% in all three industries.**

To more fully consider the alternative hydrogen supply proxy of the current electricity industry, Figure 6.6 shows the composition of the indirect and induced (7.11 FTE jobs per £1m) component of the 8.05 'Electricity supply' industry output-employment multiplier. The first thing to note is that while the overall multiplier is similar to that of the gas supply proxy, the indirect and induced (rather than direct) elements are more important in the case of electricity supply. However, Figure 6.6 demonstrates that the sectoral composition of the indirect and induced components is similar for gas and electricity. The main visible difference between Figures 6.3 and 6.6 for the gas and electricity proxies is the greater proportionate importance of manufacturing

in the latter. However, again, it should be noted that Figure 6.6 is a distribution for a smaller number of indirect and induced jobs.

Figure 6.6 Composition of indirect and induced supply chain employment requirements for the UK Electricity sector.

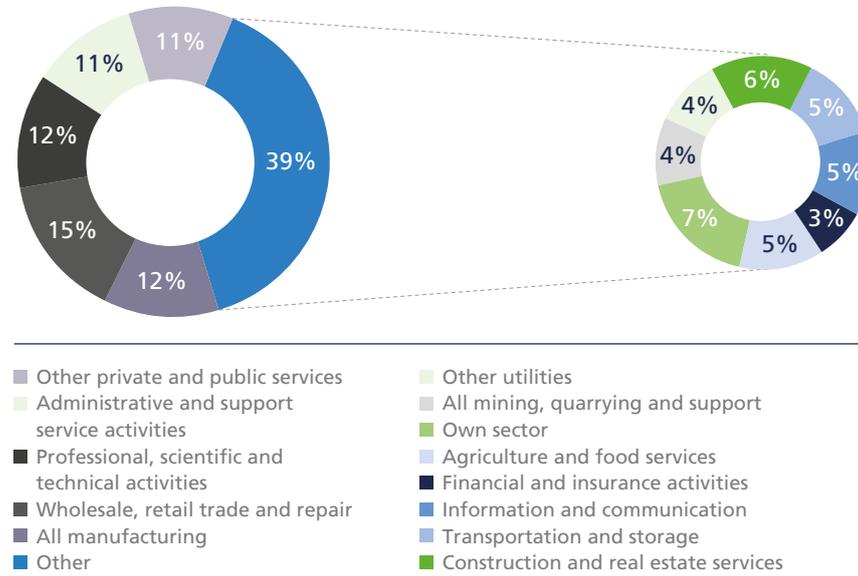
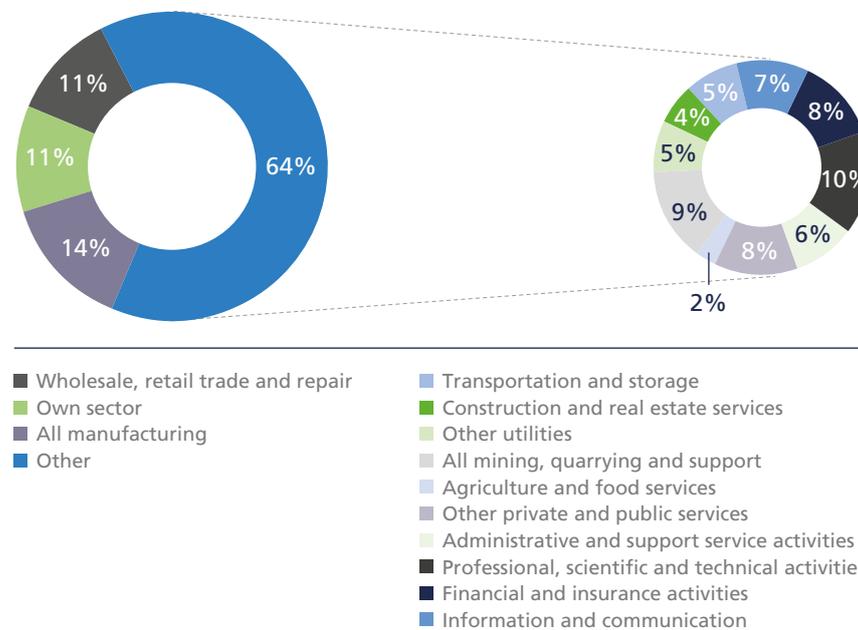


Figure 6.7 Composition of indirect and induced supply chain wage-income requirements for the UK Electricity sector.



In terms of wage income, the overall output-wage income multiplier for the electricity proxy is almost identical to that of gas, at 0.32, or £320k per £1m of final demand spending. However again, there is variation in terms of both the contribution and nature of indirect and induced elements therein. For electricity, the indirect and

induced element is 0.26 (260k per £1million, compared to 0.22 for gas). However, Figure 6.7 demonstrates the broad similarities in terms of the industrial composition of indirect and induced impacts, with the main differences being in terms of the greater role of ‘own sector’ impacts in the case of electricity and slightly larger relative contribution of mining/mining support in the case of the gas proxy. This reflects the findings reported above in Figure 6.5, where the impacts of removing the SIC 6 off-shore oil and gas extraction (a component of mining/support in Figure 6.7) are slightly larger in the case of the gas supply proxy.

Comparing Figures 6.6 and Figure 6.7 (employment and wage income respectively), the key point to note is that **the contribution of manufacturing, own sector and other utilities is greater when wage income rather than employment is the focus of attention**. This reflects the given relative high average wages in these sectors. **On the other hand, the contribution of service industries, particularly agriculture, wholesale/retail and administrative services contracts if income from rather than employment itself is considered, reflecting lower wage intensities**. Thus, in terms of the quality of employment (as reflected in wage levels and contribution to value-added) this reflects the different nature of the manufacturing, service and other (particularly utilities/mining) to the hydrogen economy.

6.4 NET MULTIPLIER EFFECTS OF A SHIFT IN FUEL SOURCE FOR TRANSPORTATION (EMPLOYMENT AND WAGE INCOME)

As highlighted above, and assessed for output and value-added in Chapter 4 (Section 4.4) it is necessary to consider the *net impacts* of shifting from the use of petrol and diesel to hydrogen in running vehicles, rather than focussing on the potential gross impacts of spending on hydrogen as a fuel. Therefore, analogous to Section 4.4, this section considers the net economy-wide impacts of a pound for pound (£million for £1million) shift in spending between petrol diesel (as outputs of the ‘Refined fuels’ industry) to hydrogen to run vehicles (considering both gas and electricity proxies). Again, the key point to note is that ‘Refined Fuels’ has the lowest multipliers (both output and value-added in Chapter 4, and employment and wage income here) of all 103 UK industries. Thus, the total net impact of reallocating spending towards any other UK produced good or service (rather than imports) will result in a net positive impact on employment and wage income earned across the UK economy. However, there will be sectoral ‘winners’ and ‘losers’.

Using the examples of a pound for pound reallocation of fuel spending, the first step in assessing the net impacts on the UK economy may simply involve using the headline multipliers for refined fuel in comparison to hydrogen supply proxy industries. The direct/total output-employment multiplier for the gas and electricity supply proxies (respectively 8.05 FTE and 8.04 FTE jobs per £1million of final spending) are both relatively high compared to that for the ‘Refined Fuels’ industry (2.9 FTE per £1million). **Thus multiplier results suggest a positive overall boost in UK employment and wage income for every pound or £million reallocated of spending between refined fuel and either hydrogen proxy**. The difference between total multiplier values suggests that any £1million reallocated from ‘Refined Fuels’ to hydrogen, this

will lead to 5.12 FTE jobs created across the UK economy if the electricity proxy is used, or 5.11 FTE jobs based on the gas supply proxy.

Similarly, for wage income, using the headline multipliers for the Refined Fuels industry against the gas or electricity proxies for hydrogen, a net potential boost to wage income from a £1million reallocation of spend would be around £0.132m under either proxy (£132,226 with gas and £132,072 with electricity). The headline results are decomposed in Table 6.2.

However, it is crucial to focus in on industries within the groupings in Table 6.2 where there may be potential gross losses in employment and wage income. Therefore Table 6.1 shows that the shift to either proxy (gas or electricity) is likely to result in net negative impacts in a few manufacturing industries, primarily the ‘Refined Fuels’ sector itself. In this industry 0.4 of an FTE job will be lost for every £1million reduction in final demand for output (again, this does not include taxes or distribution margins). To provide some idea of scale, in 2010, UK households spent £6,556million on the output of the ‘Refined fuels’ sector.

Table 6.1 Identification of industry location and magnitude of potential gross losses from the shift from petrol/diesel to hydrogen.

SIC	Sectors names	Employment		Wage	
		Refined fuel to Electricity proxy	Refined fuel to Gas proxy	Refined fuel to Electricity	Refined fuel to Gas proxy
10.4	Manufacture of vegetable, animal oils and fats	0.00	0.00	-£2	-£7
19	Manufacture refined petroleum products	-0.40	-0.41	-£10,184	-£10,242
20.3	Manufacture of industrial gases	0.00	0.00	-£91	-£141
20.4	Manufacture of petrochemicals	0.00	0.00	£43	-£823

Source: Author’s calculations based on UK input-output data produced by the Fraser of Allander Institute.

However, more generally, Table 6.1 focuses on gross losses only. In Table 6.2 the net impacts for all industries groupings were included, the results in each column would sum to the total net increases derived from the headline multipliers above. Table 6.2 shows that the utility industries gain most. In terms of employment and wage income if gas supply is used as proxy for hydrogen supply, while services industries (particularly wholesale/retail and information/communication services) gain more under the electricity supply proxy. **However, under either hydrogen supply proxy, employment or wage income impacts in service industries are again revealed as important in considering the nature of the hydrogen economy.**

Table 6.2 Net impacts on UK industry groupings of a £1million reallocation of final spending from petrol/diesel to hydrogen.

SIC	Sector name	Employment		Wage	
		Refined fuel to electricity proxy	Refined fuel to gas proxy	Refined fuel to electricity proxy	Refined fuel to gas proxy
01–03, 67,68	Agriculture and food	0.17	0.15	£3,175	£2,905
04–07	All mining, quarrying and support	0.23	0.20	£17,390	£19,583
19	Manufacture of refined petroleum products	-0.40	-0.41	-£101,838	-£102,418
08–48	All other Manufacturing	0.63	0.30	£24,915	£11,718
52–57	Other utilities	1.66	2.41	£97,992	£124,301
58,77,78	Construction and real estate services	0.23	0.28	£6,255	£7,768
49–51, 59,60	Wholesale, retail trade and repair	0.60	0.41	£16,187	£11,325
61–66	Transportation and storage	0.18	0.15	£7,103	£5,909
69–73	Information and communication	0.23	0.19	£11,377	£9,541
74–76	Financial and insurance activities	0.09	0.07	£9,688	£7,013
79–85	Professional, scientific and technical activities	0.56	0.46	£17,193	£14,023
86–92	Administrative and support service activities	0.48	0.50	£9,588	£9,650
93–103	Other private and public services	0.47	0.40	£13,047	£10,909
	Total	5.12	5.10	£132,072	£132,226

Source: Author's calculations based on UK input-output data produced by the Fraser of Allander Institute.

6.5 ENABLING THE USE OF HYDROGEN AS A FUEL: POTENTIAL FOR EMPLOYMENT AND WAGE-INCOME EXPANSION IN THE UK

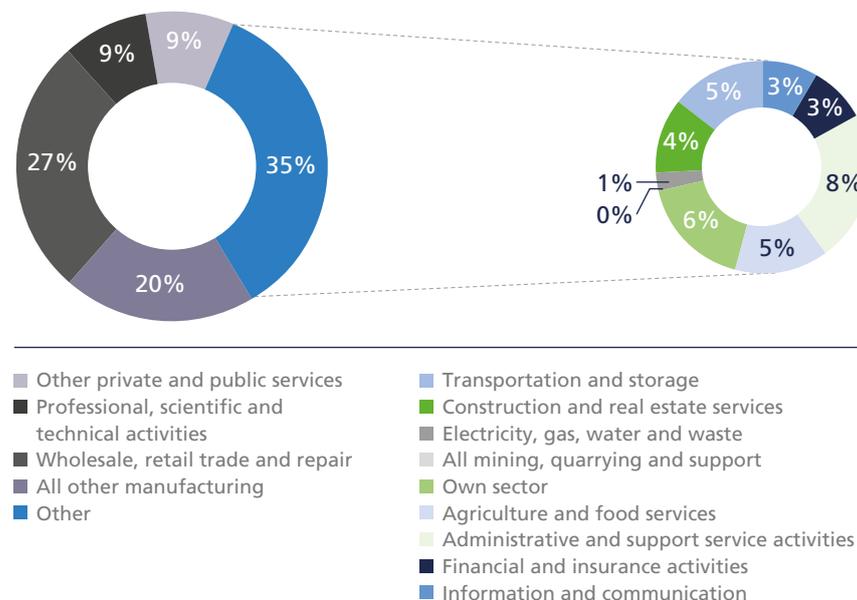
The analysis above assumes a pound for pound reallocation of spending between petrol/diesel and hydrogen fuels. However, it is not necessary in general to make this assumption while working with multipliers. Chapter 4 (Section 4.5) discussed the potential for expansion in the UK vehicle manufacturing industry if funds saved from spending on petrol/diesel not required for hydrogen fuels may be reallocated to spending on vehicles. More generally, however, hydrogen-ready vehicles are necessary to enable the use of hydrogen fuels. Therefore, it is appropriate to consider

potential multiplier impact if the UK vehicle manufacturing industry is able to exploit opportunities to increase domestic sales (and/or exports) of hydrogen-ready vehicles. This is done using the existing (2010) multipliers for ‘Manufacture of motor vehicles, trailers and semi-trailers’ industry (SIC 45), while noting that some adjustment in input mix may be required in shifting from production of petrol/diesel run cars to hydrogen-ready ones.

As previously discussed in Chapter 4, there is potential for expansion in output and value added in the UK vehicle manufacturing industry to enable the use of hydrogen fuel in transportation. This also has potential to create new FTE jobs through specialization and in support of potential increased domestic and export demand as the market for UK branded hydrogen vehicles becomes appealing to domestic and foreign households.

The headline output-employment and output-wage income multiplier for the UK vehicle manufacturing industry are identified as 13.6 FTE jobs and 10.4 per £million supported throughout the UK economy. To get some idea of scale, taking the 2010 export demand of £23,621million for goods produced in the UK vehicle manufacturing industry, and applying the output-employment multiplier, there is a total of 321,463 FTE jobs directly supported (75,480), indirectly required through supply chain linkages (160,573) and induced through spending of labour income (85,410) as a result of this export demand.

Figure 6.8 Composition of indirect and induced supply chain employment requirements for the UK Motor Vehicles sector.

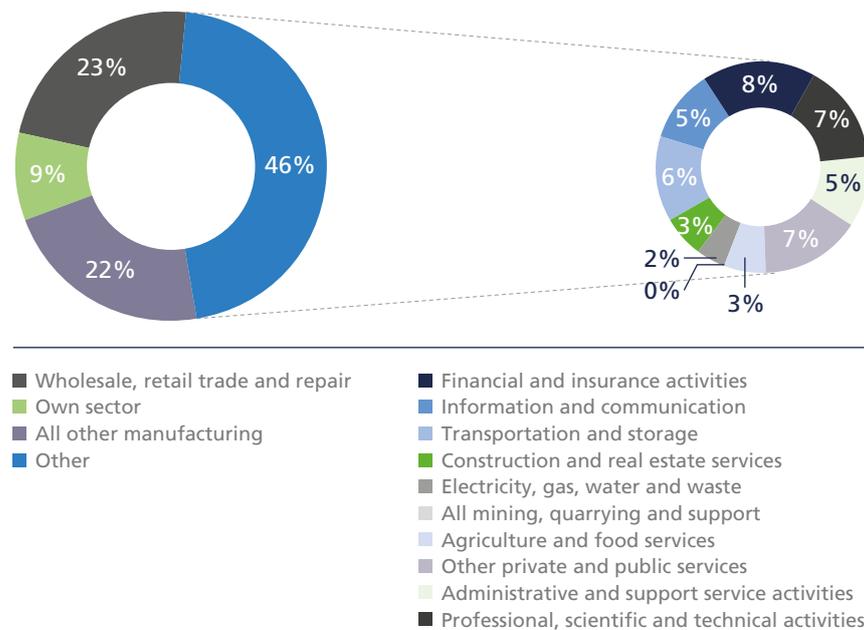


To consider the potential marginal impacts of a net increase in demand (foreign or domestic) for UK vehicles, Figure 6.8 shows where the 10.4 indirect and induced elements/components of the total 13.6 FTE jobs per £1million of final demand spending are located within the UK motor vehicle supply chain (other 3.2 jobs are direct). The main thing to note is that, while there are similarities in terms of the share located in

‘own sector’ and other manufacturing, the distribution of supported employment is somewhat different to what was found for output and valued added in Figure 4.8 and Figure 4.9 in Chapter 4. Again, this is due to differences in labour intensity, and the importance of service sectors is more pronounced in the decomposition of supported employment. In particular, 27% of indirect and induced employment is located in the ‘Wholesale, retail trade and repair’ industry which provides distribution and repair services. This contrasts with only 17% of output and 20% value-added in Chapter 4. On the other hand, while the share of employment in higher value-added sectors under the ‘Professional, scientific and technical services’ grouping is high relative to output, the share located in financial and insurance activities is low relative to the findings for output and value-added. **However, in general, service sector employment is clearly important in the car manufacturing supply chain.**

On the other hand, if attention focuses on wage income from employment rather than FTE jobs, the importance of relatively high wage service sectors, such as finance and insurance, increases. Moreover, the higher wage rates associated with manufacturing jobs more generally push up the share located in own sector and other manufacturing to 31%, compared to 26% of employment. If higher wage rates are reflective of skills levels, this result does imply that it **will be important to focus attention on building skills to support the transition to a successful vehicle manufacturing industry in a hydrogen economy.** However, the results also imply that **attention must also be given to ensuring appropriate skills in to ensure capacity in the supporting service industries.**

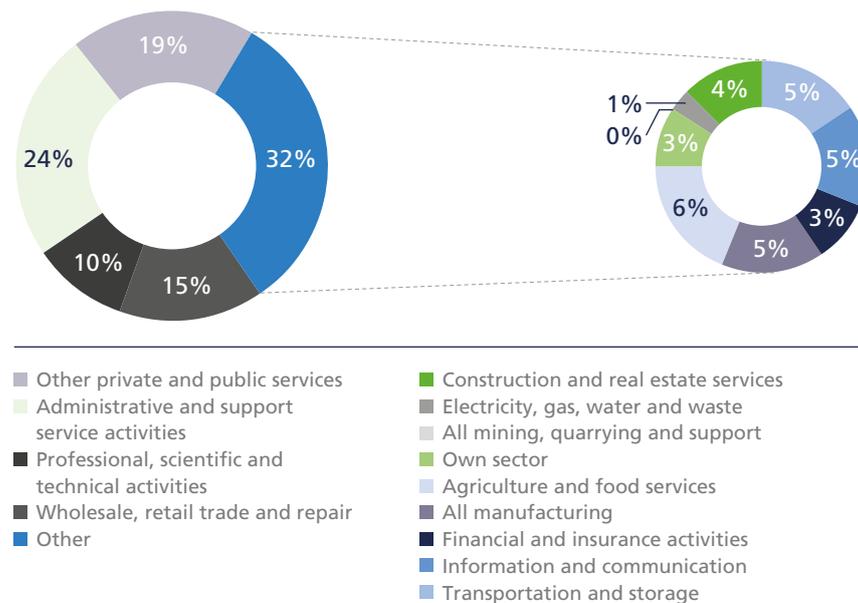
Figure 6.9 Composition of indirect and induced supply chain wage-income requirements for the UK Motor Vehicles sector.



6.6 EMPLOYMENT AND WAGE INCOME LINKED TO UK INDUSTRIES THAT MAY BE DIRECT 'INVESTMENT' TARGETS IN FACILITATING THE SHIFT TO A HYDROGEN ECONOMY: FOCUS ON R&D AND CONSTRUCTION

A key point raised in Chapter 4 (section 4.6.1) is that R&D will play an important role in move to a hydrogen economy. This is from initial exploratory stages of understanding how different required elements of hydrogen supply and use may work to more advanced and sustained hydrogen base in the energy system. At all stages, this will involve direct private and public investment in R&D to facilitate a strong domestic hydrogen-economy and developing comparative advantage in international energy systems and markets. Therefore, understanding indirect and induced employment requirements within the supply chain of the 'Scientific research and development' (SIC 72) is important. This industry already features in the analysis above of energy supply chains, as part of the 'Professional, scientific and technical activities' grouping (which also includes activities such as architectural services and advertising). As per Section 4.6.1, activity in the R&D industry that features in output, employment etc. supported by demand for other industries is part of the operational or routine spending of the driving industry. However, the current section is concerned with the employment and wage income impacts if a boost to R&D activity is required to enable a major step-up in capability and/or capacity in the context of the shift to a hydrogen economy. Again as per Section 4.6.1, this includes, but is not be limited to, any R&D required to make activities like CCS a reality and would require additional spending, potentially in the form of government and/or non-profit sector final spending.

Figure 6.10 Composition of indirect and induced supply chain employment requirements for the UK Scientific Research and Development sector.

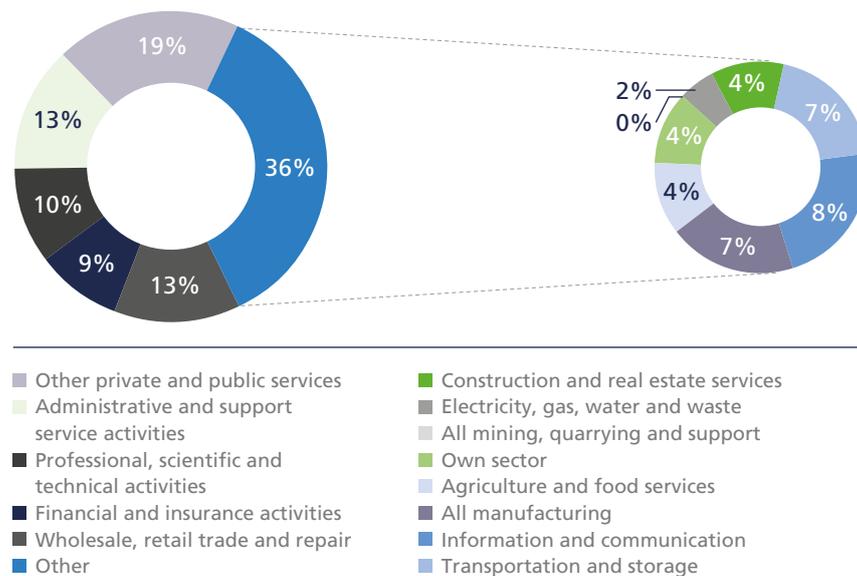


As noted in Chapter 3, the UK R&D industry has a relatively high employment intensive supply chain, with its output-employment multiplier of 25.31 FTE jobs per

£1million of final demand ranking 16th among the 103 UK industries. While this is a lower ranking than for its value-added or wage income multipliers, where it ranks second only to the UK Education sector, it is still a relatively high and important supply chain employment multiplier. On the other hand, the point made in Section 4.6.1 that the timeframe over which any boost to activity in R&D will last and thereby impact employment throughout the wider economy must be considered in applying multiplier results in 2 scenerio analysis.

Figure 6.10 shows the results of decomposing the indirect and induced employment components (13.64 FTE jobs) of the total 25.31 output-employment multiplier per £1million spend on UK R&D. Before considering the results in Figure 6.10 **Note that around half of the jobs supported are direct within the R&D industry itself.** In terms of the indirect and induced effects captured in Figure 6.10, **once again there would be an important boost in employment particularly across services industries within the R&D industry supply chain.** Most noticeable is the share of induced and indirect employment in the ‘Administrative and support service activities’ and ‘Other public and private service’ industry groupings, which together account for 43% of the total. This contrasts with the findings for output and value-added in Section 4.6.1 where the corresponding shares were 26% and 29%. This finding, combined with the importance of other professional, scientific and technical activities and the whole-sale/retail industries is important in terms of the diversity of job creation to support R&D activity to build a hydrogen economy in UK universities and research institutes. While it cannot be fully examined here (using a single country input-output model), it is important to note that any expansion in capacity of R&D provides the potential to boost both GDP and employment with further allocation of spend linked to international collaboration with other countries with similar hydrogen vision.

Figure 6.11 Composition of indirect and induced supply chain wage-income requirements for the UK Scientific Research and Development sector.



In the case of wage income associated with employment, the R&D direct wage income multiplier value of 0.99 per £1million is ranked the second highest wage-income multiplier across all 103 UK industries. **Again, most of this is direct and, reflecting a relatively high average wage rate in the R&D industries,** so that only 0.41 (410k per £1million) of the total 0.9 wage income multiplier is associated with the indirect and induced components in Figure 6.11. **As with employment, the distribution of wage income supported in the R&D supply chain is concentrated in service industries.** However, comparing Figure 6.11 with 6.10 the importance of higher wage sector, such as in the 'Financial & insurance activities' grouping is higher.

The second industry identified in Chapter 4 (Section 4.6.1) that is likely to be a direct recipient of investment spending to enable the shift to a hydrogen economy is UK Construction (SIC 41–42, including civil engineering and specialised construction services as well as building activity). It is important to note that the impacts of increased Construction activity may not last much longer than the project in question. However, given the scale of the shift required, there may be many substantial projects that take a number of years to complete.

Figure 6.12 shows the results of decomposing the indirect and induced components (11.2 of a total 19.2) of the UK construction industry output-employment multiplier. Figure 6.13 then considers the related indirect and induced wage income content, that is the 0.36 (360k per £1million) of the total 0.57 multiplier for wage income that is not directly generated in the construction sector itself.

Figure 6.12 Composition of indirect and induced supply chain employment requirements for the UK Construction sector.

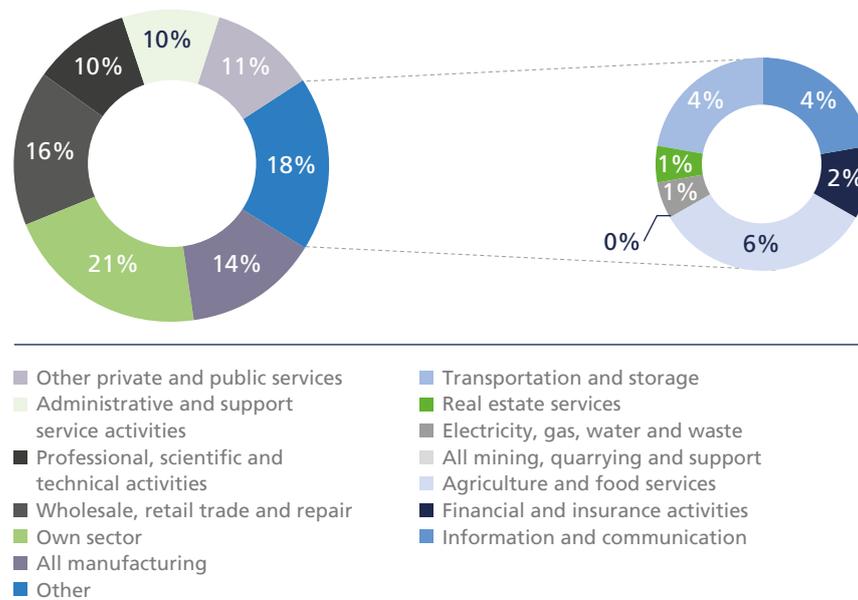
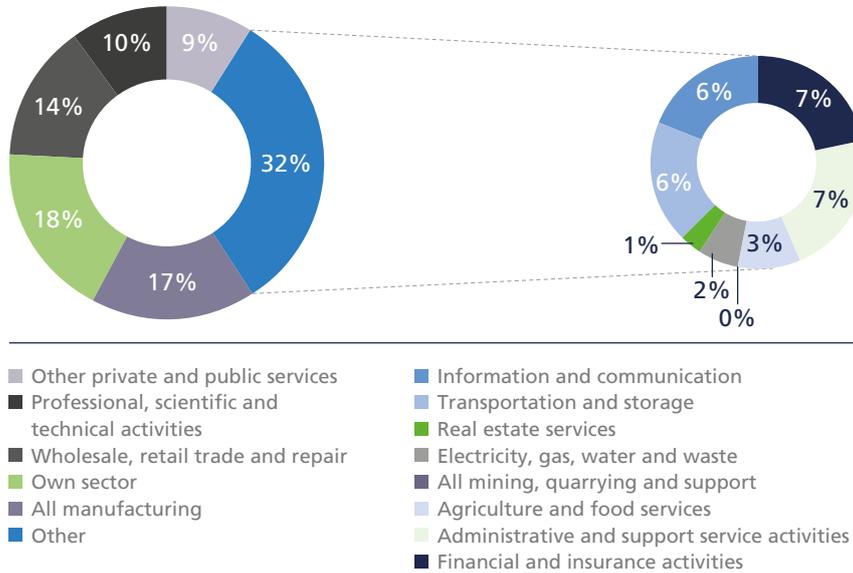


Figure 6.13 Composition of indirect and induced supply chain wage-income requirements for the UK Construction sector.



A key point to note from in Figure 6.12 is that any £1 million spend on the UK ‘Construction’ industry will boost UK employment particularly in the service industries, with the only other notable areas being indirect own sector (21%), which may (as discussed in Section 4.6.1. reflect an over-aggregation of construction activities, and manufacturing (14%).

Similarly, Figure 6.13 demonstrates that **positive impacts on wage income generated through the UK supply chain will be concentrated in the service industries**, with the distributions compared to that in Figure 6.12 being explained by differences in average wage rates. Generally in this respect, Figure 6.13 reflects a slight drop in the quality of jobs (as judged by wage income) in the service industries with **higher wage effects being located in the manufacturing industry and selected service industries (e.g. ‘Financial and insurance activities’ and ‘information & communication’)**.

6.7 CONCLUSIONS

This chapter has focussed on examining the employment and wage income embedded in the supply chains of UK industries that are likely to be directly impacted through the three key economic phases identified in Chapter 3 as likely for the UK economy to move through in realising the actualisation of a hydrogen-economy. It has done so in a similar manner to the analysis of output and GDP in Chapter 4. This is by examining the composition of industry level multipliers in terms of full-time equivalent (FTE) employment and associated wage income in different UK industries required or supported by key industries that are identified as direct players in the ‘hydrogen economy’. Again, as per Chapter 4, the analysis in this Chapter has also highlighted whether any boost to activity in a given sector is likely to be temporary (investment activity) or on-going (operation of the hydrogen economy).

In terms of employment and wage income supported in fuel supply chains, again **the central argument of the analysis is the need to consider the *net impacts* of moving away from petrol and diesel in transport activity (thereby triggering a contraction in the relevant supply chain) and towards hydrogen based fuel.**

The key finding of Chapter 4 was that, provided actual hydrogen supply shares the type of relatively strong UK supply chain linkages of current gas and electricity supply, net impacts on the UK economy are likely to be significantly positive. This finding applies throughout Chapter 6 as well, but with focus on the location of employment and wage income impacts.

The key distinction in particularly the employment results reported here is that a much smaller share of positive and negative impacts from a shift in the fuel supply originate in the off-shore oil and gas industry. This is because of a relatively low labour intensity. However, when attention turns to wage income, the impacts in the off-shore industry become more important albeit to a lesser extent (due the high capital intensity of the oil gas extraction industries) compared to output and value-added in Chapter 4.

The other key argument emerging from the employment and wage income multiplier analysis in this chapter, but this time corresponding with the output and value-added results in Chapter 4, **is the importance of impacts in UK service sector industries.** Thus, the findings suggest a need to ensure that attention to development of the UK skills base to enable a hydrogen economy includes attention to required service sector provision.

Although numbers of jobs and GDP enhancement figures are given in the various analysis sections, it would be dangerous to take those figures as being literal predictions. Modelling would need to be more sophisticated than herein and able to capture aspects of HFC such as it being a more distributed economic activity than the current UK refined fuels model. As noted elsewhere that factor alone is likely to mean that the figures given are underestimates. The main feature however is clear, that subject to qualifications, a transition to hydrogen from traditional refined road fuels can be expected to result in significant increases in UK economic activity, value creation and employment. This has not previously been assessed/considered.

CHAPTER 7

SKILLS

REQUIREMENT

7.1 INTRODUCTION AND METHODOLOGY

The greater diffusion of hydrogen and hydrogen-related technologies within the energy system will be dependent on an appropriate skills base within the work force. This chapter explores the potential skills requirement of a future hydrogen scenario, considering the extent to which existing skills may be of relevance to hydrogen and hydrogen-related technologies, and the extent to which new skills may be required.

The primary focus of this chapter is to consider the various skill requirements that would be called upon under a near-term Hydrogen HFC Market scenario, as described and discussed in previous chapters of this White Paper. However we also consider what could be the requirements of a longer-term scenario with a more ubiquitous use of hydrogen as an energy vector. For this we draw on the “Full Contribution” Scenario described by Hart et al.⁵⁵

The near-term Hydrogen HFC Market scenario ‘focusses mainly on the replacement of petrol and diesel in cars with hydrogen, with some attention to the manufacture and uptake of hydrogen-ready cars’ (this report, Section 3.1). This could involve requirements for skills upgrades in a range of areas. As well as vehicle manufacturing, it would also seem likely that a scenario with any significant use of hydrogen would also require some UK-based hydrogen production facilities, for example from electrolysis, biomass-based or fossil fuel-based production. However, it is also possible that the UK could import its hydrogen from a bulk producer in another country, in liquefied form. A scenario with significant penetration of hydrogen vehicles would also require skilled workers in the areas of hydrogen vehicle maintenance and repair.

The extent to which the scenario would require skills in the handling, transmission and distribution of hydrogen, in liquid or gaseous states, could vary depending on the specifics of the scenario. Significant amounts of new hydrogen infrastructure and hydrogen handling could be avoided in a distributed electrolysis-based scenario, which relied on the existing electricity grid to enable production of hydrogen more or less at the point of delivery. Alternatively in a scenario with more large-scale centralised production of hydrogen, the requirement for skills in the construction of transmission and distribution pipelines, and in the handling of hydrogen in various states, potentially including in liquefied form, would be significant. The operation and maintenance of hydrogen refuelling stations would also require different skills to the operation of conventional refuelling stations.

In addition to the above, Hart et al.’s ‘Full Contribution’ scenario envisages the use of hydrogen as a heating and cooking fuel in buildings. This would require further extension of distribution networks, companies that can produce hydrogen compatible domestic appliances, and a cohort of gas maintenance engineers qualified to work with hydrogen and hydrogen-related appliances.

⁵⁵ Hart D, Howes J, Lehner F, Dodds PE, Hughes N, Fais B, Sabio N, Crowther M. Scenarios for deployment of hydrogen in contributing to meeting carbon budgets and the 2050 target. London, UK: Committee on Climate Change; 2015. Available at: www.theccc.org.uk/wp-content/uploads/2015/11/E4tech-for-CCC-Scenarios-for-deployment-of-hydrogen-in-contributing-to-meeting-carbon-budgets.pdf.

As shown in modelling results from Chapters 6–10, hydrogen supply chains will also involve a lot of service sector activity. As discussed in Section 4.3.2, and shown in Figures 4.1 and 4.2, the impact of a shift to a hydrogen economy could be widespread, including on sectors such as administrative and support services, agriculture and food, and electricity, gas, water and waste. However, expansions of employment in sectors such as these would largely draw on existing skills, and as such would present no major challenge in terms of a skills gap. The focus of this chapter is on those skills areas for which there is a greater possibility of a skills gap, due to the fact that the areas do not constitute established economic activities at the present time. Thus we focus in this chapter on the hydrogen-specific skills areas summarised in the previous paragraphs of this section.

In the following sections we consider in some more detail the skills requirements in each of these areas. In each case we consider the applicability of existing skills to the new hydrogen-related activities, to what extent hydrogen-related activities might require skills upgrades, and how demanding or complex such skills upgrades might be. The main research method for this chapter is literature review from both academic and grey literature sources. The availability of applicable data within these literatures is therefore a key constraint on this analysis. Supplementary insight is also provided by reporting on personal communications with actors in relevant industrial sectors. Section 7.2 considers the automotive sector, Section 7.3 considers hydrogen production, Section 7.4 considers hydrogen transmission, distribution and refuelling infrastructure, and Section 7.5 considers hydrogen in buildings – not part of the near-term Hydrogen HFC Market scenario, but potentially part of a “full contribution” scenario. Section 7.6 then considers overall skills gaps and priorities, and finally Section 7.7 draws conclusions.

7.2 AUTOMOTIVE SECTOR

Across the automotive sector, some skills will need updating in the case of a hydrogen transition, though many would not change, or would evolve more incrementally. A study of skills for green jobs in the UK notes that ‘across the automotive sector, skilled employees including managers, professionals, supervisors, technicians, craftspersons, operators and assemblers account for 68% of the total workforce’. Because of anticipated future technological changes to motor vehicles, ‘occupations such as repair technicians will therefore need to update their skills’. However, ‘other skills such as welding car bodies, can be transferred from manufacturing of traditional (diesel/petrol) automotives to the manufacturing of low carbon vehicles’.⁵⁶ Similarly, considering jobs and skills impacts more specifically of hydrogen technologies, the US DOE notes that, ‘some tasks within the automotive sectors will remain the same, such as tasks involved in producing and assembling certain automotive parts, e.g. automobile wheels. But new skills will be required in other tasks, such as producing and installing fuel cells new powertrains and other associated equipment’.⁵⁷

56 CEDEFOP. Skills for green jobs. Country report: United Kingdom. European Centre for the Development of Vocational Training; 2010. Available at: www.ilo.org/global/publications/lang-en/index.htm.

57 US DOE. Effects of a transition to a hydrogen economy on employment in the United States. Report to Congress. USA: Department of Energy; 2008.

7.2.1 Automotive manufacturing

(Note – US DOE reference – quotes refer to this reference unless otherwise stated)

White-collar workers, including ‘engineers, engineering managers, drafters, and engineering technicians’, are a key component of automotive manufacturing. The DOE conducted interviews with industry, and report that most interviewees ‘believed that the current set of engineering skills used for conventional internal combustion engine vehicles will likely change significantly... mechanical engineering skills will focus less on purely mechanical functions and more on developing electro-mechanical systems’, although ‘non-propulsion-related systems such as heating and cooling systems will likely employ the same mechanical engineering skills that are in use today’.

However, changes in engineering skills will be **‘evolutionary rather than revolutionary’**, e.g. ‘introductions of the front-wheel drive system and various fuel injection systems, and the use of different on-board computer systems. In all of these cases, the automotive industry will rely upon internal re-training and on-the-job experience, as well as changes in curricula at universities and community colleges to support the turnover in new skills’. Further, because of work on hybrid electric vehicles, ‘there are already a significant number of engineers with either educational backgrounds or on-the-job experience’ in relevant system aspects. ‘New elements required in a fuel cell vehicle system include the fuel stack and some attendant sensing and control systems. But a great many system requirements are already present in conventional and hybrid vehicle systems’.

There is a possibility of short run problems with skills availability of high skilled graduate and post-graduate engineers if there is a particularly rapid expansion of hydrogen technologies in early years. Undergraduate engineering programmes are liable to adapt as industrial needs evolve. Evolution would incorporate hydrogen and fuel cell technology elements specifically – but equally would be losing some of the older elements which are becoming redundant. ‘It takes approximately 4 to 8 years for engineers to complete professional education, including undergraduate and graduate schools’. Hence there is some risk of some shortage of graduate level engineers if there was a rapid initial hydrogen market expansion. That said, as ‘the absolute number of engineers in these industries is small’, this is liable to present itself as a short term problem only. Note also that provision can be made for retraining of existing graduate and postgraduate qualified staff which can be relatively fast and would not involve the full 4–8 year period mentioned.

‘Blue collar workers’ are defined by DOE as including ‘manufacturing employees, construction employees, automotive service and repair technicians, service station attendants, and hydrogen fuel deliverers. Blue collar workers obtain training from vocational and technical schools where necessary’.

The DOE report that ‘computer literacy skills, knowledge of electrical systems, and the ability to use computerized diagnostic equipment will be particularly important for assembly skills in the future. Machining skills related to internal combustion

engine construction are not likely to be needed, as fuel cell stacks require little to no machining and are unlikely to be manufactured by the automobile companies themselves. Skills related to assembly of electro-mechanical systems and computer hardware would be in greater need. The balance of components required to complete the fuel cell system requires skills for assembly similar to those for a traditional gasoline engine’.

Assemblers and machine operators may be affected by changing production lines. ‘Laborers may need safety training for working with hydrogen pipelines, while plumbers, pipe fitters and welders may need training on new piping specifications and safety requirements’.

However, ‘as with engineering skill development, interviewees believed that training will be **evolutionary rather than revolutionary**’, and can be delivered through training courses and on-the-job training. Further, ‘the development of hybrid vehicles has provided an environment for the development of new manufacturing skills’. Re-training for manufacturing and construction workers may also be achieved through ‘on-the-job training sponsored by employers’.

In the UK context, graduate and post graduate level skills can be expected to develop in the same manner as the above US model and there are no obvious factors which might contest that view. In the case of UK ‘Blue collar workers’, formal craft level training generally comprises of NVQ/SVQ modules at appropriate levels to the apprenticeships or national awards being sought. Apprentice specific college provision is usually developed by colleges, qualifying authorities and industry working in concert. This is a good basis from which it can be expected that appropriate existing modules and new modules will develop. As per the US view, evolution rather than revolution is a predictable model of adaptation in the UK.

In factories owned by automotive companies which begin to produce hydrogen vehicles, internal retraining is simply necessary and will include apprenticeships. Examples of such programmes can already be seen in the case of electric vehicles. For example,⁵⁸ in preparation for producing a new electric vehicle, the French car producer Heuliez established a training plan to upgrade skills in electricity competencies of staff at its Poitou Charentes plant (p. 73 and 304). While Nissan was planning the creation of its battery manufacturing plant in Sunderland, it was reportedly expecting that the skills for its technician level jobs – representing just under half of total jobs at the plant – were to be acquired through apprenticeship schemes mostly funded by the state (p. 73).

From a manufacturing perspective, the greatest changes would come from the fuel cell stack and the hydrogen storage tank. Automotive manufacturers would need either to form partnerships with OEMs specialising in such components, or

58 Strietska-Ilina O, Hofmann C, Durán Haro M, Jeon S. Skills for green jobs: a global view: synthesis report based on 21 country studies. Geneva: International Labour Office, Skills and Employability Department, Job Creation and Enterprise Development Department; 2011.

to develop the expertise in-house. In one example, the fuel cell stacks for Toyota's Mirai FCV are assembled 'in-house'.⁵⁹

7.2.2 Automotive servicing and repair

For vehicle service and repair, 'the most significant skill set change will be in troubleshooting, repair, and service of propulsion systems... technicians will have to become more competent in computer and electrical system maintenance. However modularization of key components such as batteries, fuel cell stacks, and power converters, may reduce the amount of re-training needed. Similar to production, hybrid vehicle maintenance will provide a means of developing new repair and maintenance skills'. However safety training will be required because of the 'use of hydrogen and high-voltage electrical systems'.

Training and re-training implications are different for those specialising in mechanical elements like suspension and brake systems and those specialising in electric drive train and HFC technology. Depending on the role, re-training may range from 'as little as basic safety training to very specialized automotive technician training'. Workers of this kind are also more widely geographically distributed – in contrast to automotive manufacturing workers, who would be typically be clustered in large plants owned and operated by automotive manufacturing companies, servicing and repair technicians are typically spread through numerous small businesses.

In the UK context we can expect college provision located adjacent to automotive manufacturing to offer more specialised training options tuned to that local commercial activity, whilst other colleges offer more general options. It is important to observe that many UK technicians undertake both general college training and bespoke manufacturer specific training via the franchise dealer system. There is no reason to imagine that this form of twinned public and commercial training model will not continue as is.

There are a variety of different ways in which such training or re-training may be achieved. The US model is not very different to that employed in the UK and serves conveniently to illustrate the pattern.

Automotive service technicians and mechanics 'receive training at vocational and technical schools, and most take standard certification tests in order to be qualified to work on vehicles'. Automotive vocational and technical training based on ICEs is available at approximately 2,100 schools across the US, typically taking 1 to 2 years to complete. For hydrogen, initial training and re-training will be needed. For the years in which both technologies overlap, both conventional and electric-drive train teaching will be required. There may be some need for additional tutors and facilities (or facility modifications) to deal with overlap but the net increase in tutoring personnel and capital resource requirements are probably quite small. Conventional facilities are subject to periodic renewal in any case and local demand can be expected to lead local investment decisions.

⁵⁹ Hunt, J. *Toyota and the Hydrogen Society. The Commercialisation of Hydrogen and Fuel Cell Technology*. Birmingham, UK; 2016. Available at: www.climate-change-solutions.co.uk/wp-content/uploads/2016/03/JonHunt.pdf.

There are already some indications of how such training could be delivered. In California, the College of the Desert runs an ‘Advanced Transportation Technologies’ degree, and an ‘Automotive Alternate Fuels Certificate of Achievement’, which include a module on ‘hybrid, fuel cell and electric technology’.⁶⁰ The National Alternative Fuel Training Consortium, at the University of West Virginia, offers a 2 day course, “An overview of alternative fuel and advanced technology vehicles”;⁶¹ and a 4 hour workshop on hydrogen as a vehicle fuel, including fuel composition and safety requirements.⁶²

Indications of possible means of delivering training on technical aspects of alternative vehicles can also be gleaned from current approaches to delivering training on electric vehicles. For example, in the UK, the Institute of the Motor Industry (IMI) offers a qualification in ‘hybrid electric vehicle repair and replacement’,⁶³ as well as an accreditation of electric vehicle maintenance and repair.⁶⁴

IMI offer a number of courses within the category “Technical – hybrid and electric vehicles”⁶⁵ (p. 90–101). These range from 2–8 hour introductory courses, to more technical 1–2-day courses dealing with maintenance and repair of hybrid and electric vehicles, and replacement of high voltage components, which enable participants to gain IMI accreditation in the relevant areas. The IMI’s 2016/17 Professional Development Course Guide does not include a specific course on hydrogen and fuel cell vehicles, although their introductory course on “Electric Vehicle Batteries” also offers to provide ‘an understanding of fuel cells, super-capacitors and flywheels when used with hybrid vehicles as a form of energy storage’. Clearly an expansion of the learning programme in the areas of hydrogen and fuel cell technologies would be an important part of supporting the technician and vehicle servicing sectors in any hydrogen transition. However the UK institutions exist to do this, and it would be a case of building on existing programmes rather than starting from scratch. Further, if the training offered by IMI on electric vehicles can be taken as any kind of guide, it seems likely that a mechanic qualified to work on conventional vehicles could achieve proficiency for hydrogen vehicles by attending targeted technical training of the order of a few days.

Such training and accreditation developments would also need to be supported by regulations which require mechanics to be qualified and accredited in order to work

60 College of the Desert. 2016/17 Catalog – Programs of Study – Advanced Transportation Technologies. Accessed: 27th January. Palm Desert, CA: College of the Desert; 2016. Available at: <http://catalog.collegeofthedesert.edu/programs/advanced-transportation-technologies/> – coursestext.

61 NAFTC. Clean air and energy independence: an overview of alternative fuel and advanced technology vehicles. Accessed: 27th January. West Virginia University, USA: National Alternative Fuels Training Consortium; 2017. Available at: http://naftccourses.wvu.edu/?page_id=31.

62 NAFTC. Petroleum reduction technologies: hydrogen fleet applications. Accessed: 27th January. West Virginia University, USA: National Alternative Fuels Training Consortium; 2017. Available at: http://naftccourses.wvu.edu/?page_id=381.

63 IMI. L3 award in hybrid electric vehicle repair and replacement. Accessed: 25th January. Brickendon, UK: Institute of the Motor Industry; 2017. Available at: <http://awarding.theimi.org.uk/Qualifications/L3-Award-in-Hybrid-Electric-Vehicle-Repair-and-Replacement>.

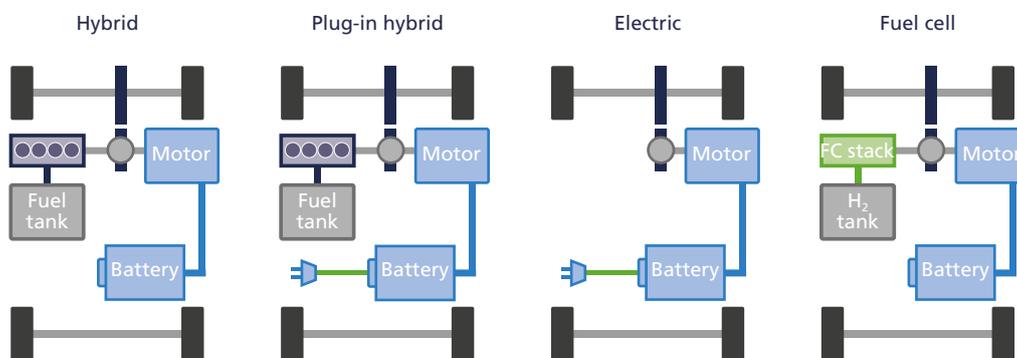
64 IMI. IMI accreditation electric vehicle. Accessed: 25th January. Brickendon, UK: Institute of the Motor Industry; 2017. Available at: <http://accreditation.theimi.org.uk/electric-vehicle-route>.

65 IMI. IMI Professional Development Course Guide. Brickendon, UK: Institute of the Motor Industry; 2016. Available at: www.theimi.org.uk/sites/default/files/documents/177830_3.pdf.

on hydrogen vehicles. The IMI has already called for such regulation to prevent unqualified mechanics servicing electric vehicles.⁶⁶

The idea that the growing experience with and training around the maintenance of EVs, could make the step up to FCVs less daunting, is also given weight by Toyota's reports of progress developing their Mirai FCV. Figure 7.1 schematically illustrates how the layout of their FCV compares to previous EV and hybrid designs. In this figure, Toyota are suggesting that the FCV design is a relatively incremental step from previous vehicle designs, being 'nestled in our hybrid DNA'.⁶⁷ The Figure indicates that much of the FCV's drive train and architecture would be employing components familiar from the EV and hybrid designs.

Figure 7.1 Schematic comparing designs of Toyota's hybrid, plug-in hybrid, electric and fuel cell vehicle designs. Source: Toyota.⁶⁸



Toyota also suggest that because the fuel cell stack has no moving parts, it will experience 'no wear', will require 'virtually no maintenance' and indeed 'will last longer than the life of the car'.⁶⁹ If this is the case, it would help to confirm the idea that this part of the system would require little if any attention from a mechanic, thereby meaning that the maintenance requirements of an FCV would not differ substantially from those of an EV.

However, a note of caution was sounded by one UK hydrogen industry actor, who made a general observation that 'hydrogen needs to be understood as a completely different gas to natural gas', and that it was at the present time 'difficult to imagine a back-yard MOT guy checking over a hydrogen vehicle'.⁷⁰ Although the specific

66 Johnston I. Electric cars: Mechanics with no specialist training 'risk death when tinkering with the vehicles'. Independent. London 16th January 2016. Available at: www.independent.co.uk/life-style/motoring/motoring-news/electric-cars-mechanics-with-no-specialist-training-risk-death-when-tinkering-with-the-vehicles-a6816786.html.

67 Hunt, J. Toyota and the Hydrogen Society. The Commercialisation of Hydrogen and Fuel Cell Technology. Birmingham, UK; 2016. Available at: www.climate-change-solutions.co.uk/wp-content/uploads/2016/03/JonHunt.pdf.

68 Hunt, J. Toyota and the Hydrogen Society. The Commercialisation of Hydrogen and Fuel Cell Technology. Birmingham, UK; 2016. Available at: www.climate-change-solutions.co.uk/wp-content/uploads/2016/03/JonHunt.pdf.

69 Hunt, J. Powering the future with H2. Energy 2016. Birmingham, UK; 2016. Available at: www.climate-change-solutions.co.uk/wp-content/uploads/2016/10/ToyotaEnergy-hub.pdf.

70 Newborough, M. ITM Power. Personal communication, 1st February 2017.

maintenance requirements of the fuel cell stack, and potentially the hydrogen storage tanks as well, might be limited, with any occasional problems requiring recall to the manufacturer rather than routine servicing by mechanics, nonetheless it should be recalled that the presence of hydrogen vehicles in maintenance situations would require mechanics to have at the very least training in hydrogen safety and the location of the hydrogen specific components within the vehicle architecture.

7.3 HYDROGEN PRODUCTION

7.3.1 SMR and fossil fuels

The technology used in producing hydrogen from fossil fuels is not uncommon in the UK. All refineries employ steam methane reforming (SMR) as a key element of extracting the maximum value from their crude oil feedstock. SMR technology is also found across a range of chemical process industries, while the oil and gas sector itself often deals with hydrogen. As a result of these activities, there has long since been a UK need to train pipefitters, safety operatives and other trades working in these sectors to safely handle and deal with hydrogen. Historically the need was even greater when around half of the UK's town gas was hydrogen. The UK has a strong trades' skills basis on which to build a more substantial production and use of hydrogen sector.

Existing training takes the form of mixed college and in-house employer training during apprenticeships mainly. With hydrogen almost certain to be a more geographically distributed economic activity than the industries referred to above, it can safely be predicted that more people will need to be trained in these skills and trades, but the UK competence base on which to do that already exists. As per the automotive examples, some evolution in NVQ/SVQ modules will be required, but these are continually reviewed and updated in any case.

Again with hydrogen liable to become more widespread and presenting somewhat different potential hazards to natural gas, there is obvious wisdom in developing appropriate NVQ hydrogen safety modules, not just for those trades working directly with hydrogen but also suitable other trades liable to encounter it.

7.3.2 Electrolysis

Currently, there are relatively few large scale electrolyzers in the UK – if we define large scale as 1MW+ input capacity – but a number of electrolyzers of around that 1MW capacity have emerged in relation to HFC demonstration projects in recent years. On the face of it SMR/fossil derived hydrogen is much cheaper than using an electricity energy input basis, but that tends to ignore constrained renewables generation capacity which is available in significant volumes in some parts of the UK, and the value in absorbing conventional excess capacity for grid balancing purposes. These sources currently represent potentially very low cost electricity, which might otherwise go unused, and which instead could be used to produce value in the form of hydrogen. Evidently renewables- and nuclear electrolysis-derived hydrogen presents a virtually carbon free means of decarbonising transport in particular. It is also worth noting that there are areas of the UK without access to mains gas, but virtually none without access to either national grid or locally produced and

networked electricity. The *prima facie* cost differential between renewables/nuclear- and SMR-derived hydrogen is likely to narrow markedly when CCS costs are factored into SMR production.

In regards to electrolysis-related skills directly, the skills involved in the electricity generation sector, and in particular renewables and nuclear components of those come to the fore, but these can be regarded as service/supply chain. More specifically the proliferation of electrolysis facilities in areas which can make best advantage of them will require both manufacturing and service skill sets. It is likely that manufacturers will be able to undertake in-house training at that level of requirement from a basis of regular manufacturing and engineering skills relatively common in electrical/electronic-related manufacturing. Wider UK service skills can readily derive from a similar more generic skills basis. As per automotive, the formal/public training provision is likely to take the form of generic NVQ modules with again, hydrogen safety being an underpinning element.

7.3.3 Summary of hydrogen production

There are clear existing skills bases from which hydrogen production could be scaled if demand was clear and growing. However, rather than being a highly distributed challenge of training up thousands of engineers across the country, a scale up in hydrogen production is likely to be led by companies with existing related specialist expertise, developing and training engineers internally. Formal/public provision is liable to take the form of NVQ modules with a focus on safety in particular.

7.4 HYDROGEN TRANSMISSION, DISTRIBUTION AND REFUELLING INFRASTRUCTURE

The extent to which a dedicated transmission and distribution infrastructure of pipes capable of carrying hydrogen would be needed, depends both on the extent and distribution of hydrogen demand, and the methods with which it was produced. In a scenario in which hydrogen demand was primarily at refuelling stations for vehicles, hydrogen could be produced from distributed electrolysers at the refuelling stations, avoiding the need for any hydrogen pipeline infrastructure. On the other hand, a hydrogen scenario with either alternative methods of production that are inherently large-scale and cannot be easily distributed, or with a more ubiquitous demand for hydrogen including as a cooking and heating fuel in buildings, would require consideration of hydrogen transmission and distribution.

Hydrogen can cause embrittlement and failure of iron-derived piping, however the UK gas network has been undertaking an Iron Mains Replacement Programme (IMRP)⁷¹ since 2002, which aims to upgrade the majority of the existing gas distribution pipes from iron to polyethylene, for health and safety reasons. The dense polythene piping is also suitable for the transmission of hydrogen. This opens the potential for the repurposing of existing network infrastructure, but also means that the skills set required for laying a hydrogen network already exists. Hydrogen

71 www.hse.gov.uk/gas/supply/mainsreplacement/index.htm.

transmission pipelines can already be found on many refinery and chemical process sectors facilities.

The transportation of gases and chemicals, including liquefied natural gas (LNG) in tankers and tube-trailers is also a well-established industrial system. As with all of the areas discussed in this chapter, some retraining to ensure awareness of the different properties of hydrogen would be necessary, but these are likely to be relatively modular upgrades to knowledge, rather than the type of retraining associated with an entire career change.

On the other hand, while specific training upgrade needs for individuals already working in comparable industries may be modest, as with other areas considered in this chapter, the overall roll-out of such training upgrades if required to cover a large number of workers over a relatively short time period in the case of rapid a hydrogen transition scenario, could be a logistical challenge, or hold up the progress of such a scenario if not well-planned. As observed by one UK hydrogen industry actor, ‘the hydrogen grid changes everything by orders of magnitude... you’re then running a gas industry’.⁷²

DOE note that training will also be needed for service station operatives and truck drivers who deliver hydrogen. The formal/public component of that falls into the same type of NVQ arrangements described above, with a focus on operative and customer safety. The UK regulatory regime for vehicles currently carrying bulk liquid fuels and other hazardous materials, including hydrogen, is already well established and those operating/active within this transport sector already deliver qualifying training for those involved.

7.5 HYDROGEN IN BUILDINGS – GAS ENGINEERS AND TECHNICIANS

In addition to using hydrogen as a vehicle fuel, Hart et al⁷³ describe a ‘full contribution’ scenario, in which hydrogen also becomes used extensively in buildings for CHP and other applications. The main additional skill area would need to be achieved by gas engineers repairing and replacing hydrogen gas components in buildings. In a similar manner to the issue of vehicle technicians and mechanics, a potential challenge here is the large number of gas engineers throughout the country, offering a potential risk of lagging the transition if it proceeded very quickly in the early years. In a parallel manner to the IMI, the role of the Institution of Gas Engineers and Managers (IGEM) could be crucial in ensuring the availability of training and accreditation programmes. Regulation would also need to be adapted to ensure that hydrogen systems can only be worked on by qualified hydrogen gas engineers.

If a particularly rapid transition to widespread use of hydrogen in buildings was being contemplated, a more nationally coordinated approach to the mass re-training of existing qualified gas engineers might be required. Here a relevant analogy is

⁷² Newborough, M. ITM Power. Personal communication, 1st February 2017.

⁷³ Hart D, Howes J, Lehner F, Dodds PE, Hughes N, Fais B, Sabio N, Crowther M. Scenarios for deployment of hydrogen in contributing to meeting carbon budgets and the 2050 target. London, UK: Committee on Climate Change; 2015. Available at: www.theccc.org.uk/wp-content/uploads/2015/11/E4tech-for-CCC-Scenarios-for-deployment-of-hydrogen-in-contributing-to-meeting-carbon-budgets.pdf.

offered by the GB transition from town gas to natural gas. At this time the Gas Council coordinated training programmes, which were organised by the Area Boards or by private contractors.⁷⁴ This would be more of an organisational coordination challenge, then a major technical barrier. However, the availability of a mass cohort of such re-trained engineers would be vital to a smooth “switchover” programme.

The development of appropriate health and safety regulation, as well as linked training and accreditation, would be crucial to support and protect manufacturers and technicians, as well as consumers and building occupants.

7.6 SKILLS GAPS AND PRIORITIES

The previous sections have reviewed the skills categories deemed to be required for the near term HFC Market scenario, and additionally for a more comprehensive ‘full contribution scenario’. These sections have considered in each area, the closest related skills that we have in sectors that currently exist; the gap between these skills and the skills required for hydrogen scenarios; the adjustments to training programmes, and other regulatory arrangements that would be required; and any lead time issues concerned with having a cohort of hydrogen-skilled workers in each area on a timeframe that does not lag the desired speed of the transition.

The key issues are summarised in the table opposite.

At present it seems that the retraining of individuals with experience in parallel industries for the handling of hydrogen is highly achievable on a case by case basis, perhaps through short courses or in-house training of manufacturers and other large employers. The challenge potentially arises if there is a wish to provide such retraining to large numbers of people very quickly. However, such a programme could be made smoother if there was a general increase in awareness of hydrogen and increase in hydrogen-related modules within relevant engineering and technical courses. As one participant noted, ‘we also need the educational sector to get to grips with hydrogen and put it in their courses. It is not necessarily an urgent issue now, but it will be five years from now, and more after that. This applies to technician courses, as well as to undergraduate gas engineering courses, which would produce the people designing the future systems.’ If hydrogen was deployed at scale, ‘there would need to be proper training at technical colleges, with additional modules. Hydrogen would need to be properly integrated into initial training, making technicians able to work with hydrogen, not just natural gas. There would probably also need to be short courses available for mid-career technicians’.⁷⁵

74 Arapostathis S, Carlsson-Hyslop A, Pearson PJG, Thornton J, Gradillas M, Laczay S, Wallis S. Governing transitions: Cases and insights from two periods in the history of the UK gas industry. *Energy Policy*. 2013;52:25–44.

75 Newborough, M. ITM Power. Personal communication, 1st February 2017.

Hydrogen component	Associated actors and organisations	Existing relevant skill base	Required new skills	Actions needed to roll out new skills	Lead-time of skills roll out
Vehicle manufacture	Automotive manufacturers and their employees	Conventional manufacturing Existing experience with EVs	Some additional electronic components and integration of fuel cell stack within BOP	Internal retraining and apprenticeships. Formal development of college NVQ/SVQ provision	Development of modules for under- and post-graduates and for professional re-training. In-house commercial (re-) training
Vehicle servicing and repair	Existing largely independent service sector The IMI	Conventional vehicles skills base. Growing knowledge of EVs	Some additional electronic components and integration of fuel cell stack within BOP Hydrogen safety awareness	Regulation, training schemes and accreditation need to be developed and made available, through colleges and the IMI	Mechanics can add hydrogen skills with on the job training, as is currently the case with EV qualifications
SMR and fossil fuels production	O&G, Refinery and chemical process sector RSC, IChemEng, IMechE <i>et sim</i>	O&G, Refinery and chemical process sector	None	–	–
Electrolysis	Electrolyser companies	Electrolyser companies Gas/elec service sectors	Service sector awareness, retraining	In-house commercial training Formal college NVQ/SVQ	Short
Transmission and distribution	Existing Utilities and subcontractors Ofgem, HSE, trade bodies etc.	Widespread	None	–	–

7.7 CONCLUSION

This chapter has considered the potential skills requirements of future hydrogen scenarios, in comparison to existing UK skills bases.

Across all of the areas considered we find evidence that workers looking to upgrade their skills to be able to work with hydrogen would not be starting from scratch. Existing skills within industries that involve the handling of gaseous fuels, as well as the manufacture and repair of vehicles, particularly hybrid and electric vehicles, already provide important and highly relevant skills bases for working with hydrogen and hydrogen technologies.

From this perspective, in most cases we find that the hydrogen skills need may be more a case of a modular ‘upgrade’ than of a complete reorientation. However there are some notes of caution to sound. Even if for any individual worker the skills upgrade need may be a relatively modest and achievable commitment, achieving the same thing for thousands of workers over a short space of time, as might be required if a very rapid transition was planned, would at the very least be a logistical challenge. In the case of a rapid transition, the skills roll out might need to be delivered in the form of a planned, national programme. The historical example of the transition from town gas to natural gas offers evidence of how this can be achieved. Alternatively, the way in which regulation, training and accreditation has kept pace with electric vehicle deployment, gives an example of a slower, more gradual and responsive market-led transition.

Further, although hydrogen is, in some senses, ‘just another gaseous fuel’, it also has different qualities which affect the way it is handled, and these need to be understood by everyone that comes into contact with the fuel or a related technology. Safety standards and regulation, and availability of training and accreditation programmes are crucial to protect not only public consumers, but also the independent and semi-independent workers such as gas technicians and vehicle mechanics, who will be required to engage with hydrogen and its related technologies.

In summary our key recommendations are:

- Work with FE and HE colleges to ensure their engineering and technical courses are gradually expanding to include hydrogen and fuel cell aspects.
- Work with bodies such as IMI, IGEM⁷⁶ and other equivalents, to ensure that their courses are gradually expanding to include hydrogen and fuel cell aspects, and that their accreditations are expanding in this way too, in a way that keeps pace with the development of any planned roadmap.
- Gradually develop legislation to ensure that as hydrogen products and appliances reach the market the legislation is up to date to ensure that anyone who carries out repairs on it is obliged to have achieved the abovementioned accreditation (and same for gas and other applications).
- Work with apprenticeship schemes to ensure they are adapting to potentially new areas of hydrogen related work, such as in fuel cell manufacture, electrolysis

⁷⁶ www.igem.org.uk.

Although for any individual worker, the skills gap may not be huge, it is still one that must be crossed before they can work with hydrogen. Thus if a rapid transition is envisaged, a coordinated skills rollout programme could be required, to ensure that enough workers are able to achieve the necessary skills upgrade in the right timeframe.

CHAPTER 8

EXPORT AND RETENTION OF INTELLECTUAL PROPERTY

8.1 INTRODUCTION

HFC technology originated in the UK and Europe; however in the last 50 years it has become global, with the US and then Asia also coming to the fore. There are a great many HFC related patents, with a great proportion of the recently filed ones originating in China. It is difficult to assess potential value of patents on the basis of numbers filed as any search of international patents will quickly discover a good proportion which look very difficult to defend. Wider than patent activity, is IP protection and certainly there is strong sensitivity in the sector with some of the leading technology actors being highly sensitive. In a situation where revenue generating markets are in their earliest stages and there is still uncertainty as to how long it may take to benefit from current and previous development of intellectual property, there may be an understandable reluctance for some HFC companies to file patents. The revelation involved in publishing patents does potentially open valuable IP to clever variation and it can be simpler and cheaper (especially for small companies) to simply keep all such strictly secret and in-house. An interesting exception to this rule is Toyota who made almost 6000 of their patents open to encourage development in this area in 2015.

The main elements of HFC IP derive from materials and design innovation. Materials IP can in many cases be relatively easy to protect in that even if the chemical composition of the materials themselves become quite widely known, actually making them can often be what we might describe as 'a black art'. Often a great deal of the functionality of a material depends as much on how it is made and structured as it does on its chemical composition. Dealing with gases, the performance of components such as electrodes is very heavily dependent on microstructure which requires electron-microscopy simply to be able to see it. And being able to see it often reveals very little about how it has been so-structured. The processing and manufacture of that type of HFC materials' element is therefore exactly the type of thing that many HFC companies will not allow visitors or customers to see.

The design of fuel cells, fuel cell stacks and systems generally is rather more obvious with the main elements being readily visible unless hidden inside an integrated system unit. There are many patents relating to cells, stack and system design but defensible ones of value tend to relate to very specific means of guiding gases and managing heat and current and also the internal management and optimisation of such systems operations. [The latter potentially involving software copyright.]

Patent protection on the use of HFC technology in different types of application can be found, as per the example above, however simply swapping one type of power source for another in an existing application, or using an FC unit as part of an array of generation source types is unlikely to be defensible – as doing that is obvious enough and not an invention per se. Broadly speaking, similar examples can be found in respect of using electrolysis technology in supposedly novel ways, but these are unlikely to be defensible either and for the same reason.

Certain types of application of both electrolysis and fuel cells where they interact with the wider energy system and markets can potentially be very complex in

management terms. When is the electricity price right to turn on the electrolyser, when is the right time to generate electricity to the grid/consumer and when is the right time to divert production into the transport market? The complexity arising from there being a number of potential energy sources and applications along with system input/output value variation with respect to time. National energy systems as a whole deal with those types of market situations as a matter of course in established and regulated ways – and have the resources to do so (half-hourly markets in the UK for instance). With renewables on many scales, batteries, hydrogen, the hydrogen and battery connection to road transport, some of those complexities can find themselves in miniature. That gives rise to the potential for smart local complex energy system management and this is something a number of companies have been involved in developing IP, technology and management software to address. Toshiba are currently supplying just such a smart management system to a demonstration project at the Hydrogen Office in Fife – that will optimise the local use of wind and PV sources to supply local businesses with electricity directly and to optimise the production of hydrogen for both energy storage and transport. These smart systems are literally looking at weather forecasts to estimate primary energy generation! There is a great deal of software IP and value in such management systems.

8.2 IP IN THE UK

The UK and Europe have applied significant budget to demonstration projects most of which (in terms of scale and investment) have involved HFC buses. Whilst buses are literally large and bring good levels of public attention to the technology (partly hence the EU's investment strategy), the buses have been small in number to date and have required relatively few fuel cell units (few of which have been made outside N. America). This has created little opportunity to date for European (including the UK) FC companies to promote their technology offerings via that type of cross-border support scheme. That is not to say that Europe has not supported those companies – there have been many relevant support actions – but the focus and bulk of EU investment in demonstration has mainly been on transport and on buses specifically.

The EU strategy of having its main commercialisation focus on transport is difficult to reference to any particular document or statement per se, the main evidence of it however is seen in the quantities of support funding made available for transport R&D and a range of demonstration projects – such as those London and Aberdeen have been and are currently involved in – relative to other application types. And expectations of market status of the application types from the mid-2000s.⁷⁷ When support changed from its earlier Framework-type mechanism to its current Joint-undertaking on Fuel Cells and Hydrogen, the new public-private partnership formed is mainly industry led and includes several EU automotives at board level. There is an almost

⁷⁷ European Hydrogen and Fuel Cell Platform, Implementation Plan Status 2006, Panel Chairs F. Jackow (Air Liquide) and J. Loughhead (UKERC at the time, now DBEIS), Table pg 15 expects mass market roll out of HFC transport ca. 2020, other applications just established or an order of magnitude smaller in deployment numbers compared to transport. This and other JU FCH documentation available at www.fch.europa.eu/page/who-we-are.

unstated assumption that relatively high value HFC transport will provide the economies of scale to rapidly drive down cost benefitting the wider HFC generically.

UK HFC IP is spread across a number of companies and contribution to the HFC sector types. Arguably some of the most valuable UK IP is tied up in the materials and processing activities of Johnson Matthey based at Royston. Although not an HFC company per se, Johnson Matthey exploit a series of patents and other IP as one of the world's largest and most important suppliers of materials used in making fuel cells. As one of the world's larger specialist materials providers, they also supply a wide range of catalysts to processing industry, including of that type that are used to make hydrogen from hydrocarbons. On that example alone, even if the UK had no HFC manufacturing companies – and it has quite a few – the UK still has a marked interest in the development of a commercial HFC sector. Tokheim, a manufacturing company in Dundee, largely unknown to the UK public but part of a US-owned multi-national fuel services' company, has provided fuel dispensing equipment to a number of EU HFC transport projects carrying the brand of one of the oil giants. It is often far from clear where technology and value actually comes from.

It is not the intention of this chapter to list and describe all of the UK HFC companies and their IP, some of their IP is frankly unknown to the authors, and for good commercial reasons (as per above) it should probably stay that way! However, Johnson Matthey provides a useful and hardly secret means of illustrating that UK interest in this sector and its IP goes well beyond necessarily obvious HFC companies. Indeed the importance of supply chain and its interactions has been a key element of this paper.

Some examples of key UK businesses both core and supply chain might include Intelligent Energy (FC), ITM Power (electrolysis), Ceres (FC), AFC (FC), Linde/BOC (gases), Rolls Royce (CCGT integrated FC), many O&G sector companies provide relevant specialist gas production and handling components and services [Wood Group, SubSea7, Clydeblowers etc.]. In addition there are a range of relevant trade bodies including the Scottish Hydrogen and Fuel Cell Association (said to be the most active in Europe), it's UK sister association and a range of more general trade associations, such as the IMI mentioned in the context of skills, whose specialisms also feed into the sector. As mentioned no list could be complete/exhaustive on account of the range of existing UK companies potentially capable of feeding into this space. All of these core HFC companies and related businesses have their own specialist IP and arguably of even more importance the critical human capacity with which to play a major role in UK success in a UK HFC sector.

Similar supply chain IP observations can be made in respect of the UK's gas handling and processing expertise – which is amongst the best the world has to offer. The UK is replete with many suppliers of specialist pumps, valves, sensors, control technologies and such like which entrain their own IP and are very relevant to an emergent UK HFC sector. And critically, are no less relevant to an emergent global HFC sector.

8.3 HIGH TEMPERATURE FUEL CELLS

It is worth a few words about high temperature fuel cells and IP. Whilst low-temperature polymer-based fuel cells and older types of low-temperature fuel cells can be regarded as fairly well established technically and having some measure of early markets, solid-oxide (SOFC) type high temperature fuel cells are rather behind the others in terms of being completely market-ready.

There is great deal of IP tied up in SOFC development on account of the high temperatures at which they operate. The difficulties involved in developing commercial product from a base technology operating at those temperatures also explains to a good extent why that form of FC technology lags somewhat behind the others in terms of its commercial readiness – it is simply more difficult to commercialise as long term durable product.

That said, SOFC technology has some very distinct operational technical advantages over its rivals. Firstly, it outputs much higher quality heat than its alternative FC types. That places SOFC technology in a much stronger position in terms of combined heat and power operation, its electricity output provides a good source of higher value revenue generation or cost displacement whilst it has a significantly more usable quality of heat output than its lower temperature technology rivals. These factors combined are capable of resulting in combined fuel conversion efficiency of around 85% and on scales eminently suitable for even moderate sized buildings. [Only the very largest of conventional generation plant is capable of reaching similar total conversions efficiencies.] Its second key advantage is its multi-fuel capability. With only a relatively simple pre-reforming stage, if that, SOFC technology can operate directly on hydrocarbon fuels including natural gas – offering the potential to plug directly into the existing gas network as is.⁷⁸ Whilst that does not eliminate CO₂ emissions, the overall conversion efficiency does offer a marked carbon improvement with respect to the production of both heat and electricity compared to conventional means of production.

In terms of UK-owned IP specifically, the UK has a number of high temperature HFC technology companies and academic interests which do own IP in this area. Those interests also include high temperature electrolysis, a variant of conventional electrolysis which like its FC counterpart offers distinct overall efficiency advantages. Although the first commercial high temperature offerings are only now coming to market, they do represent potentially significant value to the UK and they should not be ignored despite their being somewhat behind the emergence of other HFC technologies as they arguably offer the greatest potential in terms of efficiency and economic benefit.

8.4 FUEL CELL COMMERCIAL READINESS

The potential applications of fuel cells in society are ever increasing, driven by the various benefits that the implementation of fuel cells would bring over current technologies, such as environmental and efficiency improvements. Applications being

⁷⁸ The values given are based on 20kW (electrical) prototype SOFC system built at FZJ Germany www.fz-juelich.de.

considered range all the way from very small scale, requiring only a few watts to larger-scale distributed power generation of hundreds of megawatts.

The small scale power supply market is well suited for fuel cells. Indeed, fuel cells offer significantly higher power densities than batteries, as well as being smaller and lighter and having much longer lifetimes. Hence, an increasing number of applications are emerging where only a few watts are required, such as palm-top and lap-top computers, mobile phones and other portable electronic devices.

Their potential high reliability and low maintenance coupled to their quiet operation and modular nature makes fuel cells well suited to localized 'off grid' power generation, either for high quality uninterrupted power supplies, or remote applications. High temperature fuel cells (MCFC and SOFC) are suitable for continuous power production, where the cell temperature can be maintained. If the released heat is used to drive a gas turbine to produce extra energy, the system efficiency can be increased to levels as high as 80%, significantly higher than any conventional electricity generation process. Moreover, the produced heat makes SOFCs particularly suited to combined heat and power (CHP) applications ranging from less than 1 kW to several MW, which covers individual households, larger residential units and business and industrial premises, providing all the power and hot water from a single system.

The combination of their high efficiency (approaching 50% for Hydrogen PEMFC) and significantly reduced emissions of pollutants mean that fuel cell powered vehicles are a very attractive proposition, especially in heavily populated urban areas. The efficiency is to be compared with about 20% for a combustion engine. Low temperature fuel cells, in particular PEMFC, are the most suited to transport applications, because of the need for short warm-up. The concept of a fuel cell powered vehicle running on hydrogen, the so-called 'zero emission vehicle', is a very attractive one and is currently an area of intense activity for almost all the major motor manufacturers. A major advance has been the recent introduction of vehicles such the Toyota Mirai into the commercial sphere. As a further example, fuel cell powered buses, running on compressed hydrogen are successfully operated in several cities around the world.⁷⁹

Whilst hydrogen is already a significant bulk chemical with 50 million tonnes produced per annum, fuel cells are only just coming to market. That said recent fuel installations are significant with 500 MW installed in 2016 and 300 MW of capacity installed in 2015. In 2016 transport overtook stationary as the fuel cell modality. In 2016 the technologies were approximately distributed according to output as PEMFC (60%), PAFC(7%), MCFC(15%) and SOFC(10%).⁸⁰

Fuel cell-based micro-CHP systems are highly efficient and have the potential to offer the highest efficiency for small-scale applications.⁸¹ Polymer electrolyte fuel cell (PEMFC) and SOFC-based cogeneration systems have the advantage of high efficiencies and lower heat to power ratios which enables them to operate either constantly

⁷⁹ IEA Technology essentials, Hydrogen production and distribution, OECD/IEA 2007.

⁸⁰ The Fuel Cell Industry Review 2016, E4Tech.

⁸¹ J. Larminie and A. Dicks, *Fuel cell systems explained second edition*, 2003, ISBN: 978-0-470-84857-9.

or on in an electrically led application (largely independent of thermal demand). This combined with its near silent operation makes fuel cells a well suited technology for domestic micro-CHP applications.^{82,83} According to E.ON micro-CHP can be installed in most UK residential buildings potentially equal to a capacity of 24GWe.⁸⁴ With their electrical efficiency over 50% and low heat-to-power ratio, they offer significant benefits, effectively supplying the total electrical demand of homes throughout the year. The potential benefits of fuel cell-based micro-CHP units have been proven through various demonstration projects, such as the Ene-Farm Japanese fuel cell demonstration program with 120,000 units already installed.⁸⁵

8.5 RETENTION OF UK VALUE AND EXPORT

It is extremely difficult to predict which of the current UK HFC companies will establish good domestic markets and go on to export products which entrain UK-owned IP. But as per the opening statement in this chapter, HFC will begin as an already largely globalised sector with complex international interests. As described in the previous section, through the HFC supply chain the UK definitely does have a major IP-related interest in the development of a global HFC sector. Many of those supply chain companies are long-established exporters of high value materials and HFC system components.

It is worth noting that some of the UK's core HFC companies have been recipients of significant inwards investment from N America and SE Asia as a check on the idea that retention of IP value is the only relevant factor, one might expect a balance between some potential UK loss of IP value and gains from inwards IP and finance. Arguably then the UK's best strategy position is to create a bias which is net beneficial in a likely 2-way flow of these elements.

As such, the prospect of the UK not benefitting economically from the development of a global HFC sector and exporting into that is essentially zero. Even if ownership and control of those supply chain companies were to move overseas, it would prove very difficult to persuade the talent and skills involved in generating that value to leave the UK en masse. IP is very much about the people who generate it.

Focusing on the supply chain as a starting place to consider export potential, it is clear from European demonstration projects that a number of UK-based manufacturers, core HFC technology companies, have already had a measure of success in exporting their technology. Despite trying to avoid naming specific companies, it is difficult to avoid mentioning ITM Power plc (Sheffield) in that context due to their high profile involvement in supply electrolysis equipment into wind-to-gas type demonstration in Germany (and others). They have successfully managed to convince their partners that they have the best technology for that application and despite there being a number of other European suppliers (French, German and Norwegian) who

82 T. Elmer, M. Worall, S. Wu and, S.B Riffat, *Appl. Thermal Engineering*, 90 (2015). 1082–1089.

83 A. Hawkes, I. Staffell, D. Brett, N.P. Brandon, *Energy Environ. Sci.* 2 (2009) 729–744.

84 J. Harrison, *Smart Hydrogen & Fuel Cell Power Conference*, Birmingham, 2012.

85 <https://fuelcellsworks.com/archives/2015/09/23/ene-farm-installed-120000-residential-fuel-cell-units/>.

can also supply electrolysis equipment. This illustrates usefully that not only might UK companies be able to export, not only can they export, but that they can do so in the face of real competition and in that example. That UK company's strength is very much about IP, they make a quite different type of product to that of most suppliers of electrolysis equipment.

8.6 RETENTION OF IP

Retention of IP is very difficult to assess in any meaningful way in a globalised world and in a sector liable to emerge being significantly globalised. Also, with the exception perhaps of defence related industry, the UK has operated and championed an international free-market policy environment for a very long time, one that places few (if any) restrictions on overseas parties attempting to acquire established UK companies and/or UK developed IP.

It must be recognised that people generate IP rather than physical resources of any type and that IP is something that we should seek to be constantly developing. And so the retention of valuable HFC related IP in the UK becomes a matter of ensuring that the people and businesses who generate that IP find themselves in academic, innovation and business environments conducive to making them want to remain in the UK.

The bulk of innovators will be highly qualified and potentially highly mobile individuals and nascent businesses who/which are very capable of moving to the United States or China and other locations where business finance may often be more easily obtained. But there are also key factors beyond availability of finance and other business concerns such as taxation, including basic human and social factors. The human factors largely relate to quality of life, are self-evident and need not be further drawn out here, but they would not be wisely ignored as the human factors often feed strongly into the decisions that individuals make.

8.7 IP SUMMARY

Even from this brief consideration of IP, it is undeniable that UK interests will certainly generate economic activity and value from the development of UK and international HFC markets. And that a significant amount of that value will derive from exports. It is too early to predict the fate of the UK's core FC companies, but it is clear that activity and value definitely will derive from supply chain. The benefits of seeking to develop a strong internal market are surely self-evident, even where some of the components might be imported. Meanwhile there is already evidence of UK supply chain and core exports and capability to export. Barring the UK deciding to adopt a protectionist attitude to trade and markets, retention of IP and value within the UK can be expected to be good.

Many tend to think of IP in terms of patents and legally protectable IP, but ultimately its generation and retention has rather more to do with people themselves. The importance of educating and training personnel to appropriate levels, allowing them to innovate and creating a business, working and living environment in which they can flourish cannot be overstated.

CHAPTER 9

MODELLING THE IMPACT OVER TIME – CONSUMER TRANSPORT

9.1 INTRODUCTION

This chapter considers a few simple scenarios that introduce some potential scale to the input-output multiplier model analyses in Chapters 3, 4 and 6 in considering the potential wider economic impacts of a projected shift to a hydrogen economy. Again, focus is mainly on the case of private transportation and the shift from petrol/diesel (refined fossil fuels) to hydrogen, with the supply chain of the latter proxied by those of the existing UK gas and/or electricity supply sectors. The key characteristic of these proxies is the markedly stronger up-stream supply chain linkages *within* the UK economy as compared to the more import-intensive refined fuel supply industry. A central conclusion of the modelling work in this paper is that if a future hydrogen sector shares this characteristic, net positive impacts on the UK economy as whole are likely when/if private transportation transitions to the use of hydrogen as a fuel source.

In this context, the simulations in this chapter focus on the extent to which spending on hydrogen fuel in private transportation may be able to ‘absorb’ GDP and employment losses resulting from reduced demand for petrol/diesel. These are variables that may be of particular political and policy concern in any development of the energy system. Impacts are considered over several longer timeframes up to 2050.

The first step taken is to introduce forecasted scenarios across different discreet time periods for reduced demand and use of petrol and diesel as refined fossil fuels for use in private vehicles. This is translated to the projected reduction in UK household expenditure required to conduct a simulation using the input-output model. The results are then taken as a base against which to scale and compare potential uptake of hydrogen fuels (based on the gas and electricity proxies introduced in Chapter 3).

In setting up the scenario regarding reduced demand for UK refined fuels sector (which supplies petrol and diesel), this chapter draws loosely on scenario analyses conducted for the White Paper 3. However, the core of the analysis is applying multiplier tools used in Chapters 4 and 6 to consider the sectoral breakdown of the refined fuel and gas/electricity hydrogen proxy sector. That is, the current chapter introduces some potential scale to the marginal potential impacts considered in Chapters 4 and 6. Two scenarios are analysed:

Scenario 1: What are the economy-wide impacts of a change in UK household demand for refined fuel products (petrol and diesel) if demand/expenditure falls as a result of a transition to lower carbon fuel sources. This scenario is considered for various time frames between 2015 and 2050.

Scenario 2: What are the potential economy wide implications if reduced UK household expenditure on refined fuels is reallocated, to some degree, to spending on hydrogen, where the supply chain for the latter is given by one of the two proxies identified in Chapter 3 (and applied in Chapters 4 and 6). Specifically, how much spending on hydrogen may be required to prevent a net contraction in GDP and/or employment (as key macroeconomic variables) as a result of the fuel spending shift? The approach is also motivated by the fact that appropriate information (i.e. in format required to inform the economic input-output model) is not available on the level and particularly the likely price of spending required to hydrogen vehicles.

At this stage it is important to reflect on a couple of issues that are relevant in considering the transition to a hydrogen economy. First, while ideas around targets for supporting the transition to a hydrogen economy/low carbon economy are beginning to emerge, it is valid to question whether the UK is at the stage of setting a strategic plan; that is, whether goals in this respect are actually executable and achievable. Secondly, but linked to the latter point, it is not yet clear who would be responsible for making the transition to use of hydrogen fuel happen. While there is a clear role for Government in supporting such a shift, and this may be motivated by the type of potential for wider economic expansion considered here, the motivation for private firms to play a role in the hydrogen supply chain is less obvious. Similarly, the motivation and incentives for households to assume responsibility for the private investment spending (on vehicles) required for them actually use hydrogen technology and fuels is not established or straightforward. Therefore, the scenarios and potential economy-wide impacts identified here must be viewed with caution, assuming as they do that the shift takes place.

In this context, one of the overarching objectives of the economy-wide analysis in this paper is to begin to consider what may possibly happen if all actors can be persuaded to participate in the transition to hydrogen economy. In order to do so, this chapter focuses on demonstrating how the input-output multipliers identified in Chapters 3, 4 and 6 may be used to consider scaled scenarios to inform an evidence-base on the wider potential societal benefits of the transition to a hydrogen economy.

However, there is need for caution in that the scenarios considered in this chapter involve a marked change in the scale of activity in different sectors so that the restrictive assumptions (discussed in Section 3.4, chapter 3) become particularly relevant.

9.2 APPLYING MULTIPLIER ANALYSIS FOR SCENARIO ANALYSIS IN POTENTIAL DEPLOYMENT OF HYDROGEN IN THE UK

The underpinning argument of the modelling work in this White Paper is that the UK ‘Refined Fuels’ sector (sector details in Table 9.3 below), which supplies the petrol and diesel currently used to run most private cars, is import-intensive and has relatively weak upstream linkages within the UK economy. Specifically, its headline multipliers – for GDP, output, employment and wage income – are the lowest of all 103 industries identified in the UK input-output framework. The implication is that any reallocation of spending away from refined fuels towards any other UK industry is likely to result in a net positive impact on the production of goods and services and associated creation of value-added and jobs within the UK economy.

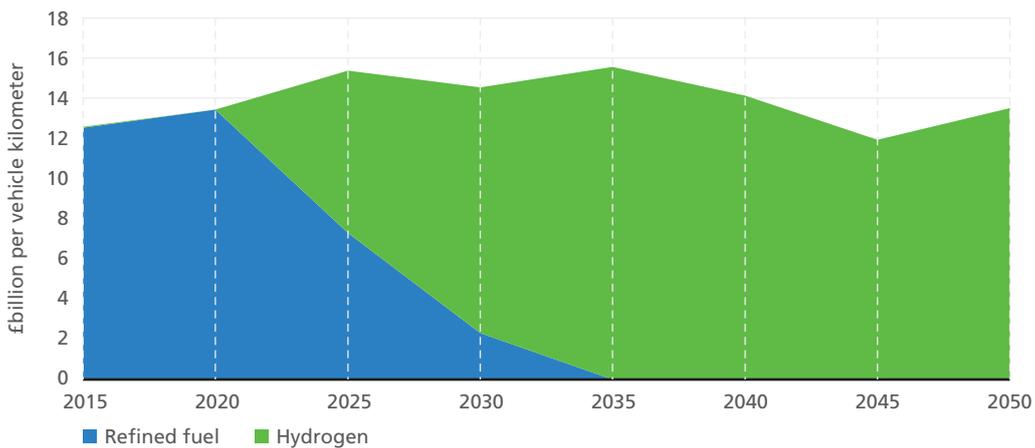
Under Scenario 2 below, the impacts of a potential contraction in the UK economy will be examined in context of the scaled reallocation of household spending towards hydrogen that would be required to deliver zero net impact on GDP, and no job losses across the economy as a whole, from switching fuel sources. Before that, this section first considers the gross impacts of a reduction in total final household demand for the output of the UK Refined Fuel sector.

This chapter examines the potential of a near term to long term role of hydrogen in the UK Transport sector, at discreet points between 2015 and 2050. For modelling

purposes, the input-output base year of 2010 is considered as a period where no hydrogen supply is present. Thus, the post 2010 period, specifically from 2015–2020, may be considered as a critical path in the transition to a hydrogen economy. At this stage it expected that investment hydrogen-enabling infrastructure is on-going and the UK is getting ‘hydrogen ready’ to facilitate long term use of hydrogen throughout the economy (the third scenario below focuses on the potential impacts of R&D investment at this stage). However, there is no deployment of hydrogen in transport sector over this period. This would be consistent with an assumption of non-uniform deployment of hydrogen across the economy (i.e. hydrogen supply for non-transport purposes may come into effect). Moreover, investment in hydrogen technologies and infrastructure would take time to be realised, which will involve factoring in consumer acceptance.

Figure 9.1 provides an illustration of the projected contraction in demand for refined fossil fuels (petrol and diesel) relative to the estimated demand and contribution of hydrogen in the UK transport sector. Specifically, it illustrates the potential expenditure (in billions of UK pounds) on refined fossils fuels in comparison to expected spend on hydrogen for all (not just private/household) car transport from 2015–2020. The blue shaded area captures what may be a ‘critical path’ through the 2015 to 2025 period where the UK economy is developing and implementing all necessary technologies, investment and innovation to support a transition to a hydrogen economy. Hence, expenditure and demand for traditional refined fossil fuels in transport remain dominant from 2015–2025. On the other hand, the green-shaded area represents what may be regarded as a ‘full contribution’ path, where it is expected the fuel used in cars is fully diversified with low carbon energy sources and hydrogen is the dominant fuel choice in UK car transport.

Figure 9.1 Expenditure on fuel/energy on all (not just household/domestic) car travel in the UK.



Source: The projected expenditure on fuel/energy for car travel in Figure 9.1 are the authors’ calculations using UK Department for Transport Statistics (2015) average new car fuel consumption: Great Britain, 1997–2014 figures⁸⁶ and Mckinsey Company (2010) A portfolio of power-trains for Europe: A fact-based analysis: The role of battery electric vehicles, plug-in hybrids and fuel cell electric vehicle report.⁸⁷

⁸⁶ www.gov.uk/government/collections/transport-statistics-great-britain.

⁸⁷ https://europeanclimate.org/documents/Power_trains_for_Europe.pdf.

For instance, if we read down the third numerical in Table 9.1, it is estimated that by 2025 hydrogen begins on a near term small scale in car transport. From this point, a gradual diversification of the fuel mix is projected, with petrol/diesel disappearing by 2035. The estimated potential direct impact of this is that UK car users will require 14billion litres of petrol and diesel to travel 259.31 Bvkm. This corresponds to a point in Figure 9.1 where there is a total spend of around £7billion. In contrast 1.82 billion kg of hydrogen would be potentially required to travel 249.03 Bvkm for hydrogen fuelled vehicles with total spend of £9million.

Table 9.1 Fuel consumption for car travel 2015–2050.

Distance travelled	2015	2020	2025	2030	2035	2040	2045	2050
Refined fuel (Billion vehicle kilometres)	437.46	472.70	259.31	82.48	0.00	0.00	0.00	0.00
Hydrogen (Billion vehicle kilometres)	0.69	0.24	249.03	436.02	595.16	567.59	497.73	583.16
Units of fuel/energy								
Refined fuel (Billion litres)	26.42	27.61	14.61	4.56	0.00	0.00	0.00	0.00
Hydrogen (Billion kg)	0.01	0.00	1.82	3.03	4.02	3.72	3.18	3.60

Source: The projected distance travelled by fuel/energy in Table 9.1 are the author's calculations using UK Department for Transport Statistics (2015) average new car fuel consumption: Great Britain, 1997–2014 figures and Mckinsey & Company (2010) A portfolio of power-trains for Europe: A fact-based analysis: The role of battery electric vehicles, plug-in hybrids and fuel cell electric vehicle report.

It is important to flag up again that the figures in Table 9.1 are approximations and should be treated cautiously. Projections are required because there are obviously no observed figures for hydrogen use in the future at the time of this exercise, and no or incomplete information is available on actual or relative hydrogen/fossil fuel prices and likely quantities involved. Therefore, comparative expenditures for refined fuels in conventional cars versus hydrogen use in appropriate new vehicle types may likely to be under or over estimated at the current time. However, the projections provide a useful basis to approximate the likely relative negative and positive impacts on UK GDP and employment through the transition period.

9.2.1 Scenario 1: Change in household demand for UK refined fuel

The previous section gives a forecast of the potential change in fuel use, focussing on petrol/diesel as refined fossil fuels in comparison to hydrogen, in different discreet time periods. Given that the economic modelling work here has placed emphasis on the fact that transition to hydrogen would involve contraction in the UK Refined Fuel supply industry, as well as any expansion around new activity involved in supply hydrogen, the period of contraction in refined fuel supply (including its domestic supply) will ultimately have implications on some UK household incomes and expenditure across different goods and services and spend across various uses.

In first scenario the potential impacts of such a contraction over discrete time periods is considered. Drawing on results from the projections discussed above, Table 9.2 provides a breakdown of potential changes in household demand for and expenditure on refined fossil fuel products supplied by the UK industry. Note that, in contrast to Figure 9.1 and Table 9.1, the information in Table 9.2 focuses on household use of fuel in cars only. However, the percentage change in the demand for refined fuels is taken to be the same as percentage change in overall car transport activity. This information is then applied to the 2010 input-output data on UK household expenditure on the domestic 'Refined Fuels' supply sector (which includes imported fuels distributed in the UK). That is, we assume that the percentage change in demand is the same as the percentage change in expenditure on the input-output sector.

Table 9.2 Reduction in UK household demand for refined fuels.

	2015	2020	2025	2030	2035	2040	2050
% Change demand for refined fuels	-2%	5%	-43%	-82%	-100%	-100%	-100%
Change in household expenditure (£million)	-148	311	-2,821	-5,373	-6,556	-6,556	-6,556
New household expenditure (£million)	6,408	6,867	3,734	1,183	0	0	0

The figures in each column Table 9.2 must be taken as independent of one another and applying in absolute terms in the year indicated in the column header. They are not cumulative. The percentage change in each year is relative to spending in the base accounting year of 2010, when the UK input-output data report a total of £6,556million (£6.5billion) in household spending on the outputs of the UK Refined Fuels sector.

For example, taking the case of 2025, Table 9.2 reports that UK total household demand and expenditure for refined fuel products is projected to decrease by 43% relative to 2010. The direct impact of this is that household expenditure on refined fuels fall by £2821million (43% of the £6,556million base). In order to consider what this means for the wider economy, simple multiplier calculations can be conducted using the various output multipliers initially reported in Table 3.1 (Chapter 3), and decomposed in Chapter 4. In this chapter focus is on overall GDP and employment impacts. However, the impacts on supply chain sectors affected may be informed by sectoral level results reported in, for example, Figure 4.2 (GDP requirements embedded in supply chain sectors for Refined Fuels), although it is important to note that this abstracts from own-sector employment in Refined Fuels. The focus in this chapter is on aggregate level results, although attention is drawn to key sectoral level impacts.

Table 9.3 is an abridged version of Table 3.1. It focuses on the value-added, or GDP, and employment multipliers for the Refined Fuels sector, the two hydrogen proxies and also the R&D sector that are the subject of simulations here. GDP and employment are selected as the macroeconomic indicators that are likely to be of most interest to policy. However, results could be calculated for output and/or wages.

Reminding the reader that multipliers are stated in terms of impacts per £1million of final demand expenditure, calculating the high level economy-wide impacts simply involves taking the product of the multiplier from Table 9.3 and the change in UK household spending on the sector from Table 9.2. For example, the GDP impact of the £148million reduction in spending in the 2015 column of Table 9.2 is calculated using the 0.33 output-GDP multiplier for Refined Fuels giving the result of a £49million contraction in UK GDP (0.33×148).

Table 9.3 Output multiplier values for selected UK industries.

		Multiplier (activity per £1million final demand)			
SIC	Sector/industry name	Output (£million)	Value-added (£million)	Employment (FTE jobs)	Wage income (GDP) (£million)
19	Refined fuel (Manufacture of coke and refined petroleum products)	1.47	0.33	2.93	0.19
35.1	Hydrogen proxy 1 (Electric power generation, transmission and distribution)	2.56	0.78	8.05	0.32
35.2	Hydrogen proxy 2 (Manufacture of gas; distribution of gaseous fuels)	2.25	0.81	8.04	0.32

Table 9.3 shows the results of conducting this calculation for each of the discreet time periods identified in the projections above. The key results selected are the change in total UK employment, and the value (in £million) of the change in UK GDP, both relative to the 2010 base in each time period simulated. The impact on UK GDP of even a 100% reduction in UK household demand for the output of the Refined Fuels supply sector is relatively small, translating to a 0.17% contraction relative to the 2010 value. Please note that there is no attempt to forecast the general growth path of the UK economy so that the focus of the results is to isolate the impacts of the reduction in spending relative to what the economy would look like with no other changes in UK real GDP. Moreover, note that the input-output model does not consider the implications of any reduced government revenues from spending on refined fuels. This would require a more sophisticated economy-wide model and analysis.

Table 9.4 Economy-wide impacts of change in demand for refined fuels: Effects in different time periods.

Economy-wide impacts of reduction in expenditure for refined fuel							
	2015	2020	2025	2030	2035	2040	2050
% Change in expenditure	-2%	5%	-43%	-82%	-100%	-100%	-100%
Employment (FTE)	-434	913	-8,274	-15,757	-19,225	-19,225	-19,225
Value added (GDP) (£M)	-49	104	-941	-1,793	-2,187	-2,187	-2,187

However, the impact on employment may cause greater public and policy concern. As soon as 2025, 8,274 full-time equivalent (FTE) jobs are lost. The main loser is the Refined Fuels sector itself, with 1,157 FTE jobs lost. However, this is only 14% of the total job losses throughout the UK economy. Losses are felt in every one of the 103 UK input-output industries. The distribution of job losses is given by Figure 6.1, and this impact is largely concentrated in the Refined Fuels industry, where the second biggest loser is the wholesale/retail distribution sector. By 2035, when household spending on the UK Refined Fuels sector disappears all together, total job losses rise to 19,225 FTE posts, and 3,277 of these are in the refined fuel and distribution sectors.

This type of result motivates the focus of the second scenario simulated. People will still need to buy fuels (Figure 9.1 shows little over all drop in fuel use to run cars), it is just the type of fuel that changes. The focus in Scenario 2 is on how much spending on hydrogen is required to absorb the key economy-wide losses reported in Figure 9.3.

9.2.2 Scenario 2: (Partial) reallocation of fuel spend to hydrogen (using proxies)

This scenario considers how much of the reduced UK household spending on petrol/diesel as refined fossil fuels to run cars would have to be reallocated to spending on hydrogen in order that there be a zero net impact at the macroeconomic level from the transition from one fuel type to another. The selected focus in the results reported here is to determine the level of spending reallocation required to deliver a zero net impact on GDP. Modelling experiments revealed that GDP losses are more difficult to compensate than employment losses. Policy and public communities are likely to prefer an outcome where GDP is unchanged but employment rises, rather than no net job gains coupled with even a slight GDP loss.

Table 9.5 shows the results of the simulation where the structure of the current (2010) UK electricity supply sector is taken as a proxy for hydrogen supply. That is the electricity industry multipliers (Table 9.3 above) are applied to the projected spending on hydrogen (the actual electricity sector is assumed to exist independently). Focus in Table 9.5 is limited to 2025 (where first hydrogen spending is present), 2030 (the last time frame before full contraction of refined fuel spending) and 2050. The hydrogen spending required to deliver the net zero GDP impact in each case is calculated by taking the contraction GDP reported in Table 9.4 (e.g. £941million in 2025) and dividing by the output-GDP multiplier of the electricity proxy from Table 9.3 (0.78). The impact on employment associated with spending on hydrogen is calculated simply by the product of the required change in the final demand proxy (£9,729million in 2025) by the electricity proxy output-employment multiplier from Table 9.3 (8.05). The net impact of the reallocation of spending (1,455 jobs gained in 2025) is calculated by adding the latter result (9,729 FTE jobs in 2025) to the gross losses from the contraction in refined fuel spending (repeated in Table 9.5 as 8,274 jobs in 2025).

The results in Table 9.5 show that net employment gains of up to 3,382 may be delivered by 2050 if sufficient spending is reallocated from refined fuels to hydrogen fuel. Note that the amount of spending required to deliver the zero net impact on GDP in any of the time periods is markedly less than the total amount no longer

required for spending on petrol/diesel. For example, in 2025, only £1,208million of the £2,821million reduction in refined fuel spending needs to be spent on hydrogen (electricity proxy) in order to deliver a zero net impact on GDP (and create 1,455 FTE jobs). The remaining £1.61million is freed up to spend either on more hydrogen (and the projections in Figure 9.1 suggest more spending would be made/required) or on other goods and services, or a combination of both. The key point is that there will be an additional spending and, as long as this has at least some UK component (rather than being entirely imported) there will be further positive impacts on GDP and employment.

Table 9.5 Summary of Scenario 2 results – Hydrogen proxy 1 (electricity supply).

Electricity proxy			
Summary of scenario 2 results	2025	2030	2050
% decrease in expenditure on refined fuels	-43%	-82%	-100%
Change in spending on refined fuel (£million)	-2,821	-5,373	-6,556
Change in GDP from contraction in refined fuel spending (£million)	-941	-1,793	-2,187
Change in employment from contraction in refined fuel spending (FTE jobs)	-8,274	-15,757	-19,225
Required spending on hydrogen proxy (£million)	1,208	2,301	2,808
Gross impact on employment from spending on hydrogen proxy (FTE jobs)	9,729	18,528	22,607
Net impact on GDP from fuel spending reallocation (£million)	£0	£0	£0
Net impact on employment from fuel spending reallocation (FTE jobs)	1,455	2,772	3,382
Freed up funds for spending on hydrogen or other goods and services (£million)	1,613	3,072	3,748

However, an important qualification regarding the use of the electricity proxy (and corresponding gas one below) detailed in Section 4.3 of Chapter 4 must be noted. The supply chain jobs (and GDP) in the proxies include jobs in the UK off-shore oil and gas extraction sector. If the resource used to produce hydrogen is not one that would be extracted by the UK off-shore industry (SIC 6) then the employment and value-added components of the impacts calculated using either electricity or gas proxies will be reduced. For example, in 2050, 199 of the 22,607 gross jobs created by spending on hydrogen are located in the off-shore oil and gas sector.

As noted elsewhere employment and money figures make no account of the additional ‘HFC layer’ directly involved in hydrogen production itself or of its likely more distributed nature. Figures given are likely to be significantly underestimated relative to those which might be obtained from a more sophisticated model. They do however indicate the direction of travel.

Table 9.6 Summary of Scenario 2 results – Hydrogen proxy 2 (gas supply).

Gas proxy			
Summary of scenario 2 results	2025	2030	2050
% decrease in expenditure on refined fuels	-43%	-82%	-100%
Change in spending on refined fuel (£million)	-2,821	-5,373	-6,556
Change in GDP from contraction in refined fuel spending (£million)	-941	-1,793	-2,187
Change in employment from contraction in refined fuel spending (FTE jobs)	-8,274	-15,757	-19,225
Required spending on hydrogen proxy (£million)	1,169	2,226	2,716
Gross impact on employment from spending on hydrogen proxy (FTE jobs)	9,395	17,892	21,830
Net impact on GDP from fuel spending reallocation (£million)	0	0	0
Net impact on employment from fuel spending reallocation (FTE jobs)	1,121	2,135	2,605
Freed up funds for spending on hydrogen or other goods and services (£million)	1,652	3,147	3,840

In Table 9.6 a corresponding set of results are shown if the gas proxy is used for a potential hydrogen supply sector rather than the electricity one above. The key point to note is that the gas proxy has a larger output-GDP multiplier than the electricity proxy (0.81 compared to 0.78). This means that a smaller reallocation of spending to hydrogen (e.g. £1,169million in 2025) is required to deliver a zero net impact on GDP. However, this also means that a smaller net boost to employment (1,121 FTE jobs in 2025) is associated with the required reallocation of spending (the gas and electricity employment are almost the same at 8.04 and 8.05 respectively). However, this simply means that more funds (£1,652million in 2025) are freed up to spend on other things.

9.3 CONCLUSIONS

In the absence of appropriate information to inform fuller simulation analysis using the economic input-output models of changes in projected expenditure on hydrogen fuels, this chapter has focussed instead on considering the amount of hydrogen spending that would be required to absorb any GDP losses arising from contracted household spending on petrol/diesel. The results show that it is likely that only a partial reallocation of previous spending on refined fossil fuels would be required to compensate GDP losses and deliver an employment boost. **This is because of the stronger domestic up-stream supply chain linkage associate with a hydrogen supply sector that shares characteristics of the current UK gas and electricity supply proxies.** In short, as long as hydrogen supply is less import-intensive and has relatively strong domestic linkages, it is likely that any fuel switch will deliver gains at the economy-wide level.

However, it is important to note that there are likely to be sectoral ‘losers’. In Chapter 4, Section 4.4, input-output modelling results suggested that only around three or four (out of 103) UK industries would suffer net losses in terms of output, GDP (and the same is true of employment). However, this was in terms of considering a pound for pound reallocation spending. In this chapter, the key result is that the compensating (at economy-wide level) hydrogen spend would be less than one pound for every pound lost to refined fuel. Therefore, the number of UK industries losing out is likely to be greater. However, the largest overall losses should be expected in the Refined Fuels industry itself: again, a key point to note is that the modelling results here suggest that the petrol/diesel to hydrogen fuel switch will free up income to spend on other things, and these in turn (depending on where money is spent) will have positive multiplier effects throughout the UK economy.

CHAPTER 10

THE INTERNATIONAL CONTEXT

10.1 INTRODUCTION

This section gives an outline discussion of how hydrogen and fuel cells are developing outside the UK and becomes especially important as the UK begins the process of shaping its new international relationships. It addresses Europe firstly as the UK's nearest potential export market, before going on to consider further afield discussing mainly North America and Asia. Finally, it address Brexit directly as Brexit could potentially have far reaching implications for some parts of the UK HFC sector.

10.2 EUROPEAN CAPABILITY

In part thanks to the way the EU has supported HFC innovation as a collaborative exercise, development activities and their largely derived resultant businesses are well spread across Europe.

The greatest concentration of activity is to be found in the larger economies of Germany, France and Italy (and the UK) as well as Norway and Switzerland. The larger/stronger economies have the mass with which to support strong public sector activity which has generally fed into the relevant national private sectors. There has been current or historical interest and investment from most of Europe's oil and gas companies, specialist industrial gas companies along with strong involvement and investment from European-based automotive concerns.

In structural terms, Germany is most organised and has a clearly defined public innovation sector ranging from fundamental research at universities, investment in strategic pre-commercial R&D via its Helmholtz Gemeinschaft organisation's national R&D facilities, through to its Fraunhofer Institutes which focus exclusively on specific issues relating to current industry challenges. Unsurprisingly, that highly coordinated public sector approach combined with well-defined German Federal and local state policy to support the nascent German HFC industry feeds into a relatively large number of sector-active businesses including supply chain. Industrial giants such as Siemens have had long-term core and supply chain interests in the sector, while the German automotive sector has significant investment already expended and is expected to bring vehicles to market around 2020.

Mercedes have been a major investor in the development of HFC transport in Europe and have played a major role in hydrogen bus demonstration projects. Formal public introduction of Mercedes passenger vehicles has been touted for some time now, with both A and B-Class sized vehicles having been extensively road-trialled in Germany and Norway⁸⁸ mainly. From 1997 Mercedes-Daimler, Ford and Ballard Power Systems had an exclusive formal relationship (incorporated as The Automotive Fuel Cell Partnership, AFCC) aimed at commercialising fuel cell technology for passenger vehicles. The relationship is no longer exclusive but AFCC continues its mission.⁸⁹

⁸⁸ Private Communication, Y. Larring, Sintef, Norway.

⁸⁹ Available from: www.afcc-auto.com/company/about-us/.

BMW formed a technology sharing partnership with Toyota in 2011 and more recently that has included sharing of engine and fuel cell technology.⁹⁰ 2015 saw the first road trials of a fuel cell powered 5-Series GT employing using both Toyota and BMW's in-house fuel cell expertise.

There is direct UK supply-chain interest in that German activity involving both component suppliers and specialist technology development services. Also the world-leading automotive systems consultancy and component designer Ricardo (UK-owned/based) has its fuel cell development team located at Aachen in Germany. This location is close to the headquarters of both Ford and GM Europe, who both have major manufacturing operations in Aachen and Köln.

Over a decade ago, German Federal agencies pooled and ring-fenced resources to form a single German Agency responsible for driving HFC transport and technology more generally. It is responsible for strategy and German engagement with EU programmes including the EU's Ten-T trans-European transport network infrastructure programme. NOW is coordinating Germany's hydrogen transport infrastructure development and having registered H2 Mobility as a company in 2015 aims to have 100 hydrogen filling stations constructed by 2018.

“NOW GmbH (National Organisation Hydrogen and Fuel Cell Technology) is responsible for the coordination and management of the National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP) and the Electromobility Model Regions programme of the Federal Ministry of Transport and Digital Infrastructure (BMVI). In addition, NOW also supports the BMVI in the continued development of the Mobility and Fuel Strategy as well as for the implementation of EU Directive 2014/94/EU on the development of alternative fuels infrastructure (CPT).”⁹¹

France has perhaps a less organised public policy and support, but nonetheless has good levels of academic and national research organisation activity as well as the involvement of its utility, petrochemical and automotive sectors. The Nissan-Renault partnership has seen both French and Japanese built fuel cell variants of battery-electric vehicles currently being sold under both brands in the UK. The (battery-electric) Nissan e-NV200 has a very similar construction and electric drivetrain to the Renault e-Kangoo, they can be regarded as sister-vehicles. Both eNV200 and e-Kangoo have fuel cell variants, some of which are already in the UK.⁹² Interestingly, one of the Nissan NV200 variants has been trialling high temperature fuel cells making these capable of operating on methanol rather than hydrogen.⁹³ The French multinational Michelin are understood to be one of main investors in the French Symbio fuel cell

⁹⁰ www.autonews.com/article/20150702/OEM05/150709965/bmw-begins-tests-of-fuel-cell-car-developed-with-toyota.

⁹¹ Extract from NOW's background/mission statement which can be found at: www.now-gmbh.de/en/about-now/aufgabe.

⁹² HyKangoos can be found in London, Aberdeen and Fife.

⁹³ Details at: <http://nissannews.com/en-US/nissan/usa/releases/nissan-unveils-world-s-first-solid-oxide-fuel-cell-vehicle>.

company.⁹⁴ French company McPhy has strong interests in hydrogen production and storage, having acquired a German electrolysis company in 2013, of late it has been addressing the (green) power to gas and transport sectors with clients such as Audi AG.

Italy follows the same general pattern as France with less obvious policy and support structure and a reasonable level of commercial activity as might be expected in an emergent markets situation. Fiat, via its New Holland agricultural vehicle brand has been trialling HFC tractors for some time now, though it is understood that these may be a distance from market yet.⁹⁵

Smaller European economies tend to have smaller spreads of interest but are often more focussed on specific aspects of HFC technology related to their indigenous industry and/or future needs. Most of these have some level of public and at least academic activity, often involving national technical research organisations such Sintef in Norway and VTT in Finland.

Out-with public sector activity in Europe, nationality of ownership can be rather nebulous in that, as per the UK, there are often few restrictions on acquisitions and mergers and it has been the case that a number of core HFC companies have been acquired by parties from out-with their country of origin. Also some of the HFC active companies are evidently pre-established publically quoted multi-nationals and hence nationality of ownership is to some extent meaningless. Arguably more important is the location of employment and physical business activities generating: employment taxes, corporation tax, business rates and VAT.

Europe and the EU have mainly targeted the development of its road transport HFC sector in terms of its investment in demonstration projects. However the EU's investment in more fundamental research and in other hydrogen and fuel cell technology applications preparation R&D has been much wider and less exclusive to road transport. That includes support for direct carbon fuel cells which can generate electricity directly from coal and other forms of finely divided carbon (including sustainable forms) at very efficiency.⁹⁶

The European (and EU) decision to focus mainly on road transport as the key early market recognises the otherwise largely intractable issue of road transport emissions and the inability of battery-only vehicles to offer 1:1 replacement of conventional road vehicles. That strategy was heavily influenced by the major European Automotives, and with automotive interests mainly at the helm. The latter became key partners of the current EU FCH Joint Undertaking as development moved from being dominated by fundamental research towards early market deployment. Transport was and is also generally recognised as being the most valuable market for HFC technologies on account of the sheer size of the potential mass market and also due to the fact that people in Europe pay more for personal transport on a per unit work delivered basis than they do for electricity and heat.

⁹⁴ <https://transportevolved.com/2014/05/14/michelin-invests-hydrogen-fuel-cell-company/>.

⁹⁵ www.newholland.co.nz/?id=155.

⁹⁶ RFCR-CT-2011-00004.

But it must be made clear that transport is seen in Europe as the high value early market which will act to reduce hydrogen and fuel cell costs and make hydrogen a widely available commodity. Europe has not neglected other application areas at all and has extensively supported the development of hydrogen production for energy storage, wind to gas, combined heat and power fuel cell systems, fundamental materials and has supported early deployment of some of these including in the UK.

10.3 BEYOND EUROPE

Whilst the EU has been very significant element of UK HFC development to date, the global development of HFC and its early markets has arguably been as strong and stronger in some respects in areas of North America and the Far East. In the United States development has arguably been patchy. In part that has been due to a lack of consistent US Government policy with respect to emissions reductions and also due to seemingly misguided quasi-technical arguments relating to whether battery-vehicle or HFC vehicles would be ‘the silver-bullet’ type solution. Established Federal support programmes for HFC technologies have been completely axed at some points in favour of investment in battery technologies only for those decisions to be later reversed. Much HFC development in the United States has occurred independent of Federal support, much of it privately financed and in some cases with support from individual states, particularly those such as California which has strong internal environmental ambitions that are often at odds with other states and the Federal Government. California has quite a few public vehicle hydrogen refuelling facilities and it is already possible to buy HFC vehicles there (a key early market for some of the Japanese manufacturers), whereas other states have virtually nothing.

There are Federal HFC support programmes which mostly originate in the US Departments of Energy and Transport. The United States is recognised to have some of the world’s best academic and other public funded HFC researchers – there is a good level of involvement from its PNNL and Sandia and other National Laboratories network and it has produced a substantive number of companies who have gone on to develop early market product. It is important to note that historically however, the United States has produced the bulk of earlier fuel cell type technologies, including those employed on NASA’s space shuttle programme.

The main challenge that the United State presents to non-US developers and companies seeking to export into the nascent market there is competition with indigenous US companies and the relative ease with which venture capital funding can be obtained in places like California (certainly compared to the UK and Europe).

Curiously perhaps given the size and general capabilities of the United States, Canada has emerged as one of the key global players in HFC technologies, albeit that its HFC companies have strong links to the US and some linkages to Europe. Ballard Power Systems, a Vancouver-based, manufacturer of FC systems is widely believed to be the world’s only FC company which is already profitable and has largely paid back its development investors. That financial success has been largely predicated on a long term development relationship with 2 of the world’s largest automotive companies

and the establishment of a commercial HFC materials handling vehicle market in the United States. The same Canadian company has to date provided almost every FC system used in the EU HFC bus demonstration projects. Canada also has a long established manufacturers of electrolysis equipment (Canada has a lot of sustainable hydro-power) which has also begun to establish itself as a supplier of FC systems – some of which can be found in a Scottish demonstration project now under commissioning. Evidently these Canadian companies have made significant efforts already to develop export markets and they are also known to be selling product into India and China. More recently Hydrogenics (Ontario) which was traditionally an electrolysis business has branched out into fuel cell systems and both of their main product types can be found in Europe (including the UK⁹⁷).

The Asian HFC sector has perhaps predictably developed mainly from the basis of its industrial conglomerates that tend to dominate many sectors in that part of the world. In South Korea in particular it is quite likely that the parent company of the one building your car will also be building ships, nuclear reactors and domestic appliances. Names like Mitsubushi Heavy Industries are synonymous with an immense internal capacity to undertake the type of cross-disciplinary development work which is required to deliver complex energy technologies including HFC. It is unsurprising then that the Japanese and S Korean automotives have been the first to bring HFC vehicles to the early stages of mass manufacture and marketing. Toyota, Honda and Hyundai already have retail market offerings, the numbers are relatively small as yet but ramp up is planned and ongoing. A limited number of their early vehicles can be already found in the UK. Nissan has well developed programme predicated on its established electric drive platform and thanks to the Nissan-Renault partnership there are also small numbers of Renault branded battery-HFC hybrids already in the UK and elsewhere. [Already established technology-sharing relationships between SE Asian and European automotive manufacturers were described in the preceding section.]

Asia already has a greater density of hydrogen vehicle refilling stations than anywhere else, the bulk of those being found in Japan. The relatively advanced level of Japanese (in particular) HFC development has been extensively supported and incentivised by the Japanese state and also by private industry including its general utilities as well as the conglomerates. Being essentially 100% dependent on imported hydrocarbon fuels gives the Japanese state, its businesses and people a very particular national security driver to rid itself of such dependence on those imports. That national view was if anything intensified following the relatively recent Fukushima tragedy and has since driven a strong push towards a renewables-derived hydrogen sector.

This has been illustrated in Europe and the UK as Japanese companies such as Toshiba⁹⁸ have been obtaining EU CE marking for some of their domestic products (Toshiba, HFC CHP units) and making decisions on which countries they will target

⁹⁷ Hydrogenics provided electrolysis plant for Aberdeen and Levenmouth, Fife, demonstration projects and also stationery fuel cell generation plant also to Fife.

⁹⁸ Information obtained directly from Toshiba UK during discussions in relation to an ongoing Scottish Government supported project in Fife of which Toshiba are a participant.

as early EU markets for their exports. In 2016 executives from Toshiba toured parts of Scotland to inspect for themselves renewables provisions on account of the particular interest in the development of a renewables-derived hydrogen sector. They commented that their nuclear generation business interests were in effect dead (not entirely unrelated to a lack of alternative bids for the Hinckley Point development) and that the Japanese state had made it very clear to them that they are now living in a renewables + energy storage policy environment.

Japan is widely recognised as having some of the world's best HFC research academics, some of whom who have direct access to very extensive research facilities. It is known that whilst state funding of such innovation is extensive, industrial sponsorship and partnership of that public sector activity is also substantive. A relatively recent South Korean trade mission to the UK saw the S Korean premiere sign a wider memorandum of understanding on cooperation with the UK in Downing Street. HFC interests relating to that MOU subsequently spent time in parts of the UK discussing potential HFC cooperation in particular. The general feeling from those discussions was that whilst S. Korea lacked some of the innovation capacity of the UK (and other familiar international locations), that they had very considerable and highly coordinated industrial capability, policy and ambitions for their own HFC sector including significant export ambitions.

Both S. Korea and Japan already have established domestic HFC combined heat and power sectors, initially incentivised by government, those incentivised are now being reduced but technology prices have fallen sharply and sales levels have largely held up. It is that type of domestic technology which is currently being CE marked (in Germany) for safety-approved domestic usage in Europe.

China is certainly the elephant in the room in respect of her potential to become the world's dominant source of HFC technology. Whilst China does not have the same quality or quantity of historical innovation as some of the other countries already discussed, it has had a reasonably long history of undertaking academic research in the area and has long since been training increasing numbers of Chinese scientists and engineers to expert levels in HFC technologies. Chinese graduates have made up significant numbers of recent UK, other European and other post-graduate students and continue to do so. The effects of that, Chinese government policy on emissions reduction and unrelated international trade surpluses on which to invest is now beginning to become apparent and sees increasing numbers of vehicle and other often indigenously developed HFC technology projects. China has seen fit to import some state of the art first-world HFC technology, but there is no reason to imagine that any need to do this will be long term. Chinese labour costs are unlikely to match those in the West and Japan for some time to come and its capacity to compete in an international HFC market will certainly become significant.

Continued substantive public investment in developing both innovation and manufacturing capability in conjunction with policy designed to support a potentially enormous internal market probably leave China best placed to become the dominant source of a great deal of the world's HFC technology in due course. It is equally likely

that Western investment may choose to manufacture in China once mass markets establish themselves as this will create a powerful driver towards cost reduction.

10.4 BRITAIN'S PLACE IN EUROPE

The UK's international context in respect of HFC technologies like so many industries has changed significantly as a result of the 2016 "Brexit" referendum. A significant amount of HFC technology development in Europe including the United Kingdom has been reliant on European Union support programmes and European collaboration for many years. The UK has been particularly successful in acquiring academic funding support and deployment demonstration actions. Perhaps only Germany has benefited more from those headline programmes than the UK. Very few significant UK academic or industry HFC groups have not been the direct beneficiaries of such support.

It is also worth pointing out that the UK has also received significant direct support on HFC development and deployment from the EU form funding streams which are less obviously HFC related. The Aberdeen hydrogen bus projects were directly augmented via Intereg support⁹⁹ in respect of European coordination and networking, whilst ERDF Structural Funds have allowed a number of early deployment projects to go ahead in Scotland.¹⁰⁰ Similar examples can also be found in Wales at least.¹⁰¹

Some of these funding streams are often restricted to public sector or 3rd-Sector not-for-profit owners and as such may be less visible to those focussing on direct support for businesses. It is important to remember that public and 3rd sector actors are often those taking on the customer risks involved in adopting very early deployment technologies. And evidently these public and 3rd sector actors are spending money which is going directly into the relevant businesses (local and international) which supply the technology – so although this type of support is supporting HFC businesses albeit indirectly.

The main question among many in the wider HFC community is where will any potentially equivalent support be coming from post-Brexit? Is the UK Government willing to make such support available and how will it be distributed? How will many current European partnerships and key members of our workforce be impacted?

It should be said however that a number of UK companies have expressly avoided participation in EU supported HFC development programmes often over fears of the loss of IP. And as noted elsewhere, that inwards investment has been obtained from outside Europe and that potentially valuable non-European overseas partnerships do exist. Moving out of the development stage and into deployment however and the scale of the EU market, and access to it, becomes a potential issue for UK companies attempting to develop early UK export markets for their non-EU related products.

99 <http://archive.northsearegion.eu/ivb/projects/details/&tid=151>.

100 The authors have directly participated in some of these including: <http://brightgreenhydrogen.org.uk/funders/european-regional-developments-funds-erdf/>.

101 www.h2wales.org.uk.

In the chapter discussing IP, it was mentioned that a number of UK cities, companies and some academics are currently involved in the EU's HFC bus commercialisation programme. That programme sees EU-wide resources concentrated into relatively few EU locations in order to generate a sufficient mass of HFC bus activity to strongly drive the local deployments towards being financially competitive with conventional vehicles. This costs a lot of money, and although the UK will/would be contributing a significant level of match funding to participate, that UK stands (stood?) to benefit significantly from a disproportionately high level of EU support fund spending in the UK as a result of that participation.

Whilst it is difficult to imagine that the UK government will not continue to support at least the completion of existing participatory projects, and whilst it is a little unsettling to be unaware of how that specifically might be engineered, the bigger question is what happens after those complete?

Via the research councils and government agencies such as: UK Innovate; less frequently DECC (as it was) and DfT, the UK HFC sector has received important levels of UK support in its activities for which it is duly grateful. Demonstration projects have seen additional UK support from The Scottish Government, the Welsh Assembly, The City of London and other participating local authorities on a specific project-by-project basis (often helping to match-fund European programme and structural funds). Between these elements the overall support level has not perhaps been as high as Germany, but it has been quite good. It is clear therefore that the UK has not been unresponsive to the needs of the HFC sector, but is it prepared to make good the now seemingly inevitable loss of EU support? Is this something that can find a place in the UK Government's recent Industrial strategy perhaps?

The European/EU element goes much further than funding however. A great many of the technical advances made in Europe derive directly from the collaborative nature of the joint enterprises. The bus commercialisation programme is a prime example of that, whereby it would cost the UK vastly more to attempt that type of activity without both funding support and the supply of expertise and knowledge amassed elsewhere in Europe – but do note that the Canadian company Ballard Power Systems has been a key player in that specific. As noted in the chapter on IP, the innovation aspects of HFC involve a great many highly mobile individuals. There has been a great deal of human movement in and around the EU HFC sector, with much of the current UK expertise having lived and worked at some point in other EU countries. There has already been discussion of where currently UK-domiciled researchers might want to relocate to in the event of an anticipated unsatisfactory eventual Brexit outcome.

This paper cannot address all of the issues Brexit brings and it is primarily about aspects of the economic potential HFC technologies offer to the UK, but this is a sector which has entirely developed in the context of the UK being an EU member. It has only ever known the type of collaborative actions the EU has facilitated and the financial support the EU has contributed. A nascent UK HFC sector is in no position to dictate UK Government policy with respect to international matters, nor would it try to, however government and its officers should be aware of how unsettling and

potentially deleterious Brexit is and could be to this sector. Of course, it is highly unlikely that a nascent HFC will be alone in that respect, membership of the EU has created many such models of working in many sectors. But it is important that the HFC sector adds its voice to those asking the UK Government to consider such things very carefully and to make appropriate provisions to ensure that the UK HFC sector does not lose out to EU competition as a result of these recent developments.

Given that the UK electorate has mandated the UK Government to deliver the UK's exit from EU membership, there would be merit in the UK Government considering seriously the adoption of the Swiss and Norwegian models of EU project participation. Whereby things carry on as is in respect of project applications but the UK Government supplies the funding support for successful UK participants. This will require additional UK funds evidently, but it is clear where those UK funds are going – and the EU does take care of the administration.

It is also hoped that the UK Government will construct the type of immigration policy required to continue the relatively free movement of the highly qualified persons often involved in this sector. It is recognised that Brexit and wise immigration policy could in fact make the flow of personnel from the United States, Canada, India, Japan, S. Korea etc. easier than it currently is. Also, that if the UK is no longer restricted by EU State-Aid regulation there may be more the opportunity to see more substantial UK policy and support interventions underpinning the establishment of a strong domestic UK HFC sector.

Inwards investment potentially becomes a Brexit-related issue and ease of access to the European market is likely to play a major role in the UK being best-fitted to continue to attract such investment. This issue has already raised itself in respect of much publicised discussions of a potential 'special deal' for the UK automotive sector. Recognising that HFC transport is likely to form the first path-leading mass market for HFC technology, a portion UK HFC sector interest falls directly into that wider automotive market access consideration, or it should. But and as noted elsewhere, equally UK companies developing HFC CHP, hydrogen production and other HFC technologies will also need to secure early export opportunities and EU market access is no less important to them. Inwards investment into the UK may well be predicated on ease of EU market access. A good UK-EU deal is essential, but the UK Government can hardly be unaware of this. This paper's consideration is more concerned with emphasising the particularly sensitive nature of some of the UK's HFC sector to this issue and as a reminder to those charged with obtaining that deal.

10.5 SUMMARY OF THE INTERNATIONAL CONTEXT

From the above discussion it should be evident that there is considerable global interest in HFC technologies and that development, and more critically investment levels have already exceeded a level whereby there is any realistic possibility of HFC markets failing to appear on a substantive scale. Transport is now very close to full mass market implementation and there is considerable progress in other HFC application types which are not far behind in terms of market readiness.

Whilst the UK and indeed Europe is arguably behind the Far East in some respects, it is arguably ahead in others and it would be hard to believe that Europe collectively does not possess an overall competitive edge in terms of innovation and the scale of the value of the market Europe offers is more than adequate to attract inwards investment. Whether Europe and the UK prove capable of keeping their current levels of innovation and securing a substantial level (and value) of indigenous manufacturing in the face of internal competition is difficult to assess. It is certain that there will be stiff competition and there is clear evidence of that already emerging.

The extent nature of collaboration and close links between UK and other European HFC development are likely to continue in some form or another post-Brexit, particularly in respect of the near completely globalised vehicle supply chain sector. It is difficult to imagine how that could or would change, at least in the short to medium-term.

Nevertheless, current uncertainty in regard to how Brexit will impact relationships between UK and other European HFC active organisations into the immediate future presents an existential risk – namely that this uncertainty will retard the progress of the UK HFC sector. It is important that UK HFC organisations establish themselves at a relatively early market stage and as is seen from the above discussion, market formation is occurring now. International competition and inwards investment is already appearing, mainly from Asia and North America. On that basis, Brexit is occurring around the worst of all possible times for the UK core HFC sector.

The bulk of UK HFC supply-chain sector is already pre-established forming a basis of supplying other industry and thus should be relatively insensitive to Brexit – notwithstanding the outcome of Brexit-related trade settlements and the general health of the UK and other market economies.

It should be noted that a good trade agreement between the UK and the EU will be essential if the UK is to remain a key English-speaking destination for inwards investment with free, or at least very easy, access to the EU market. That is hardly a point unique to the nascent HFC sector, but as a native English speaking destination the UK has been an obvious choice for inwards investment from the Far East, North America and the Middle East (even) long since and the nascent HFC sector is potentially as likely to be able to benefit from that as any. As above, parties from the Far East have already been scouting out our potential to develop a strong internal market (at least).

The competition which the United States might present is difficult to assess in that although it has very significant innovation and business potential, it may find itself dramatically realigning its energy policy in favour of fossil energy following the 2016 presidential election. Nevertheless and as noted above, US Federal policy is not definitive in terms of the potential of individual US states and businesses to develop highly competitive local environments and products – California and others are likely to keep up the pressure to decarbonise. And with the willingness of US venture capitalists to take on significant levels of risk, including many of the dot-com billionaires (as well as the companies they founded who have invested in HFC tech directly), the

United States will certainly present a level of serious competition seeking its potential export markets in respect of at least some applications.

The US also represents direct inwards investment potential for the UK in that Ford (in particular) was part of the German-US-Canadian HFC development alliance and that both Ford and GM have HFC vehicle programmes (see 10.2) which we can reasonably expect to translate into UK production at some point.

The UK is in a relatively good position and can play an important part in the emergence of a global HFC sector and can benefit economically from that, but there will be stiff international competition and it is essential that the UK Government develops a range of policy and support positions to ensure best value to the UK is delivered.

It is clear that the UK Government should move quickly to ensure that the currently vibrant UK automotive manufacturing sector keeps pace with developments and investment currently being seen in Europe and Asia if the UK is maintain its current sector vibrancy.

Moving beyond the European Union the UK can and should form strong trading and cooperation arrangements with many countries and many of these can and will offer both UK HFC sector export markets and inwards investment potential.

CHAPTER 11

CONCLUSIONS

AND

RECOMMENDATIONS

The emergence of both domestic and international hydrogen and fuel cell sectors presents a demonstrably significant economic opportunity to the UK.

Hydrogen represents a disruptive change to energy models because for the first time it will become possible to serve consumer transport, electricity and heat mass markets using exactly the same energy vector. This raises questions over hydrogen's relative value in each of these sectors. Relative consumer values for hydrogen in heat, electricity generation and heat were determined to be approximately 1 : 1.6 : 3.9 respectively. These are qualified however in that they refer only to average UK consumer mass markets and heat is assumed to be derived from natural gas. The relative values could be quite different in places where mains gas is not available. CHP complicates matters also, in that the value of heat, whilst taken to be relatively low generally, may be of sufficient additional value to its consumer that it provides the revenue-stacking/cost-displacement financial justification to invest in HFC CHP. Neither do they account for potential appliance (including vehicles) price differences.

From the ratio set and subject to qualification, transport offers the best value within the UK markets and for this reason the paper's new modelling work focused mainly on the supply of hydrogen to the transport sector (replacing conventional refined hydrocarbon fuel) and the UK motor vehicle sector. It employs both the existing UK gas and electricity sectors economic behaviour as proxies for a UK hydrogen supply sector. Consideration of the hydrogen production supply-chain finds that it has very significant similarity to both of those existing UK sectors in terms of its input components and indeed both of those existing sectors would form the bulk of the inputs to a widespread UK hydrogen supply sector. The additional elements associated with hydrogen production may add an additional amount of economic activity associated with hydrogen, this is likely to mean that the estimated impact of hydrogen is somewhat understated. No attempt is made to quantify the extent of any such difference (beyond scope).

As a result of the bulk of the HFC supply chain comprising of components already common to the existing electricity and gas sectors, the UK already possesses a significant element of the HFC supply chain in terms of both manufacturing and services activity.

The main result of the new modelling work indicates that the underlying reason supporting the contention that hydrogen presents a major opportunity to the UK economy derives from the difference between the multipliers associated with the refined fuel sector and those for the electricity and gas proxies.

The UK refined fuel sector has amongst the lowest multiplier of all of the UK's 103 SIC sector classified sectors. That results from the extent of UK imports of refined fuel (leaking value from the UK economy) and the high degree of automation and low levels of employment and other activity associated with the UK's indigenous refinery sector (on a per unit value output basis). Contrasting that, both gas and electricity sectors have (quite similar) mid-range multipliers, both of which are multiples of that for the refined fuels sector.

In general terms and in the context of the production of hydrogen for use as a transport fuel, the net impact is shown to be that a switch to hydrogen will create many more jobs and other UK economic activity than would be lost as a result of the contraction of the UK's current refined fuels sector. Some aspects modelled for hydrogen production in transport will certainly be paralleled by similar impacts where hydrogen is produced for other application types.

It initially seems counter-intuitive, but thanks to the reduction in value leakage from the UK economy (due to the elimination of refined fuels import) in combination with the increased overall energy efficiency of HFC vehicles compared to conventional ones, the UK looks capable of generating a substantial increase in domestic economic activity without any significant increase in cost to the consumer. [Fuel excise duty and VAT was removed from the cost of conventional fuels in this assessment and is not a factor.]

Those results are new and represent the first attempt the authors are aware of to assess the likely macro-economic impact of a switch to hydrogen as a road fuel in this manner.

The results of the modelling are necessarily qualified by a number of factors and assumptions. They do not account for the potential need for the UK to import more natural gas than the existing sector's economic data already accounts for. Additional imports would reduce the positive benefit of H₂ as a significant UK road fuel. Similarly unpredictable reductions in current UK imports of refined fuels would reduce the relative positive differential hydrogen is showing. The modelling assumes that the projected hydrogen prices employed (McKinsey/EU) are achievable, higher prices may adversely impact consumer acceptability. Broadly speaking however, the hydrogen vs. refined fuel differential appears to be large enough that the prediction of a significant net benefit to the UK economy of a switch to hydrogen is largely guaranteed within the parameters of any likely changes to those qualifications.

The paper also makes a general assessment of a range of other factors in order to present the economic impact potential that hydrogen has for the UK economy.

It is extremely important to understand that although the production of transport fuel has formed the main focus of modelling work in this paper, essentially the same economic multiplier effects will act in respect of producing hydrogen for other applications also. **Transport is expressly not being recommended as the only UK market for hydrogen.** The key point is more that its relative value in the transport market will act to drive economies of scale and the widespread availability of hydrogen – which can then be widely exploited in other applications.

This tends to suggest that the UK would be wise to strongly build up its HFC automotive and transport sector to take advantage of HFC opportunities – also to avoid being left behind by other vehicle manufacturing countries – but to be cautious that it does not ignore and does support other options for hydrogen that transport will draw in its wake. E.g. If the UK pushes transport, it is likely that the emerging market will begin

to pull other applications along with it. Of course the UK needs to be ready and able to take advantage of the ‘pulled’ applications and hence should adequately support the development and early deployment of those applications also.

The UK’s core-HFC companies employ many of the same components, skills and fabrication techniques employed in other extant UK manufacturing, including automotive. It is reasonable to expect therefore that the development of those companies will generate significant GDP and employment value in much the same way that this has been demonstrated in transport fuel supply and automotive manufacture.

The UK is well placed in terms of skills and the ability to train for a vibrant HFC sector – it is very much a matter of evolution rather than revolution. This evolution will almost certainly see a public-private partnership in terms of its formal training provision.

Rather than electricity generation per se, hydrogen is arguably more important in energy storage thanks to its ability to time-shift when renewables (in particular) are available to when there is demand for electricity. The value proposition for hydrogen and fuel cell re-generation would be much stronger if energy storage in the UK was better valued generally. Energy storage will only become increasingly important as more and more intermittent/variable primary generation facilities come on line. The UK should act to support energy storage in a much stronger way and perhaps especially on scales which are smaller and more distributed than large scale pumped hydro facilities. Meeting local demand locally reduces the need for long distance transmission and for expensive grid reinforcement. It also results in increased local energy security. The issue around a lack of concrete UK support for energy storage equally impacts battery and other means of storage.

A key observation in both the general assessment and modelling is that a substantial proportion of the potential derives from the UK’s pre-established supply chain actors and from services. The physical support services required to operate a UK hydrogen supply sector cannot be relocated overseas and it seems unlikely that pre-established UK supply chain companies would relocate either. These form a base level of UK economic activity associated with the emergence of such a domestic sector and would exist generating UK value irrespective of where other elements of such a sector come from.

That indigenous UK HFC supply chain will also generate exports and has in many cases been doing so for many years in relation to the export of O&G-related components, chemical processing industry components, sensors and monitoring equipment, specialist materials and others along with expert services. Finance, legal and other businesses services will also largely be indigenous to the UK.

The UK does have a number of core HFC technology companies with potential for substantive growth at different stages of development. As noted above, although transport/automotive looks like UK HFC’s driver, it is important that non-transport HFC companies are prepared and able to exploit opportunities that arrive in the wake

of the widespread availability of hydrogen or indeed in addressing low carbon technology needs. It would be advantageous for the UK to have a supported programme of domestic early deployment/market-seeding in order to be best prepared. Especially in the light of Brexit which may close down some opportunities for UK companies to be involved in the EU's early markets support programmes.

As noted above, academic and public-sector (early deployment) innovation has been well supported under a range of EU programmes, and not all of them obviously relevant to hydrogen and fuel cells. Academia and the public sector are often prepared to take innovation risks which can be difficult, if not impossible, to justify on a privately funded basis, although the freedom of restraints from public sector support can often outweigh the funding benefits. Spinning out a company from a university, a public demonstration programme or the devolved governments having their enterprise and other agencies directly involved in administering both UK sourced and EU regional funding support, academia and public bodies have played an important role in bringing a real UK HFC sector closer than ever. Innovate UK (DBEIS) has supported many important UK HFC developments also. But the HFC funding landscape in the UK has been mixed and confusing at times, with many different UK (inc. devolved) and EU agencies being potential supporters. Whilst disturbing for many in academia and the public sector, Brexit does create an opportunity for the UK to set up its own single support agency after the fashion of Germany's NOW. This could see ring-fenced funding from all of the relevant agencies (as per Germany) and either one UK agency or one with devolved arms/deals to deal with our constitutional arrangements. A single agency has many advantages, as well as supporting a UK sector, it could also act in respect of regulatory change, overseeing training standards and many of the other administrative aspects that an emerging HFC sector implies.

In summary, from the basis of general appraisal and modelling undertaken, the UK seems well placed to benefit economically from the development of a domestic HFC sector and its prospects for high value export already look good. There are many qualifications to the modelling undertaken and it is only a narrow snapshot of what could become a very large and highly interconnected sector. But the indications, even from that limited extent modelling, are good. The economics of hydrogen production will underpin all applications of hydrogen – it has to be made to apply it anywhere! The more of that which the UK can capture – and hydrogen is difficult to transport cheaply (other than by pipe), the more the UK will gain. Every additional hydrogen appliance/application will require more hydrogen. Modelling of the transport market, very definitely, grossly underestimates the potential scale to which hydrogen production could grow. And with the type of economic impact its proxy multipliers are suggesting this could be extremely positive for the UK economy.

Not without potential hurdles however. The paper has not assessed the impact of HFC vehicle or other HFC appliance prices. Nor has it looked at infrastructure investment. These are capital items however and in most cases there will be ways of financing those if there is an adequate economic return from operations. Lack of infrastructure is often cited as 'a killer' of hydrogen and fuel cell technologies, but perhaps only by those with short memories. With the will to do so, the UK built its entire high

pressure gas network in a remarkably short period of time given its scale. The idea that the UK is somehow incapable of doing much the same thing today is ..., a bit silly. And who is to say that today we are not able to do it faster, better and cheaper? We like a challenge.

11.1 Recommendations

1. Given ongoing political changes, the UK Govt. should consider very carefully the idea of setting up a UK Hydrogen (and Fuel cells) Agency charged with coordinating support for a UK HFC sector. Possibly also dealing with relevant regulation, formal training and similar administrative aspects. Funding could be ring-fenced from relevant UK departments (transport, energy, environment, industry *et sim.*). The German NOW agency makes a good example to follow. Parallel arrangements could be made with devolved parts of the UK.
2. In aligning with 8 of the announced strategic pillars of the UK Govt.'s Modern Industrial Policy announcement and consultation the development of a strong domestic HFC sector and market (including export) should be a priority.
3. The UK Govt. should be conscious that the public sector, 3rd sector and academia has been significantly reliant on EU support in respect of HFC and may want to consider seriously the option of buying into the relevant EU programmes following Brexit. Norway and Switzerland serves as potential examples of how this could be done, whereby their national governments agree to cover the public support element of the costs of participation by their own nationals, the EU undertake the administrative elements. A unique UK-EU arrangement may be no less welcome. Any UK-EU arrangement would also wisely allow UK companies to participate in and access EU early-deployment markets/programmes.
4. The UK Govt. should be aware that UK HFC offers strong potential export earnings. Relationships already exist between UK HFC businesses and companies/organisations in North America, Asia and Japan, strengthening these and the development of others would be wise. Further inwards investment could and should be sought. UK HFC businesses would benefit from joining trade missions in particular.
5. As and when EU-State Aid regulations cease to apply, the UK Govt. may want to consider boosting support to UK HFC businesses to levels the regulations would have otherwise prevented. The sector is facing strongly entrenched incumbency in the existing energy markets and often extremely high development costs. UK HFC companies are largely still SMEs and they will struggle in the face of competition from Japanese and other SE Asian conglomerates which have immense market power, exceptional internal R&D capabilities and a capacity to raise R&D finance which few UK SMEs can match. Many are also closely linked to state funded research facilities. Such action would level the playing field to some extent.
6. In relation also to 5. Additional tax and investment instruments would also help to bolster the probability of UK HFC businesses growing beyond SME scale.

7. The UK automotive sector should be strongly encouraged to ensure that it stays abreast of HFC vehicle manufacture and does not become left behind by Japanese and German manufacturers in particular. Indeed current focus upon build of electrical vehicles in UK, offers an important platform to build the intimately related, fuel cell electric vehicles. The UK state has invested heavily in the sector and it is essential that this public investment is protected by the speedy evolution of the UK sector into HFC vehicles. The UK Govt. can drive this by means of its input to that existing investment. There could be substantial merit in linking an HFC Industrial cluster directly to that state investment (possibly a 3rd very specific cluster type linked directly to UK automotive manufacturing industry (see section 8.)). There are potential Chinese, Indian and other partnership deals which could be pursued, possibly involving additional inwards investment. Ricardo, the UK-owned world-leading automotive systems consultancy, has its automotive FC team located in Aachen in Germany – close to GM-Europe and Ford-Europe HQs and their German production facilities – the UK ‘owns’ very real HFC expertise in this area. Modelled employment herein assumes retention of the current vehicle import/export balance – retention is not guaranteed. This area should be examined closely and urgently, Germany, Japan and S Korea are not waiting for the UK.
8. Domestically the establishment of one (or more) HFC cluster(s) should be given priority. This will accelerate the UK’s ability to develop a valuable domestic HFC market which cannot readily be relocated off-shore. The idea of 2 such clusters (linked) has merit, with one focussing on densely populated urban deployment and a natural gas energy base, with the other focussing on exploiting renewables opportunities (usually) in less densely populated areas. (Devolved governments may be interested on partnering with the UK Govt. on the latter.) The idea of a possible 3rd cluster is mentioned in 7.
9. The UK is not homogenous in terms of its energy production or markets. A one-size-fits-all policy approach to incentivising renewables has arguably resulted in far too much renewables capacity in some areas (investors seeking abnormal profits rather than supplying for demand) and too little elsewhere. A more nuanced regional approach with respect to incentivising/supporting investment in HFC would be wise. HFC technology offers zero carbon energy storage and transport fuel when coupled to renewables and can deal with the intermittency of renewables. A significant amount of zero-carbon HFC transport and storage in some areas of the UK can make a significant impact on overall UK emissions. However these areas may not have the same access to finance and other factors of other, often more densely-populated, areas. The UK Govt should give serious consideration to developing nuanced regional support programmes capable of incentivising local investment but which cannot be employed elsewhere to support locally inappropriate facilities. This is subtle and would require work, but ultimately it is about supporting appropriate levels of local supply and demand and preventing imbalance. Imbalance can result in very substantial costs, usually in the form of new grid capacity investment.
10. The UK Govt. should move swiftly to properly incentivise investment in energy storage generally. All forms of energy conversion suffer physical losses and those

physical losses can result in actual financial loss upon regeneration. Very few significant scale storage facilities (of any kind) have been built for decades and it is evident that the market, as is, is incapable of driving such investment. Arbitrage can work for larger scale facilities, but small local storage has very little chance of repaying its investment within acceptable periods currently. Incentivising storage should focus mainly on smaller local scale storage as sufficient quantities of this on grid will reduce the need for costly grid reinforcement. The incentivising of storage should probably be technology neutral.

11. UK and devolved Govts. should ensure that their further education sectors are aware of an emergent HFC sector and are ready to work with trade, industry and relevant official bodies to develop appropriate NVQ/SVQ HFC training modules for college students and retraining/CPD offerings for those tradespeople and professionals who may need to adapt.
12. The Higher Education sector, from which much UK HFC development has emerged, is better aware, but not all institutions have been involved and where appropriate encouragement could be given by state agencies for them to keep abreast of developments/requirements.

APPENDIX

Table A1 Production sectors/activities identified in the UK IO table, 2010.

Sector names	IOC	Industry group	SIC
A Agriculture, forestry and fishing	1	Crop and animal production, hunting and related service activities	01
	2	Forestry and logging	02
	3	Fishing and aquaculture	03
B Mining and quarrying	4	Mining of coal and lignite	05
	5	Extraction of crude petroleum and natural gas and mining of metal ores	06 and 07
	6	Other mining and quarrying	08
	7	Mining support service activities	09
C Manufacturing	8	Processing and preserving of meat and production of meat products	10.1
	9	Processing and preserving of fish, crustaceans, molluscs, fruit and vegetables	10.2–3
	10	Manufacture of vegetable and animal oils and fats	10.4
	11	Manufacture of dairy products	10.5
	12	Manufacture of grain mill products, starches and starch products	10.6
	13	Manufacture of bakery and farinaceous products	10.7
	14	Manufacture of other food products	10.8
	15	Manufacture of prepared animal feeds	10.9
	16	Manufacture of alcoholic beverages	11.01–6
	17	Manufacture of soft drinks; production of mineral waters and other bottled waters	11.07
	18	Manufacture of tobacco products	12
	19	Manufacture of textiles	13
	20	Manufacture of wearing apparel	14
	21	Manufacture of leather and related products	15
	22	Manufacture of wood and products of wood and cork, except furniture; manufacture of articles of Straw	16
	23	Manufacture of paper and paper products	17
	24	Printing and reproduction of recorded media	18
25	Manufacture of coke and refined petroleum products	19	

26	Manufacture of paints, varnishes and similar coatings, printing ink and mastics	20A
27	Manufacture of soap and detergents, cleaning and polishing, perfumes and toilet preparations	20B
28	Manufacture of other chemical products	20C
30	Manufacture of petrochemicals	20.4
29	Manufacture of industrial gases, inorganics and fertilisers (inorganic chemicals)	20.3
31	Manufacture of dyestuffs, agro-chemicals	20.5
34	Manufacture of cement, lime, plaster and articles of concrete, cement and plaster	23
36	Manufacture of basic iron and steel	24.1–3
37	Manufacture of other basic metals and casting	24.4–5
39	Manufacture of fabricated metal products, excluding weapons and ammunition	25.4
41	Manufacture of electrical equipment	27
42	Manufacture of machinery and equipment N.E.C.	28
43	Manufacture of motor vehicles, trailers and semi-trailers	29
44	Building of ships and boats	30.1
32	Manufacture of basic pharmaceutical products and pharmaceutical preparations	21
33	Manufacture of rubber and plastic products	22
35	Manufacture of glass, refractory, clay, porcelain, ceramic, stone products	23.5–6
38	Manufacture of weapons and ammunition	25
40	Manufacture of computer, electronic and optical Products	26
45	Manufacture of air and spacecraft and related machinery	30.3
46	Manufacture of other transport equipment	30
47	Manufacture of furniture	31
48	Other manufacturing	32
49	Repair and maintenance of ships and boats	33.15
50	Repair and maintenance of aircraft and spacecraft	33.16
51	Rest of repair; Installation	33.17–20

D	Electricity, gas, steam and air conditioning supply	52	Electric power generation, transmission and distribution	35.1
		53	Manufacture of gas; distribution of gaseous fuels through mains; steam and aircon supply	35.2–3
E	Water supply, sewerage, waste management and remediation	54	Water collection, treatment and supply	36
		55	Sewerage	37
		56	Waste collection, treatment and disposal activities; materials recovery	38
		57	Remediation activities and other waste management services	39
F	Construction	58	Construction	41–43
G	Wholesale and retail trade; repair of motor vehicles and motorcycles	59	Wholesale and retail trade and repair of motor vehicles and motorcycles	45
		60	Wholesale trade, and motor vehicles and motorcycles	46
H	Transport and storage	61	Rail transport	49.1–2
		62	Land transport services and transport services via pipelines, excluding rail transport	49.3–5
		63	Water transport	50
		64	Air transport	51
		65	Warehousing and support activities for transportation	52
		66	Postal and courier activities	53
I	Accommodation and food services activities	67	Accommodation	55
		68	Food and beverage service activities	56
J	Information and communication	69	Publishing activities	58
		70	Motion picture, video and tv programme production, sound recording and music publishing activities and programming and broadcasting activities	59–60
		71	Telecommunications	61
		72	Computer programming, consultancy and related activities	62
		73	Information service activities	63
K	Finance and insurance activities	74	Financial service activities, except insurance and pension funding	64
		75	Insurance and reinsurance, except compulsory social security and pension funding	65.1–3
		76	Activities auxiliary to financial services and insurance activities	66

L	Real estate activities	77	Buying and selling, renting and operating of own or leased real estate, excluding imputed rent	68.1–2		
		78	Real estate activities on a fee or contract basis	68.3		
M	Professional, scientific and technical activities	79	Legal activities	69.1		
		80	Accounting, bookkeeping and auditing activities; tax consultancy	69.2		
		81	Activities of head offices; management consultancy activities	70		
		82	Architectural and engineering activities; technical testing and Analysis	71		
		83	Scientific research and development	72		
		84	Advertising and market research	73		
		85	Other professional, scientific and technical activities	74		
N	Administrative and support service activities	86	Veterinary activities	75		
		87	Rental and leasing activities	77		
		88	Employment activities	78		
		89	Travel agency, tour operator and other reservation service and related activities	79		
		90	Security and investigation activities	80		
		91	Services to buildings and landscape activities	81		
O	Public Administration and defence	92	Office administrative, office support and other business support activities	82		
		93	Public administration and defence; compulsory social security	84		
		P	Education	94	Education	85
		Q	Human health and social work activities	95	Human health activities	86
		R	Arts, entertainment and recreation	96	Residential care and social work activities	87–s88
97	Creative, arts and entertainment activities			90		
98	Libraries, archives, museums and other cultural activities			91		
99	Gambling and betting activities			92		
100	Sports activities and amusement and recreation activities			93		
S	Other services	101	Activities of membership organisations	94		
		102	Repair of computers and personal and household goods	95		
		103	Other personal service activities	96		

Table A2 Sectoral aggregation scheme.

	Sector names	SIC 2007	IO groups
1	Agriculture and food services	AI	01–03,67,68
2	All mining, quarrying and support	B	04–07
3	All manufacturing	C	08–48
4	Electricity, gas, water and waste	DE	52–57
5	Construction and real estate services	FL	58,77,78
6	Wholesale, retail trade and repair	C33/G	49–51,59,60
7	Transportation and storage	H	61–66
8	Information and communication	J	69–73
9	Financial and insurance activities	K	74–76
10	Professional, scientific and technical activities	M	79–85
11	Administrative and support service activities	N	86–92
12	Other private and public services	OPQRS	93–103