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.

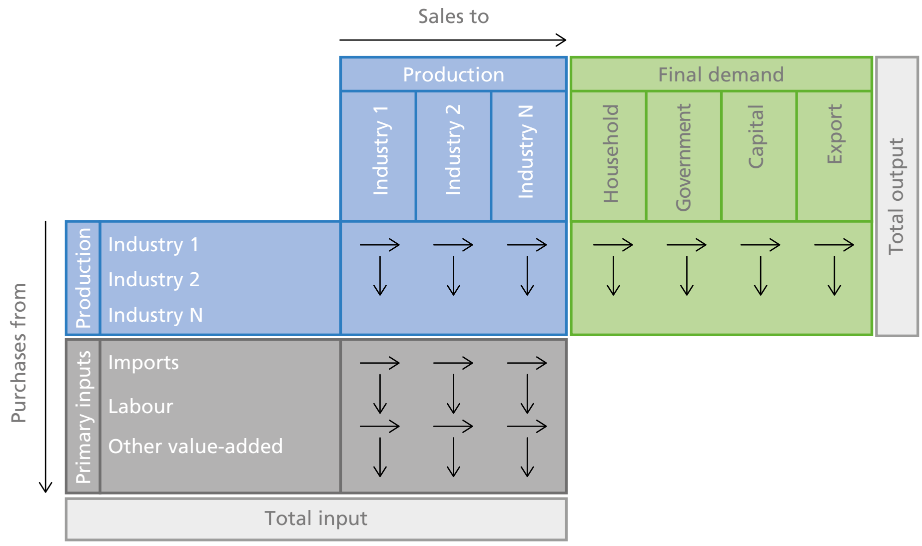
3.3 THE INPUT-OUTPUT MODEL – THE ECONOMIC MULTIPLIER TOOL

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.automotivecouncil.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, 2007[32]) 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

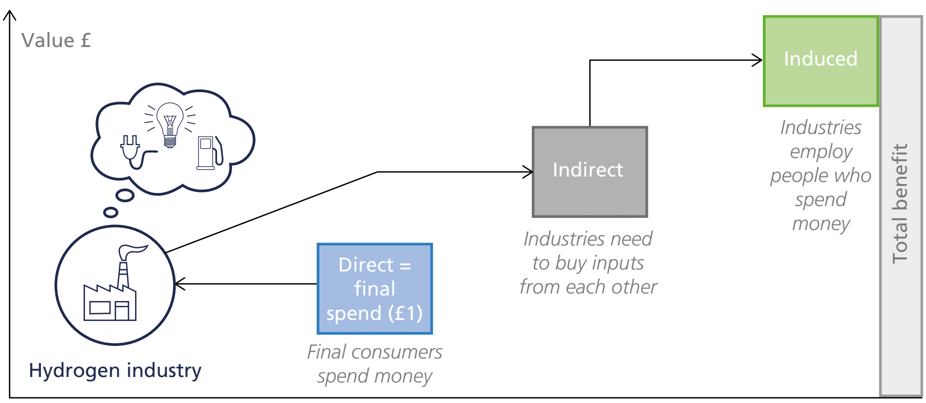
30 UK Input-output supply and use tables for 1994 to 2014,Available at: www.ons.gov.uk/economy/nationalaccounts/supplyandusetables/datasets/inputoutputsupplyandusetables.
31 System of National Accounts 1993, Available at: http://unstats.un.org/unsd/nationalaccount/sna1993.asp.
32 Standard Industrial 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, thought 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, they 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 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 plumping, 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 though 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 term 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.