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 projects[37] 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 macroeconomic 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 Strategy[41] 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 word 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 Industry[44] 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 £1mllion) 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.

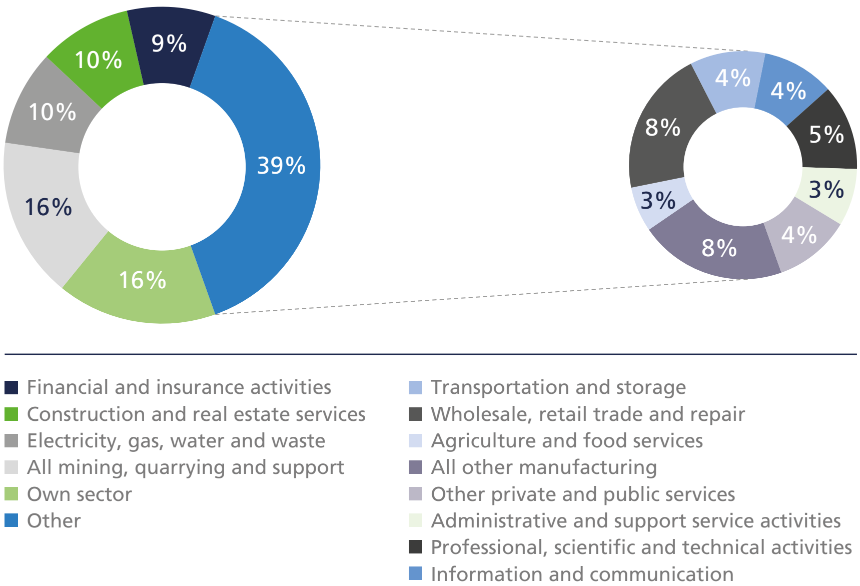
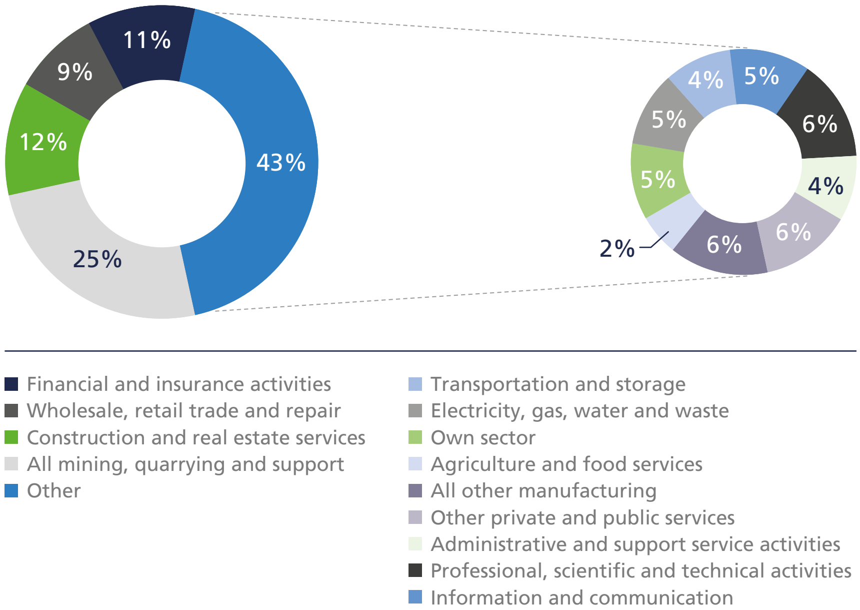


Figure 4.1 shows that 42% of the indirect and induced supply chain linkages within the UK for 'Refined fuel' are own sector, extraction 'All mining, quarrying & support' and utilities ('Electricity, gas, water & waste') industries. A further 8% are located in UK manufacturing.[45] The key point to note 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.

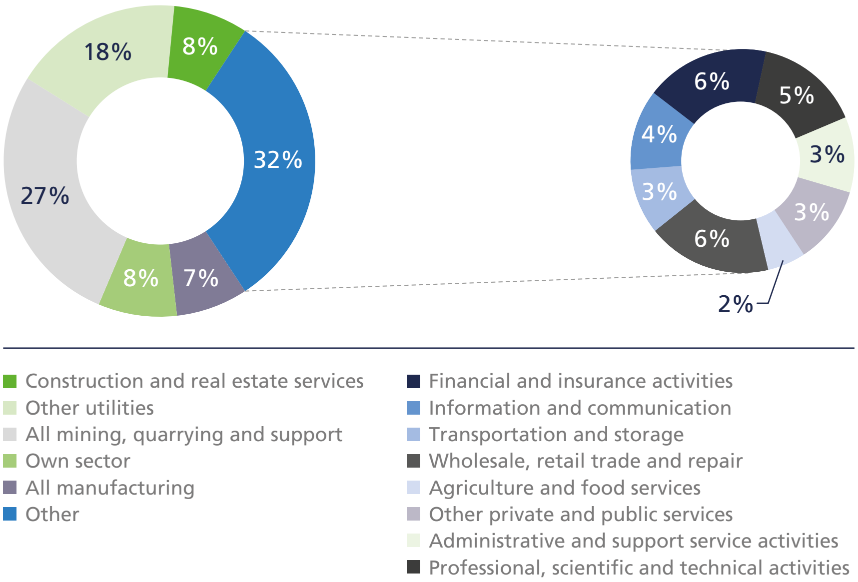
At a high level of analysis, **in 2010 UK households spent just under £6556million on the outputs of the 'Refined fuel' sector**. Applying this figure to the overall multipliers, this equates to £9,646million in UK output, £2,187million of which is value-added or GDP content, and supporting 19,225 full-time 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**.

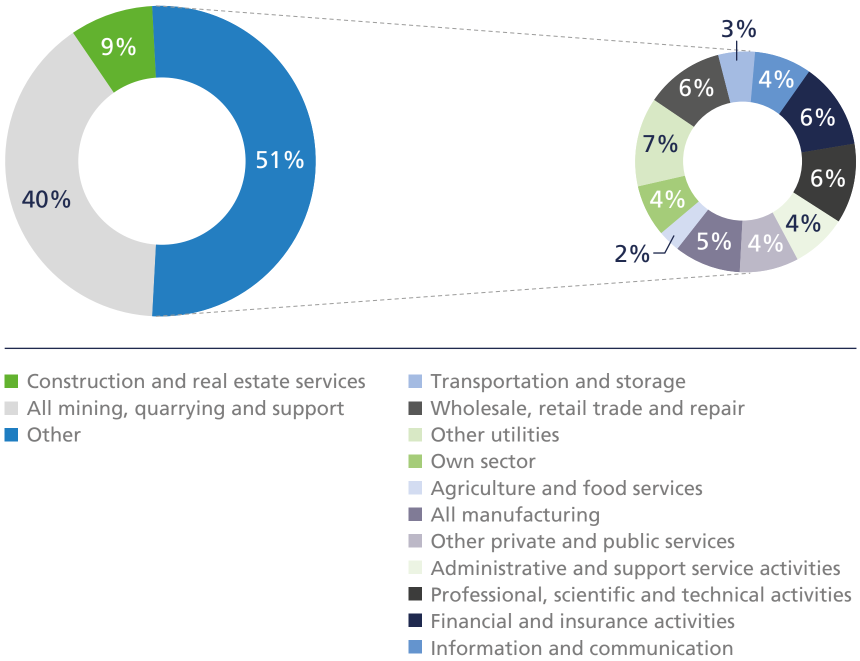
Another crucial point to be made is that marginal multiplier values reflect the operating costs of the proxy hydrogen supply industry. However, this assumes that sufficient investment will be made up-front to permit the industry to operate in a similar way to that reflected in Figure 4.3 for gas supply 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.



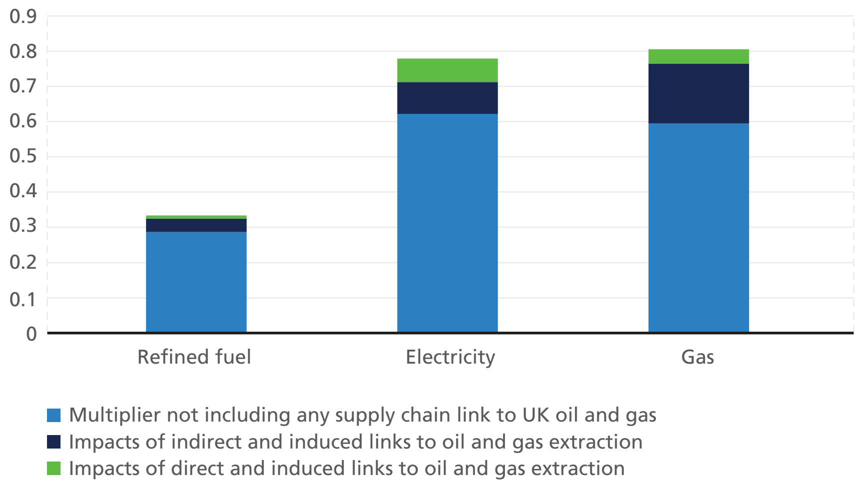
Two key results are apparent in Figure 4.4. The first is, once again **the relative importance of service industries**. The second is the **dominating impact of value-added required or supported by spending on gas in the UK mining and mining support composite group**. Again, as with refined fuel supply 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.

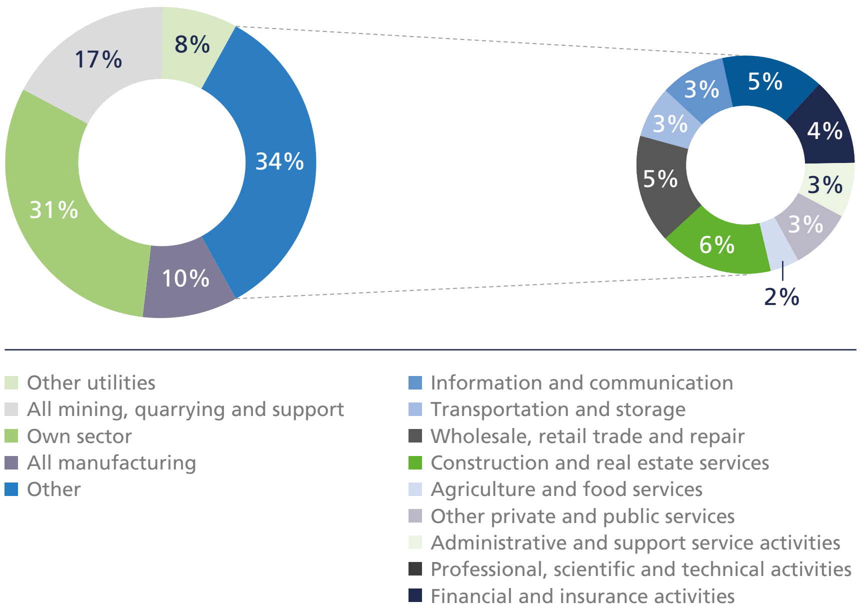
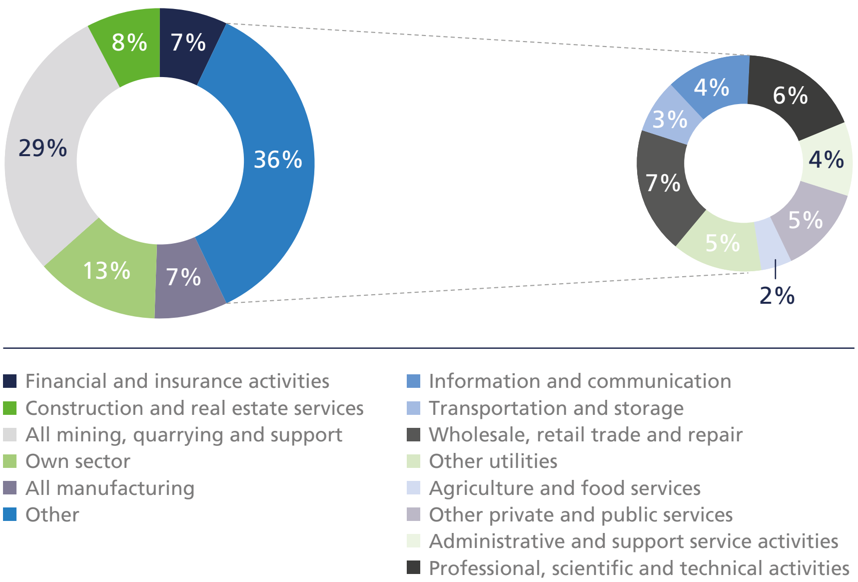


Figure 4.7 Composition of indirect and induced supply chain value-added (GDP) requirements for the UK Electricity sector.



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 £0.78millin (£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, £0.81milion 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.

		Output		Value added	
SIC	Sector name	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 is 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.

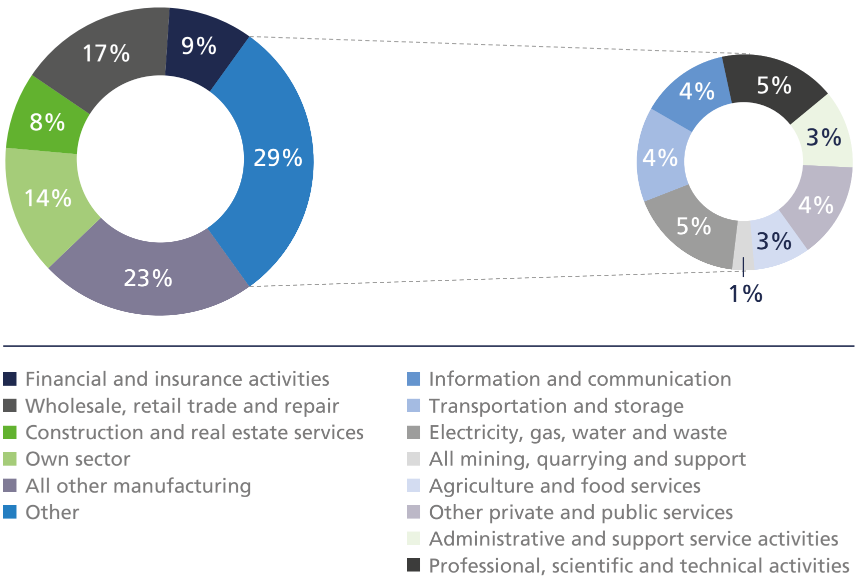
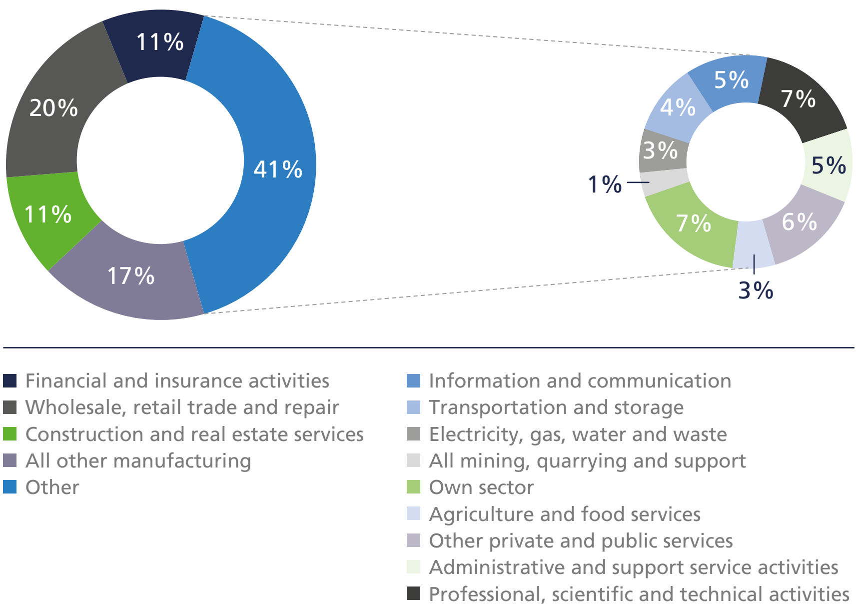


Figure 4.9 Composition of indirect and induced supply chain value-added (GDP) requirements for the UK Motor Vehicles sector.



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.

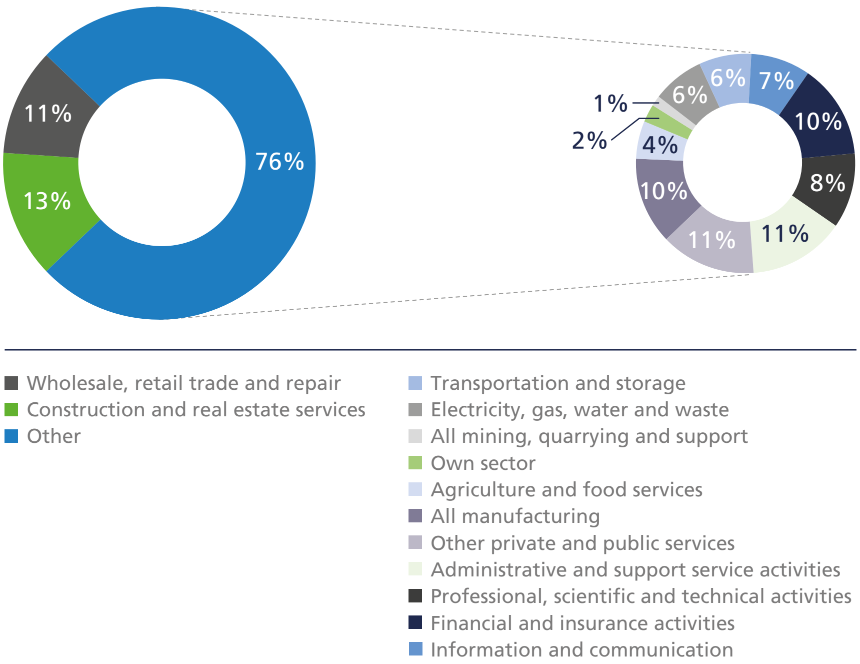
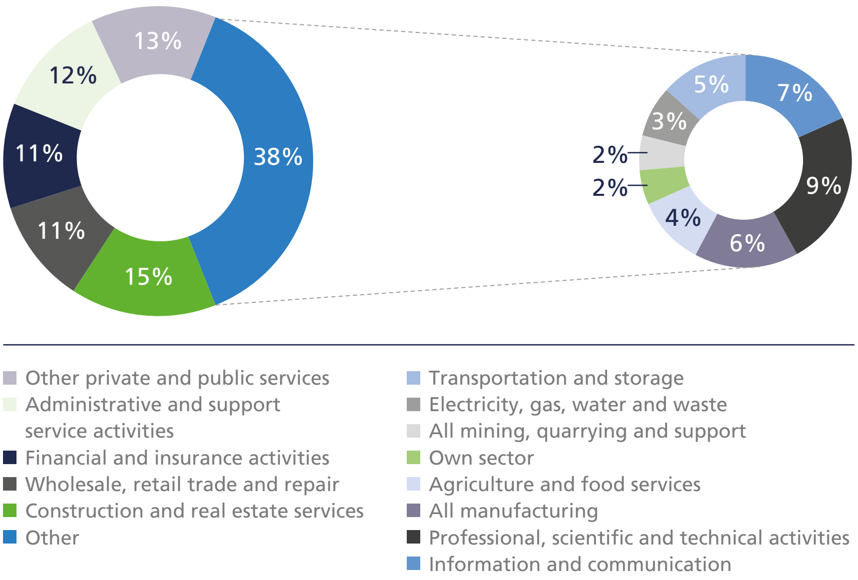


Figure 4.10 shows the results of decomposing the indirect and induced components (1.39 of a total 2.39) of the UK R&D industry output multiplier (it is separated from 'other professional scientific and technical activities'). Figure 4.11 (below) then considers the related GDP content. As noted above, 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.

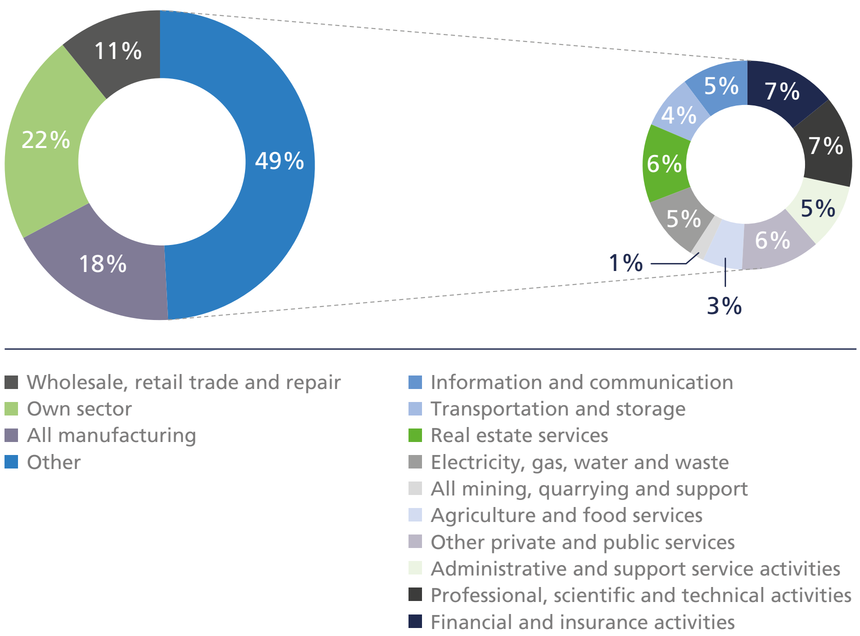
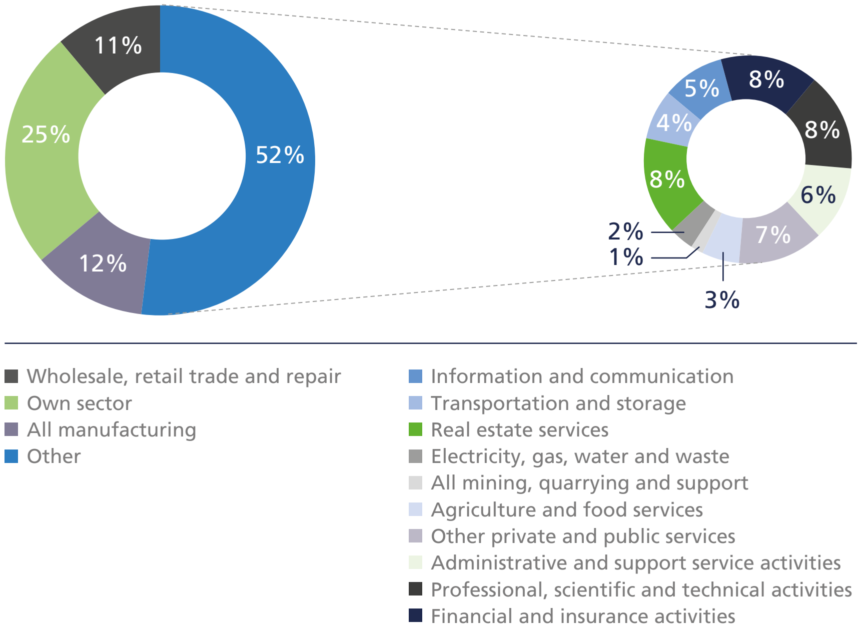


Figure 4.13 Composition of indirect and induced supply chain value-added (GDP) requirements for the UK Construction sector.



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.