Study on Value Chain and Manufacturing Competitiveness Analysis for Hydrogen and Fuel Cells Technologies

FCH contract 192

Findings Report

E4tech (UK) Ltd for FCH 2 JU in partnership with Ecorys and Strategic Analysis Inc.

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1 Executive Summary

Fuel cells and hydrogen could bring significant environmental and economic benefits

Fuel cells and hydrogen (FCH) could bring significant environmental benefits across the energy system if deployed widely: low carbon and highly efficient energy conversions with zero air quality emissions. The socio-economic benefits to Europe could also be substantial, through employment in development, manufacturing, installation and service sectors, and through technology export. Major corporations are stressing the economic and environmental value of FCH technologies, and the importance of including them in both transport and stationary energy systems globally[1], while national governments and independent agencies are supporting their role in the energy systems transition[2].

Fuel cell and hydrogen markets are growing, but cost reduction is still required and the supply chain remains nascent

Published figures show that strong growth in fuel cell shipments – over 20% year-on-year growth in megawatts (MW) shipped – has continued in 2018[3] (Figure 1). Much of the 2018 increase was in fuel cell cars, but stationary applications also saw increased volumes. While deployment of water electrolysers in 2018 was less than 100 MW, there were new project announcements, the launch of technology platforms that can scale to 100 MW+ systems, manufacturing capacity additions and hiring campaigns[3]. But to continue growing and to become competitive across a greater range of applications, cost reduction and supply chain strengthening for a range of different technologies is required.

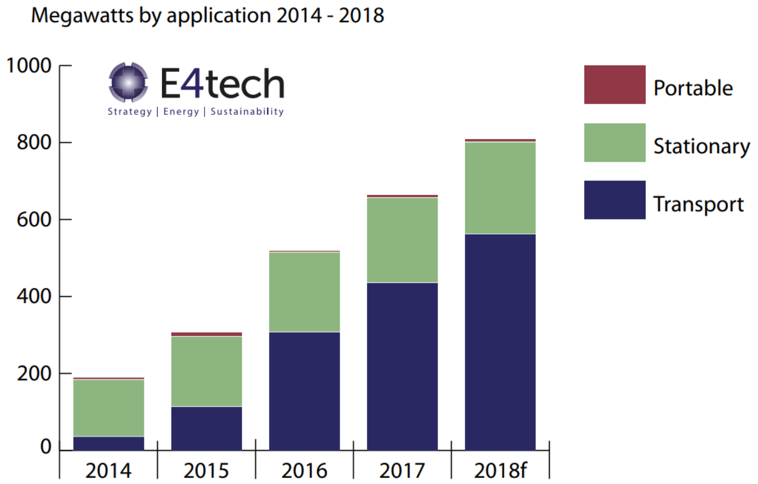

Figure 1: Growth in MW of fuel cells shipped, 2014-2018

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[1] Hydrogen Council January 2017 'How hydrogen empowers the energy transition' http://hydrogeneurope.eu/wp-content/uploads/2017/01/20170109-HYDROGEN-COUNCIL-Vision-document-FINAL-HR.pdf

[2] METI Strategic Roadmap for Hydrogen and Fuel Cells, 2016 http://www.meti.go.jp/english/press/2016/0322_05.html
Scottish Government Draft Climate Change Plan - the draft Third Report on Policies and Proposals 2017-2032 http://www.gov.scot/Publications/2017/01/2768
E4tech 2016 Development of a roadmap for hydrogen and fuel cells in the UK to 2025 and beyond. http://www.e4tech.com/wp-content/uploads/2016/08/HFCroadmap-MainReport.pdf
Energy Transitions Commission 2018 'Mission Possible' http://www.energy-transitions.org/sites/default/files/ETC_MissionPossible_FullReport.pdf
IEA Workshop on Hydrogen, 2019 https://www.iea.org/workshops/hydrogen-workshop.html

[3] E4tech Fuel Cell Industry Review 2018 http://www.fuelcellindustryreview.com/

The supply chain is still developing. Though some applications are already commercially attractive, fuel cells and hydrogen technologies are generally not yet mature. Greater numbers of qualified companies are required in each segment to ensure suitable competition and innovation throughout. This offers an opportunity for organisations and countries alike to position themselves for future growth and value capture, and Japan, Korea and increasingly China are investing particularly heavily in this positioning.

The sector is complex and interlinked, so considerable analysis is required to assess it

The 'pure-play' FCH sector is fragmented and consists mainly of relatively small organisations, specialists either in final application assembly or in components, but rarely in both. Major companies also participate, but FCH is only a small part of their activities. The pure-play companies tend not to be profitable, and the spend within the large companies into this area is also still largely viewed as investment for the future. This study conducted detailed surveys and significant amounts of interviews and desk work to develop a database of relevant organisations, and also polled many of them to understand their views on the current and anticipated future position of the technology, their peers, and Europe within a global context.

Europe has world class component and product providers today across the supply chain

European companies and research actors are world class today in many of the technologies needed for fuel cell and hydrogen applications and supply chains. This study documented nearly 300 companies with known positions directly in FCH, and more exist in other supply chain areas. Even more with latent capabilities exist, who could strengthen Europe's position if they entered. These suppliers are supported further by more than 250 identified knowledge-based actors across different domains of expertise. Many of these knowledge-based actors have world-class capabilities and support not only European companies but also others in leading countries worldwide.

For transport applications, Europe has particular **strengths in key components** of fuel cell stacks: **catalysts, membrane electrode assemblies, bipolar plates** and **gas diffusion layers**. Over 30 European companies sell these products worldwide today, and are well positioned to take a significant share of the growing markets for fuel cell cars, trucks, buses and forklifts, as well as supplying stack producers for other applications of the same fuel cell technology, such as combined heat and power (CHP) and auxiliary power units (APUs).

Europe is also home to competitive **stack** developers and producers in applications from transport through to small-scale stationary power. Different types of fuel cell are represented, including both low and high temperature chemistries. Some parts of the supply chains are common or similar across different applications, so support and development for one could bring benefits to others.

Unlike in most world regions, Europe has smaller, specialised integrators developing and launching new vehicle products and concepts in addition to the major car manufacturers. These bring additional supply and purchasing opportunities. Thousands of buses could be deployed in cities across Europe. In the stationary sector, micro-CHP used in a range of buildings could soon become a market of tens of thousands of units, and many more in the future. Given the right support and frameworks, substantial portions of these supply chains would be European, and these deployments would also strongly support local economic development in installation and servicing.

Europe has further international strength in the **hydrogen production and handling technologies** needed to supply fuel cell applications. Europe is a global leader in **electrolysis**, in all technology types, from component supply to final integration capability, with no other single region able to match its depth and breadth across all the technologies and all the components. European companies supply markets worldwide. About 20 European companies offer or develop electrolysis systems, while 10 European companies offer **hydrogen refuelling stations**.

Knowledge-based actors are also strong across many FCH-related fields, from fundamental research through engineering to social science and business studies. European universities and research institutes support companies globally in solving a wide range of FCH problems, and are vital in developing the human resources needed for the FCH sector to succeed.

The value that could be captured is considerable, as the sector enters profitability

The purpose of this study was not to forecast uptake of FCH, which depends on many factors, but to consider plausible market scenarios and evaluate the implications and requirements. Industry scenarios were developed in which the size of uptake globally was varied, influencing the size of the market that could be captured by any entity, including European ones. Other scenarios considered the level of support within Europe, thus identifying differences between proactive and passive sector development. In Scenario A, a low global growth scenario is coupled with low European support, while in Scenario C both are high.

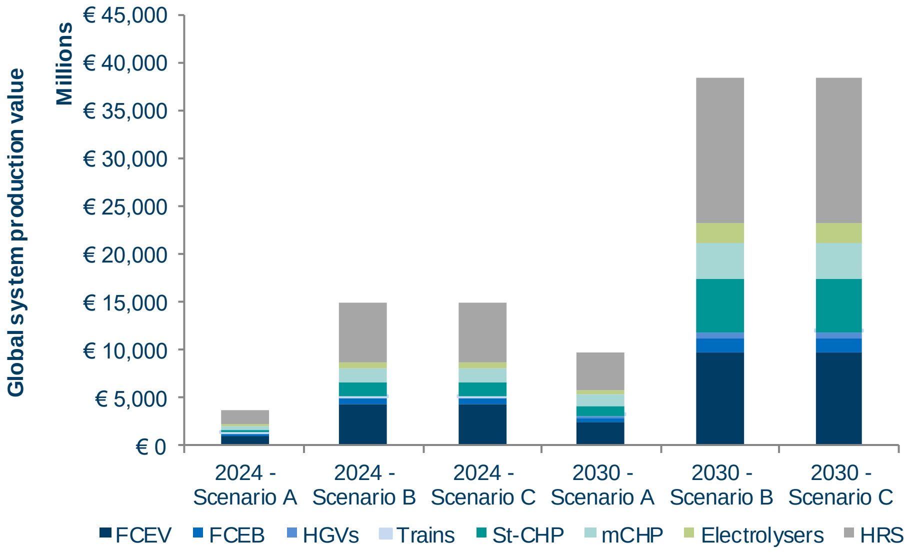

Figure 2: Global system production value for the selected applications by industry scenario (2024 and 2030)

As can be seen, the total global production value of the selected components and systems in this example varies from €4 bn to €40 bn (Figure 2), and Figure 3 shows that Europe could capture around €1.5 bn of the former and €10.7 bn of the latter, with between €500 m and €3.5 bn in value added to Europe. European trade balance would be broadly neutral in the first case, but positive to the order of close to €2 bn in the latter.

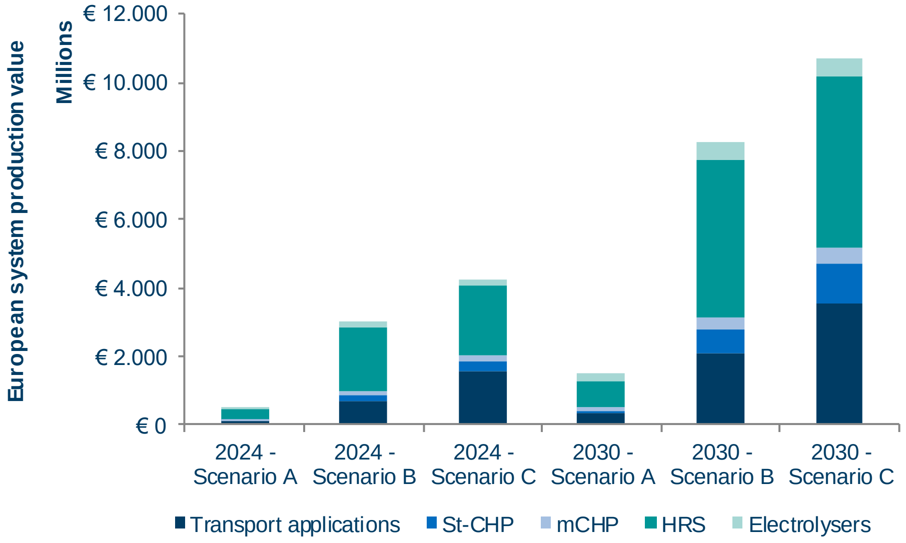

Figure 3: European system production value for the selected applications by industry scenario (2024 and 2030)

Table 1 gives a high level summary of the socio-economic values associated with the scenarios outlined above, for selected industries and components/systems. It shows that in addition to the monetary values, direct and indirect employment benefits are considerable.

Table 1: Key socio-economic figures for the selected applications per industry scenario (2024 and 2030) in millions of Euros

Year	**2024**			**2030**		
	Scenario A	**Scenario B**	**Scenario C**	**Scenario A**	**Scenario B**	**Scenario C**
Global Market						
Global system production value (million)	€ 3,600	€ 14,900	€ 14,900	€ 9,800	€ 38,400	€ 38,400
Global system O&M value (million)	€ 300	€ 1,000	€ 1,000	€ 1,100	€ 4,300	€ 4,500
European market and production						
European production value (million)	€ 500	€ 3,000	€ 4,200	€ 1,500	€ 8,200	€ 10,600
European O&M value (million)	€ 0	€ 200	€ 200	€ 200	€ 900	€ 900
Macro-economic impact						
Value added - Total (million)	€ 200	€ 1,000	€ 1,400	€ 500	€ 2,700	€ 3,500
Value added - Labour (million)	€ 100	€ 400	€ 600	€ 200	€ 1,200	€ 1,500
Value added - Capital (million)	€ 100	€ 400	€ 600	€ 200	€ 1,000	€ 1,300
Value added - Margin (million)	€ 0	€ 200	€ 300	€ 100	€ 500	€ 700
European annual trade balance impact (million)	€ 0	€ -300	€ 800	€ 0	€ 0	€ 1,900
Employment impact						
Direct employment system production (fte)	1,900	11,600	15,100	5,400	30,400	38,500
Direct employment O&M (fte)	300	1,600	1,600	1,300	7,300	7,300
Indirect employment (fte)	1,800	12,600	23,100	6,200	41,600	63,900
Sum (fte)	4,000	25,800	39,800	12,900	79,300	109,700

It is important to reiterate that these figures are developed using scenarios of plausible futures. They are not exhaustive, and subject to multiple assumptions. However, the assumptions are as far as possible conservative, e.g. not all industries, applications or components have been considered, and sector growth has been constrained to well within the most optimistic levels possible, and so the size and value of the future markets could be greater.

The general trends are borne out by industry information: each year, more applications become commercially viable. This is in part due to lower cost technology and better business strategies, and strongly due to supportive policy. The regions and cities enacting zero emissions zones are directly supporting electric vehicles, including FCH, and the sharp reductions in the cost of renewables driven by policy decisions are allowing large-scale renewable hydrogen supply plans to be drawn up.

Maintaining and increasing the value to Europe largely depends on support and deployment in Europe

Even using a relatively narrow definition of value-added activity, the analysis shows that support within Europe is essential to allow the greatest value capture. If global growth is strong but Europe takes a *laissez-faire* attitude then Europe exports less overseas, and overseas companies export more into Europe. If global growth is low but Europe has strong internal support, European companies capture a greater share, but of an inevitably smaller market. By supporting both deployment (helping to increase the global market by increasing the European market) and the positioning and growth of companies, Europe has the greatest chance of capturing long-term value. This value is likely to go elsewhere if either is lacking, as other regions will develop more mature capabilities and supply chain clusters.

As an example, analysis of existing conventional supply chains shows that whilst mature supply chains for some products are global, for others (such as cars) supply chains gravitate towards the control of the original equipment manufacturer (OEM), and towards the country or region of deployment. OEMs tightly control supply chains, which can include design and assembly in-house and partnering with suppliers on design, optimisation and even investment. For high volume production, suppliers of appropriate components will co-locate with final assembly plants. So as the fuel cell industry and its supply chain mature, it could become increasingly hard for EU component suppliers to sell to non-EU OEMs, as these OEMs build and strengthen internal and local capabilities. Conversely, support measures targeted at driving deployment in the EU could serve to activate the supply chain. For instance, the detailed value-added analysis suggests that a significant fraction of the value added can be captured for both FCEVs and HRSs provided the FCEV and HRS system assembly occurs in the EU. A coordinated vehicle and refuelling station deployment programme could (a) help directly capture the value in those applications, and (b) could also support the development of an ecosystem of upstream sub-system and component suppliers. Following standard automotive sector practice, these would likely be local in the longer term. This would also position EU component suppliers to supply both EU and non-EU OEMs located in Europe.

For many other applications, OEMs have less power, and supply chains are likely to be global, so EU suppliers will rely less on EU deployment for sales. Nevertheless, deploying fuel cell and hydrogen applications in the EU will strongly support their development, through providing experience and direct feedback from local markets. It will also enable provision of support services such as installation, maintenance and fuelling, all of which generate significant value and employment, and help inform the activities of the knowledge-based actors.

Many fuel cell and hydrogen applications will also benefit from supply chain support

Whilst there are European companies and researchers active in most areas of fuel cell and hydrogen supply chains and strong in many, gaps do exist: areas where the EU is behind other regions, or where there are no strong players globally. Opportunities therefore exist here for European companies to build positions, and different types of support could help them to do this.

Given that many supply chains will be global, it is not necessary to try to construct a whole supply chain from EU companies, but is better to focus on areas of strength, need, or competitive advantage. European car OEMs are not leading in FCEV, though have interest and programmes, but the Tier 1s and other actors in the supply chain are very engaged, and supplying globally. Even if overseas OEMs deploy vehicles in Europe in response to policy measures, they are likely to use local production capabilities and even European supply chain companies if these have already built a strong position.

The picture in stationary fuel cell systems is mixed, with the production and supply of large systems currently dominated by US and Asian manufacturers. Some European companies are better positioned in micro-CHP, and looking to enter overseas markets, but the commercial CHP sector of tens to about 100MW is discussed as a very promising opportunity, building on already-developed mCHP technology. Europe is well positioned in SOFC in particular.

Hydrogen refuelling stations (HRS) stand out as an area of potentially high total value and added value, but it is important to note that the figures for HRS include the total cost and value added for installation of the station, and not only production of the systems. Indirect employment effects for other applications – notably transport – are higher, and roll-out of stations will only come with roll-out of vehicles, so the two require an integrated support approach.

Electrolysers are a further area where Europe is well-placed, in part thanks to indigenous technology that has developed over many years, and in part because European support schemes for both electrolyser-based HRS and for stationary applications such as power-to-gas have been more consistent than in many other regions, allowing capacity and expertise to be developed.

The FCH sector offers Europe a chance to benefit economically and environmentally from an emerging industry and strengthen its position in clean technologies generally, but must be appropriately supported

The FCH sector contains many large and small players globally, and many applications are on the verge of economic competitiveness after years of investment and development. Major industrial nations such as Japan, Korea and the US are strengthening or developing positions, and China is emerging rapidly. Europe is well positioned to profit from European component and system manufacture, both for European deployment and export. Scenarios developed in this study show likely markets of multiple billions of Euros. Europe will also benefit from deploying overseas technology locally, both through environmental improvements and through local employment, though to a lesser extent.

This study has looked in some detail at hundreds of organisations, multiple FCH components and applications, and a range of different growth scenarios. From the analysis it is possible to make general recommendations about areas of the industry and the kind of support that could allow Europe to capitalise on the strong base and high levels of interest in the sector. These include:

- Co-ordination of EU and national visions, to allow companies and other entities to optimise incentives and investment for transport and infrastructure;
- Supporting FCH in transportation applications, not only in cars but also in heavy-duty applications such as trucks, trains and marine applications. This should help both strengthen multiple parts of the component supply chain and ease the roll-out of infrastructure;
- A continued focus on standards and regulations, to ensure wherever possible that deployment is not held up by either, and that standards across different sectors do not conflict;

- Engagement of the finance sector in providing suitable and potentially innovative financing for scale-up and deployment, where capital requirements are high for small companies, or loan guarantees may be needed to overcome risks inherent in an emerging technology;
- Support for companies capable of producing competitive heat and power solutions, whether in the residential, commercial or industrial sectors. Measures here could include scale-up support, or market mechanisms that fairly value the benefits that such technologies bring (lower CO_2 emissions, air quality benefits, grid support capability);
- Addressing the skills gap that is emerging in the sector, by ensuring it is communicated as a good opportunity for future employment, plus dedicated training and certification;
- Aligning electricity markets and regulations with the stated need for low-carbon hydrogen, by reducing or removing tariffs and levies on electricity that render the hydrogen produced expensive, where these costs are not justified or are double-counted;
- Stimulation of local integration and manufacturing capability for HRS and compressed hydrogen storage; plus support for export if appropriate.

These generic recommendations need ideally to be translated into specific actions to be taken by given actors, and timing assessed. Despite the depth of analysis in this report, however, the majority of this specificity depends on local conditions and individual actors. What is right for one company and one country or region will not suit another, and so such specificity is not attempted here. In any event, co-ordination at EU level will be important, useful and advisable.

The FCH sector is poised to grow, and Europe is still well positioned, but action is required

Strong indicators suggest that the FCH sector is poised for growth, and that this growth must be relatively rapid in order to create the size of industry and mature supply chains required for it to be self-sustaining. The supply chain is currently global and likely to remain so, and Europe occupies a strong position within it. FCH technologies can act as a strong complement to other ‘clean’ technologies and as a system solution which improves performance across a very wide range of sectors.

To maintain and grow this position will require European actors to invest, both politically and financially, in deploying products locally and in strengthening technical and manufacturing capabilities. Letting other regions take the lead will dramatically reduce the chances of Europe profiting – either from an industrial or an environmental perspective – as a smaller proportion of global value will be captured, and fewer products will be deployed locally. If Europe wishes to profit from FCH technology as well as benefit from the environmental improvements it can help to bring, it should act now.

2 Introduction

2.1 This 'Findings' report

The outputs of this study are divided into three reports:

- A 'Summary' report that provides a synthetic overview of the full study;
- This 'Findings' report that presents the approach and findings of the study;
- and an 'Evidence' report that provides the detailed background information and analysis that supports the findings and recommendations.

The study described in this report was large, and considered multiple aspects of FCH value chains from many perspectives. The accompanying 'Evidence Report' discusses all of these in detail.

This report is a summary of the approach and findings of the study. It is intended to be synthetic, not exhaustive, and draw out the main aspects of the analysis and conclusions rather than delving into detail. It describes the approach taken, the main outcomes of the analysis, and the conclusions drawn.

2.2 The study

Fuel cells and hydrogen could bring significant benefits across the energy system, enabling low carbon, zero air quality emissions energy options, and efficient energy conversion. Whilst these benefits may be achieved irrespective of the geographical origin of the technologies used, the benefits to Europe could be greater if the European industrial supply chain for fuel cells and hydrogen were to play a strong role. These benefits could be:

- *Economic*: as an expanding area for green growth, generating revenue for European countries and creating highly skilled jobs in a knowledge-based sector;
- *Environmental*: through ensuring that the technologies developed are appropriate for European markets, that they are available for European deployment when required, and because there may be greater willingness to promote and support deployment of European technologies in Europe.

FCH technologies are sometimes seen as competing with other emerging solutions to environmental and economic problems, such as battery electric vehicles (BEVs). As BEVs are in a more advanced state of manufacturing development and deployment, more analysis has been conducted on their national and international value proposition. More rigorous evaluation of FCH technologies is providing information and data against which to compare these and other technologies and sectors.

FCH 2 JU is a public-private partnership between the European Commission, European industry and European research organisations, and supports RTD activities in FCH technologies in Europe. Recognising the potential benefits from a strong FCH supply chain in Europe, and the opportunities for initiatives to support new energy supply chains, FCH 2 JU commissioned and received a preliminary analysis of the FCH sector and its supply chain status in 2017. This study examined a subset of applications and primary actors, as well as providing initial inputs on potential areas of strength and weakness for Europe. The FCH 2 JU has commissioned this study as an in-depth follow-on analysis. It looks at more applications, in more detail, not only at the supply chain opportunities and threats, but also at the broader value chain. This piece of work has produced a more comprehensive database, and provides recommendations for actions that can be taken to support the successful growth of a European supply chain.

While Europe has a very strong research and technology base, and strong supply chain actors in some areas, Japan, Korea and some parts of the US have been the early movers in the actual deployment of fuel cell and hydrogen technologies, and they are now being joined (and are likely to be overtaken) by China. National industries and initial supply chains have begun to evolve. Apart from in the US, FCH technologies in these regions are supported by a clear vision to build a local industry to serve the domestic market, and eventually to become a leading exporter of these new technologies when other world regions embrace FCH. Policies such as the Clean Energy Manufacturing Initiative in the US, the New and Renewable Energy Portfolio Standard in Korea and the Ene-Farm programme in Japan represent some of these efforts to build national markets and industries. And although high volume deployment has not taken place in Europe so far, the European FCH industry has profited from the deployments in the US, Korea and Japan: the major system integrators serving those markets rely on a global supply chain including many European actors; and some technologies developed overseas have been re-engineered to local standards and conditions and integrated into the product lines of European suppliers for sales in Europe.

The European FCH sector is very diverse but well interconnected (partly thanks to the significant activities of the FCH 2 JU). Some European countries have mapped their own fuel cell and hydrogen industry and knowledge-based actors (e.g. Fuel Cell Industry Guide Germany 2016[4], Hydrogen and Fuel Cells: Opportunities for Growth – A Roadmap for the UK[5], Swiss Hydrogen & Fuel Cell Activities: Opportunities, barriers and public support[6]). In contrast, this study systematically looks at selected full value chains and manufacturing competitiveness at a European level, which has not been done before. While the global and European market for these technologies is still small, it is growing rapidly and expected to continue to do so. Now is the right moment to secure a leading role for Europe. To do this, targeted interventions may be necessary, and these can be informed by thorough analysis of the European supply chain and knowledge base, and a clear view of their strengths and weaknesses, put in the context of the opportunities to be grasped.

The FCH 2 JU's overall objective for this study is to assess the contribution that the FCH sector could make to green growth in Europe, as well as to climate and energy goals, and to make recommendations to political and other actors on how to maximise this contribution. This study thus has several main functions:

- To provide a database of actors in the European supply chain, from which useful data and information can be extracted, and with the potential to be updated on an ongoing basis;
- To provide a view on the most valuable or most fragile parts of the value chain, from an economic and strategic perspective and in a global context, including with respect to important competing alternatives;
- To develop plausible scenarios for the role of the FCH sector in Europe that give all interested parties a common understanding of the opportunity;
- To provide robust analysis of the value that the sector could bring to Europe, high quality supporting data, and rigorous recommendations that can be used to further develop and support the European FCH sector.

2.3 Study objectives and approach

The objectives were agreed as:

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[4] Fuel Cell Industry Guide Germany 2016 https://www.vdma.org/en/article/-/articleview/13175963

[5] E4tech Development of a roadmap for hydrogen and fuel cells in the UK to 2025 and beyond. Report published at http://www.e4tech.com/wp-content/uploads/2016/08/HFCroadmap-MainReport.pdf

[6] E4tech Assessment of the Swiss hydrogen and fuel cell sector, Report published at http://www.bfe.admin.ch/php/modules/enet/streamfile.php?file=000000011234.pdf&name=000000290993

1. **In-depth analysis and updated mapping of industrial actors in European FCH supply chain** for selected applications in the transport and energy sectors, including the manufacturing supply chain;
2. **In-depth analysis and updated mapping of the European FCH knowledge-based actors**, such as research centres and universities that contribute to the same European FCH supply chains today, or with potential to contribute in the future;
3. **Value chain and manufacturing competitiveness analysis**, identifying the parts of the supply chain of greatest value at component level for transport and energy applications, the capabilities of supply chain companies and European research in comparison with global competition; and bottlenecks and barriers to the successful exploitation of these opportunities for Europe;
4. **Development and assessment of potential scenarios for the European FCH value chain and manufacturing competitiveness to 2024 and 2030**, including global and EU deployment modelling, evolution of the future competitiveness of European supply chains, and quantified scenario impacts;
5. **Recommendations for specific actions and investments**, providing actions at component and application level, and for the European sector as a whole, which could improve European competitiveness and value creation.

The project approach is summarised in Figure 4 below:

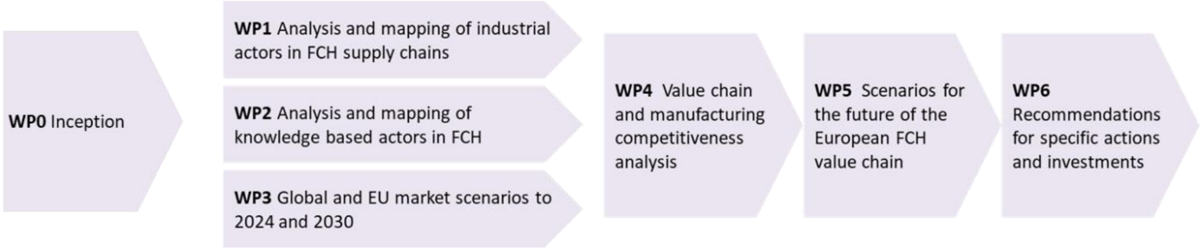

Figure 4: Project approach

The details of the work packages undertaken were finalised during the inception phase. In **WP1** the FCH supply chains were mapped and described for selected applications and components, SWOT and gap analyses were conducted against other leading world regions, and a database of European actors was populated. The same was done for knowledge-based actors in **WP2.** For **WP3** Global and EU market scenarios to 2024 and 2030 were developed: deployment scenarios were produced for each application globally and regionally, and multiplied by cost figures to give indicative market turnover by application and component.

A value chain and manufacturing competitiveness analysis was then carried out in **WP4**, based on the outputs of the previous WPs. Areas of opportunity at application and component level for Europe were identified, along with the barriers to achieving them. These identified opportunities were used in **WP5** to develop scenarios for the future of the FCH value chain in Europe – combining European competitiveness with market turnover from WP3 to give scenarios for the future of the European FCH sector. Specific actions and investments were then recommended in **WP6**, to help enable opportunities to be exploited in components, applications, and the European FCH sector as a whole.

2.4 Scope

The scope of applications included within this study is shown in Table 2, with comments where necessary to clarify the scope of the application considered.

Table 2: Application scoping

Application	In?	Comments
TRANSPORT APPLICATIONS		
FCEV (fuel cell electric vehicles i.e. cars)	Yes	
FC (Fuel cell) buses	Yes	
HRS (Hydrogen refuelling stations)	Yes	Includes small compressors and stationary storage
FC Forklifts	Yes	
Maritime and inland boats	Yes	
HGVs (heavy goods vehicle propulsion)	Yes	
Trains and light rail	Yes	
UAVs (unmanned aerial vehicles)	No	Very small market and GHG savings
STATIONARY APPLICATIONS AND HYDROGEN SUPPLY		
Micro-CHP (combined heat and power)	Yes	0 to 5 kW output
Commercial FC CHP	Yes	5 to <100 kW output
Larger FC CHP & primary power	Yes	100kW – multi MW output scale
Fuel cell APUs (auxiliary power units) for trucks	No	Small near-term market, limited GHG benefit
Electrolysers	Yes	
Hydrogen storage	Yes	Focus on compressed hydrogen
Compressors	No	Small compressors within HRS. Large compressors are supplied by existing mature supply chains
FC Back-up power systems and FC power generators (gensets)	Yes	These categories were combined as they use similar technologies and systems
Fuel processors / reformers	Yes	
APUs for boats / recreational vehicles	No	Very small market and GHG savings
Ammonia and liquid organic hydrogen carriers (LOHC)	Yes	
Use of hydrogen in industry	No	Not primarily related to the FCH supply chain.
Gas turbines	No	Not distinct from the natural gas turbine industry
CROSS CUTTING TECHNOLOGIES		
Test benches and test equipment		Important supporting capabilities for supply chains, discussed at high level only in an Appendix of the accompanying Evidence Report.
Dedicated manufacturing equipment		

This initial list of applications was further scoped down within the project. In some cases, **WP3** showed that an application has a small global market size and value, meaning the EU share of this market will inherently be small, and these applications were scoped out. Applications with similar upstream value chains were grouped together in **WP5.**

The **scope of countries** included is defined as the EU plus Horizon 2020 associated countries[7]. For brevity, the term 'EU', 'Europe' and 'European' is used to represent these countries in this report.

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[7] As of 01 January 2017, the following countries are associated to Horizon 2020: Iceland, Norway, Albania, Bosnia and Herzegovina, the former Yugoslav Republic of Macedonia, Montenegro, Serbia, Turkey, Israel, Moldova, Switzerland, Faroe Islands, Ukraine, Tunisia, Georgia, Armenia

3 Methodology

The applications selected in Section 1 were mapped in different ways to provide a set of input data and information for the analysis and recommendations. For each application a supply chain diagram was produced, from final application all the way upstream to specialised material, with a focus on FCH-related specialisation rather than generic components or materials.

From this, the database structure was agreed, so that companies operating at similar points in the different supply chains could be grouped and assessed. In some cases simplifying assumptions were made, to enable common approaches between different chains (for example the different SOFC architectures – planar, tubular, etc. were considered in common). Data and information on the FCH industry and the surrounding knowledge-based actors were gathered through multiple methods, for inclusion in the database and for informing the analysis. These data included the actor's position in the supply chain, numbers of units shipped, readiness levels, employment statistics and other fields.

An online questionnaire (an overview is in Figure 5) was publicised as widely as possible to allow FCH sector actors to complete their own information; this was supplemented with desk-based research and compiled into a database which already included information from an earlier supply chain study. Over 400 responses to the questionnaire were received, from just under 200 individual actors, which although a good response rate still did not represent all of the industry. Considerable additional manual entry filled gaps and was used to sense-check all entries.

The questionnaire included very detailed requests and in many cases actors either were not able or not willing to include all of the information, meaning that aspects of the analysis had to be modified or curtailed. The raw data from the questionnaire were gathered in a secure online database and then post-processed to allow easier interpretation and visualisation. A final person-readable database was produced in the form of an Excel workbook for internal use by the FCHJU.

Company profile

- Locations, number of staff, share of staff involved in FCH, share of FCH staff based in Europe
- Global, FCH-related turnover and share generated by business units based in Europe
- Investment in FCH activities and share invested in Europe

Technology and application selection

- Choice of applications in fuel cells, electrolysers, hydrogen storage and transport, hydrogen refuelling stations and fuel processors. Choices are categorised by the supply chain position (e.g. user, manufacturer), the technology (e.g. fuel cells), the chemistry (e.g. PEM) and the application (e.g. buses).

Detailed questions for each selected application / product

- Product information
- 2017 shipment data and share manufactured or assembled by business units based in Europe
- Current production capacity and planned production capacity in 2020
- Technology, manufacturing and commercial readiness levels

Figure 5: Overview of questionnaire for industrial actors

The database allows data extraction for visual representation (e.g. an interactive map on the FCHJU website) and for further analysis (e.g. of the number of suppliers in a particular region, or part of the supply chain).

Each supply chain map was then populated with leading European industry actors. The number and type of actors gave an initial indication of approximate areas of strength or fragility, though the list could not be considered fully comprehensive. It is however relatively detailed and the majority of relevant actors are included. Knowledge-based actors or KBAs were also examined for the different applications and included in the supporting database. KBAs typically work on areas that are applicable to multiple FCH technologies, often in fundamental research which is not simple to link to single components or application fields. The KBAs were not therefore mapped in the same way as the industry players, but were discussed and included in the further analysis of gaps, actions and recommendations.

The supply chain maps, actor identification and other 'structuring' steps enabled a methodical and appropriately comprehensive approach to be taken to develop the analysis and subsequent recommendations. Nevertheless, the lists are detailed but not totally comprehensive, and subtle differences in technology and individual company approach mean that the structuring is a compromise that will likely not be perfectly correct for any real set of actors. It is however a very close representation, and is sufficient to draw robust conclusions. Because each supply chain map contains a set of actors, it is easy to infer that suppliers upstream definitely supply those downstream. This is not necessarily the case – supply relationships are often confidential, and no conclusions about actual relationships should be drawn from the diagrams.

A competitiveness survey was carried out to supplement the data gathered through the questionnaire and online work. The questionnaire was designed to elicit information on areas of European strength and weakness, and more nuanced and qualitative input than the quantitative data captured in the database. This was used to feed into the value analysis and the recommended actions in particular.

The cost of FCH applications is an important factor in their competitiveness and uptake. Some components or materials are major cost contributors, and the amount of cost reduction possible through mass production or other means varies considerably. Cost breakdowns were derived for the selected applications from literature and from other work conducted by the consortium members, and used to guide several aspects of the analysis. Costs were one element in the selection of critical components, and the ease or likelihood of cost reduction was an important factor in suggesting actions. Costs were also one of the essential inputs into the economic value analysis, broken down by labour, materials and other factors. This analysis allowed the identification of areas of potential interest for the FCH sector, and for associated actors, such as regional or other authorities.

The FCH sector covers a wide variety of applications and each supply chain breaks down into a multitude of components. To allow a manageable and meaningful analysis, components were ranked using a set of measures including their effect on system performance, their contribution to cost, the strength of the supplier base, and the potential for new markets to arise. These criteria were not chosen specifically to identify the components which required the most R&D or other support, nor to exhaustively cover every application or part of the supply chain. They were chosen to represent the focal aspects of this study in particular – the level of technology development, European versus other capabilities, and the socio-economic potential for the different applications. This subset of critical components resulted in a long list, with some repetition across the different applications, so a further choice was made to define subsets of these into 'selected' critical components. These selected components represent the different attributes relevant to the study, and were then used as the basis for further analysis.

4 Industry Overview

This study not only considered the potential for value creation through and around the FCH supply chain, but also (at a high level) the competitive position of Europe vis-à-vis other leading world regions. This informed the analysis in terms of assessing the likelihood of Europe gaining a significant share, but also the actions that might be taken to improve European opportunities. Japan, South Korea, China and North America were examined to provide this information. Each has significant strengths, though China is somewhat lagging in technology status. Nevertheless, as the current growth engine for many parts of the FCH economy, its policy and industry landscape was important to understand the future state of the industry globally.

4.1 Europe

Europe is well positioned in almost all aspects of FCH, at least on a par with its peers in most applications and technologies, and ahead in some aspects. A few areas of weakness or limited investment exist.

For example, the leading OEM integrators for **FCEVs** are in Asia, with Hyundai, Toyota and Honda all well advanced. Daimler is currently the only European OEM with a ‘commercial’ product, in very limited production, though Audi, BMW, Fiat and others have suggested that they may have vehicles around 2020. Europe does however have several entrepreneurial integrators targeting different applications: French company Symbio offers converted Renault Kangoo vehicles with range-extender fuel cells, German company Streetscooter intends to produce FC range-extender electric vehicles and UK-based Riversimple has designed a car from the ground up. Japan and Korea do use European suppliers when appropriate, though are very focused on developing local alternatives, and specifically support their local supply chain actors. In the near term, Chinese firms are looking for JVs and technology transfer as they ramp up production, evidenced by the strong relationships held by Ballard, Hydrogenics and other non-European fuel cell manufacturers in China; the engagement of Impact Coatings of Sweden for a specialist coating line; and initiatives such as the German-based company Fuel Cell Powertrain, which was started using Chinese investment. Other European firms could potentially use this opportunity to develop technology and export markets and also gather valuable in-use performance data.

Europe is well placed in **fuel cell bus** development, having seen the majority of the early roll-out, though China is now deploying more vehicles. European manufacturers have been largely dependent on Canadian technology from Ballard and Hydrogenics for stacks and subsystems, though Europe has suppliers (e.g. Proton Motor) developing these capabilities and who could fill this gap if the technology can be suitably well proven. Costs remain high, in part due to small historical order numbers, though this is changing through larger orders. These larger numbers are typically the result of local, national or international programmes, such as run by the FCHJU. Gaps remain in areas such as integration know-how and capacity, as the small numbers of buses made in Europe thus far have mainly been individually hand-built. In many places a gap also exists in bringing together the right funding to allow local bus operators to take advantage of the technology. More broadly, a gap exists in availability of skilled integration personnel and in financing for public transport authorities to make the transition to these currently expensive buses.

Fuel cell **forklifts** were one of the earliest fuel cell applications to be commercialised, in a market niche which values rapid recharge and zero emissions. They fall under the broader category of material handling equipment, which also includes ground support equipment at airports and seaports. In Europe, H2Logic’s activities were taken over by Ballard through Danish subsidiary Dantherm and a collaboration continues with Taiwanese company M-Field. Linde also manufactures FC forklifts. The potential exists in Europe for FC forklifts to be produced and deployed, with an important gap in demand related to the comparatively weak economics of the systems. This may require costs to come down before it can be resolved, if novel or integrated business models are not developed. European developers such as Proton Motor have ceased development activities in forklifts, but indigenous capabilities exist should the market evolve.

To simplify this analysis, **heavy goods vehicles** or HGVs are those weighing more than 3.5 tonnes, a broader definition than in many instances, including both medium duty and heavy duty trucks. Although some specific component sizes and architecture will differ, enough similarity exists to consider them jointly here. In Europe, a few trucks have been integrated, including Renault Maxity, Scania and MAN vehicles, the latter modified by ESORO. Stacks come from Symbio, from PowerCell and from Hydrogenics. These are conversions by specialist external integrators, and no truck OEM is currently building vehicles, though some are showing interest. However, others are more, aggressive evidenced by Hyundai's announcement of 1,000 trucks for Switzerland starting in 2019. Nikola Motor of the USA is designing and developing its own long-haul unit with stacks from PowerCell in Sweden. Suitable hydrogen storage for heavy, very long-distance driving is not yet available however, either in Europe or globally. If liquid hydrogen is chosen, liquefaction capacity could become a bottleneck, but this will take some time to materialise.

In Europe, Germany has taken a global lead in implementation, and regional **trains** powered by hydrogen fuel cells are now in operation. The trains are made by Alstom and fuel cell systems come from Hydrogenics. Ballard has also announced a tie-up with Siemens aimed at the same market. The Alstom and Siemens rail businesses have announced a merger, still in process, which would potentially affect this nascent supply chain. One reason for the merger was to compete better against emerging Chinese competition in rail. In general, rail systems are built around existing architecture designed for bus and heavy-duty uses.

Fuel cells used in **maritime** and inland boats could help make significant reductions in GHG emissions and to mitigate a significant source of smog producing pollutants near port towns. Fuel cells could be applied for both propulsion and hotel loads, but the former is likely only for relatively short journeys (e.g. ferries) in the near term. There have been several shipboard fuel cell power demonstrations, primarily in Europe. PEMFC and SOFC are the primary fuel cell chemistries considered, while MCFC has also been demonstrated but does not appear to be preferred for this application. Maritime propulsion is the focus of this study, and PEMFC is attracting considerable interest for this application. SOFC and MCFC are not examined here, as their on-board use for hotel loads is very similar to conventional stationary applications. Europe is probably marginally stronger than many other regions as this area has been a focus for some time, even though activity has been limited.

Europe has several **HRS** integrators with a global reputation and reach, including Linde, Air Liquide, Nel (H2 Logic) and ITM Power. Europe is also well positioned across most key components in HRS, and some European actors are working on the development of new components (e.g. the dispenser and hosing). There is still a lack of flow meters that meet the accuracy requirements of weights and measures authorities, but there is relevant development activity by some European actors. Other areas, such as in-line purity assurance remain an area of R&D activity, also by component developers. Europe has several hydrogen compressor suppliers to choose from, including some with novel compression technologies. Europe suffers from the same gaps as other global regions, so is not specifically at a disadvantage, but successful development and commercialisation of higher performing and lower-cost dispensing equipment, hoses, metering equipment and sensors would position Europe well. Other gaps include test capabilities to ensure HRS meet tough standards for refuelling protocols, and a service infrastructure for installed HRS. The availability of reasonably-priced and reliable compressors is a gap here and in other applications.

For **micro-CHP** Europe has strong heating appliance integrators with varied but increasing degrees of participation in fuel cells. Many have a long history in heating appliances (e.g. boiler manufacturers) and in technology integration, but very few have in-house fuel cell stack development. No European player has the depth of experience that is found in Japan, and European PEM stacks and systems are in the early stages of (subsidised) 'commercial' deployment. Some actors have even stopped in-house activity, preferring to source from and partner with the strongest providers globally, who are typically Japanese players (e.g. Panasonic). Although many systems installed in Europe are hence based on imported technology, these are adapted for European conditions and certified locally, with some components also locally sourced. After Japan, where the Ene-farm programme has led to massive micro-CHP deployment in recent years, Europe, and in particular Germany show the highest activity internationally, both in terms of breadth of technology suppliers as well as efforts to roll out systems into the market.

Europe is well-regarded in **SOFC for mCHP**, with several strong players throughout the supply chain. In addition to its own developments, SOLIDpower acquired an established Australian technology with production in Germany, although some components come from other regions, e.g. China. Ceres Power does not yet have a full commercial product but has important partnerships within and outside Europe, which could result in significant export markets in addition to local sales. Other developers are at different stages of progress, including Viessmann, which is embarking on a new iteration of the SOFC system it already has on the market, Sunfire and Bosch. European actors have strong skills in system modelling, reactor design, catalysts, cell materials and other areas, on a par with other global regions.

There are very few PEM commercial **FC prime power and CHP** integrators either in Europe or globally. The German company RBZ Fuel Cells have developed a small commercial 5 kW PEM CHP unit. Nevertheless, this area is considered as potentially a stronger market than micro-CHP: the specific cost of the units can be lower because of balance of plant scale effects; and the business case may be better as more consistent heat and power loads can enable higher utilisation factors.

AFC systems are actively developed in Europe at AFC Energy, targeted at large-scale applications. The units are at an early stage and the supply chain is still evolving, but since very few organisations are developing this chemistry the supply chain is somewhat *ad hoc*. Israel's GenCell has commercial units of around 5 kW for sale, but no known work is going on elsewhere. Export opportunities for Europe would mainly be around sales of complete systems to other countries, not of components.

European **large PEM** has thus far only been deployed by Nedstack in China, as part of the FCH JU project DEMCOPEM-2MW. It requires some further development and optimisation before it is fully commercial. Whilst CHP is an option for these plants, in practice they are likely to operate in power-only mode unless a suitable local heat requirement exists. This affects the economics both because less of the input energy can be used, but also because the non-CHP system is lower cost.

Europe has limited product development in **large-scale CHP** more broadly. AFC Energy is building final systems, much like Nedstack, but these are at demonstration stage and not yet mass produced. Again, they have an almost completely different materials and component supply chain from other fuel cell types. FuelCell Energy is primarily engineering systems produced in the US, but also has some integration capacity in Europe, and Doosan Babcock uses units from its parent company Doosan, which have largely US and Korean technology, though the catalyst supply is European. Europe has good engineering firms capable of putting these systems together and some deploy outside Europe, but the markets to date have been very small.

Fuel cell systems used for **emergency and off-grid power** are in many cases commercially available, up to a capacity of 10 kW. These are often used for telecoms systems and end-uses that require an uninterruptable power supply (UPS). The majority of such systems are PEMFC and DMFC, though AFC plays a small role, and a few specialised SOFC systems are also deployed, though not in Europe or produced by European companies. One industrial actor, SFC Energy, produces DMFC systems for this application, for example for military and recreational customers. They are differentiated from other stationary systems because they run intermittently, requiring different systems configurations, lifetime and durability. Small but growing markets for FC back-up power and gensets exist in North America and Asia in particular, and for specialist systems such as emergency services grid networks in Europe. Countries with particularly unreliable grid connections or areas without grid connection may offer good business cases for back-up or off-grid systems. This favours sales in developing and emerging markets. The market in Europe is not as attractive, partly because of the generally good reliability and coverage of the electricity grid networks in European countries.

Europe is well positioned generally in **electrolysis.** Alkaline electrolysis is commercially proven as a base-load hydrogen generator, and suitable system design makes it viable also for more variable and intermittent operation profiles. Europe is one of the leaders in today's global alkaline electrolysis industry with the two major manufacturers, Nel and Hydrogenics, producing in Norway and Belgium respectively, and with other companies such as McPhy gaining momentum. Major players such as ThyssenKrupp have technologies used for chlor-alkali production which could be used for water electrolysis. China, Japan and the US also have production capacity, but are less active in the global market than the European actors. European companies are positioned well to benefit from market growth.

PEM electrolysis is a much younger technology than alkaline, though it has benefitted from PEM FC research and development. Its commercialisation was pioneered in the US, building on developments for the military. Several North American companies have developed technology or products including Giner, now in partnership with Spanish company H2B2, and Proton OnSite, now owned by Norway's Nel, as well as Hydrogenics in Canada. European developers such as Siemens, Areva, and ITM Power are commercialising their own PEM electrolysers, most of them in view of expected market growth as part of the energy transition. There is little public information on sourcing of components by the system integrators, but many of the supply chain companies currently supplying PEM fuel cell integrators also offer components for PEM electrolysers. This means that Europe is well positioned all along the PEM electrolyser supply chain, however, the electrolyser-specific supply chain is in general less developed than that for PEM fuel cells.

Solid oxide electrolysis (SOEL) is globally at the technology demonstration stage, and European actors appear to be leading commercialisation. There is some activity in the US, but Europe is ahead with Sunfire, Sylfen, Haldor Topsoe, and SOLIDpower all engaged, for example. Given the early stage of the technology it is not yet clear what role SOEL will play in the future mix of electrolysis technologies, though in principle it could help to bring down costs and raise (electrical) efficiencies significantly. Similar to SOFC, Europe has a breadth of suppliers and developers with excellent knowledge of the technology and the key stack components, though few of the European suppliers have experience with larger volume manufacturing.

Europe has strong skillsets in a wide range of **hydrogen storage technologies** at many scales, including world-leading science in novel storage technologies. Europe is generally well-positioned, with suppliers or developers in relevant areas, though weaknesses in the supply chain exist. For example, although compressed storage appears to have many players, not all produce tanks in Europe. Hydrogen compressed tank supply has some strong Asian and N American actors, with specialist materials, notably high-grade carbon fibre, coming more from Asia. Valves and regulators are an important area for cost reduction and good opportunities exist for export, though there are few suppliers generally and both the regional and the global supply chain need strengthening. Europe does, however, have a base of high-quality balance of plant component suppliers such as OMB Saleri in Italy and Pressure Tech in the UK, which would be well positioned to supply a growing market. The main gaps in hydrogen storage are related to the availability and cost of tanks and some other components. Carbon fibre availability is a bottleneck and European-based supply could alleviate some concerns about supply risk. Europe's relatively limited industrial supply base is being augmented by new entrants, but these are primarily looking at tank manufacture and supply, and less at materials. Manufacturing scale is also lacking, though it would be comparatively straightforward to increase existing capacity given investment. The broad availability of low-cost reliable components such as regulators would also help advance the industry and support Europe's competitive position.

As interest in large-scale renewable or low-carbon hydrogen grows, methods of storing and transporting it, particularly for long distances, become more important. **Liquid organic hydrogen carriers (LOHC) and ammonia** are increasingly considered, though very few LOHCs are under serious development. Nevertheless, they could form an important part of the future value chain. Europe has conventional industrial strengths in ammonia technologies, plus some smaller-scale developers, and one or two organisations developing LOHC, including Areva and Hydrogenious. LOHC and ammonia are in the early stages of development as hydrogen carrier technologies. The supply chains are relatively straightforward, and currently somewhat *ad-hoc*, driven by the product integrator. In a currently very limited application space, Europe is well placed in terms of both industrial actors and KBAs, including those on reaction chemistry and catalysis.

4.2 Other regions

4.2.1 Japan

Japan is very strong in most areas in FCH, from fundamental science to applications and manufacturing. It has expertise in every fuel cell chemistry, although arguably has only recently caught up (and perhaps overtaken) Europe on SOFC industrialisation. Japan is the strongest region globally in terms of plans and linkages between government, research and industry actors, who all meet and discuss these frequently. Japanese technology is also typically strong, often developed incrementally, through multiple iterations, rather than breakthroughs. Many major corporations in Japan have hydrogen and/or fuel cell technology programmes, and others have increasing interests in business models and technology exploitation.

The Japanese fuel cell industry is given strong direction and financial support through national government policy, with hydrogen embedded into the national energy strategy and supported through three key phases: roll-out of fuel cells (and cost reduction); hydrogen mass production (and cost reduction); and making the hydrogen used 'CO_2 free' (green hydrogen). Much of this is overseen by the Ministry of Economy, Trade and Industry (METI), and research support comes mainly from the government agency New Energy and Industrial Technology Development Organisation (NEDO), funding R&D to the amount of $100m USD in FY 2018. Current Japanese projects include the import of significant amounts of hydrogen in 2020 from abroad, via liquefied hydrogen made from brown coal in Victoria, Australia and via a chemical carrier using hydrogen from renewable sources in Brunei[8].

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[8] Reuters (2017) 'Norway races Australia to fulfill Japan's hydrogen society dream' Available at: https://www.reuters.com/article/us-japan-hydrogen-race/norway-races-australia-to-fulfill-japans-hydrogen-society-dream-idUSKBN17U1QA

4.2.2 Korea

Korea has a large market for stationary fuel cells, in particular, but does not have the mature native technology of the global leaders, other than perhaps in Hyundai, although there is major investment in building Korean development, manufacturing and installation capabilities. The Government has announced a US$2.3bn programme for hydrogen research, development, manufacturing capability, infrastructure and vehicles to 2022[9]. Several of the large Korean players are looking to capitalise on a possible FCH future. So far, this has resulted in acquisitions and partnerships with companies with the required technology from different regions (mainly North America). For example, Doosan acquired ClearEdge Power in 2014 and LG bought a controlling stake in Rolls Royce's Fuel Cell Systems. Kolon Industries has developed an MEA and mass production technology, after acquiring patents and research facilities from Samsung SDI and manufacturing technology via licence from W.L Gore and Associates Inc.[10].

Korea's globally important market for stationary fuel cells is strongly driven by its policy for renewable energy. The national Renewable Portfolio Standard obligates power generators to produce renewable electricity and the use of stationary fuel cells for this produces a multiple of renewable energy credits. The transport market has lagged stationary, though the US$2.3bn programme should make a significant impact. This is likely to dovetail with a roadmap announced by the Ministry of Environment which specifies the hydrogen fuel cell vehicle share to be more than 10% of new cars and 520 HRS by 2030[11]. This is an estimated 180,000 FCEVs.

4.2.3 China

China has had strong fundamental research into FCH for at least two decades, and has also had some industrial activity, but only recently has it started to deploy sufficient numbers of units to be able to inform its local R&D in more depth. Strong fundamental research centres exist both in universities and in Key State Laboratories, and some of the university research is more applied, and acts almost as the R&D department of a company (for example Shanghai's Tongji University conducts a lot of applied R&D for Shanghai Automotive Industry Corporation (SAIC). Chinese technology is advancing rapidly but the majority of indigenous products still do not perform as well as overseas units, and so Chinese companies are setting up joint ventures both in China and abroad, as well as investing in companies in other countries, to speed up the inbound transfer of know-how and technology.

This industrial interest is driven partly by Chinese government policy goals (Table 3). These are linked both to deploying clean technologies locally – to improve air quality, for example – and to developing indigenous high-value industries. FCH technologies are a stated focus area for both, as is summarised in the table below. FCEV and FCEB enjoy generous subsidies under the New Energy Vehicle support programme.

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[9] Green Car Congress (2018) 'S Korea to invest $2.3B in hydrogen fuel cell vehicle industrial ecosystem over next 5 years' http://www.greencarcongress.com/2018/06/20180625-korea.html

[10] Business Korea (2016) 'Kolon Industries Secures Core Technology for Fuel Cell' Available at: http://www.businesskorea.co.kr/news/articleView.html?idxno=16404

[11] Hyundai (2016) 'FCEB Development Status in Korea' Available at: http://www.cte.tv/wp-content/uploads/2016/12/4_Jeon.pdf

Table 3: Chinese FCH development goals[12,13,14]

Goal	2020	2025	2030
Industry value, CNY billion/year	300 (~34 bn€)	-	1,000 (~115 bn€)
H2 production for energy use, billion m3/year	72	-	100
Vehicles on road, unit	• 5k* • 60% commercial & 40% car⁺ • 10k±	• 50k* • 20% commercial & 80% car⁺	• 1million* • 2million±
Other Infrastructure	50 train/tram demonstrations and shipping	-	3000km H2 pipeline
Refuelling stations	100	300	1,000
FC system production capacity per company, units/year	1,000	10,000	100,000

*Note: The goals come out of roadmaps from associations and are not official policy goals. * From Developmental roadmap (2017); ⁺ From SAE (2016); ± From Blue Book (2016). The Blue Book is supposed to be official, but most China experts refer to the developmental roadmap (2017) figure*

The Chinese Ministry of Science and Technology plays an important linking and guiding role, and local and regional governments are increasingly active, with Rugao City, for example, aiming to become a ‘hydrogen city’.

4.2.4 North America

The United States (US) and Canada have significant FCH activity at all levels of public and private research, government policy, and industry, while Mexico does not appear to be actively engaged. At the federal level, the US has maintained consistent funding levels around US$100m at the US Department of Energy (DoE) in programs dedicated to addressing FCH technical barriers[15]. Some states have local funding, e.g. to increase fuelling infrastructure (California) or support local manufacturing development (Ohio and Connecticut). There is considerable collaborative R&D among the DoE National Laboratories, research universities, global and emerging companies, with a focus on shared pre-competitive R&D to address technical challenges coordinated by the DoE. In Canada, the British Columbia province stands out as a fertile region of fuel cell innovation which is or has been supported by efforts at, *inter alia,* research universities, the National Research Council Canada, Ballard, and the Automotive Fuel Cell Cooperation. Several North American companies are growing or at least are showing promising growth in their sales figures[16].

In contrast with Japan and some other regions, there is no clear linkage between Federal R&D funding and an articulated national policy to directly support or foster FCH markets in North America, though tax credits at the state and federal level support renewable energy installations. The Residential Renewable Energy Tax Credit was renewed in 2018 and is set to expire in 2021. It includes residential fuel cells and offers a maximum tax credit of 30% of the cost of the installed system. From 2009-2011 the American Reinvestment and

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[12] CATARC (China Automotive Technology and Research Center), China Fuel Cell Vehicle Developmental Roadmap, 2017
[13] China Standardisation Committee, China Hydrogen Industry Infrastructure Development Blue Book, 2016
[14] SAE, Hydrogen Fuel Cell Vehicle Technology Roadmap, 2016
[15] Program Record #17006, “Historical Fuel Cell and Hydrogen Budgets” (2017), https://www.hydrogen.energy.gov/pdfs/17006_historical_fuel_cell_h2_budgets.pdf
[16] https://www.energy.gov/sites/prod/files/2017/10/f37/fcto_2016_market_report.pdf

Recover Act (ARRA) was a national-level effort to spur economic activity in the US, which has not been continued. Demonstration projects in early market applications, material handling equipment[17] and backup power[18], were subsidised leading to a clear business case and a growing market for these applications. At the state level California has committed US$200m over 10 years to building out hydrogen fuelling infrastructure, while a coordinated effort between Toyota, Air Liquide and five states in the Northeast (New York, New Jersey, Massachusetts, Connecticut, and Rhode Island) is expected to begin this year[19]. In addition to supporting fuelling infrastructure installation, there are state-level tax rebate incentives to support zero emission vehicles, including FCEVs.

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[17] Program Record #17003, "Industry Deployed Fuel Cell Powered Lift Trucks"(2017), https://www.hydrogen.energy.gov/pdfs/17004_industry_deployed_fc_bup.pdf

[18] Program Record #17004, "Industry Deployed Fuel Cell Backup Power"(2017), https://www.hydrogen.energy.gov/pdfs/17004_industry_deployed_fc_bup.pdf

[19] https://www.airliquide.com/united-states-america/air-liquide-plans-network-new-hydrogen-filling-stations-united-states

5 Criticality and Cost Assessment

All applications contain a very large number of components, some of which are not unique to FCH, and some of which are already manufactured in large quantities. To identify the most important areas in FCH for Europe, and to render the analysis manageable, it was constrained in several dimensions. Applications with small markets were not analysed in detail; areas with European supply chain strength were prioritised, and only a subset of components was analysed in depth. A short list of 'critical' components was drawn up using a scoring approach described below, and then only a subset of 'selected critical' components within that short list was analysed in detail.

All components are of course vital to the final application, and so this exercise was *not* designed as a ranking of where research funding or other support should be allocated. Alongside this, it is of course impossible to find a perfect definition of 'criticality', or a score that all stakeholders will agree with. However, the selected components are considered representative and suitable for this analysis, in that they span a range of technology areas and supply chain positions and offer transferable insights into the wider potential for the sector. The focus allowed a meaningful depth of analysis for the selected components, and simpler communication of the results and conclusions.

This analysis considers value add for Europe and not only technical performance, socioeconomic and market considerations were included in the six ranking criteria:

- **Performance** – system performance is significantly affected by component or sub-system performance.
- **Cost** – the component or sub-system represents a significant fraction of the system cost.
- **Technical evolution** – the component or sub-system is undergoing or is expected to undergo technological evolution that will lead to significant cost reduction or system performance improvement in the near-term.
- **Supplier base** – there is a limited supplier base of appropriate quality or the supply base is controlled or concentrated in one global region.
- **New market** – growth of the fuel cell and hydrogen market would result in a unique new market for the component or sub-system.
- **Socioeconomic impact** – the component or sub-system represents a unique area of job growth.

For each application, a representative system and list of components was defined, and the components tested against the six critical characteristics above, informed by cost analysis literature, the team's collected knowledge and data sets, and external experts as needed. A score of 1 (meets the definition) or 0 (does not meet the definition) was assigned to each characteristic, and components that scored 4 or above were deemed 'critical'. This subset of components would generally be intuitively familiar to an expert in the field.

An illustrative example is shown in Table 4 for a component that **meets** all six criticality characteristics, and hence scores 6 points in the assessment: catalyst in automotive PEM fuel cells, and one that **does not** meet the definition, DC-to-AC inverters (Table 5).

The majority of 'selected critical components' score 6, i.e. they meet all of the assessment criteria. In a few cases they have been promoted to help inform the analysis, for example where there is a clear economic interest in Europe. For example, while pressure vessels scored lower than some components, they were selected as critical components given their importance in enabling the spread of multiple applications.

Table 4: Automotive catalyst criticality evaluation

Criteria	Score	Rationale
Performance	1	Platinum-based catalysts bear primary responsibility for converting hydrogen chemical energy into electrical power; the fuel cell power plant size, cost, and durability are all directly linked to the catalyst.
Cost	1	Due to high platinum material costs, PEMFC cost is sensitive to the amount of catalyst required.[20]
Technical evolution	1	About 50% of the U.S. Department of Energy Fuel Cell Program budget is spent on catalyst development. Due in part to these investments, projected fuel cell system costs have decreased by nearly half.[21]
Supplier base	1	Due to the cost and complexity of handling precious metals and the technical complexity of fuel cell catalyst manufacture, only a small number of suppliers have the capability to supply catalyst for high volume automotive production.
New market	1	Catalyst is a unique component specially designed for PEMFCs and is not shared with other technologies. Thus, catalysts would represent a new market opportunity.
Socioeconomic impact	1	Catalyst production is technically complex and is expected to provide a range of jobs.

Table 5: Automotive power electronics / inverters criticality evaluation.

Criteria	Score	Rationale
Performance	0	Stack cost and performance is independent of inverter performance.
Cost	1	Inverter cost can be nearly twice the fuel cell system cost.[22]
Technical evolution	1	Research into wide bandgap semiconductors has the potential to significantly improve inverter efficiency.
Supplier base	0	The technology is mature and has a competitive supply base
New market	1	DC-to-AC inverters are common to all electric vehicles.
Socioeconomic impact	1	Impact is not known from cost models, but we anticipate that it would be similar to other semiconductor industries. Thus, growth in electric vehicle markets is expected to result in highly skilled jobs to support demand for power electronics.

Typical components selected for the analysis included the catalyst and membrane for PEMFC and PEMEL, the ceramic electrolytes and seals for SOFC and SOEL, pressure vessels for on-board hydrogen storage in vehicles, and the integration step in several cases. Table 6 is an example criticality assessment, for PEMEL.

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[20] Brian D. James et al., 2017, "Mass Production Cost Estimation of Direct H_2 PEM Fuel Cell Systems for Transportation Applications: 2016 Update" https://energy.gov/sites/prod/files/2017/06/f34/fcto_sa_2016_pemfc_transportation_cost_analysis.pdf

[21] Dimitrios Papageorgopoulos, 2017, "Fuel Cells R&D Overview" https://www.hydrogen.energy.gov/pdfs/review18/fc01_papageorgopoulos_2018_o.pdf

[22] Battelle, 2016, "Manufacturing Cost Analysis of 1, 5, 10 and 25 kW Fuel Cell Systems for Primary Power and Combined Heat and
A 'Technology Readiness Level' (TRL) and a Manufacturing Readiness Level (MRL) could in principle be assigned to the key components discussed. These levels represent the status of maturity of a component or system, as defined by NASA and the US Department of Energy, amongst others[22].
Power Applications", https://energy.gov/sites/prod/files/2016/07/f33/fcto_battelle_mfg_cost_analysis_pp_chp_fc_systems.pdf

Table 6: Example of criticality assessment – PEMEL

Application	Critical component	Supply Chain Sector	Score	Selected?
PEMEL	Catalyst	Specialised materials	6	Yes
	Membrane	Sub-component	6	Yes
	Membrane electrode assemblies	Sub-component	6	Yes
	PEMEL stack	Sub-system	6	Yes
	Ionomer	Specialised materials	5	
	Porous transport layer / gas diffusion layer	Sub-component	5	
	Bipolar plates	Sub-component	5	
	PEMEL system	System	5	Yes
	Membrane support	Specialised materials	4	
	H2 sensor	Sub-component	4	
	H2 conditioning	Sub-system	4	
	AC-DC power supply	Sub-system	4	

Cost breakdowns were also provided, derived from publicly-available analyses and broken down to a level that allowed the assessment of turnover and added-value in different relevant sections of the supply chain. For many applications, such as FCEV, some stationary systems, HRS and others, good cost analyses exist. The majority of open literature in this area has been sponsored by the US DoE, so many of the costs reported come from those sources. While these are not perfectly translatable to European conditions (different labour rates, land prices etc.) the common sourcing means they are broadly comparable, and the variations are within the uncertainty margins that already affect these calculations. Raw materials prices, exchange rates and many other factors change over time, driving these costs higher or lower, but also changing relative costs within applications. For example, speculation may drive platinum prices higher, or currency fluctuations push them lower, but this cannot be captured here. For applications which did not have sources it was necessary to use extrapolation, including expert assumptions on system size and performance to estimate reasonable cost breakdowns. The cost breakdowns were reported with respect to projected annual production in 2024 and 2030, to provide a clear connection between cost breakdowns and the deployment scenarios. Where deployment scenarios were not projected, cost breakdowns are reported with respect to the generic annual production levels provided in the source materials. An example cost breakdown, for SOFC CHP, is given in Table 7. The full set of cost data is available in the Evidence Report.

Table 7: Cost breakdowns for medium (100kW) SOFC for CHP

	2024			2030		
	Low	**Medium**	**High**	**Low**	**Medium**	**High**
System cost	€ 120,000	€ 120,000	€ 110,000	€ 110,000	€ 110,000	€ 100,000
System integration	€ 7,900	€ 7,600	€ 7,100	€ 7,300	€ 6,800	€ 6,500
BOP	€ 74,000	€ 71,000	€ 65,000	€ 66,000	€ 62,000	€ 58,000
Projected stack cost	€ 42,000	€ 42,000	€ 41,000	€ 41,000	€ 40,000	€ 40,000
Balance of stack	€ 11,000	€ 11,000	€ 11,000	€ 11,000	€ 11,000	€ 11,000
Interconnectors	€ 2,200	€ 2,100	€ 2,000	€ 2,000	€ 1,900	€ 1,900
Porous metal layers	€ 1,900	€ 1,900	€ 1,800	€ 1,800	€ 1,800	€ 1,800
Seals	€ 1,500	€ 1,500	€ 1,400	€ 1,400	€ 1,400	€ 1,400
Cell (EEA, MEA)	€ 15,000	€ 15,000	€ 15,000	€ 15,000	€ 15,000	€ 15,000

6 Supply Chain Mapping by Application and Technology

Supply chain diagrams were created for each of the chosen applications, to show the specific components and subsystems required for each application, and to allow relevant actors to be mapped onto the relevant parts of the chain. FCH technology approaches are sufficiently varied, even at the specific application level, that in some cases slight simplifications were made to the representations. This meant that not all current FCH systems exactly followed the supply chain logic (some PEMFC systems do not include humidifiers, for example) though in all cases it was extremely close. Equally, it was not possible to be exhaustive with the actors included.

The different supply chains for components and applications overlap in many ways, and so to allow different perspectives this analysis has been approached from two directions. Assessing the supply chains by application allows the identification of actors who could deliver a specific final product into a market, but does not easily allow the analysis of strengths and weaknesses *within* that chain. Assessing them by technology allows the identification of strengths and weaknesses in the chain but not of the importance or accessibility of a final market. The two approaches are shown below, using the example of transport applications (Figure 6) and PEMFC technology (Figure 7).

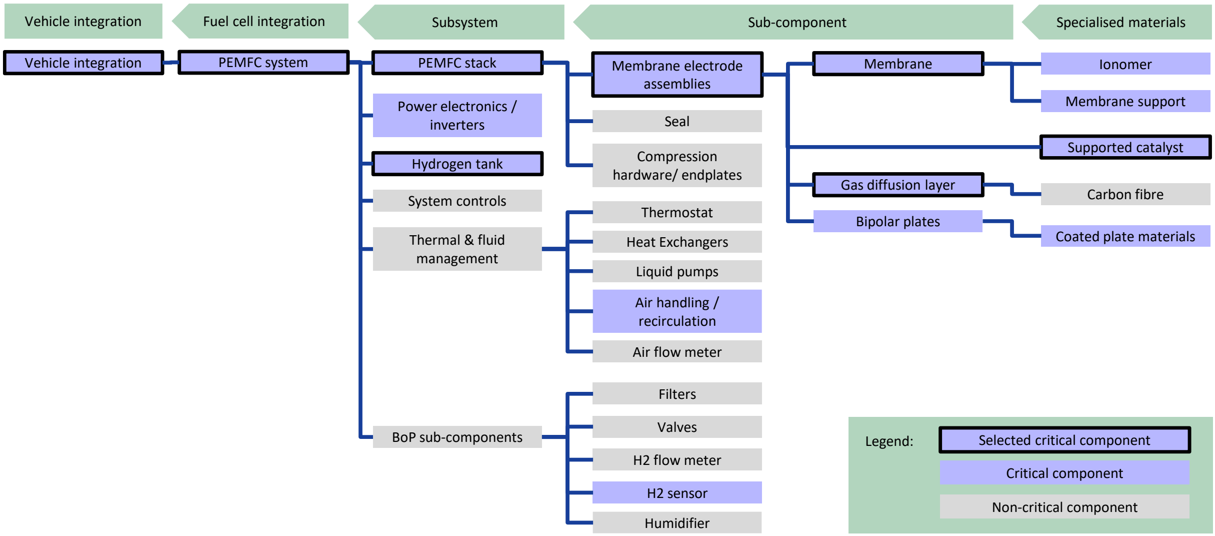

Figure 6: Fuel cells for transport supply chain structure

For each application supply chain a description was provided, outlining the relevant elements of the market or technology, and this was followed by a SWOT analysis examining the application and Europe's position within it, and then the external environment. An example of the former is strong European actors in FC bus integration, and latter is the strong competition of BEV in zero emissions buses generally. The former is an internal consideration regardless of the success of the application, while the latter affects the application but does not directly consider the internal strengths. A discussion of important gaps followed each SWOT, and included aspects such as areas of the supply chain with no European actors, or skills or funding shortages in specific areas.

The discussion of the supply chain by technology allows common components and their supply characteristics to be examined. The first characterisation focused on systems and integrators, where the second examined the component and materials level, laying out the critical components in the technology's supply chain and the actors associated with them. It is important to reiterate that only the **selected** critical components are assessed in depth, as a representation of the important issues and opportunities facing the industry.

The fuel cell and electrolyser technologies consist primarily of a stack and supporting subsystems, with a large overlap between some of the subsystems across the technologies. For example, power electronics and system controls are very similar across the different fuel cell technologies. While they vary by application and scale of the system, the chemistry is not the determining factor, unlike other balance of plant (BoP) components, which can vary widely with the chemistry of the fuel cell. Selection and sizing of components like filters and valves will depend on the operational characteristics of the technology, and operating temperature will have a considerable impact. Thermal management also differs between high temperature technologies, such as SOFC, and low temperature technologies, such as PEMFC and DMFC.

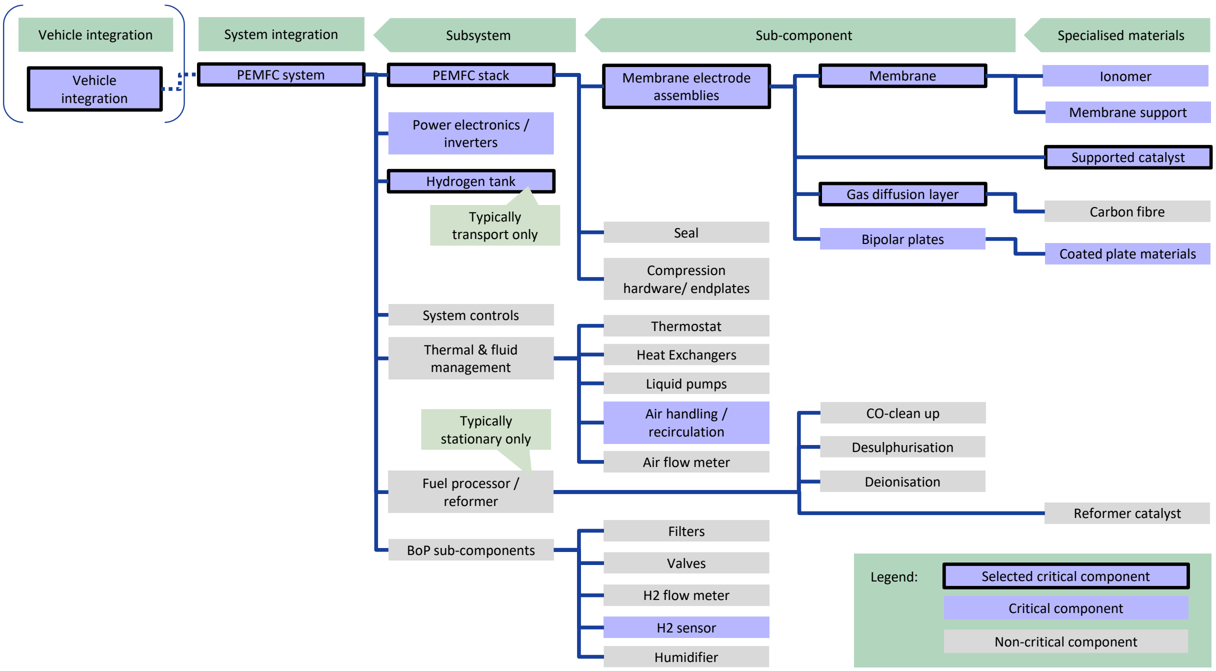

Figure 7: Generic PEMFC supply chain structure

7 Value chain analysis

7.1 Definition of value chains for targeted FCH applications

To define the value chains for FCH applications we make a conceptual distinction between the relatively narrow definitional scope of a supply chain, and the wider and deeper scope of the value chain definition. Essentially, in addition to the elements of the supply chain, the definitional scope of the value chain (as shown in Figure 8) includes:

- *Horizontal extensions*: post-production processes, such as distribution, after-sales (operations and maintenance support), end-of life / decommissioning (e.g. recovery, recycling, disposal);
- *Vertical extensions*: enablers, which can be sub-divided into:
    - Technology development processes: e.g. product/process technology development, production/manufacturing technology development and engineering;
    - Supporting business processes: e.g. logistics, finance, design, marketing and sales, customer services;
    - Other supporting processes: e.g. education and training, infrastructure development (e.g., fuelling stations in the case of transport applications) and policy making activities

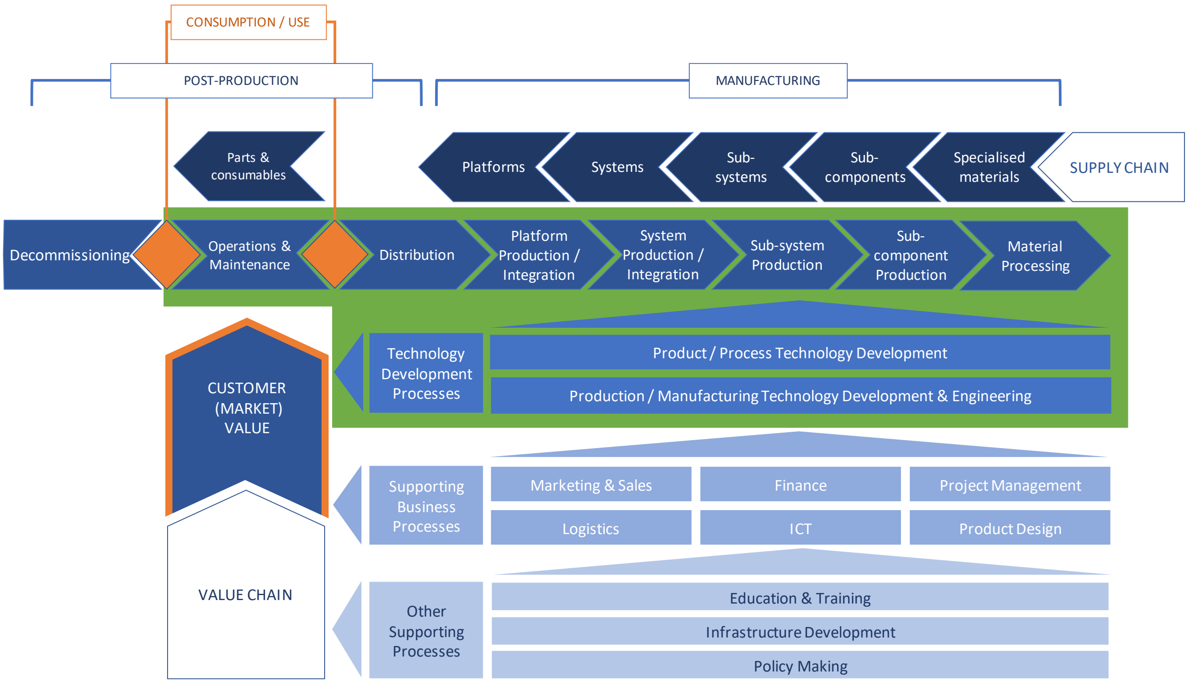

Figure 8: Stylised representation of a value chains

For the assessment of the potential for value creation, taking into account the availability of relevant data and information, we have employed both

- a narrow value chain definition, for which a quantitative assessment of the potential for value creation was undertaken, and
- a wide value chain definition, that includes additional elements for which qualitative assessments of value creation potential were made.

The narrow value chain definition encompasses value creation within the 'horizontal' supply chain (i.e., associated with, for example, materials processing, sub-component production, sub-system production, system production, platform production), together with distribution, and operations and maintenance activities. Also included in the narrow value chain definition are the 'vertical' elements associated with technology development processes; which covers both value creation potential arising from product-related and process-related technological development, as well as value creation potential arising through technological development related to production/manufacturing capabilities. The elements covered within the scope of the narrow value chain definition are shown within the green box in Figure 8.

In addition to the narrow value chain elements, the wide value chain definition encompasses the vertical element of 'supporting business processes' and 'other supporting processes'. It also covers 'horizontal' value creation arising from decommissioning.

For the purpose of assessing key competitiveness drivers, the EU's relative competitive position, and for the SWOT and gap analysis, our analysis was based on the wide value chain definition.

7.2 The shape of future supply chains

7.2.1 Supply chain definitions

To understand how FCH supply chains may evolve it is important firstly to establish a clear definition of a supply chain in the context of manufactured products. Although definitions vary slightly, **a supply chain is generally seen as the physical flow of raw materials and components from suppliers, through manufacturing, to finished goods delivered to customers**. Supply chain literature sometimes refers to webs rather than chains and to adjacent flows of data and money, but a physical flow definition is appropriate for this assessment. It is fully recognised that many other interactions occur.

Secondly it is important to define the perspective to be applied for examining future supply chains for manufactured goods. Manufactured products typically integrate a wide range of components and sub-assemblies, themselves made up of components and materials. Looking forwards along the chain, the customer of each supplier is the supplier of another, until the final consumer. For most fuel cell and hydrogen products the final consumer is a business, though not necessarily in the case of fuel cell cars and micro CHP. Given that fuels cells are not the end product and also that final distribution is not of primary interest for this study, the perspective applied here is of the product integrator[23] (also referred to as the assembler, product manufacturer, product builder or original equipment manufacturer (OEM) – according to industry custom). For integrators, fuel cells and hydrogen generally fall into the category of sourced components or specialised materials, at supply chain Tier 1 or 2, as illustrated in Figure 9.

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[23] By contrast and to illustrate, an analysis of fast-moving consumer goods would need to look more closely at the distribution step.

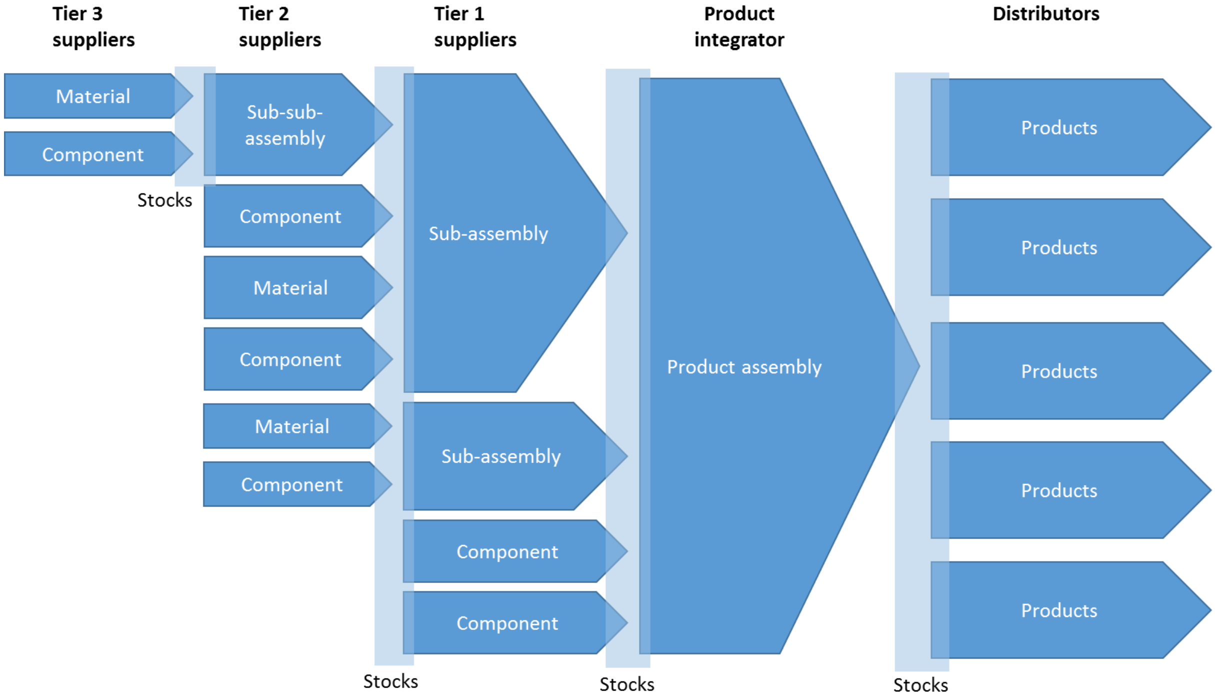

Figure 9: Illustrative supply chain for manufactured product showing physical flows

7.2.2 Manufactured product supply chain influences

In long-established industries powerful integrators developed over decades, and with them the capability to manufacture all but minor components. This vertical integration became commonplace in industries such as automotive and aerospace, but went into reverse from the 1980s as companies began to sell off non-core operations. Internal supply was replaced by procurement of components from tiered external suppliers (and services from outsourced providers), leaving integrators to focus on design, manufacture and brand-building. ‘Supply chain management’ emerged as a discipline, combining outward-facing planning, logistics, procurement and collaboration. Supply chain management continues to develop, supported by digital platforms providing easier collaboration and tighter connections than in the past.

Current FCH supply chains are immature. Several resemble the pre-supply chain management world, in which most components are made in-house (in small volumes). Sometimes FCH companies integrate their own final products to overcome lack of engagement by established manufacturers. This will change as markets grow, and many FCH supply chains will be reshaped. A central premise of the analysis is that the future supply chain shape for products featuring FCH will be determined by prevailing industrial logic and that FCH, though potentially different from incumbent technologies, will not fundamentally alter this logic. The term ‘shape’ is used here to describe several closely-related aspects of a supply chain from an integrator’s perspective, in particular:

- The market needs and structure that determine what integrators require of suppliers
- The power and influence that integrators and suppliers can exert upon each other
- The customs and culture of integrator collaboration with suppliers
- The physical location of suppliers relative to integrators.

Shape is not solely a description of location and product flow therefore, though these are physical manifestations of the underpinning relationships and approach.

The four overlapping aspects of supply chain shape are broken down into five separate influence categories, as shown in Figure 10.

End consumer requirements	Consumer expectations of cost, delivery time, customisation and product life cycle set overall demands that flow along supply chain via integrators
Buying power of integrators	An industry with a few dominant integrators is more likely to control supplier prices and influence specifications than numerous smaller integrators
Component criticality, IP & value	An integrator of a sub-assembly or final product will seek to secure supply of high value or critical components by vertical integration or partnership with suppliers
Need for collaboration in supply chain	Innovation or co-development of components between supply chain partners is more readily achieved when language and distance do not create a barrier
Logistical and technical contraints	Bulky or hard to transport components need to be supplied close to point of assembly

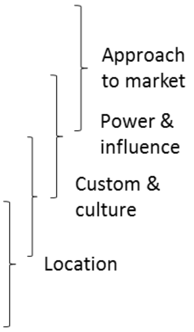

Figure 10: Influences upon manufactured product supply chain shape[24]

The first of these aspects (end consumer requirements) is supported by analysis by H D Perez[25] which identifies different overall supply chain styles appropriate to customer needs, summarised as:

Efficiency-oriented supply chains:

a. *Lowest cost*. Commodity products made continuously in high volumes on a forecast-matching basis to ensure high utilisation. Examples: cement, chemicals
b. *Continuous flow*. Standard products made in high volumes on a make-to-stock basis so orders can be met without delay. High plant utilisation important. Examples: bread, household appliances
c. *Fast renewal*. Rapid product changes in response to market shifts, requiring short production runs against forecast. Standard materials, forecast accuracy and low stock levels keep costs down. Example: catalogue fashion goods.

Responsiveness-oriented supply chains:

d. *Agile*. Unique product specification per customer and unpredictable demand, satisfied by applying a make-to-order approach. Some excess capacity and small batch sizes enable fast response. Example: packaging, (some) military hardware
e. *Custom-configured*. Products configured from a set of components into one of several set variants according to customer order. To avoid delays and reduce costs, a continuous flow supply chain of main inputs is combined with agile assembly and delivery. Example: laptop computers, fast food restaurants
f. *Flexible*. Unpredictable and urgently-required products bespoke manufactured to order. Fast turnaround is assured by maintaining spare capacity and adaptable resources; cost is a lesser consideration. Example: oil platform replacement parts.

Despite this variety, only a small number of the above styles are likely to apply in mature supply chains featuring the FCH systems considered in this study. These are discussed in the following section, along with other influences on future supply chain development.

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[24] Based upon work by E4tech and on H D Perez in www.supplychainquarterly.com/topics/Strategy/20130306-supply-chain-strategies-which-one-hits-the-mark/

[25] H D Perez in http://www.supplychainquarterly.com/topics/Strategy/20130306-supply-chain-strategies-which-one-hits-the-mark/

7.2.3 Implications for fuel cell and hydrogen supply chains

The influences discussed above will affect the supply chains for FCH products as they evolve from their current embryonic state towards (assumed) maturity and higher volumes. In this section the shape of example future supply chains is forecast based upon industrial logic, recognising that each chain has different characteristics. The combined implication of the influences for each example chain is summarised in Table 8.

Table 8: Potential supply chain shape for example future FCH-based products

Integrated product	Relevant FCH components	Descriptors of supply chain shape			
		Approach to market	Power & influence	Custom & culture	Location
Cars	Fuel cells, storage	Each OEM will offer range of FC powertrains, assembled into final product to match order	Strong OEMs will seek to own FC system design and assembly, and put cost pressure on component suppliers	Collaboration with e-chemistry suppliers may be needed, but more capable OEMs will build internal knowledge.	Regional if not local component supply to meet OEM demands
Buses	Fuel cells, storage	Bus builders will assemble FC 'engines' supplied as complete systems in low volumes, plus storage	Few bus builders able to exert strong price pressure, but will build close supply partnerships	FC development will be by FC system suppliers, also storage	FC and storage sourced globally, though some supplier regionalisation may occur to improve market access
Micro-CHP	Fuel cells	Continuous flow production to make standard products to stock	Large appliance makers may own stack supply, most will buy from close partners	Modular requirements may be used to diminish reliance upon a specific supplier	Regional or local stack supply preferred by large integrators
Larger CHP & primary power	Fuel cells	Low volume highly customised products	FC company may be final product integrator, or in partnership with a channel to market	FC company will require its suppliers to collaborate in product evolution	Product complexity and low volume make single assembly location per supplier most likely
Electrolysers	Electrolysers	Built to order products based on narrow range of product variants	Electrolyser company likely to be final product integrator	Electrolyser company will have key partners	Single assembly location per supplier likely

HRS	Compressors bulk storage	Built to order product configured from several options	The few HRS builders will work closely with suppliers of key components e.g. compressors	Co-development may not be needed, but local understanding of regulations helpful	Global supply possible, though hard for larger components (hydrogen storage)

Several overall observations emerge from this assessment:

- Most supply chains for finished products will evolve to a custom-configured style, with components and subassemblies supplied on a continuous flow basis and assembled and delivered on an agile basis (small CHP and very large power/CHP are possible exceptions).
- Powerful integrators control a large section of current ICE-based supply chains and are unwilling to allow value and control to leak from their domain. They will exert their power in a variety of ways (already evident in passenger car lithium-ion batteries), for example:
  - The most technically able vehicle integrators will develop in-house design and assembly of fuel cell systems, buying in components to a precise specification (which may be developed with expert support). This is equivalent to ICE design and manufacture. Hydrogen tanks could follow a similar route.
  - To prevent Tier 1 suppliers becoming too capable, critical components may be sourced on a 'make-to-print' basis rather than co-developed. This allows integrators to benefit from Tier 1 low cost manufacturing whilst controlling IP.
  - To avoid extended supply lines with high working capital value in transit and the risk of disruption, suppliers of critical components will co-locate with final assembly plants – in exchange for long term supply contracts.
  - Where an integrator of FCH systems has a complex product range requiring several FCH configurations, modular systems will be demanded of suppliers. This allows the integrator to easily reconfigure and allows them to compare several suppliers.
  - Partnering will be used by integrators to ensure ongoing access to future FCH technologies.
- Less powerful integrators will be in a weaker position to influence the specification, price and manufacturing location of FCH components. Examples include: buses, electrolysers, APUs, HRS and larger power/CHP – although exceptions may exist in all of these. Integrators will be keen to secure partnerships with relevant FCH suppliers in these supply chains.
- Integrators of APUs, electrolysers and large power/CHP sit close to the end of their supply chains, in some cases being the final product integrator. Their 'power' will depend upon market conditions, but supply chain management is as relevant to them as to other product integrators and they will need to secure supplies of critical inputs.
- The likely geographical location of FCH suppliers depends upon the power balance referred to above – those serving powerful integrators will be more likely to co-locate production with final assembly, though may keep R&D elsewhere. Supply volumes and ease of transportation also have a bearing upon location, but global supply from a single location could apply for integrators of some products such as APUs, electrolysers, HRS and large power/CHP. However, distributed supply may be chosen to satisfy market access considerations, especially where local content affects procurement; examples include buses and possibly HRS.

A graphical illustration (Figure 11) of the as-yet immature supply chain indicates one of the aspects under consideration[26]. In practice both of these options may exist simultaneously, for different sets of players.

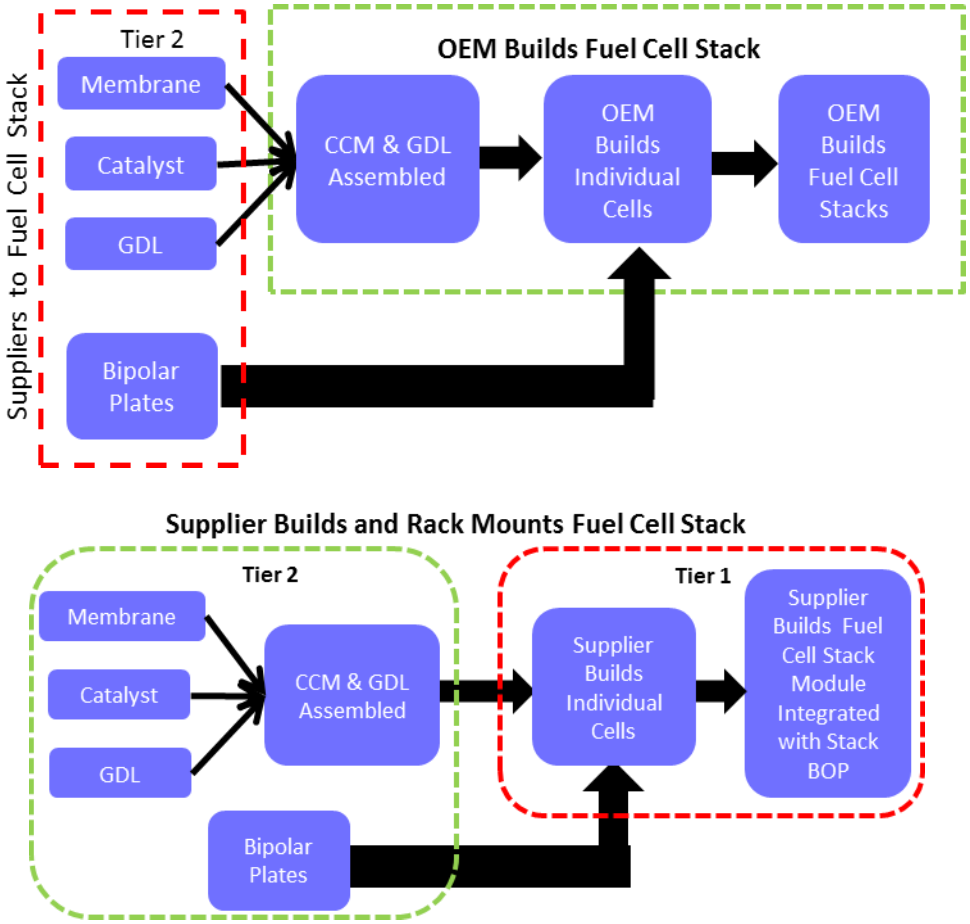

Figure 11: Two plausible options for future automotive FC supply chains[27]

In closing, it is important to note that this assessment of future supply chain shape assumes that FCH will reach maturity and will be adopted by integrators. In practice the ramp-up may not be smooth and intermediate supply chain states may apply. It will be important to identify the leading indicators that signal that a new stage is being reached and so the supply chain model should be adjusted.

7.3 Global and EU market scenarios to 2024 and 2030

7.3.1 Approach

Deployment scenarios have been developed for the global and EU markets for each application to 2024 and 2030. Three scenarios – for high, medium and low levels of deployment – in units and/or MW of capacity have been developed.

The scenarios reflect widely known scenarios and forecasts such as the IEA Energy Technology Perspectives, national existing FCH roadmaps, H2 mobility scenarios, scenarios from the Hydrogen Council and targets from national FCH funding programmes.

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[26] After DJ Wheeler Technologies

[27] After DJ Wheeler Technologies

The specific approaches used to develop the scenarios depended on what data was available for a given application. Broadly, one or more of the four following approaches was used:

- **Existing application-specific forecast:** Where an application-specific forecast or scenario exists this was used or adapted. This was relevant for the most established applications such as FC passenger cars for instance.
- **Conventional application forecast plus an FCH penetration rate:** Where an application-specific forecast does not exist, a forecast of the equivalent conventional (non-FCH) application was used as the basis for the analysis. Different FCH penetration rates were used for the different scenarios. This approach was relevant for some of the vehicle applications, for instance HGVs.
- **Current conventional market plus growth and FCH penetration rate:** Where a forecast of the equivalent conventional application does not exist, a forecast was developed based on a current market size and assumed compound annual growth rate (CAGR). Different FCH penetration rates were then used to estimate the FCH application deployment.
- **Derived from other scenarios and forecasts:** For certain applications, a deployment estimate was derived from the scenarios for related applications. For instance for hydrogen refuelling stations, there will necessarily be a relationship between the size of the deployed FC vehicle fleets and the number of refuelling stations.

The deployment scenarios are then used to derive estimated annual sales. This data has been combined with the cost data to estimate global market turnovers by application and to inform the value chain and socio-economic impact analysis.

7.3.2 Deployment scenarios by application

The global and European deployment scenarios for each application are summarized in Table 9 to Table 12 below. Deployments are presented in both number of units and capacity as appropriate. To avoid double counting, no separate deployment scenarios for compressed hydrogen storage or fuel reformers are provided as these components are part of the systems in the other applications.

The deployment scenarios are not intended to be forecasts but rather to capture a range of outcomes that could reasonably be expected if the various applications begin to be deployed commercially. It is possible that commercial deployment of some applications may not start at all due to external factors such as a regulatory barrier in a key market or a policy driver that favours other solutions for that application.

Table 9: Global deployment scenarios in number of units

Application	Comments	Units	2024			2030		
			L	M	H	L	M	H
FCEV	Passenger cars and light commercial vehicles (LCV)	millions	0.33	0.90	1.8	1.6	5.5	10
FC Buses		thousands	16	24	35	61	120	190
HGV		thousands	3.0	3.8	10	20	37	80
FC Forklifts		thousands	48	67	93	85	140	230
Trains and light rail		units	87	190	490	420	1,200	2,400
Maritime and inland boats		units	16	38	110	75	240	520
HRS		thousands	0.76	1.9	3.9	3.5	11	20
Micro CHP	1-5 kW$_e$	millions	0.75	1.4	1.7	2.3	4.8	7.0
Commercial CHP	5-100 kW$_e$	thousands	4.7	7.3	26	31	72	200
Large CHP	> 100 kW$_e$	thousands	7.3	14	27	17	45	97
Back-up power and gensets		thousands	42	60	75	85	150	230
Electrolysers	Not applicable as stack sizes vary significantly							

Table 10: Global capacity deployment scenarios in watts

Application	Comments	Units	2024			2030		
			L	M	H	L	M	H
FCEV	Passenger cars and light commercial vehicles (LCV)	GW	34	84	170	170	560	1,000
FC Buses		GW	2.0	3.0	4.5	8.0	16	26
HGV		GW	0.60	0.75	2.1	3.9	7.5	16
FC Forklifts		MW	240	340	470	420	710	1,100
Trains and light rail		MW	26	58	150	130	360	710
Maritime and inland boats		MW	9.4	23	65	45	140	310
HRS	Not applicable							
Micro CHP	1-5 kW	GW	0.8	1.5	1.8	3.0	5.7	10
Commercial CHP	5-100 kW	GW	0.5	0.7	2.6	3.1	7.2	20
Large CHP	> 100 kW	GW	7.3	14	27	17	45	97
Back-up power and gensets		MW	70	140	150	190	400	570
Electrolysers		GW	1.6	3.2	4.5	5.6	12	21

Table 11: European deployment scenarios in number of units

Application	Comments	Units	2024			2030		
			L	M	H	L	M	H
FCEV	Passenger cars and light commercial vehicles (LCV)	millions	0.060	0.20	0.48	0.3	1.2	2.6
FC Buses		thousands	1.0	1.7	3.0	3.6	8.4	16
HGV		thousands	0.44	0.66	2.20	2.90	6.5	17
FC Forklifts		thousands	0.96	2.0	4.7	1.7	4.3	11
Trains and light rail		units	23	61	180	110	390	870
Maritime and inland boats		units	2	4	11	8	24	52
HRS		units	130	400	990	600	2,300	5,000
Micro CHP	1-5 kW_e	millions	0.05	0.12	0.18	0.16	0.43	0.77
Commercial CHP	5-100 kW_e	thousands	0.27	0.75	3.5	1.8	7.5	27
Large CHP	> 100 kW_e	thousands	0.07	0.65	2.2	0.29	4.0	10
Back-up power and gensets		thousands	1.3	3.0	5.2	2.5	7.6	16
Electrolysers	Not applicable as stack sizes vary significantly							

Table 12: European capacity deployment scenarios in watts

Application	Comments	Units	2024			2030		
			L	M	H	L	M	H
FCEV	Passenger cars and light commercial vehicles (LCV)	GW	6.2	19	45	31	120	270
FC Buses		GW	0.12	0.21	0.38	0.47	1.1	2.2
HGV		GW	0.09	0.13	0.43	0.57	1.3	3.3
FC Forklifts		MW	4.8	6.7	9.3	8.5	14	23
Trains and light rail		MW	7.0	18	54	34	120	260
Maritime and inland boats		MW	1.2	2.4	6.6	4.8	14	31
HRS	Not applicable							
Micro CHP	1-5 kW	GW	0.06	0.13	0.20	0.21	0.51	1.0
Commercial CHP	5-100 kW	GW	0.03	0.08	0.35	0.18	0.75	2.7
Large CHP	> 100 kW	GW	0.070	0.65	2.2	0.29	4.0	10
Back-up power and gensets		MW	2.1	6.9	10	5.8	20	40
Electrolysers		GW	0.52	0.81	0.91	1.8	3.0	4.3

7.3.3 Turnover of the global market

Based on the global deployment scenarios given above and the cost breakdown data presented in the Evidence Report, an estimate of the range of global turnover associated with each application is given in Table 13 below. Note that for the transport applications the turnover estimate is based on the cost of just the fuel cell and hydrogen components – i.e., the cost of the rest of the vehicle is not included.

More detailed assessments of the economic value of selected applications in Europe is given in the value chain analysis in Sections 7.4 and 7.6.

Table 13: Global turnover estimate

Application	Comments	2024 € millions	2030 € millions
FCEV	Passenger cars and light commercial vehicles (LCV)	1,000-5,100	1,900-9,800
FC Buses		240-520	390-1,400
HGV		66-220	170-580
FC Forklifts		19-52	19-64
Trains and light rail		5-29	11-50
Maritime and inland boats		4-24	7-37
HRS		1,300-6,400	3,500-18,000
Micro CHP	1-5 kW	390-1,300	1,100-3,600
Commercial CHP	5-100 kW	290-1,700	910-5,400
Large CHP	> 100 kW	1,500-9,100	2,500-16,000
Back-up power and gensets		36-82	37-140
Electrolysers		230-740	450-2,000
Total		5,200-25,000	11,000-57,000

7.4 Value analysis

7.4.1 Estimation of value-added creation potential within FCH supply chains

This sub-section presents an assessment of the value creation potential of supply chains for FCH applications. The assessment uses estimates of the cost breakdown for FCH systems (provided in the Evidence Report), consistent with the global and EU market deployment scenarios – for high, medium and low levels of deployment – which are translated into annual production volumes for 2024 and 2030.

The assessment of the value creation potential of production activities within the supply chain uses an economic value-added approach, where (gross) value-added equates to the sum of compensation of labour, return on capital (i.e. annualised capital expenditures, capex) and a margin (i.e. gross profits) as shown in Figure 12.

In practice value-added is the difference between the price of a manufactured part and the price of the materials and components used to manufacture it, and is typically a small fraction of the overall price of the part (Figure 12). Equivalently, value-added is the difference between the value of production outputs (i.e. sales revenue or turnover) and the cost of intermediate production inputs, including overhead costs.

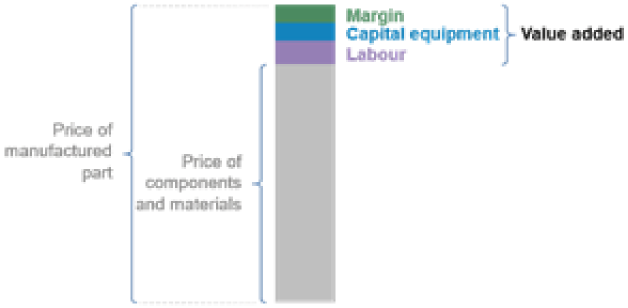


Figure 12: Definition of value-added

The estimates provided in this sub-section are indicative only. Their purpose is to support the assessment of the relative value creation potential across selected FCH applications at the FC system level, and from the production of different components and sub-systems, including assembly and integration activities. The estimates are based on assumed 'typical' production structures and cost estimates, and assumptions on cost development occurring over time and for different production scales. The estimates are used to categorise the value creation potential of production activities within the supply chain and should not be interpreted as estimates of actual future value-added potential. All monetary values are expressed in current (2017) prices.

7.4.1.1 Approach to the calculation of supply chain cost estimates

For each critical component, a learning rate curve was developed. Where detailed, bottoms-up cost studies were available, the reported data were fit to a learning rate for each critical component. Figure 13 shows an illustrative example of a curve fit to several data sources for a PEM membrane electrode assembly. Learning rate cost curves for individual sub-components—catalyst, membrane, and gas diffusion layer, for example—were similarly developed. It was possible to directly fit available cost data for the majority of the applications and critical components; however, it was necessary to assume a cost correlation for applications for which only survey-based system costs were available.

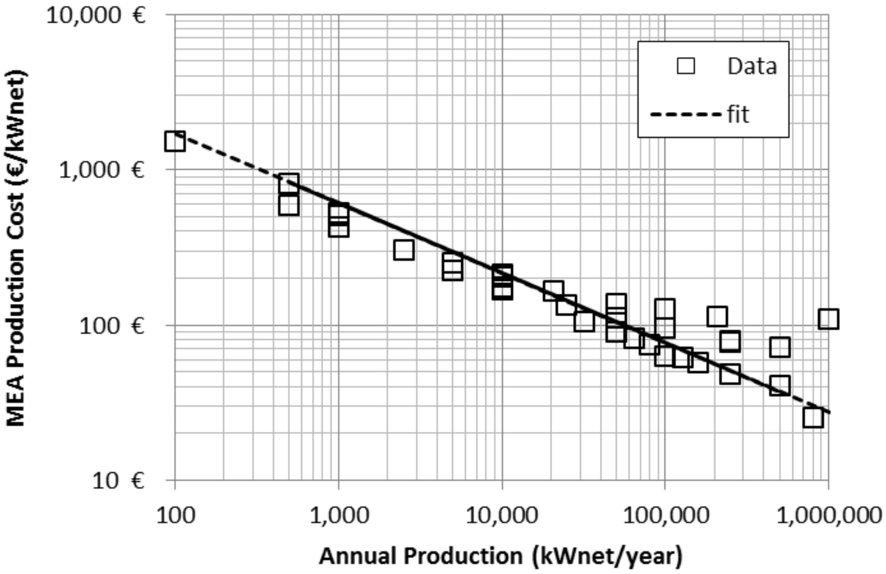


Figure 13: Illustrative example of fitting cost analysis data from multiple sources

The cost curves were expressed in terms of unit annual production (e.g. kW/year, kgH_2/year, etc.), which allowed deployment specific component costs across multiple unit sizes to be predicted. The leading producer annual production is set at 60% of annual deployments, which is used in the value-added calculations. Due to their modular nature, annual production of fuel cell stacks for bus, HGV, and train applications are assumed to come from a single supplier. This assumption effectively decreases the cost by sharing manufacture for multiple applications. By contrast, deployments of some applications such as electrolysers and commercial CHP systems represent aggregate deployments for all chemistries, thus it was necessary to disaggregate them.

Material, labour, and capex splits for each component were derived from the cost studies based on their contributions at full production plant utilization to prevent spurious high capex contributions due to oversized manufacturing equipment.

The distinction between cost and price depends on the perspective within the value chain. Cost, throughout this analysis refers to a supplier's cost, whereas price refers to the estimated 'factory-gate' price (or cost) for the end-user. Following on the example of an MEA, the sub-component cost breakdowns for catalyst, GDL, and membrane to the MEA manufacturer include a mark-up for each respective supplier. Similarly, the MEA material cost to the fuel cell integrator includes a mark-up the MEA manufacturer applies. Mark-up rate assumptions are described below.

7.4.1.2 Approach to the calculation of supply chain value-added

The estimation of (gross) value-added potential is composed of three components:

- **Labour:** taken directly from the calculation of cost estimates;
- **Capital:** taken directly from the calculation of cost estimates;
- **Margin (or profit):** The estimation of the margin is based on two elements:
  - **Standard ('normal') margin.** The standard margin (profit rate) is set at 5% of the total cost of production inputs (labour + capex + materials and other intermediate production inputs), excluding overhead costs. The standard profit rate is applied to all production steps (i.e. production of components and sub-systems, and integration and assembly activities).

- **Excess ('supra-normal') margin.** The excess margin (profit rate) is based on an evaluation of the supply characteristics of each production step. It is intended to 'proxy' the additional margin that may arise as a result of some form of market dominance of firms active within the production step resulting from market (supply) entry barriers. Such barriers may include *inter alia* intellectual property (e.g. patents, proprietary technology, know-how, etc.), investment costs (e.g. costs of R&D or production capital), presence of scale economies for incumbent suppliers, etc. Three values for the excess margin are used in the value-added estimations: zero (0%, only standard margin applies), medium (5%), high (10%). In contrast to the standard margin, it is assumed that excess margins are not charged on the cost of materials and other intermediate production inputs but only on labour and capital costs (capex) (Table 14 to Table 16).

It should be noted that if a standard margin is assumed for all production inputs within a system, and corresponding integration and assembly activities, the estimated market revenues correspond directly with the baseline revenue estimates for the global and EU market deployment scenarios. Where an excess margin is applied to one or more elements of the supply chain, it will result in higher revenue estimates than those of the baseline market deployment scenarios.

Table 14: Assumed excess margin by application and production step – PEM fuel cells

Activity/Component	PEMFC				
	FCEV	Buses, HGVs, Trains	Micro - CHP	CHP	Electrolyser
System integration	High	High	High	High	High
Tank	High	High	N/A	N/A	N/A
Balance of plant	Medium	Medium	Medium	High	Medium
Stack integration	High	High	Medium	Medium	High
Balance of stack	Medium	Medium	Medium	Medium	Medium
Bipolar plates	Medium	Medium	High	High	High
MEA	High	High	Medium	Medium	Medium
Membrane	High	High	High	High	High
Catalyst	Zero	Zero	High	High	High
GDL/Porous layer	High	High	High	High	Medium

Table 15: Assumed excess margin by application and production step – Solid oxide fuel cells

Activity/Component	SOFC		
	Micro-CHP	CHP	Electrolyser
System integration	High	High	High
Balance of plant	Medium	Medium	Medium
Stack integration	High	High	High
Balance of stack	Medium	Medium	Medium
Interconnectors	Zero	Zero	Medium
Porous layers	Zero	Zero	Medium
Seals	Zero	Zero	Medium
Cells	Medium	Medium	High

Table 16: Assumed excess margin by production step – Hydrogen refuelling stations

Activity/Component	Hydrogen refuelling station
Station integration	Medium
Balance of station	Medium
Compression	Medium
Dispensers	High

7.4.2 Overview of supply chain value-added estimates

Value is added at each stage of the manufacturing process. For later manufacturing stages, value-added from earlier stages becomes part of the price of materials (Figure 14). By tracking the value added for key components as well as for the system, the study is able to provide insight into which parts of the supply chain have the potential to create the biggest economic benefits.

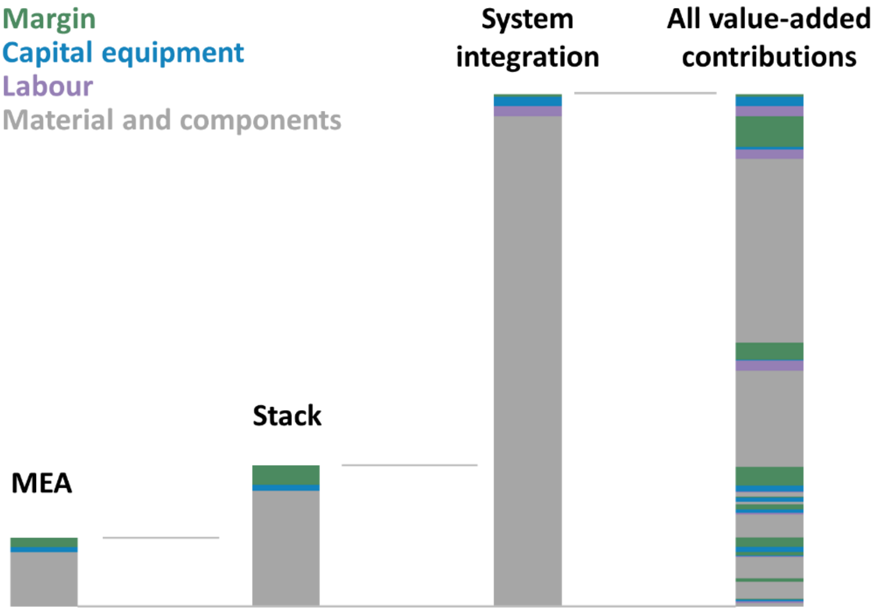


Figure 14: Build-up of value-added through the supply chain illustrating that value-added is typically a small fraction of turnover

The different elements of value-added yield economic benefits in different ways:

Labour

- Value is captured as local employment
- Manufacturing plants located in the EU yield EU value
- Home country of business entity is not critical

Capital

- Value is captured by suppliers of capital equipment
- Requires EU capital equipment suppliers to yield EU value

Margin

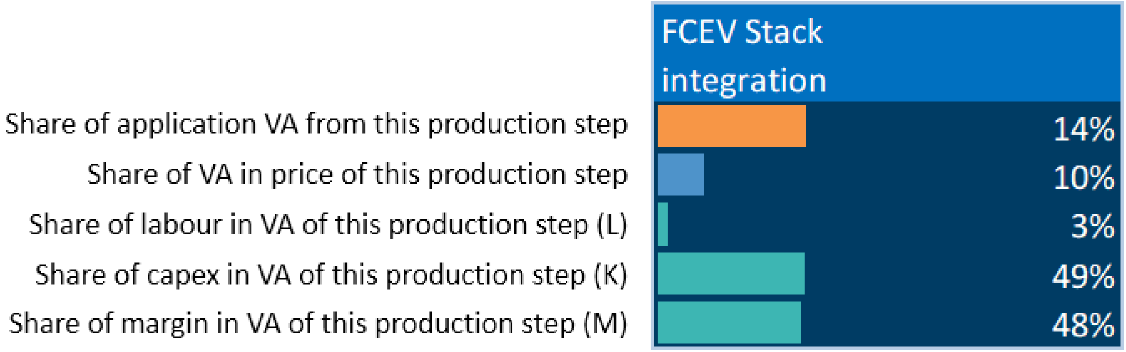
- Captured as revenues of business entity
- Requires EU business entity to yield EU value

The sections below present the estimated breakdown of value-added generated in the supply chain of fuel cell systems for each of the selected applications. The box below gives a short description of the interpretation of the value-added indicators shown in the figures for each application.

Interpretation of value-added decomposition figures

For each element (stage) in the supply chain:

- **Row 1** (orange bar) shows the share of the production stage in total value-added created in the FCH system supply chain. The higher the value shown for a production stage, the greater is its share of total value-added generated within the supply chain for the FCH system.
- **Row 2** (blue bar) shows the intensity of value-added creation of the production stage, measured as the ratio of value-added (labour, capital consumption, and margin) to the sum of value-added plus overheads and the cost of added materials, where added materials includes the costs of components and sub-systems for which costs are attributed elsewhere in the overall supply chain calculations. A high value indicates that this production step generates a lot of value-added compared to the costs of performing that step.
- **Rows 3 to 5** (turquoise bars) show the composition of value-added of the production stage in terms of the share of its labour (L), capital cost (K) and margin (M) components.



The analysis for the FCEV application is given as an example below with the details for all the applications given in Appendix A.

7.4.2.1 Estimated value creation potential for FC systems for passenger cars and light commercial vehicles

Figure 15, Figure 16, and Table 17 show the estimates of the breakdown of value-added for FC systems for passenger cars and light commercial vehicles, under the low and high market scenarios for 2030; corresponding to annual production volumes of 300 thousand and 1.8 million vehicles, respectively. A comparison of the breakdown of value-added creation for all three deployment scenarios for the years 2024 and 2030 is given in Table 27.

The pattern of value-added estimates indicates that at low levels of production, membrane electrode assembly (MEA) activities capture the greatest share of total value-added generated in the supply chain of fuel cell systems for cars and light trucks – 27% of value-added in the low scenario for 2030 – but their share declines substantially as production levels are scaled-up; the share of MEA falls to 8 percent by 2030 under the high deployment scenario. Conversely, the share of value-added captured by system integration increases at higher production levels, as is also the case for hydrogen tanks. These findings reflect differences in the underlying assumptions for opportunities for overall cost (output price) reductions at higher volumes of production, which are assumed greater for MEAs than for system integration and tanks. In terms of value capture across downstream and upstream manufacturing, the estimations clearly show that more value is captured downstream (at the system and subsystem level). This holds for both low and high market deployment scenarios. Notably, a large part of overall value creation potential is embedded in integration and assembly activities.

The highest intensity of value-added creation, at around 60 percent, is in the production of balance of stack items, which covers components such as seals and compression hardware. However, as is also the case for the balance of plant at the system integration stage, this reflects an average estimate across a variety of components for which separate cost estimates have not been made. Gas diffusion layer (GDL) production has the second highest share of value-added in both high and low scenarios, at slightly less than 50 percent. However, despite this high share, the value-added captured at the GDL stage remains low at only 5 percent of total value-added generated in the FCEV supply chain in the low scenario, which decreases as production levels increase.

In terms of the breakdown of value-added by ‘production factor’ category, under all deployment scenarios the highest overall share is attributed to the annualised cost of capital (capex), which is estimated to account for about half of value-added generated in the low scenario for 2024 and a third of value-added in the high scenario for 2030. Both the share of labour costs and the share of margins in total value-added are shown to rise with increases in the volume of production, with the share of labour costs increasing slightly more rapidly than the share of margins. At the level of individual components and integration/assembly activities, the share of labour costs in total value-added is estimated to be relatively high for balance of plant (for system integration), tanks, gas diffusion layer (GDL), and system integration. The share of capital costs in value-added is highest for balance of stack, membrane electrode assembly, and bipolar plates.

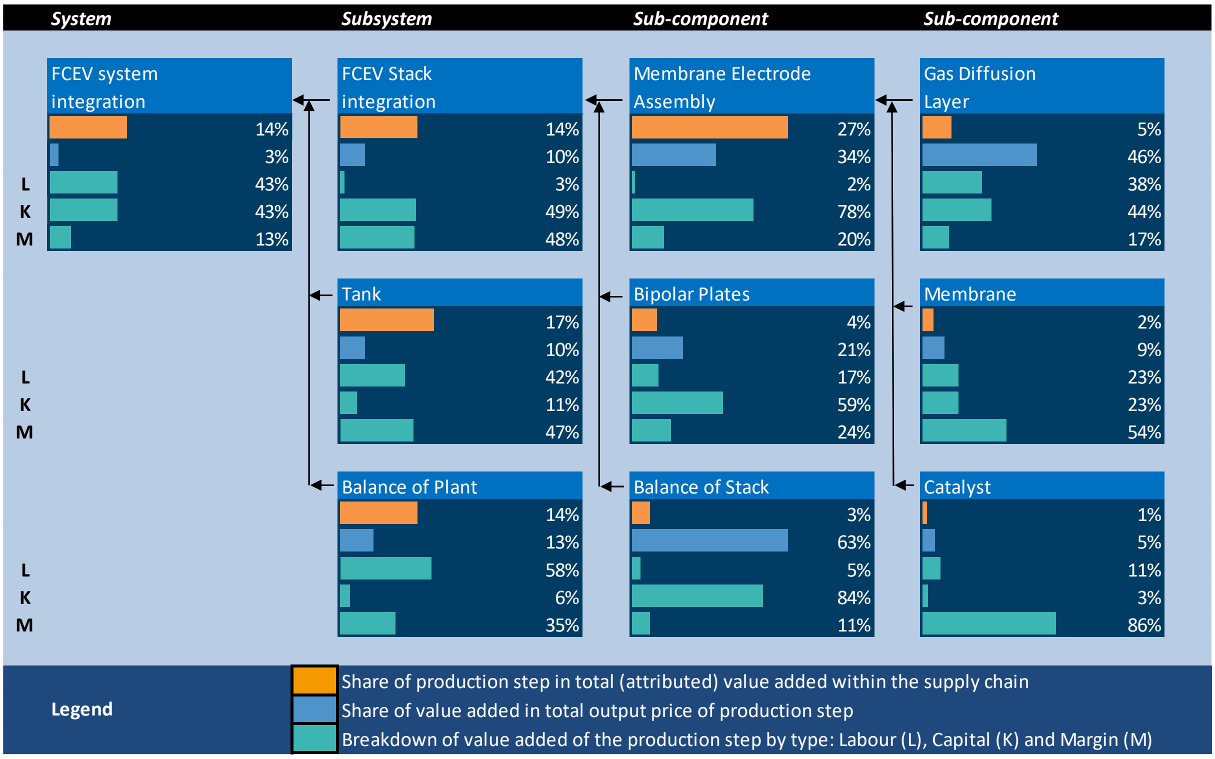


Figure 15: Value-added decomposition for FC system for cars and light commercial vehicles, low market deployment scenario, 2030

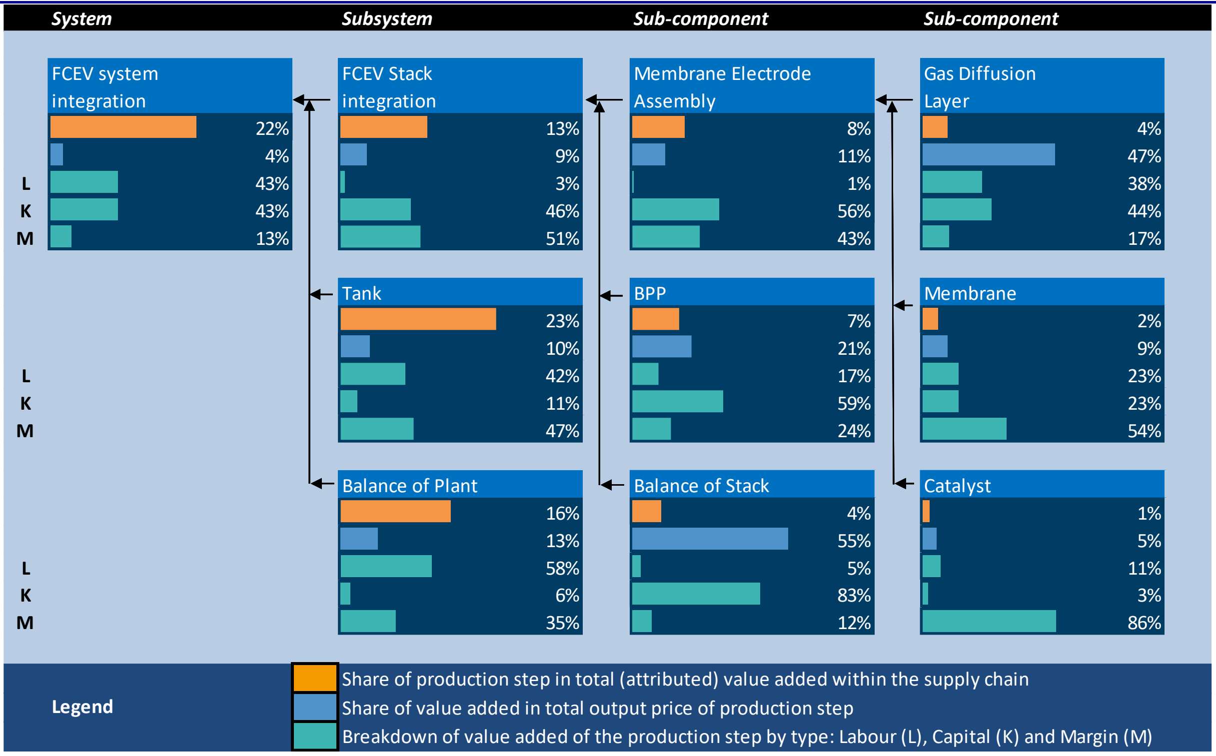


Figure 16: Value-added decomposition for FC system for cars and light commercial vehicles, high market deployment scenario, 2030

Table 17: Value-added decomposition for FC system for cars and light commercial vehicles by market deployment scenario, 2024 and 2030

Year	**2024**			**2030**		
Deployment scenario	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Total annual production (Thousand units)	95	352	645	304	1,062	1,796
Annual production rate of leading manufacturer (Thousand units)	57	211	387	182	637	1,077
System cost (Output price)	€ 10,800	€ 7,800	€ 6,800	€ 8,100	€ 6,100	€ 5,400
Total VA within system	€ 2,900	€ 1,800	€ 1,500	€ 1,900	€ 1,300	€ 1,100
Application VA as a share of total costs (VA / output price)	27%	23%	22%	23%	21%	20%
Rate of VA (VA / material & overhead costs)	37%	30%	28%	31%	27%	26%
Breakdown of VA by component or activity						
Total VA in system (excl. MEA and Stack)	**35%**	**45%**	**51%**	**44%**	**55%**	**61%**
FCEV system integration	10%	14%	17%	14%	19%	22%
Tank	13%	17%	19%	17%	21%	23%
Balance of Plant	12%	14%	15%	14%	16%	16%
Total VA in stack (excl. MEA)	**19%**	**21%**	**21%**	**21%**	**23%**	**24%**
FCEV Stack integration	14%	13%	13%	14%	13%	13%
Bipolar Plate	3%	5%	5%	4%	6%	7%
Balance of Stack	2%	3%	3%	3%	4%	4%
Total VA in MEA	**46%**	**34%**	**28%**	**35%**	**22%**	**15%**
ME Assembly	38%	26%	20%	27%	14%	8%
Gas Diffusion Layer	6%	5%	5%	5%	4%	4%
Membrane	2%	2%	2%	2%	2%	2%
Catalyst	0%	1%	1%	1%	1%	1%
Breakdown of total VA by cost category						
Labour cost	21%	26%	28%	25%	30%	33%
Capex cost	50%	43%	40%	45%	37%	33%
Margin	28%	31%	32%	30%	33%	34%
Total	100%	100%	100%	100%	100%	100%
Notes: numbers may not add up due to rounding of data						

7.5 Industry scenarios

Industry scenarios were developed for eight down-selected applications. The industry scenarios lay out possible futures of the European FCH value chain, exploring what could happen in the future and what the implications of these possible futures might be. The scenarios are not intended to be 'normative' in the sense that they do not set out an ideal or expected outcome. Rather they serve as a framework for assessing the socio-economic impacts of possible futures with more or less developed European FCH value chains. This assessment can then provide insight into the conditions that may be necessary to maximize the European socio-economic benefits of the FCH value chain.

Two key parameters are varied in the scenarios: 1) the extent of deployment of FCH technologies, and 2) the share of FCH production that is captured by EU actors. The three scenarios are shown graphically in Figure 17.

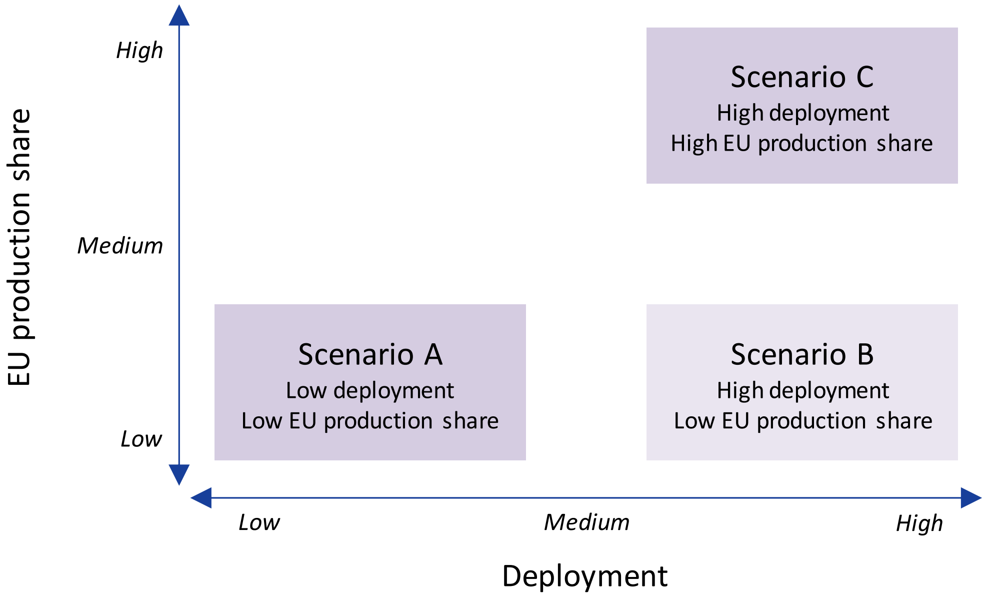


Figure 17: Industry scenario summary

In Scenario A, global and EU deployment of FCH technologies is assumed to be low while for Scenarios B and C, that deployment is assumed to be high. In Scenarios A and B EU actors capture a low production share of the global FCH market, primarily as specialty producers of subsystems and components. Whereas in Scenario C, EU actors capture a higher share of production including capturing a more significant role in system integration for some applications.

A more detailed description of how Scenarios A and C might manifest is given in the subsections below for each of the applications for which detailed value analysis was conducted. These scenario descriptions were validated in a workshop with industry and EC experts and the scenarios have been adapted to reflect the feedback received from the experts.

The industry scenarios were then used to evaluate the potential European socio-economic impacts of each application. The results of this assessment are presented in Section 7.6.

7.5.1 Approach to describing the scenarios

For each application and scenario a snapshot of what the application-specific industry might look like in the 2020s and by 2030 is captured. This snapshot shows the location of system assembly focussing on the three key global regions of Europe, North America and Asia (primarily China, Japan and S. Korea). The snapshot also indicates what trade flows – in components, systems or both – would be expected at that time, in that scenario, for that specific application. The snapshots are accompanied by a bullet point description of key aspects and drivers of the industry for that application in that scenario in that timeframe. The snapshots focus on illustrating the situation of the relevant European industry so some flows, e.g., to N. America may have been omitted for clarity.

An example snapshot diagram along with a key is shown in Figure 18. This example shows system assembly occurring in Asia (Japan) with flows of components from Europe and N. America to Asia and a flow of systems from Asia to Europe. The industry scenarios for the FCEV application are shown as an example in Section 7.5.2 below and all the scenarios are in Appendix B.

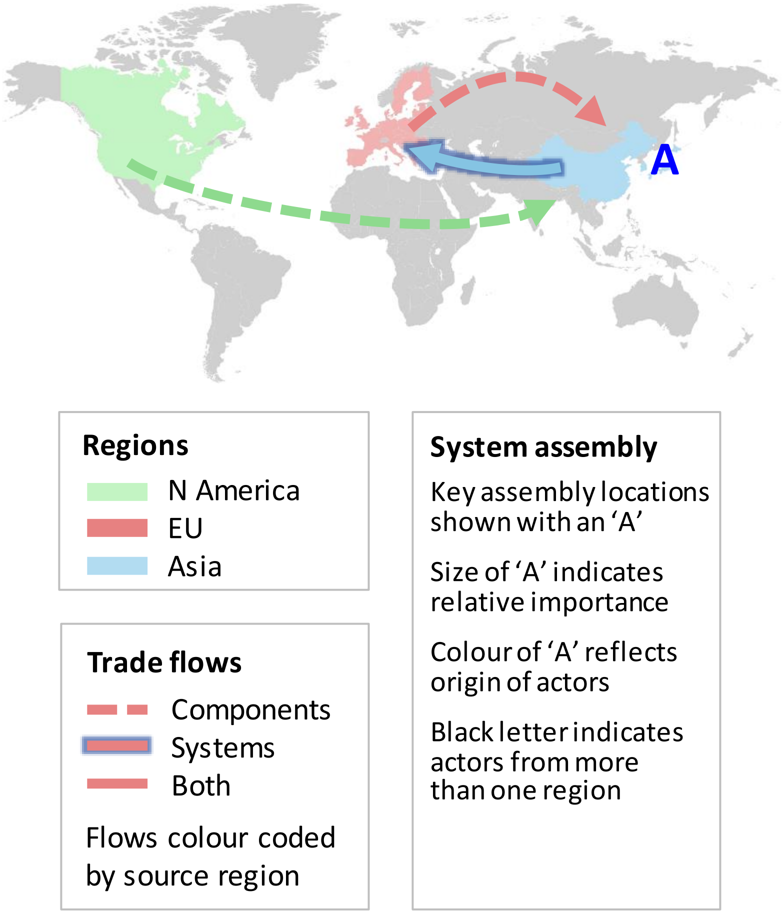


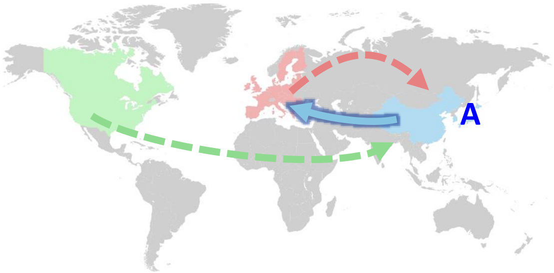
Figure 18: Example industry scenario snapshot diagram with key

7.5.2 FCEV industry scenarios

- Automotive OEMs are global actors and rely on a highly optimized global supply chain in which Tier 1 suppliers play a key role
- OEM production processes accommodate both low volume (1,000s to 10,000s per year) and mass market (100,000s per year) models

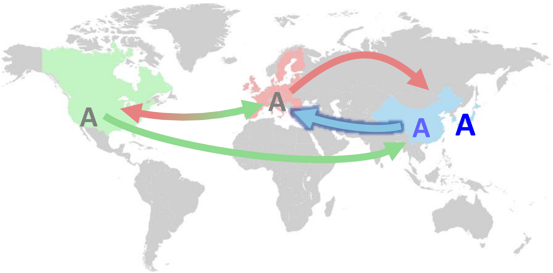
- OEMs ship vehicles internationally as well as putting in place local assembly capacity in other regions
- For higher volume lines, suppliers will put in place local production capacity to support the assembly plant

Scenario A: 2020s



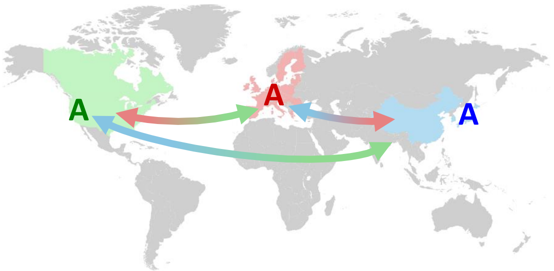
- Asian OEMs dominate
- Initial supply chain is global using available suppliers
- Some EU actors export components to Asian OEMs
- Vehicles are imported from Asian OEMs

Scenario A: By 2030



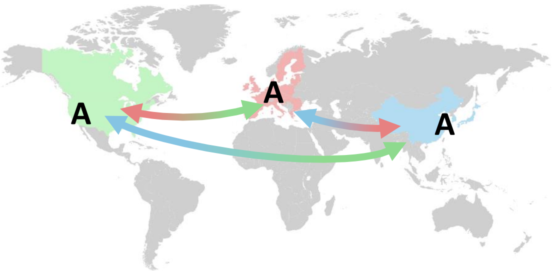
- Asian OEMs are starting to build manufacturing capacity in other regions
- EU and NA OEMs are still in early stages of developing capacity
- Regional supply chains in EU and N America are being put in place
- EU actors supply components primarily to local production but also to other regions

Scenario C: 2020s



- EU, Asian and NA OEMs all play a role
- Initial supply chain is global using available suppliers
- EU actors export and import components
- Vehicles are imported and exported

Scenario C: By 2030



- Supply chain is starting to consolidate around Tier 1s rather than pure FC players
- Proportion of locally produced content increases
- Component suppliers (EU and global) build manufacturing capacity close to vehicle assembly
- EU actors export and import components
- Higher volume models are trending towards local assembly by global OEMs with locally produced parts from global suppliers

7.6 Socio-economic impacts

This section provides an overview of socio-economic impacts that can be expected to be related to the European industry performance as sketched out in the two scenarios A and C as described in Section 7.5

above. The analysis takes as a starting point the global and European market scenarios as presented in Section 7.3 and is based on the assumptions already described in Section 7.4. The main socio-economic impacts of the key applications are highlighted below. The value-added and socio-economic impact figures reported in this section relate to FCH manufacturing and its immediate ecosystem of suppliers. The impact estimates take into consideration the following elements (see Section 7.1 on Value chain definition):

- **Direct jobs**: The labour contributions to value-added at each level of the supply chain covered by the cost breakdown were translated into an estimate of direct jobs associated with those manufacturing activities. The supply chain covered by the cost breakdowns only extends upstream as far as components and processed materials and does not cover the extraction of raw materials.
- **Indirect jobs**: The cost breakdown of each component includes the cost of materials added in that production step. As the supply of these materials is separate from the upstream components explicitly listed in the cost breakdowns, the jobs created in the supply of these materials are estimated as 'indirect' jobs. For the transport applications considered, this included jobs in the supply of the non-FCH elements of the application, namely the rest of the vehicle. Although these jobs are listed as 'indirect', they are still manufacturing jobs that are needed to supply components and materials that go into the FCH applications. **This is different and much narrower than the typical usage of an indirect employment multiplier to capture broad vertical and horizontal extensions to the value chain** (e.g., demand for services generated by manufacturing employees). The numbers in this category will therefore be smaller than for studies with a broad indirect employment definition.
- **Maintenance**: Jobs in maintaining the deployed FCH units are captured separately. This is the only down-stream extension included in the analysis.

It is important to note that the socio-economic impact assessment is focused on manufacturing and does not include other extensions such as:

- 'Horizontal' extensions, e.g. the provision of hydrogen for transport applications, the revenues generated by operating the FCH equipment, or the provision of other services related to the FCH applications.
- 'Vertical' extensions, e.g. other supporting business functions: administration, logistics, finance, marketing and sales etc. that are often captured in indirect employment estimates.

The included scope is shown graphically in Figure 19 below. Figure 20 shows how employment in manufacturing in the supply chain is classified as direct and indirect.

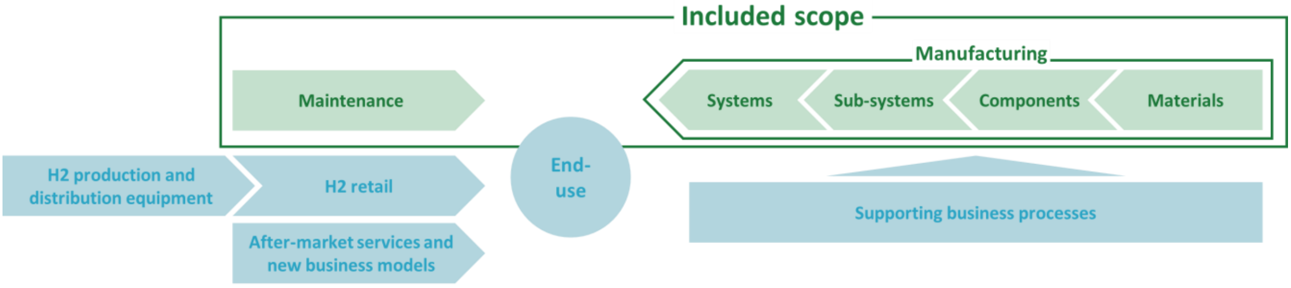


Figure 19: Value chain schematic showing scope included in socio-economic impact assessment

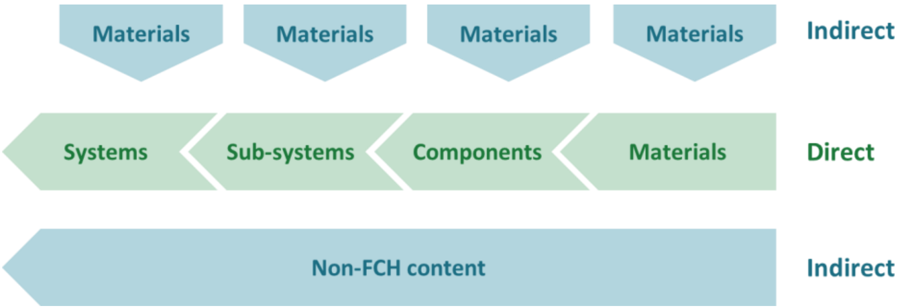


Figure 20: Classification of direct and indirect employment in FCH manufacturing in the analysis

7.6.1 FCEVs

Table 18: Key socio-economic figures for FCEVs by industry scenario (2024 and 2030)

Year	**2024**			**2030**		
	Scenario A	**Scenario B**	**Scenario C**	**Scenario A**	**Scenario B**	**Scenario C**
Global Market						
System unit cost	€ 10,800	€ 6,800	€ 6,800	€ 8,100	€ 5,400	€ 5,400
Global annual deployment	100,000	650,000	650,000	300,000	1,800,000	1,800,000
Global system production value (million)	€ 1,000	€ 4,400	€ 4,400	€ 2,500	€ 9,800	€ 9,800
Global system O&M value (million)	€ 70	€ 250	€ 250	€ 260	€ 1,090	€ 1,090
European market and production						
European annual deployment (units)	20,000	170,000	170,000	60,000	470,000	470,000
European production value (million)	€ 100	€ 600	€ 1,400	€ 300	€ 1,800	€ 3,100
European O&M value (million)	€ 10	€ 70	€ 70	€ 50	€ 290	€ 290
Macro-economic impact						
Value added - Total (million)	€ 30	€ 170	€ 400	€ 80	€ 450	€ 760
Value added - Labour (million)	€ 10	€ 40	€ 90	€ 20	€ 120	€ 190
Value added - Capital (million)	€ 10	€ 80	€ 200	€ 30	€ 200	€ 340
Value added - Margin (million)	€ 10	€ 50	€ 110	€ 20	€ 140	€ 230
European annual trade balance impact (million)	-€ 100	-€ 600	€ 200	-€ 100	-€ 800	€ 500
Employment impact						
Direct employment system production (fte)	200	1,000	2,400	500	3,100	5,100
Direct employment O&M (fte)	100	600	600	400	2,400	2,400
Indirect employment (fte)	800	6,700	16,100	3,200	25,400	43,600
Sum (fte)	1,100	8,300	19,100	4,100	30,900	51,100

Industry scenario A: Low deployment, low EU Production share

- *Direct employment* – With an annual global production volume of 300 thousand units, only 39,000 passenger cars and light commercial vehicles (13%) are expected to be produced in Europe. The total European Production value of fuel-cell related parts is therefore limited in this scenario, as the European share in an already low global market scenario is limited and as European production is below that. The production value of FC systems amounts to €300m per year [28], with a corresponding value-added of

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[28] The total estimated value of FC systems per car is € 8,114

about €80m[29]. Most value-added would come from subsystem and (sub-)component production and much less so from system integration. Overall European number of employees on the production line related to these activities would be minimal – on the order of 500.

- *Maintenance* – Maintenance would be expected to amount to €50m annually [30] due to the already installed capacity built up in the years prior to 2030, employing a further 400. Other horizontal extensions are not included[31].
- *Indirect employment* – The production of upstream activities including the provision of inputs such as raw materials and supplies would employ another estimated 700 staff. As FC systems would only make up a share (expected is 27%) of the vehicles' value, the total non-fuel cell related production value would be expected to be around €800m, engaging a further 2,500 employees[32].
- *Trade balance* – As the European demand in this scenario would be rather weak, the case for (Asian) OEMs to build production capacity in Europe would be rather weak too. Whilst European exports would be meaningful for a number of components (as mentioned above), overall trade balance for Europe would be negative, on the order of €100m. This would be due mostly to the fact that OEM assembly would still, to a large extent take place outside of Europe (demonstrated by the fact that the total number of units sold in the European market would be 60,000, whilst the European production would be only 39,000 units).
- In conclusion, the overall value-added and employment related to the production of FC systems would be low in this scenario. Several multipliers would make the overall socio-economic impact more substantial. It would however be doubtful – with European value chains being rather fragmented whether the European production basis in this scenario would be sufficiently strong to withstand and/or substantially expand in the subsequent period – in light of global competition and weak European market development.

Industry scenario C: High deployment, High EU production share

- *Direct employment* – This is a radically different scenario, not only because global production volume of 1.8m units, but also due to the fact that over 30% of these passenger cars and light commercial vehicles (570,000) are expected to be produced in Europe. The expected production value of European-produced FC systems amounts to €3.1 bn per year[33], with a corresponding value-added of about €760m[34]. Overall, the European number of direct employees on the production line related to these activities would be around 5,100.
- *Maintenance* – Maintenance would be expected to amount to €290m annually[35] due to the already installed capacity built up in the years prior to 2030, employing a further 2,400. Other horizontal extensions are not included[36].

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[29] The value-added by component has been described in section 7.4.

[30] Assuming maintenance to be 2% of capital costs. Assumption based on https://www.leaseplan.com/corporate/news-and-media/newsroom/2018/car%20cost%20index; AND https://elib.dlr.de/75697/1/EVS26_Propfe_final.pdf

[31] This ratio between production and non-production workers is typically 1:4 in mature automobile manufacturing; however due to the relative low production volumes in this scenario and the less mature nature of FCEV production by 2030, a more conservative 1:3 ratio could be applied. This would amount to another 1,500 jobs, which are not included in the above table.

[32] It is assumed that the non-FC system part (the 'glider' i.e., vehicle without a drive train) estimate amounts to €21,648 (based on information from the ICCT and TMU.

[33] The total estimated value of FC systems per car is € 5.500, lower than in Scenario A due to economies of scale.

[34] The value-added by component has been described in section 7.4.

[35] Assuming maintenance to be 2% of capital costs. Assumption based on https://www.leaseplan.com/corporate/news-and-media/newsroom/2018/car%20cost%20index; and https://elib.dlr.de/75697/1/EVS26_Propfe_final.pdf

[36] This ratio between production and non-production workers is typically 1:4 in mature automobile manufacturing; however due to the relative low production volumes in this scenario and the less mature nature of FCEV production by 2030, a more conservative 1:3 ratio could be applied. This would amount to another 15,300 jobs, which are not included in the above table.

- *Indirect employment* – The production of upstream activities including the provision of inputs such as raw materials and supplies would employ another estimated 7,000 staff. FC systems would only make up a small share (expected is 20%) of the vehicles, due to the fact that economies of scale would apply only to the FC system part and not to the remainder of the vehicle. Hence, the total non-fuel cell related production value would be expected to be over €12 bn, engaging a further 37,000 employees.[37, 38]
- *Trade balance* – As the European production in this scenario would be much stronger, the supply chain is starting to consolidate around Tier 1s rather than pure FC players. The proportion of locally produced content increases, whilst component suppliers (European and global) build manufacturing capacity close to vehicle assembly. European actors export and import components, but the overall trade balance for Europe is positive – amounting to about €500m. This can be illustrated by the fact that the overall amount of vehicles produced in Europe (570,000) is expected to be higher than European demand (470,000), thus allowing for exports of 100,000 units.
- In conclusion, the overall value-added and employment related to the production of FC systems would be entirely different in this scenario. Whilst direct value-added and employment at FC system production lines would only be modest, several multipliers would make the overall socio-economic impact substantial. European value chains being much more developed, Europe's competitive position would be much more advantageous vis-à-vis other global players – offering substantial room for expansion in the period after as well.

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[37] It is assumed that the non-FC system part (the 'glider' i.e., vehicle without a drive train) estimate amounts to €21,648 (based on information from the ICCT and TMU) – hence similar to Scenario A, as economies of scale are expected to apply only to the FC-system.

[38] It can be observed that the overall cost price difference for FCEV's as a whole amounts to only 10% between the scenarios A and C. It is therefore expected that differences in demand are mostly exogenous, e.g. through the policy framework.

7.6.2 Fuel cell buses

Table 19: Key socio-economic figures for fuel cell buses by industry scenario (2024 and 2030)

Year	2024			2030		
	Scenario A	Scenario B	Scenario C	Scenario A	Scenario B	Scenario C
Global Market						
System unit cost	€ 59,400	€ 46,600	€ 46,600	€ 46,900	€ 34,900	€ 34,900
Global annual deployment	4,000	10,000	10,000	10,000	40,000	40,000
Global system production value (million)	€ 240	€ 470	€ 470	€ 470	€ 1,400	€ 1,400
Global system O&M value (million)	€ 20	€ 40	€ 40	€ 60	€ 150	€ 150
European market and production						
European annual deployment (units)	200	1,000	1,000	600	3,800	3,800
European production value (million)	€ 10	€ 40	€ 50	€ 20	€ 110	€ 160
European O&M value (million)	€ 1	€ 3	€ 3	€ 3	€ 12	€ 12
Macro-economic impact						
Value added - Total (million)	€ 3	€ 8	€ 13	€ 5	€ 22	€ 33
Value added - Labour (million)	€ 1	€ 2	€ 3	€ 1	€ 6	€ 8
Value added - Capital (million)	€ 2	€ 4	€ 6	€ 3	€ 9	€ 14
Value added - Margin (million)	€ 1	€ 3	€ 4	€ 2	€ 7	€ 11
European annual trade balance impact (million)	€ -3	€ 0	€ 0	€ -6	€ 0	€ 0
Employment impact						
Direct employment system production (fte)	20	50	70	30	150	220
Direct employment O&M (fte)	10	30	30	30	100	100
Indirect employment (fte)	110	380	570	260	1,450	2,170
Sum (fte)	140	460	670	320	1,700	2,490

Industry scenario A: Low deployment, low EU Production share

- *Direct employment* – With an annual global production volume of 10,000 thousand, only 600 are expected to be deployed in Europe and only 470 produced. The total European production value of fuel cell-related parts is therefore limited in this scenario – €20m per year, with a corresponding value-added of about €5m. Overall, the European number of employees on the production line related to these activities would be around 30.
- *Maintenance* – Maintenance would be expected to amount to €3m annually[39] due to the already installed capacity built up in the years prior to 2030, employing a further 30. Other horizontal extensions are not included[40].
- *Indirect employment* – The production of upstream activities including the provision of inputs such as raw materials and supplies would employ another estimated 50 staff. As FC systems would only make up a share (expected is 24%) of the vehicles' value, the total non-fuel cell related production value would be expected to be around €70m[41], engaging a further 210 employees.
- *Trade balance* – European demand in this scenario would be weak, and the case for local system integration not strong. European component manufacturers would export some, notably to North America but overall OEMs to build production capacity in Europe would be rather weak too. Whilst

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[39] Assuming maintenance to be 2% of capital costs. Given the intensive use of FC buses this estimate is likely to be conservative.

[40] This ratio between production and non-production workers is typically 1:4 in mature automobile manufacturing; however due to the relative low production volumes in this scenario and the less mature nature of FCEB production by 2030, a more conservative 1:3 ratio could be applied. This would amount to another 90 jobs, which are not included in the above table.

[41] Across the scenarios, the total estimated value of non-FC systems parts per bus is estimated at a constant € 150.000

European exports would be meaningful for a number of components (as mentioned above), overall trade balance for Europe would be negative (net imports of €6m).

- In conclusion, the overall value-added and employment related to the production of FC buses systems would be very low in this scenario. Several multipliers would make the overall socio-economic impact somewhat more meaningful.

Industry scenario C: High deployment, High EU production share

- *Direct employment* – Global as well as European deployment are more substantial in this scenario, and on balance the European demand for 4,000 buses annually would be similar to European production levels. The expected production value of European-produced FC buses amounts to €160m per year, with a corresponding value-added of about €33m. Overall, the European number of employees on the production line related to these activities would be around 220.
- *Maintenance* – Maintenance would be expected to amount to €12.4m annually – due to the already installed capacity built up in the years prior to 2030, employing a further 100. Other horizontal extensions are not included[42].
- *Indirect employment* – The production of upstream activities including the provision of inputs such as raw materials and supplies would employ another estimated 380 staff. As FC systems would only make up a share (expected is 21%) of the vehicles' value, the total non-fuel cell related production value would be expected to be around €600m, engaging a further 1,800 employees.
- *Trade balance* – Overall, European trade balance would be zero, however this would mask the fact that European bus stack manufacturers have a strong share of the European bus market and are exporting stacks and subsystems.
- In conclusion, although the overall value-added and employment related to the production of FC bus systems would be modest in this scenario, several multipliers would make the overall socio-economic impact of this segment meaningful.

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[42] This ratio between production and non-production workers is typically 1:4 in mature automobile manufacturing; however due to the relative low production volumes in this scenario and the less mature nature of FCEB production by 2030, a more conservative 1:3 ratio could be applied. This would amount to another 660 jobs, which are not included in the above table.

7.6.3 HGVs (trucks)

Table 20: Key socio-economic figures for HGVs (trucks) by industry scenario (2024 and 2030)

Year	2024			2030		
	Scenario A	Scenario B	Scenario C	Scenario A	Scenario B	Scenario C
Global Market						
System unit cost	€ 70,600	€ 54,400	€ 54,400	€ 54,700	€ 40,000	€ 40,000
Global annual deployment	1,000	4,000	4,000	4,000	17,000	17,000
Global system production value (million)	€ 80	€ 230	€ 230	€ 240	€ 680	€ 680
Global system O&M value (million)	€ 0	€ 10	€ 10	€ 20	€ 70	€ 70
European market and production						
European annual deployment (units)	200	1,000	1,000	600	4,000	4,000
European production value (million)	€ 10	€ 40	€ 70	€ 30	€ 130	€ 220
European O&M value (million)	€ 1	€ 3	€ 3	€ 3	€ 15	€ 15
Macro-economic impact						
Value added - Total (million)	€ 3	€ 12	€ 18	€ 7	€ 30	€ 52
Value added - Labour (million)	€ 0	€ 2	€ 4	€ 1	€ 7	€ 12
Value added - Capital (million)	€ 2	€ 6	€ 10	€ 4	€ 14	€ 24
Value added - Margin (million)	€ 1	€ 3	€ 5	€ 2	€ 9	€ 16
European annual trade balance impact (million)	€ -2	€ 0	€ 0	€ -7	€ 0	€ 0
Employment impact						
Direct employment system production (fte)	10	60	100	40	180	320
Direct employment O&M (fte)	10	20	20	30	130	130
Indirect employment (fte)	100	520	810	360	1,980	3,330
Sum (fte)	120	600	930	430	2,290	3,780

Industry scenario A: Low deployment, low EU Production share

- *Direct employment* – The market for HGVs is limited in this scenario, and unit numbers are somewhat below those for FCEBs. With an annual global production volume of 4,000 thousand, only 600 are expected to be deployed in Europe and only 500 of those produced in Europe. However, due to the need for high-powered vehicles and the larger size and/or number of stacks, the FC-related system costs are expected to be substantial (€54,700 per unit), resulting in a total European production value of fuel-cell related parts of €30m per year, with a corresponding value-added of about €7m – comparable to that of buses. Overall European number of employees on the production line related to these activities would be around 40.
- *Maintenance* – Maintenance would be expected to amount to €3m annually[43] due to the already installed capacity built up in the years prior to 2030, employing a further 30. Other horizontal extensions are not included[44].
- *Indirect employment* – The production of upstream activities including the provision of inputs such as raw materials and supplies would employ another estimated 60 staff. As FC systems would only make up a share (expected is 26%) of the vehicles' value, the total non-fuel cell related production value would be expected to be around €100m[45], engaging a further 300 employees.

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[43] Assuming maintenance to be 2% of capital costs. Given the intensive use of HGVs this estimate is likely to be conservative.

[44] This ratio between production and non-production workers is typically 1:4 in mature automobile manufacturing; however due to the relative low production volumes in this scenario and the less mature nature of FC HGV production by 2030, a more conservative 1:3 ratio could be applied. This would amount to another 120 jobs, which are not included in the above table.

[45] Assuming the non-FC part of the HGV is € 200,000 per unit

- *Trade balance* – Imports and exports of components mostly, however the overall trade balance for Europe would be negative (net imports of €7m).
- In conclusion, the overall value-added and employment related to the production of HGV systems would be very low in this scenario. Several multipliers would make the overall socio-economic impact somewhat more meaningful.

Industry scenario C: High deployment, High EU production share

- *Direct employment* – Annual global production volume of 17,000 thousand, of which 4,000 deployed in Europe, allows more room for production in Europe – about 5,000 are produced in Europe by 2030. Economies of scale start to kick in (FC-related system costs are expected to come down to €40,000 per unit), resulting in a total European production value of fuel-cell related parts of €220m per year, with a corresponding value-added of about €52m. Overall European number of employees on the production line related to these activities would be around 320.
- *Maintenance* – Maintenance would be expected to amount to €15m annually – due to the already installed capacity built up in the years prior to 2030, employing a further 130. Other horizontal extensions are not included[46].
- *Indirect employment* – The production of upstream activities including the provision of inputs such as raw materials and supplies would employ another estimated 500 staff. As FC systems would only make up a share (expected is 21%) of the vehicles' value, the total non-fuel cell related production value would be expected to be around €950m[47], engaging a further 2,800 employees.
- *Trade balance* – Imports and exports of components, with a neutral trade balance as a result.
- In conclusion, the overall value-added and employment related to the production of HGV systems would be moderate in this scenario. Several multipliers would make the overall socio-economic impact related to the production of HGVs meaningful.

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[46] This ratio between production and non-production workers is typically 1:4 in mature automobile manufacturing; however due to the relative low production volumes in this scenario and the less mature nature of FC HGV production by 2030, a more conservative 1:3 ratio could be applied. This would amount to another 960 jobs, which are not included in the above table.

[47] Assuming the non-FC part of the HGV is € 200,000 per unit

7.6.4 FC systems for trains and lightrail

Table 21: Key socio-economic figures for FC systems for trains and lightrail by industry scenario (2024 and 2030)

Year	2024			2030		
	Scenario A	Scenario B	Scenario C	Scenario A	Scenario B	Scenario C
Global Market						
System unit cost	€ 206,100	€ 167,100	€ 167,100	€ 167,600	€ 128,900	€ 128,900
Global annual deployment	30	160	160	80	400	400
Global system production value (million)	€ 10	€ 30	€ 30	€ 10	€ 50	€ 50
Global system O&M value (million)	€ 0	€ 0	€ 0	€ 0	€ 10	€ 10
European market and production						
European annual deployment (units)	10	70	70	20	160	160
European production value (million)	€ 1	€ 9	€ 12	€ 3	€ 17	€ 23
European O&M value (million)	€ 0	€ 1	€ 1	€ 0	€ 3	€ 3
Macro-economic impact						
Value added - Total (million)	€ 0	€ 2	€ 2	€ 1	€ 3	€ 4
Value added - Labour (million)	€ 0	€ 0	€ 1	€ 0	€ 1	€ 1
Value added - Capital (million)	€ 0	€ 1	€ 1	€ 0	€ 1	€ 1
Value added - Margin (million)	€ 0	€ 1	€ 1	€ 0	€ 1	€ 1
European annual trade balance impact (million)	€ 0	€ 0	€ 0	€ -1	€ 0	€ 0
Employment impact						
Direct employment system production (fte)	-	10	20	-	20	30
Direct employment O&M (fte)	-	10	10	-	20	20
Indirect employment (fte)	50	420	580	150	1,020	1,400
Sum (fte)	50	440	610	150	1,060	1,450

Industry scenario A: Low deployment, low EU Production share

- *Direct employment* – By 2030, this application is considered only a niche market in this scenario, and global deployment is expected to be only 80 units, however Europe captures a relatively higher share of this (25%). Due to the need for very high-powered systems vehicles and the larger size and/or number of stacks, the FC-related system costs are expected to be substantial (€167,600 per unit), resulting in a total European production value of Fuel-cell related parts of €3m per year, with a corresponding value-added of about €1m. Overall European number of employees on the production line related to these activities would be negligible.
- Indirect socio-economic impacts are considered insufficiently small to report about.

Industry scenario C: High deployment, High EU production share

- *Direct employment* – By 2030, this global deployment is expected to be almost 400 units, of which 40% exercised by Europe. Total European production value of fuel cell-related parts is estimated at €23m per year, with a corresponding value-added of about €4m. Overall European number of employees on the production line related to these activities would be around 30.
- *Indirect employment* – Indirect socio-economic impacts, notably those related to the production of the trains as a whole, could however be much higher, at an estimated 1,400, as the non-fuel-cell related value of trains will be high [48].

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[48] The non-FCH-related value of a unit is estimated at € 2.8m.

- In conclusion, it would be important to see FC train systems production together with that of buses and HGVs, and to be aware of the (strategic) importance of the remainder of the non-FCH part of the value chain – especially as conventional train production capacity in Europe is high and as its future competitiveness will be at stake.

7.6.5 HRS industry scenarios

Table 22: Key socio-economic figures for HRS industry scenario (2024 and 2030)

Year	2024			2030		
	Scenario A	Scenario B	Scenario C	Scenario A	Scenario B	Scenario C
Global Market						
System cost - retail station	€ 4,900,000	€ 4,200,000	€ 4,200,000	€ 4,800,000	€ 3,600,000	€ 3,600,000
System cost - bus fleet station	33,700,000	28,900,000	28,900,000	30,100,000	22,400,000	22,400,000
Global annual deployment	€ 200	€ 1,300	€ 1,300	€ 700	€ 3,700	€ 3,700
Global system production value (million)	€ 1,400	€ 6,200	€ 6,200	€ 3,900	€ 15,200	€ 15,200
Global system O&M value (million)	€ 100	€ 360	€ 360	€ 420	€ 1,620	€ 1,620
European market and production						
European annual deployment (units)	€ 40	€ 340	€ 340	€ 110	€ 920	€ 920
European production value (million)	€ 280	€ 1,860	€ 2,010	€ 800	€ 4,590	€ 4,970
European O&M value (million)	€ 20	€ 90	€ 90	€ 70	€ 410	€ 410
Macro-economic impact						
Value added - Total (million)	€ 100	€ 690	€ 800	€ 300	€ 1,720	€ 1,980
Value added - Labour (million)	€ 50	€ 340	€ 390	€ 150	€ 840	€ 960
Value added - Capital (million)	€ 40	€ 250	€ 290	€ 110	€ 610	€ 710
Value added - Margin (million)	€ 20	€ 110	€ 130	€ 50	€ 280	€ 310
European annual trade balance impact (million)	€ 50	€ 310	€ 460	€ 130	€ 760	€ 1,150
Employment impact						
Direct employment system production (fte)	1,300	8,900	10,200	3,800	22,000	25,200
Direct employment O&M (fte)	100	800	800	600	3,400	3,400
Indirect employment (fte)	500	3,500	3,600	1,500	8,500	8,900
Sum (fte)	1,900	13,200	14,600	5,900	33,900	37,500

Industry scenario A: Low deployment, low EU Production share

- *Direct employment* – By 2030, European production value is expected to be around €800m (20% of global system production value). Most of the market would be related to bus fleet stations, rather than retail stations. Corresponding value-added would be about €300m, of which half would be labour. The overall European number of employees related to system production would therefore be high, 3,800.
- *Maintenance* – Maintenance would be expected to amount to €70m annually[49], employing a further 600. Other horizontal extensions are not included[50].
- *Indirect employment* – The production of upstream activities including the provision of inputs such as raw materials and supplies would employ another estimated 1,500 staff.

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[49] Assuming maintenance to be 2% of capital costs.

[50] A conservative 1:2 ratio between production and non-production workers would result in a further 7,600 staff, which are not included in the above tables.

- *Trade balance* – Overall trade balance would be positive, at a value of about €130 million. Integration may take place locally in each region, however European producers would be well placed to supply subsystems and components globally.

Industry scenario C: High deployment, High EU production share

- *Direct employment* – By 2030, European production value is expected to be a substantial €5 bn, about 1/3 of global production value (€15 bn). Corresponding European value-added would be €2 bn, of which about half is related to labour inputs. The overall European number of employees related to system production would therefore be very high, 25,000.
- *Maintenance* – Maintenance would be expected to amount to €406m annually[51], employing a further 3,500. Other horizontal extensions are not included[52].
- *Indirect employment* – The production of upstream activities including the provision of inputs such as raw materials and supplies would employ another estimated 9,000 staff.
- *Trade balance* – Overall trade balance would be substantial and positive, at a value of over €1 billion (€1,150m). Whilst system integration would take place in each region, EU actors could contribute through joint ventures. Exports shift down to predominantly subsystems and components.

7.6.6 Electrolyser industry scenarios

Table 23: Key socio-economic figures for electrolyser industry scenario (2024 and 2030)

Year	2024			2030		
	Scenario A	Scenario B	Scenario C	Scenario A	Scenario B	Scenario C
Global Market						
Global system production value (million)	€ 230	€ 730	€ 730	€ 500	€ 2,000	€ 2,000
Global system O&M value (million)	€ 20	€ 140	€ 140	€ 120	€ 450	€ 450
European market and production						
European production value (million)	€ 91	€ 180	€ 190	€ 190	€ 480	€ 520
European O&M value (million)	€ 6.4	€ 10	€ 10	€ 20	€ 42	€ 42
Macro-economic impact						
Value added - Total (million)	€ 29	€ 58	€ 66	€ 64	€ 160	€ 180
Value added - Labour (million)	€ 10	€ 19	€ 21	€ 21	€ 52	€ 59
Value added - Capital (million)	€ 13	€ 26	€ 30	€ 29	€ 73	€ 84
Value added - Margin (million)	€ 6.6	€ 13	€ 14	€ 14	€ 36	€ 40
European annual trade balance impact (million)	€ 15	€ 29	€ 44	€ 32	€ 81	€ 120
Employment impact						
Direct employment system production (fte)	260	500	560	550	1,400	1,600
Direct employment O&M (fte)	54	85	85	170	360	360
Indirect employment (fte)	180	350	370	390	960	1,000
Sum (fte)	490	940	1,000	1,100	2,700	2,900

Industry scenario A: Low deployment, low EU Production share

- *Direct employment* – By 2030, European production value is expected to be around €190m. Corresponding value-added would be about €64m. The overall European number of employees on the production line related to these activities would be 550.

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[51] Assuming maintenance to be 2% of capital costs.

[52] A conservative 1:2 ratio between production and non-production workers would result in a further 50,000 staff, which are not included in the above tables.

- *Maintenance* – Maintenance would be expected to amount to €20m annually[53], employing a further 170. Other horizontal extensions are not included[54].
- *Indirect employment* – The production of upstream activities including the provision of inputs such as raw materials and supplies would employ another estimated 390 staff.
- *Trade balance* – Overall trade would be positive (€32m), reflecting the strong position of European integrators having added some system production capacity in Asia to serve the rapidly growing market.

Industry scenario C: High deployment, High EU production share

- *Direct employment* – By 2030, European production value is expected to be around €520m. Corresponding value-added would be about €180m. Overall European number of employees on the production line related to these activities would be 1,600.
- *Maintenance* – Maintenance would be expected to amount to €42m annually, employing a further 360. Other horizontal extensions are not included[55].
- *Indirect employment* – The production of upstream activities including the provision of inputs such as raw materials and supplies would employ another estimated 1,000.
- *Trade balance* – Overall trade would substantial and positive (€120m surplus), as EU integrators still lead and dominate the EU market, supplemented by exports of components.

7.6.7 Micro CHP industry scenarios

It is assumed that by 2030 the split between PEM micro CHP and SOFC will be 40/60% based on deployment numbers in all industry scenarios. However, costs of SOFC micro CHP per unit will be higher than for PEM micro CHP, leading to differentiated socio-economic impacts.

Table 24: Key socio-economic figures for micro CHP industry scenario (2024 and 2030)

Year	2024			2030		
	Scenario A	Scenario B	Scenario C	Scenario A	Scenario B	Scenario C
Global Market						
Global system production value (million)	€ 400	€ 1,300	€ 1,300	€ 1,200	€ 3,600	€ 3,600
Global system O&M value (million)	€ 50	€ 100	€ 100	€ 140	€ 400	€ 400
European market and production						
European production value (million)	€ 25	€ 130	€ 160	€ 74	€ 360	€ 440
European O&M value (million)	€ 3.5	€ 11	€ 11	€ 10	€ 44	€ 44
Macro-economic impact						
Value added - Total (million)	€ 6.1	€ 30	€ 37	€ 17	€ 79	€ 97
Value added - Labour (million)	€ 2.9	€ 15	€ 18	€ 8.4	€ 39	€ 48
Value added - Capital (million)	€ 1.7	€ 7.9	€ 10	€ 4.5	€ 19	€ 23
Value added - Margin (million)	€ 1.5	€ 7.6	€ 9.3	€ 4.3	€ 21	€ 25
European annual trade balance impact (million)	-€ 2.8	-€ 14	€ 14	-€ 8.2	-€ 40	€ 40
Employment impact						
Direct employment system production (fte)	76	390	470	220	1,000	1,300
Direct employment O&M (fte)	17	53	53	45	200	200
Indirect employment (fte)	56	300	360	170	840	1,000
Sum (fte)	150	740	890	440	2,100	2,500

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[53] Assuming maintenance to be 2% of capital costs.

[54] A conservative 1:2 ratio between production and non-production workers would result in a further 1,100 staff, which are not included in the above tables.

[55] A conservative 1:2 ratio between production and non-production workers would result in a further 3,200 staff, which are not included in the above tables.

Industry scenario A: Low deployment, low EU Production share

- *Direct employment* – By 2030, European production value is expected to be around €74m (€22m PEM and €52m SOFC). Corresponding value-added would be about €17m (€6m PEM and €11m SOFC). The overall European number of employees on the production line related to these activities would be 220 (70 in PEM and 150 in SOFC).
- *Maintenance* – Maintenance would be expected to amount to €10m annually[56] (mostly in SOFC), employing a further 50. Other horizontal extensions are not included[57].
- *Indirect employment* – The production of upstream activities including the provision of inputs such as raw materials and supplies would employ another estimated 170 staff.
- *Trade balance* – Overall trade would be limited, with European system integrators mostly selling within the EU, and importing stacks and reformers (leading to a slightly negative trade balance).

Industry scenario C: High deployment, High EU production share

- *Direct employment* – By 2030, European production value is expected to be around €440m (€120m PEM and €320m SOFC). Corresponding value-added is about €100m (€40m PEM and €60m SOFC). Overall European number of employees on the production line related to these activities would be 1,300 (400 in PEM and 900 in SOFC).
- *Maintenance* – Maintenance would be expected to amount to €44m annually, employing a further 200. Other horizontal extensions are not included[58].
- *Indirect employment* – The production of upstream activities including the provision of inputs such as raw materials and supplies would employ another estimated 1,000 (260 in PEM, 770 in SOFC).
- *Trade balance* – Overall trade would be modest but with an export surplus, as European system integrators would export systems to other regions more than they would import stacks and components.

7.6.8 Commercial CHP industry scenarios

It is assumed that by 2030 the split between PEM and SOFC commercial CHP will be 50/50% in all industry scenarios based on deployment numbers. However, system unit costs are expected to be substantially higher for PEM than for SOFC commercial CHP, leading to different socio-economic impacts.

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[56] Assuming maintenance to be 2% of capital costs.

[57] A conservative 1:2 ratio between production and non-production workers would result in a further 440 staff, which are not included in the above tables.

[58] A conservative 1:2 ratio between production and non-production workers would result in a further 2,600 staff, which are not included in the above tables.

Table 25: Key socio-economic figures for commercial CHP industry scenario (2024 and 2030)

Year	2024			2030		
	Scenario A	Scenario B	Scenario C	Scenario A	Scenario B	Scenario C
Global Market						
Global system production value (million)	€ 300	€ 1,600	€ 1,600	€ 1,000	€ 5,600	€ 5,600
Global system O&M value (million)	€ 16	€ 76	€ 110	€ 93	€ 530	€ 750
European market and production						
European production value (million)	€ 16	€ 190	€ 320	€ 54	€ 680	€ 1,200
European O&M value (million)	€ 0.9	€ 10	€ 10	€ 5.5	€ 71	€ 71
Macro-economic impact						
Value added - Total (million)	€ 4.5	€ 54	€ 96	€ 15	€ 200	€ 360
Value added - Labour (million)	€ 2.1	€ 26	€ 49	€ 7.5	€ 98	€ 180
Value added - Capital (million)	€ 1.3	€ 14	€ 25	€ 3.9	€ 52	€ 91
Value added - Margin (million)	€ 1.1	€ 13	€ 23.0	€ 3.7	€ 47	€ 85
European annual trade balance impact (million)	-€ 1.8	-€ 21	€ 29	-€ 6.0	-€ 75	€ 110
Employment impact						
Direct employment system production (fte)	56	700	1,300	200	2,600	4,800
Direct employment O&M (fte)	8	86	86	46	600	600
Indirect employment (fte)	34	400	670	120	1,400	2,400
Sum (fte)	98	1,200	2,000	360	4,600	7,800

Industry scenario A: Low deployment, low EU Production share

- *Direct employment* – By 2030, European production value is expected to be around €54m (€33m PEM and €21m SOFC). Corresponding value-added would be about €15m (€8m PEM and €7m SOFC). The overall European number of employees on the production line related to these activities would be 200 (100 from both PEM and SOFC).
- *Maintenance* – Maintenance would be expected to amount to €5.5m annually[59], employing a further 46. Other horizontal extensions are not included[60].
- *Indirect employment* – The production of upstream activities including the provision of inputs such as raw materials and supplies would employ another estimated 120 staff.
- *Trade balance* – Overall trade would be limited, with European component manufacturers exporting to system integrators in all regions, however such systems being imported back into Europe.

Industry scenario C: High deployment, High EU production share

- *Direct employment* – By 2030, European production value is expected to be around €1,200m (€490m PEM and €680m SOFC). Corresponding value-added would be about €360m (€125m PEM and €235m SOFC). Overall European number of employees on the production line related to these activities would be 4,800 (1,500 in PEM and 3,300 in SOFC).
- *Maintenance* – Maintenance would be expected to amount to €71m annually, employing a further 600. Other horizontal extensions are not included[61].
- *Indirect employment* – The production of upstream activities including the provision of inputs such as raw materials and supplies would employ another estimated 2,400 (1,100 in PEM, 1,300 in SOFC).

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[59] Assuming maintenance to be 2% of capital costs.

[60] A conservative 1:2 ratio between production and non-production workers would result in a further 400 staff, which are not included in the above tables.

[61] A conservative 1:2 ratio between production and non-production workers would result in a further 9,600 staff, which are not included in the above tables.

- *Trade balance* – Overall trade would be relatively modest but with an export surplus of an expected €100m, as European system integrators would export systems to other regions more than they would import stacks and components.
- In conclusion, commercial CHP has in this scenario important socio-economic impacts. The high system unit costs in relation to the high number of systems produced (12,000 in Europe) lead not only to high GVA but also to high value-added compared to other applications – even when European production and deployment shares have been kept modest in this scenario (14% of global production and 13% of global deployment). The total direct and indirect employment of commercial CHP production are likely to exceed 10,000 jobs by 2030 in this scenario.

8 Implications and recommendations

8.1 European supply chain strengths and opportunities

European companies and research actors are world class today in many of the technologies needed for fuel cell and hydrogen applications and supply chains. This study documented nearly 300 companies with known positions directly in FCH, and more exist in other supply chain areas. Even more with latent capabilities exist, who could strengthen Europe's position if they entered. These suppliers are supported further by more than 250 identified knowledge-based actors across different domains of expertise. Many of these knowledge-based actors have world-class capabilities and support not only European companies but also others in leading countries worldwide.

For transport applications, Europe has particular **strengths in key components** of fuel cell stacks: **catalysts, membrane electrode assemblies, bipolar plates** and **gas diffusion layers**. Over 30 European companies sell these products worldwide today, and are well positioned to take a significant share of the growing markets for fuel cell cars, trucks, buses and forklifts, as well as supplying stack producers for other applications of the same fuel cell technology, such as combined heat and power (CHP) and auxiliary power units (APUs).

Europe is also home to competitive **stack** developers and producers in applications from transport through to small-scale stationary power. Different types of fuel cell are represented, including both low and high temperature chemistries. Some parts of the supply chains are common or similar across different applications, so support and development for one could bring benefits to others.

Unlike in most world regions, Europe has smaller, specialised integrators developing and launching new vehicle products and concepts in addition to the major car manufacturers. These bring additional supply and purchasing opportunities. Thousands of buses could be deployed in cities across Europe. In the stationary sector, micro-CHP used in a range of buildings could soon become a market of tens of thousands of units, and many more in the future. Given the right support and frameworks, substantial portions of these supply chains would be European, and these deployments would also strongly support local economic development in installation and servicing.

Europe has further international strength in the **hydrogen production and handling technologies** needed to supply fuel cell applications. Europe is a global leader in **electrolysis**, in all technology types, from component supply to final integration capability, with no other single region able to match its depth and breadth across all the technologies and all the components. European companies supply markets worldwide. About 20 European companies offer or develop electrolysis systems, while 10 European companies offer **hydrogen refuelling stations**.

Knowledge-based actors are also strong across many FCH-related fields, from fundamental research through engineering to social science and business studies. European universities and research institutes support companies globally in solving a wide range of FCH problems, and are vital in developing the human resources needed for the FCH sector to succeed.

8.2 Socio-economic value and implications

8.2.1 Job creation and turnover

The purpose of this study was not to forecast uptake of FCH, which depends on many factors, but to consider plausible market scenarios and evaluate the implications and requirements of these. Industry scenarios were developed in which the size of uptake globally was varied, influencing the size of the market that could be captured by any entity, including European ones. Other scenarios considered the level of support within Europe, thus identifying differences between proactive and passive sector development.

The study assessed the following socio-economic indicators by application, covering the FCH-specific elements of applications:

- Turnover
- Value-added
- Employment in
  - Direct manufacturing
  - Maintenance (O&M)
  - Indirect manufacturing

A summary for 2030, for all deployment and industry scenarios, is shown in Figure 21 below:

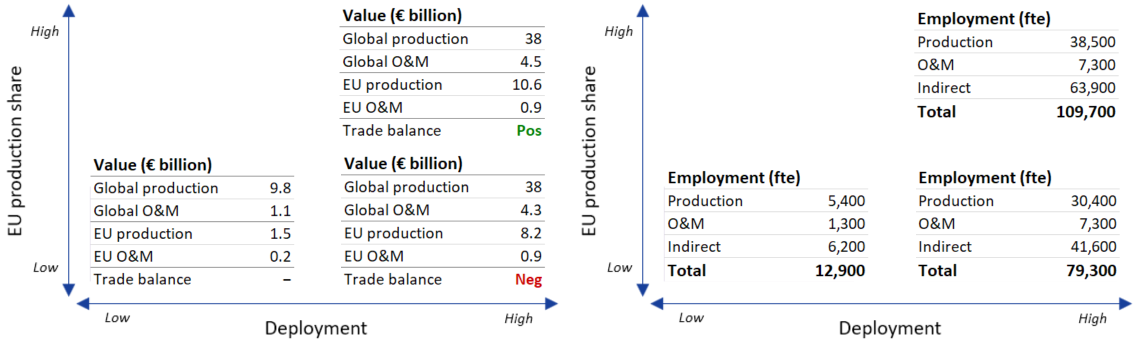


Figure 21: Sector-level socio-economic indicators

8.2.2 Value added for European industry

Important findings and implications arising from the estimated value-creation potential within FCH supply chains can be summarised as follows:

- **Socio-economic impacts of selected applications vary significantly**, depending on overall market size, competitive strength of European production capacity, value added that can be captured, operation and maintenance needs, etc.
- **By 2030, the *European* production value of all of the FC systems combined is expected to amount to €1.5 bn under a low scenario, and €10.6 bn for a high one** (Table 26 and Figure 23), with value added of €500 m and €3.5 bn respectively (Table 26 and Figure 24). Operation and maintenance add a further €200 m and €900 m. The European annual trade balance is neutral in the first instance, but brings almost €2 bn into Europe in the second. Global production values are correspondingly high, between €4 bn and €40 bn (Table 26 and Figure 22).

Table 26: Key socio-economic figures for the selected applications per industry scenario (2024 and 2030) in millions of Euros

Year	2024			2030		
	Scenario A	Scenario B	Scenario C	Scenario A	Scenario B	Scenario C
Global Market						
Global system production value (million)	€ 3,600	€ 14,900	€ 14,900	€ 9,800	€ 38,400	€ 38,400
Global system O&M value (million)	€ 300	€ 1,000	€ 1,000	€ 1,100	€ 4,300	€ 4,500
European market and production						
European production value (million)	€ 500	€ 3,000	€ 4,200	€ 1,500	€ 8,200	€ 10,600
European O&M value (million)	€ 0	€ 200	€ 200	€ 200	€ 900	€ 900
Macro-economic impact						
Value added - Total (million)	€ 200	€ 1,000	€ 1,400	€ 500	€ 2,700	€ 3,500
Value added - Labour (million)	€ 100	€ 400	€ 600	€ 200	€ 1,200	€ 1,500
Value added - Capital (million)	€ 100	€ 400	€ 600	€ 200	€ 1,000	€ 1,300
Value added - Margin (million)	€ 0	€ 200	€ 300	€ 100	€ 500	€ 700
European annual trade balance impact (million)	€ 0	€ -300	€ 800	€ 0	€ 0	€ 1,900
Employment impact						
Direct employment system production (fte)	1,900	11,600	15,100	5,400	30,400	38,500
Direct employment O&M (fte)	300	1,600	1,600	1,300	7,300	7,300
Indirect employment (fte)	1,800	12,600	23,100	6,200	41,600	63,900
Sum (fte)	4,000	25,800	39,800	12,900	79,300	109,700

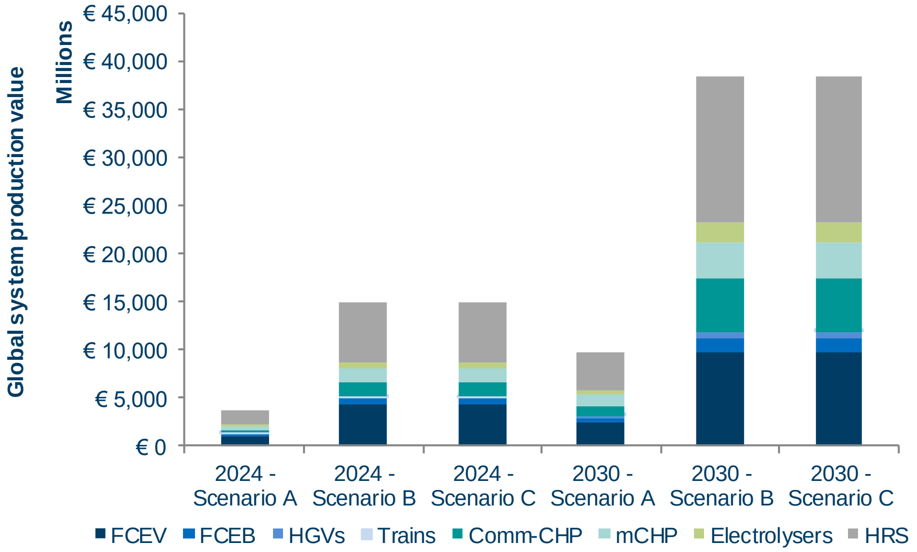


Figure 22: Global system production value for the selected applications by industry scenario (2024 and 2030)

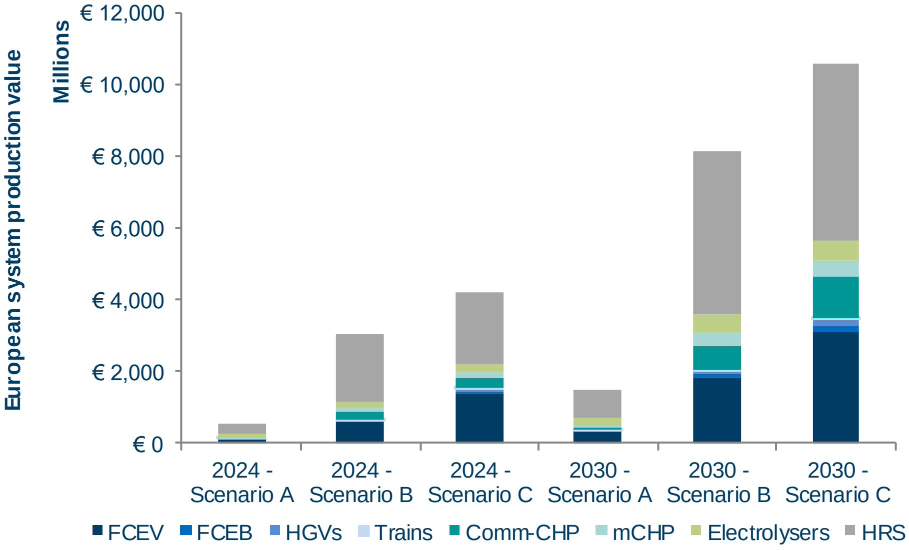


Figure 23: European system production value for the selected applications by industry scenario (2024 and 2030)

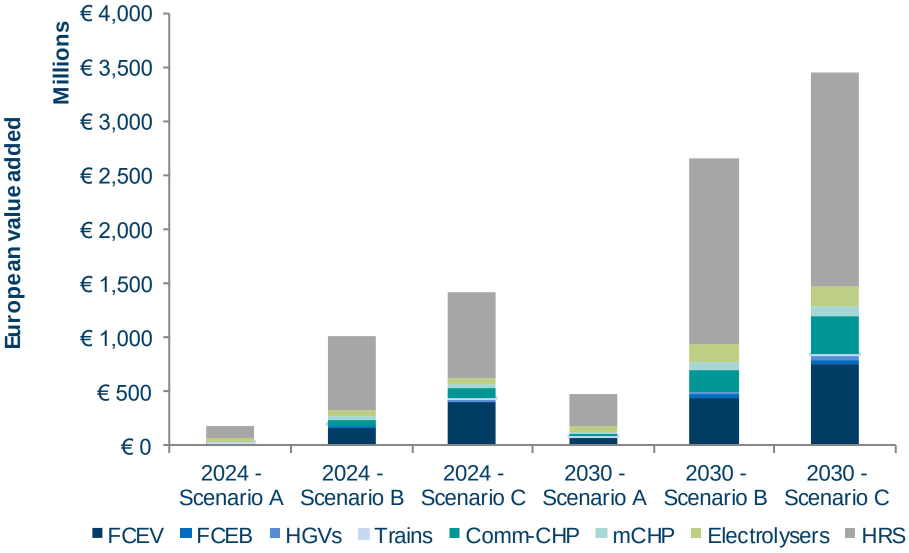


Figure 24: European value added for the selected applications by industry scenario (2024 and 2030)

- **Participation *in the whole value chain* leads to stronger export performance.** If European production focuses mostly on components, as in the scenarios with a low European participation, exports are offset by imports of systems and subsystems. The strong export performance in a high scenario comes from stronger European participation in the full value chain, from (sub-)components all the way through to subsystems and system integration (Table 26 and Figure 27).
- ***Direct* employment related to system production is only a small part of overall employment impacts**. Direct employment estimates focus on system production and production staff – 5,400 to 38,600 depending on the scenario (Table 26 and Figure 25). Whilst this number may seem modest, the non-production workers (activities such as sales, site maintenance, planning, management) for transport applications can be easily a factor 3 greater. Additional employment in operations and maintenance

would be expected to be in the range of 1,300 to 7,300, even when based on rather conservative maintenance to capital ratios.

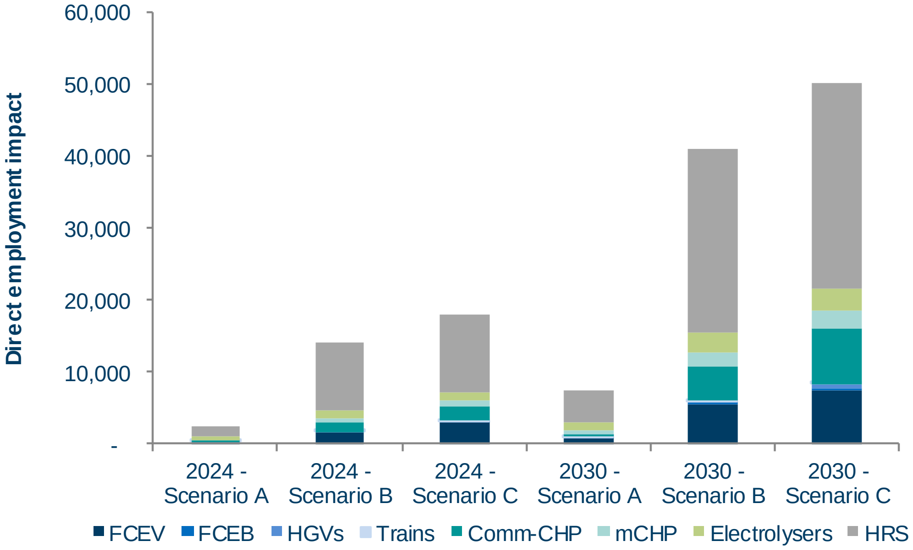


Figure 25: European direct employment for the selected applications by industry scenario (2024 and 2030)

- **Indirect employment can be substantial – especially in transport applications.** The indirect employment figures (6,200 to 64,000 people) in this study is defined as the provision of components and materials not listed in the cost breakdowns (Table 26 and Figure 26). For transport applications this includes the value of the non-FCH parts – namely the rest of the drivetrain and vehicle. These are considered part of the same transport manufacturing value chain, as a strong uptake of FCH systems is expected to benefit the non-FCH parts of production as well. Conversely, a weak roll-out of FCH-systems by European producers (compared to non-EU producers) could pose threats to the continuity of traditional, non-FCH parts of the value chain.

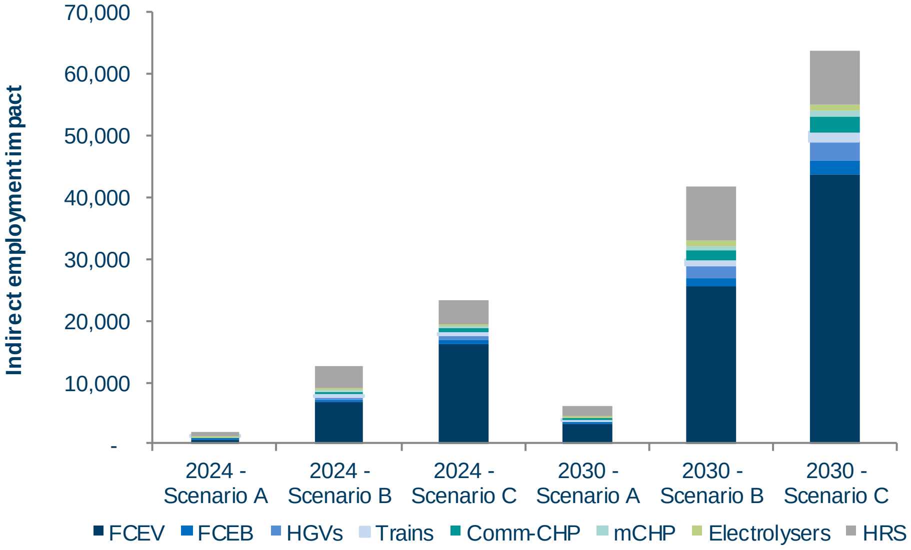


Figure 26: European indirect employment for the selected applications by industry scenario (2024 and 2030)

- **Hydrogen refuelling stations generate substantial economic benefits.** In every scenario, hydrogen refuelling stations show the largest contribution to turnover, value added and direct employment. These significant socio-economic impacts are consistent with expectations for the roll out of new infrastructure. The roll-out of hydrogen refuelling stations will only happen if FC vehicles roll out too, and so HRSs cannot be supported in isolation – an integrated approach is required.
- **Employment multipliers are stronger for transport applications.** It is important to distinguish between direct and indirect employment effects. Whilst *direct* FC-related employment is likely to be highest in relation to hydrogen refuelling stations, this does not translate into equally strong *indirect* employment effects. Transport applications have considerably higher indirect employment effects, due above all to the inclusion of non-FCH parts within the same value chain. Additionally, employment in hydrogen refuelling stations is likely to peak during the build-up of the infrastructure, then level off and possibly stabilise at lower levels in later years, once the infrastructure has been put in place. Any policy aimed at realising socio-economic impacts would need to take an integrated and possibly phased approach – taking into account the interdependencies between various applications, and their development over time.

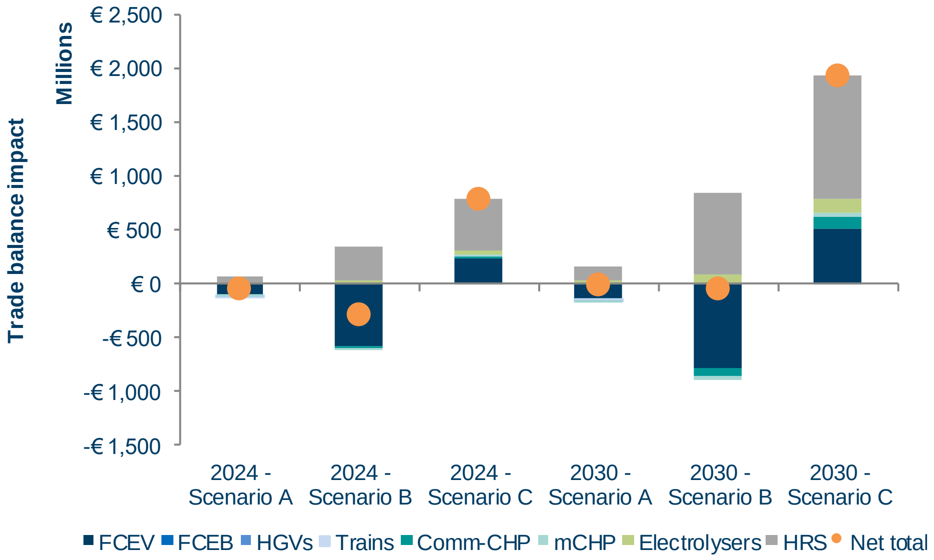


Figure 27: Trade balance impact for the selected applications by industry scenario (2024 and 2030)

- **Only a combination of high European demand and strong European production capacity is expected to lead to strong export performance.** The trade balance varies between applications as well as scenarios. Europe has a strong position in HRS and electrolysers, which leads to positive trade balances in all scenarios. The situation is more varied in transport applications, where imports are expected to exceed exports in a low growth scenario A – as the exports of components will be more than offset by the imports of systems. The trade balance is considerably more negative in scenario B (not extensively discussed here), which combines high global and European demand with low European production volumes (Table 26 and Figure 27).
- **A holistic approach is important.** It may be tempting to pick and choose those applications that show the greatest potential benefits. But because both markets and supply chains are closely interlinked, this risks undermining some of the benefits and slowing down deployment.

- **Increases in annual production volumes of PEM systems for transport applications are associated with important shifts in value-added away from upstream production** of components (including MEA) towards downstream activities of system integration (including production of tanks and balance of plant). This suggests that over the longer term, as production volumes increase, it will be important for the FCH industry to be positioned in downstream assembly and integration activities. However, a high proportion of value-added generated by these activities comes from labour inputs, and so the competitiveness of European-based production may in part depend on its costs of labour. For production within Europe, lower labour cost locations (e.g. in Eastern Europe) may be favoured for assembly and integration activities, as to an extent has already occurred in the automotive sector.
- **Potentially substantial opportunities arise for production machinery and equipment suppliers from increased production of PEM systems for transport applications**. PEM systems for transport applications have a high share of capital costs (capex) in total value-added. This reflects the capital-intensive nature of production activities and, therefore, the large value of investments in production equipment necessary to support any substantial increase in production volumes. Other applications where production equipment is a significant contributor of value-added include CHP system integration, solid-oxide fuel cell and electrolyser cell production, PEM electrolyser integration, and HRS integration.
- **Value-added in the supply chains of PEM systems for stationary applications is concentrated in downstream production activities:** system integration and production of associated balance of plant items. By 2030, the combined shares of these supply chain segments could account for around nine-tenths of value-added generated in the production of large PEM CHP systems, three-quarters of the value added of PEM micro-CHP systems, and two-thirds of value-added from PEM electrolyser production.
- **Value-added from the production of solid oxide systems for stationary applications is distributed comparatively evenly throughout the supply chain.** Around two-thirds of value added for solid oxide micro-CHP systems is in downstream system integration and associated balance of plant items. However, the supply chains for large solid oxide CHP systems and solid oxide electrolysers should retain substantial value-added in stack integration and associated balance of stack items, and in cell production. This is consistent with the diverse and less concentrated organisation of large solid oxide system suppliers, who are less likely to achieve the production volumes to drive supply chain consolidation and economies of scale.
- **Labour inputs account for over half of value added from the production of solid oxide systems for stationary applications.** Compared to PEM systems, the labour share in value-added from the production of upstream components and balance of stack and balance of plant items for large SO systems is expected to remain large. This is consistent with comparatively limited supply chain optimisation and production automation which leads to lower capital intensity of production.

8.3 How could some of the economic value be realised?

8.3.1 Maintaining and increasing the value to Europe largely depends on support and deployment in Europe

Even using a relatively narrow definition of value-added activity, the analysis shows that support within Europe is essential to allow the greatest value capture. If global growth is strong but Europe takes a *laissez-faire* attitude then Europe exports less overseas, and overseas companies export more into Europe. If global growth is low but Europe has strong internal support, European companies capture a greater share, but of an inevitably smaller market. By supporting both deployment (helping to increase the global market by increasing the European market) and the positioning and growth of companies, Europe has the greatest chance of capturing long-term value. This value is likely to go elsewhere if either is lacking, as other regions will develop more mature capabilities and supply chain clusters.

As an example, analysis of existing conventional supply chains shows that whilst mature supply chains for some products are global, for others (such as cars) supply chains gravitate towards the control of the original equipment manufacturer (OEM), and towards the country or region of deployment. OEMs tightly control supply chains, which can include design and assembly in-house and partnering with suppliers on design, optimisation and even investment. For high volume production, suppliers of appropriate components will co-locate with final assembly plants. So as the fuel cell industry and its supply chain mature, it could become increasingly hard for EU component suppliers to sell to non-EU OEMs, as these OEMs build and strengthen internal and local capabilities. Conversely, support measures targeted at driving deployment in the EU could serve to activate the supply chain. For instance, the detailed value-added analysis suggests that a significant fraction of the value added can be captured for both FCEVs and HRSs provided the FCEV and HRS system assembly occurs in the EU. A coordinated vehicle and refuelling station deployment programme could (a) help directly capture the value in those applications, and (b) could also support the development of an ecosystem of upstream sub-system and component suppliers. Following standard automotive sector practice, these would likely be local in the longer term. This would also position EU component suppliers to supply both EU and non-EU OEMs located in Europe.

For many other applications, OEMs have less power, and supply chains are likely to be global, so EU suppliers will rely less on EU deployment for sales. Nevertheless, deploying fuel cell and hydrogen applications in the EU will strongly support their development, through providing experience and direct feedback from local markets. It will also enable provision of support services such as installation, maintenance and fuelling, all of which generate significant value and employment, and help inform the activities of the knowledge-based actors.

8.3.2 Specific support to specific FCH supply chains is needed

European companies and researchers are active in most areas of fuel cell and hydrogen supply chains, and are strong in many of them. Gaps do exist though, both in areas where the EU is behind other regions, or where there are no strong players globally. This brings opportunities for European companies to build positions, and different types of support could help them to do this. This would typically fall under existing mechanisms such as accelerated depreciation for capital equipment, simplified or standardised permitting for manufacturing plants, or favourable tax regimes for manufacturers and suppliers.

However, support should be given judiciously. Given that many supply chains will be global, it is neither necessary nor plausible to try to construct a whole supply chain only from EU companies. A better outcome will come from a focus on areas of strength, need, or competitive advantage. For example, European car OEMs are not leading in FCEV, though some have interest and programmes. Nevertheless, the Tier 1s and other actors in the supply chain are strongly engaged and are supplying globally. But even if non-European OEMs deploy vehicles in Europe in response to policy measures, they are likely to use local production capabilities and even European supply chain companies, if these have already built a strong position.

The picture in stationary fuel cell systems is mixed, with the production and supply of large systems currently dominated by US and Asian manufacturers. Some European companies are well positioned in micro-CHP, and looking to enter overseas markets, and the commercial CHP sector (tens to about 100 kW) is considered a very promising opportunity, scaling up from already-developed micro-CHP technology. Europe is well positioned in SOFC in particular.

Hydrogen refuelling stations (HRS) stand out as an opportunity of both potentially high total value and value-added, but it is important to note that the figures for HRS in this study include the total cost and value-added for installation of the station, and not only production of the systems. Nevertheless, installation benefits may only arise if the supply chain is supported, so that competitive systems can be produced.

Electrolysers are a further area where Europe is well-placed, in part thanks to indigenous technology developed over many years, and in part because European support schemes for both electrolyser-based HRS and for stationary applications such as power-to-gas have been more consistent than in many other regions, allowing supply chain capacity and expertise to be developed.

8.3.3 Deployment of FCH solutions in Europe need to be appropriately supported

The FCH sector contains many large and small players globally, and many applications are on the verge of economic competitiveness after years of investment and development. Major industrial nations such as Japan, Korea and the US are strengthening or developing positions, and China is emerging rapidly. Europe is well positioned to profit from European component and system manufacture, both for European deployment and export. Scenarios developed in this study show likely markets of multiple billions of Euros. Europe will also benefit from deploying overseas technology locally, both through environmental improvements and through local employment, though to a lesser extent.

This study has looked in some detail at hundreds of organisations, multiple FCH components and applications, and a range of different growth scenarios. This breadth means it is not appropriate to make specific recommendations for regions or actors, as they depend strongly on local conditions. However, the analysis allows for general recommendations about areas of the industry and the kind of support that could allow Europe to capitalise on the strong base and high levels of interest in the sector. These include:

- Co-ordination of EU and national visions, to allow companies and other entities to optimise incentives and investment for transport and infrastructure;
- Market activation support, to help crystallise demand and allow supply chains and economic benefits to build around it;
- Supporting FCH in transportation applications, not only in cars but also in heavy-duty applications such as trucks, trains and marine use. This should help both strengthen multiple parts of the component supply chain and ease the roll-out of infrastructure through the creation of large local demand nodes;
- A continued focus on rapid development of appropriate standards and regulations, to ensure wherever possible that deployment is not held up by either, and that standards across different sectors do not conflict;
- Engagement of the finance sector in providing suitable – and potentially innovative – financing for scale-up and deployment, where capital requirements are high for small companies, or where loan guarantees may be needed to overcome risks inherent in an emerging technology;
- Support for companies capable of producing competitive heat and power solutions, whether in the residential, commercial or industrial sectors. Measures here could include scale-up support, or market mechanisms that fairly value all of the benefits that such technologies bring (lower CO_2 emissions, air quality benefits, grid support capability);
- Urgently addressing the skills gap that is emerging in the sector, by ensuring it is communicated as a good opportunity for future employment, plus supporting dedicated training and certification, and early introduction of relevant subjects into curricula;

- Aligning electricity markets and regulations with the stated need for low-carbon hydrogen, by reducing or removing tariffs and levies on electricity that render the hydrogen produced expensive, where these costs are not justified or are double-counted;
- Stimulation of local integration and manufacturing capability for HRS and compressed hydrogen storage; plus support for export if appropriate.

These generic recommendations need to be translated into specific actions to be taken by given actors, and timing assessed. To do this effectively requires a good understanding of local conditions and individual actors. What is right for one company and one country or region will not suit another, and so such specificity is not attempted here. Under all circumstances, some level of co-ordination at EU level will be important, useful and advisable.

8.3.4 Boosting the EU supply chain

A number of actions and investments could boost the role of EU supply chain players in the global market, to strengthen them and enable them to win or keep business. These are discussed by application below. Note that these actions do not consider technical development needs for each component, and instead focus on the role of the EU players.

FCEVs

Value from *integration* of FCEVs for the EU market will come to Europe irrespective of the origin of the OEM. However, through faster EU development in the near term, EU OEMs could capture an increased share of global markets. This might be achieved through:

➔ The targeted support of continued FCH innovation within large OEMs through RD&D funding where possible

  o The majority of components and systems are at close to commercial level though remain expensive. R&D targeted at cost reduction would likely be the most effective support, and would typically cost in the low millions of Euros if well directed.

➔ The establishment of supplier parks, with a cluster of component suppliers around an assembly plant to shorten the supply chain and increase cooperation between OEM and suppliers.

  o Individual countries and local regions will take decisions on clusters and support, in part dependent on their existing strengths and skills. The timescale for decisions on support is relatively short, with facilities in early stages of development already. Costs for providing some setup costs or depreciation or tax benefits will typically be in the low millions of Euros.

➔ Strengthening the upstream supply chain in components that are not considered in detail here is also important. Europe has strengths in many more generic areas (heat exchangers, water handling etc), which are required in FCEVs and where increased component performance and reduced cost could have good benefits.

  o Greater information and liaison with these companies, including details on the size and development of the FCH opportunity, could help stimulate interest in an emerging market.

➔ Addressing the growing skills gap in automotive engineering, and that for manufacturing and assembly of FCEVs, to increase the industry's capability to grow.

  - The required skills for FCEV and related technologies are relatively new, and there is a general shortage of qualified people. This takes time to address and many of the skills are cross-cutting into EVs more generally, stationary systems and other applications, so mechanisms to boost them are likely to be supportive of many areas. Costs for training could be in the millions of Euros depending on the local delivery structures.

Support for local deployment, scale up of manufacturing and help to access markets in new regions could enable **smaller FCEV OEMs** gain a greater share of global markets. Actions to support this could include:

- ➔ Support for RD&D would help small OEMs develop compelling vehicle offerings, and support for manufacturing in the EU, such as through local, regional or national level capital grants or tax exemptions for production plants, would help them to scale up.
  - Smaller OEMs do not have the access to balance sheet or low-cost external capital available to most large OEMs and so targeted support as they grow could significantly improve their chances of success. Few currently exist, and a support programme would ideally be designed with their input. Although more costly than some other measures, these should not represent more than tens of millions of Euros.
- ➔ As the choice of suppliers is more limited than for larger OEMs, due to more specialist components, lower volumes and lower buying power, these players will also benefit strongly from any support aimed at increasing the range of EU stack and component suppliers.

By 2030, larger global markets will lead to a strengthening of global supply chains, and market growth for the strongest existing players. However, automotive supply chains currently have several suppliers for each component, to reduce risk, and so more suppliers are needed. The number of suppliers in the EU will grow through building the capabilities of smaller players, and encouraging those with related capabilities to enter the market sooner than they would have done otherwise. These suppliers could supply multiple markets for components: primarily FECVs but also FCEBs, forklifts, HGVs and other PEM applications. Actions to support this could include:

- ➔ Supporting suppliers that are at earlier stages of development to reduce stack production costs, for example through support for production plants through local, regional or national level capital grants or tax exemptions
  - The timing for these measures should be agreed with industry, as there may not yet be companies easily able to take advantage, and increased demand will be essential for companies to take these investment decisions. Effective costs could be in the tens of millions of Euros but not necessarily as direct subsidies.
- ➔ Access to capital, support for exports, and de-risking of scale-up, such as loan guarantees, will help smaller players – and players late to the market – to become competitive quickly
- ➔ Support for quality assurance processes for component manufacturers, particularly for high speed roll to roll processes, will help them compete. This could involve supporting producers of manufacturing equipment, manufacturers themselves, and those who develop equipment used to test quality
  - These measures should be adopted relatively early as high-speed quality assurance is a pre-requisite for cost reduction and mass production. It would also position Europe well competitively. Costs are hard to estimate as the requirements are comparatively specialised.

- ➔ Addressing the skills gap in electrochemistry and electrical engineering would allow more and bigger companies to develop
  - o Similar to the FCEV-relevant training above, skills development requires time and so should be initiated as soon as possible. Costs will depend on the training delivery mechanism.
- ➔ Targeted support in certain components, such as sensors, could help Europe develop an early strong position in specific parts of the supply chain
  - o As with quality equipment, sensors and some other components act to support many different applications. Targeted R&D programmes already exist, so additional support would require co-ordination with these programmes.

FCEBs

The role of the EU supply chain could be boosted by enabling EU stack suppliers to compete in global markets, through early action to help them to prove reliability. This would increase the number of EU bus stack manufacturers by 2030, increasing the EU market share. This would also help build more coordinated supply chains in the EU in general, increasing the share of the EU market that is supplied by buses including EU stacks. This could be enabled by:

- ➔ Supporting field trials for EU bus stack manufacturers, to allow them to show proven reliability and enable sales to bus OEMs globally
- ➔ Encouraging local content in EU FCEB deployment, to the extent allowed
  - o Bus field trials have now evolved into mass procurement exercises, and suppliers are competing to supply stacks and systems to integrators. Additional incentives or requirements for European stack manufacturers to be considered in the evaluation could help provide both test data and early market opportunities. If done, this should be as soon as possible, to allow them to catch up somewhat with overseas entities. Costs could be relatively low, if this were a requirement within existing programmes
- ➔ Helping European suppliers build export relationships with China and other emerging regions, to enable more rapid manufacturing growth while also adding to the data available to prove stack lifetimes
  - o Chinese entities are very open to external technology use and are prepared to invest in acquisition and manufacturing. Helping them liaise with European manufacturers through trade missions, information provision and other mechanisms could be a low-cost means of ensuring that deals can be done if appropriate
- ➔ The support for FCEV components described above, will also support bus supply chains where the components are common

FC trains and maritime applications

Much of the supply chain considered in the study is broadly common between trains, maritime and other transport applications, and so all will be boosted by actions in other areas. The train and maritime applications require more focus on large-scale stacks and systems, and on large-scale hydrogen storage and delivery.

- ➔ Engagement programmes between FCH providers and existing rail or maritime suppliers could increase awareness and help clarify opportunities or needs for larger-scale components
    - o These measure would primarily be low-cost, and relatively quick and simple to implement, but would require input from trade associations and FCH suppliers, with the former likely to provide the leadership
- ➔ Helping EU stack suppliers enter demonstration programmes would put them on a path to catching up with North American competitors
    - o This is conceptually similar to the bus programme support described earlier, and there may be some crossover, such as trying to set requirements for buses, that could also help the development of train- or ship-ready stacks and systems. This would require careful planning and discussion with the industry. Such demonstration programmes could be relatively high cost, given the large scale of the applications, but still in the few tens of millions of Euros. The lead time for such demonstrations is long and interest is already high, so measures should be taken as soon as possible.

Micro CHP

EU activity could be further boosted by actions to allow early proving of EU-produced stacks and products, to give a more competitive position in global markets, and through support for EU integration.

- ➔ Further micro-CHP demonstration programmes could help narrow the large gap with the Japanese manufacturers. This has already begun through the German (KfW) and FCHJU programmes supporting fuel cell micro-CHP, which will bring deployment of larger numbers of units than currently. Some further programmes, in other countries, would be useful here, although there are diminishing returns from further programmes in terms of their benefits. Programmes would need to include hundreds or thousands of units, with multiple product types, and include building capacity for installation and servicing, to enable further roll-out. This means that programme costs would be very high, potentially in the hundreds of millions of Euros.
    - o If action is taken here it should be very soon, as otherwise the existing companies in the market may struggle to increase production and reduce costs. If designed well, measures here may also support commercial CHP products which are anticipated to be a more cost-effective product than mCHP in many regions.
- ➔ Access to low cost capital for companies integrating mCHP products would help, as a huge amount of capital is required to scale up manufacturing and bring costs down to a competitive level
    - o Such support mechanisms are typically regional and would require discussion with manufacturers to allow the right type and level of support to be considered. Many mCHP producers are now linked to major appliance manufacturers, and so they may not require this incentive.
- ➔ EU integrators could strengthen overseas links and try to ensure more EU content goes into overseas systems
- ➔ A robust, low-cost reformer would likely be in strong demand in other regions – the EU has some strengths in this area which could be further supported

Large FC CHP and primary power

Helping existing EU players prove their products and to scale up manufacturing would increase the EU role in the supply chain and help ensure the success of existing EU players. This could be enabled through:

- Support for demonstrations and field tests for data gathering of a relatively small number of large units
- Access to low cost capital for producers

Electrolysers

Europe is strong in electrolysis and few supply chain weaknesses have been identified, assuming that strong development and increased market sizes from enable mass-production to become commonplace. Novel electrolyser types and improved materials should also be pulled through directly by increased market demand, but some RD&D support will remain important as these newer technologies become more widely used and their characteristics become better known.

- Electrolyser roll-out will be driven mainly by demand for competitive low carbon hydrogen. Measures to reduce electricity tariffs for electrolysis will aid competitiveness
- Loan guarantees or other access to low-cost capital could help smaller electrolyser companies to increase manufacturing capacity and compete for larger orders
- Increasing awareness in different markets, to generate increased demand from sectors such as grid services and industrial chemicals could further enable electrolyser developments and markets

HRSs

The situation for HRSs remains anchored in local capabilities. Given that an HRS is more like an integrated set of disparate components than many FCH applications, two discrete sets of actions may be required to support them. The first relates to stimulating greater numbers of supply chain players. Current weaknesses are often either in components designed for other uses (e.g. industrial compressors) or where very few suppliers participate (hoses and nozzles), but capability exists and a larger market potential is likely to prompt investment in these areas. The second is to stimulate more integrators to participate and develop the know-how required to make the final product more competitive

- The export potential of HRS is important, and specific promotion measures could be considered to support innovative business models targeted at European companies (including installation, maintenance, servicing, etc.). This could also be part of existing cooperation in the field of energy (including EU Partnership programmes).

Hydrogen storage

To help support European pressure vessel development, several activities could be supported:

- A broad skills and technologies audit for latent capabilities in tank making, including a range of materials and production processes
    - Several European actors are developing capabilities in this area, and the FCH industry is increasingly interested in the opportunity and the current gaps, so further awareness-raising through skills audits may require only a light touch and little cost

- ➔ An EU-wide competition to find new tank technologies that can overcome the reliance on imported high price carbon fibre, and avoid complicated winding processes, to make manufacture cheaper
- ➔ Supporting production facilities for tanks in the EU
    - o Innovation in tank manufacturing would position Europe very strongly in future markets globally, and a competition could potentially help achieve this at relatively low cost. Supporting manufacturing facilities could add further impetus, but is likely to require regional participation and agreement with the manufacturers, which will also determine costs
- ➔ Supporting EU companies to access export markets
    - o Limited support is required in this area as export markets will become accessible, to some extent, if new technology can be developed. Nevertheless, trade missions and other traditional means of support can only help, and at low cost.

8.3.5 Boosting EU deployment

A range of actions that would **increase deployment of FCH applications in the EU**, with the knock-on supply chain and value benefits elaborated in the study, are suggested below. Where relevant an indication of time and possible cost is also given.

Coordinated EU and national visions

- ➔ National and EU level visions for FCH, which help countries and other entities to coordinate activity across FCH applications will underpin investment in infrastructure and contribute towards an expectation that large EU companies, such as automotive OEMs, will build a leading position in these technologies.
    - o This is required as soon as possible, but does not entail any significant cost.

Supporting uptake of FCH in transport applications

- ➔ Further coordinated programmes of vehicle (FCEV, FCEB, HGV) and infrastructure roll out, similar to H2 Mobility Europe or existing national initiatives, will help bring critical mass to individual HRS economics and the development of dependable networks, and support supply chains for vehicles. This coordinated support must ensure enough infrastructure provision so that both EU and non-EU suppliers deploy FCEVs and FCEBs in the EU at similar speeds to other regions. This would enable the EU to keep pace with supply chain development. HRS for buses should help support FCEVs also. HGVs may operate on separate infrastructure, if it is tied to fleets, but could be allowed or given incentives to integrate as far as possible.
    - o Timing for these incentives should be carefully co-ordinated to allow benefits to be captured, so that neither vehicles nor infrastructure lie idle. The cost will depend heavily on the type of action – a mandate or zero emission zone policy entails little direct cost, other than for enforcement, but a subsidy scheme could require multiple million Euros of budget to be meaningful.
- ➔ Clear and enforced EU, national and city level regulations for air quality and CO_2 will be required, including stringent tailpipe targets, tax differentials, low emission zones and preferential city access. This is essential to giving industry players confidence that there will be a market for FC vehicles and refuelling infrastructure, though this alone will not drive uptake in the near term.

  - Such measures are already underway in many places and while additional measures will help to drive the market, the timing should ideally be aligned with availability of solutions. Setting expectations for future policy (in an applicable period, such as 2-5 years) and then implementing it as stated would help to set expectations within the industry and allow risk management. Additional cost for these measures is small.

- ➔ FC trains could be included as a required consideration for stock replacement and line electrification planning, and infrastructure analysis associated with infrastructure for road vehicles.
  - Trains are not yet a mature application, so measures in this sector can be appraised and put in place over several years. Cost will depend strongly on how the requirements are defined and how trains are funded in the local environment, for example directly by the taxpayer or by private operators.
- ➔ Enforced air quality and other emissions limits in ports, and maritime cities more generally, may help to open up possibilities for waterborne fuel cell transport.
  - As with trains, this sector is not yet quite ready for major deployment, and so setting expectations now for future policy measures, and then applying them, should be adequate. The cost simply for the policy will be low, though compliance could entail significant costs, for example in provision of infrastructure, depending on how this is funded.
- ➔ Continued capital support for FC deployment in transport, such as through vehicle grants, tax reductions etc, will enable early deployment when FC volumes are small, and costs high.
  - This action, if applied, should be done as early as possible, in order to stimulate and maintain markets in the early development phase. Costs will be high however, if the measure is to be effective, in the tens to hundreds of millions of Euros depending on the level of ambition of the mechanism.
- ➔ Public procurement of FCEV cars and vans for fleets such as local authority vehicles would allow volume to be built.
  - These programmes should be implemented as soon as practicable, but discussed in advance with the industry to enable them to match deployment capacities and suitable locations. Cost should be relatively low if the procurement is designed effectively, as the methodology is to provide industry with a set of targets to meet in exchange for a guaranteed volume of business, rather than simply buying down the cost of technology or vehicles.
- ➔ Demonstration programmes for trucks would provide comparative information to truck OEMs on their potential benefits for fuel saving, air quality etc
  - Such measures will be most effective if conducted with the input of the truck OEMs, as it will require vehicles which are not yet generally available. While a support programme could cost several million Euros, this sector is under consideration already as a promising option, and so it is likely that only limited support is required to help move the market forward.
- ➔ Continued and strengthened city and regional support for ZEBs and specifically FCEBs will enable manufacturers to invest, supported further by joint procurement strategies, bus clusters, public procurement and other collaborative initiatives

  - As these initiatives are best conducted in concert with other complementary ones, cost and timing must be considered together, but early implementation is appropriate given the ongoing developments in the market.

- ➔ Rapid development of appropriate standards for HRS (e.g. safety zones, failsafe requirements) will enable infrastructure deployment, and speed vehicle rollout.

  - This requires national and international co-ordination to be effective, and while some activity has been underway for a long time, more would be beneficial. Given the typically long lead times, this should be initiated as soon as practical. Costs should be comparatively low.

- ➔ Innovative financing models or other risk-reduction techniques are needed for many HRS, particularly those with on-site hydrogen production, to overcome high capital cost and underutilisation for first movers. Options could include joint ventures, permits for early refuelling station deployment, and public-private partnerships, along with encouraging involvement of industrial asset financers and entrepreneurs with mixed debt/equity models.

  - These measures should be implemented as soon as possible, as improved infrastructure economics will strongly benefit many applications and could provide the additional impetus needed to nudge markets forward. The cost for this should be low, as the intention is for them to be essentially self-financing, though guarantees and other backstop mechanisms may be required.

- ➔ Integration of hydrogen infrastructure into spatial planning in cities would ensure space availability for HRSs, particularly for buses.

  - This measure is an immediate no-regrets move if implemented correctly. It should not be a mandate that such infrastructure is built, but that it is considered and evaluated at any appropriate juncture. It should be low in cost, as it would fit alongside the existing planning process.

- ➔ Reliable, freely and widely available information on the status and location of refuelling stations would help give early adopters comfort that they could refuel easily.

  - Such measures are already in place in some regions, and these can be used as models for future schemes. The cost of the transmitting side will be borne by the HRS provider if the implementation is through a design requirement, and the cost of the data management and access portal could be shared across industry or through a public funding programme, but it would not be large.

- ➔ Improving station reliability and availability would also aid consumer confidence. Building clusters of stations such that some redundancy can be achieved, and ensuring learning on reliability issues is captured and shared, to reduce future problems across the industry, could help

  - An integrated approach to developing infrastructure during the pre-profitability period could be supported through explicit inclusion in any support programmes, as well as industry best practice.

- ➔ Anti-idling laws would support use of alternative fuelling options for trucks, driving interest in FC APUs.

  - These are typically regional or city-wide pieces of legislation, and could be implemented rapidly, at very low cost.

Informing and enabling consumers in other applications

- ➔ Information provision for forklift fleet owners on the comparative benefits of FC forklift options would support demand, including investigating the potential to link to other hydrogen uses, such as also refuelling trucks.
    - o This is more of an industry association task than a government one, and could be done with the engagement of the industry at relatively low cost.
- ➔ Novel financing mechanisms may be needed for customers of large CHP and prime power to overcome high capital costs.
    - o Rather than direct subsidies, which may be very expensive, innovative financing mechanisms may allow more rapid deployment of these applications at relatively low cost. Large-scale fuel cells are already available and so a support scheme could be implemented rapidly to help build the market.
- ➔ Promoting greater awareness of FC CHP in the building industry would help overcome barriers of conservatism, including linking with housebuilders and other building suppliers to provide micro or large scale FC CHP as part of new build packages.
    - o Again, this mechanism is more relevant for an industry association than a public-sector body, but is a low-cost means of increasing awareness and hence markets. It could be put in place very soon.
- ➔ Support for skills development in micro-CHP installation and servicing would help rollout.
    - o Although training programmes already exist, additional efforts could be promoted in the near term to help support increased rollout of mCHP driven by other measures. Costs for training are very low in comparison to those for subsidising deployment of equipment.

Valuing the additional benefits of selected FCH applications to improve their business case

- ➔ Establishment of suitable regulatory structures would allow micro-CHP units, large CHP and prime power units and electrolysers to benefit from the benefits and services they can provide in addition to their 'core' purpose. These include local air quality emissions reduction for FCs, and services to electricity networks (e.g. frequency response) for all of these technologies.
    - o The redesign of regulations that cover multiple sectors is relatively complex and could take a considerable period of time. Even those that cover single sectors require careful design. The cost derives primarily from the expert time that needs to be committed.
- ➔ Consideration of the attributes and benefits of FC CHP (e.g. low emissions) in building regulations and standards would allow building specifiers to quickly identify the opportunity to use FC CHP products.
    - o Building standards vary considerably between countries, and some take into consideration different heating measures and options. Including detail on FC CHP should not entail major cost, though it requires co-ordination with building engineers and others.
- ➔ Local regulations to require and enforce low air pollutant emissions from stationary power applications, and promotion of local decentralised energy applications would favour FCH technologies, amongst others.

    - These regulations are not technology-specific and are increasingly being brought in, so the focus of the FCH community might be to work with other organisations whose technologies offer clean air benefits and speed the uptake of such regulations. Little cost would be entailed.

- ➔ Additional market-based support for hydrogen with lower greenhouse gas emissions, for example from electrolysers using renewable electricity, compared with hydrogen from natural gas, could boost the electrolyser market.

    - Regulatory structures that give additional incentives for renewable hydrogen, in price or carbon accounting terms, could further support the electrolyser market, though this appears to be growing well in any case.

- ➔ Stricter regulation on greenhouse gas emissions from the fertiliser industry could also create a large market for renewably-generated or otherwise 'green' hydrogen, as could mechanisms that favour the use of renewable rather than fossil hydrogen in refineries and chemicals production. The anticipated cost of delivered renewable hydrogen from large-scale renewables is already low, but industry is only considering it an option in isolated cases. Increased regulatory pressure would take time to negotiate, but cost of implementation would be limited, unless compensatory measures were negotiated by industry.

8.3.6 Boosting socio-economic spin-offs

In addition to the above recommendations, several actions can be envisaged to promote the socio-economic spin-offs of FCH developments in Europe.

- ➔ Capture the value arising from capital investments. Building-up FCH production capacity (in Europe as well as globally) is capital-intensive. Europe has a strong competitive and export position in machinery and toolmaking in general, and there appears to be a large potential for European companies to supply the FCH industry. A more detailed review of such opportunities – as well as their quantification – has been outside of the scope of this study but would be worth considering.

- ➔ Operation and maintenance. Although operation and maintenance activities will initially be modest in terms of value-added and employment, they will consistently grow over time as deployment levels build up. European companies are well placed to service FCH equipment, through innovative business models including leasing, service level agreements, guarantees, etc. European companies are known world-wide for their reliability and quality, and this asset could be exploited.

Appendix A Value analysis

Estimated value creation potential for FC systems for passenger cars and light commercial vehicles

Figure 28 and Figure 29 show the estimates of the breakdown of value-added for FC systems for passenger cars and light commercial vehicles, under the low and high market scenarios for 2030; corresponding to annual production volumes of 300 thousand and 1.8 million vehicles, respectively. A comparison of the breakdown of value-added creation for all three deployment scenarios for the years 2024 and 2030 is given in Table 27.

The pattern of value-added estimates indicates that at low levels of production, membrane electrode assembly (MEA) activities capture the greatest share of total value-added generated in the supply chain of fuel cell systems for cars and light trucks – 27% of value-added in the low scenario for 2030 – but their share declines substantially as production levels are scaled-up; the share of MEA falls to 8 percent by 2030 under the high deployment scenario. Conversely, the share of value-added captured by system integration increases at higher production levels, as is also the case for hydrogen tanks. These findings reflect differences in the underlying assumptions for opportunities for overall cost (output price) reductions at higher volumes of production, which are assumed greater for MEAs than for system integration and tanks. In terms of value capture across downstream and upstream manufacturing, the estimations clearly show that more value is captured downstream (at the system and subsystem level). This holds for both low and high market deployment scenarios. Notably, a large part of overall value creation potential is embedded in integration and assembly activities.

The highest intensity of value-added creation, at around 60 percent, is in the production of balance of stack items, which covers components such as seals and compression hardware. However, as is also the case for the balance of plant at the system integration stage, this reflects an average estimate across a variety of components for which separate cost estimates have not been made. Gas diffusion layer (GDL) production has the second highest share of value-added in both high and low scenarios, at slightly less than 50 percent. However, despite this high share, the value-added captured at the GDL stage remains low at only 5 percent of total value-added generated in the FCEV supply chain in the low scenario, which decreases as production levels increase.

In terms of the breakdown of value-added by 'production factor' category, under all deployment scenarios the highest overall share is attributed to the annualised cost of capital (capex), which is estimated to account for about half of value-added generated in the low scenario for 2024 and a third of value-added in the high scenario for 2030. Both the share of labour costs and the share of margins in total value-added are shown to rise with increases in the volume of production, with the share of labour costs increasing slightly more rapidly than the share of margins. At the level of individual components and integration/assembly activities, the share of labour costs in total value-added is estimated to be relatively high for balance of plant (for system integration), tanks, gas diffusion layer (GDL), and system integration. The share of capital costs in value-added is highest for balance of stack, membrane electrode assembly, and bipolar plates.

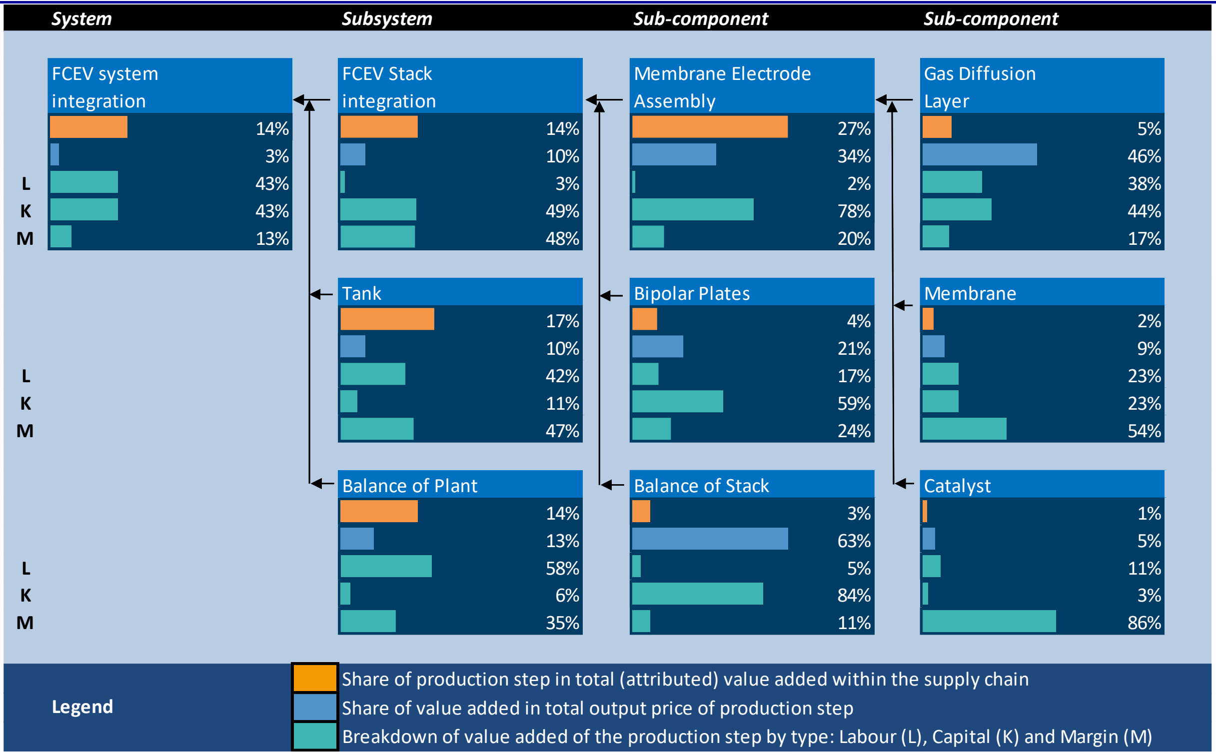


Figure 28: Value-added decomposition for FC system for cars and light commercial vehicles, low market deployment scenario, 2030

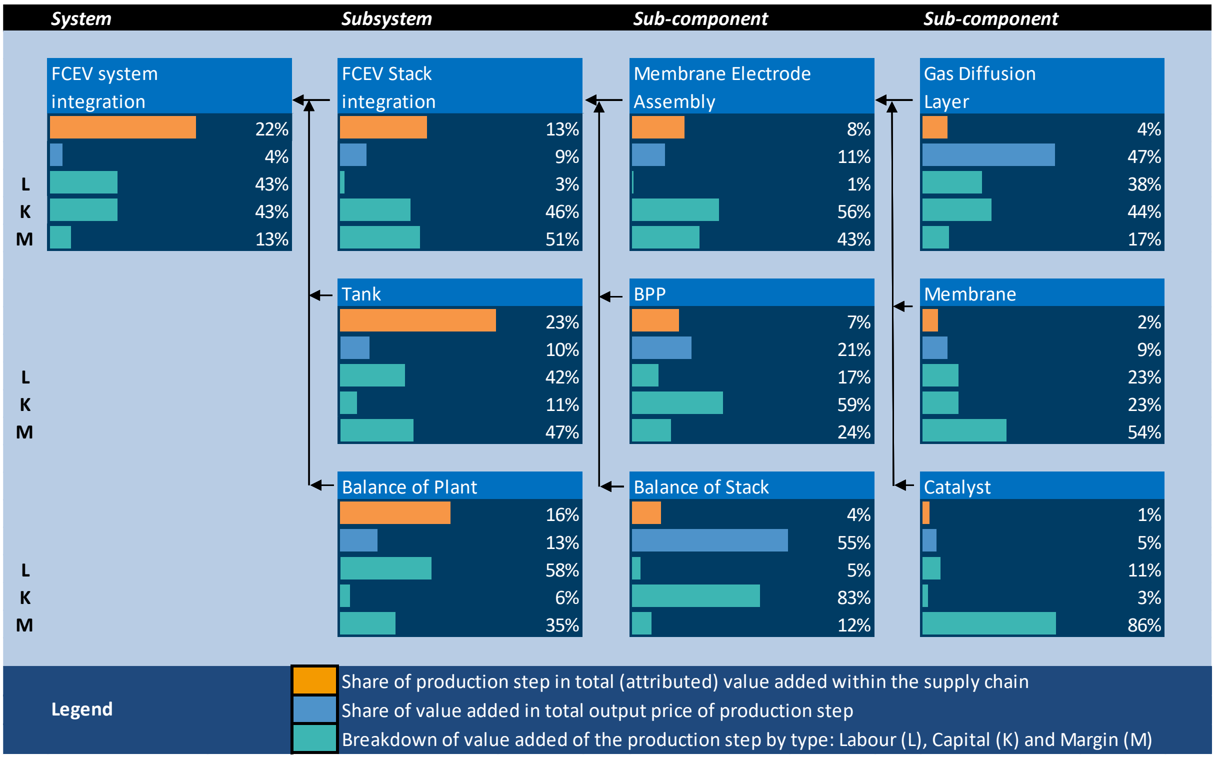


Figure 29: Value-added decomposition for FC system for cars and light commercial vehicles, high market deployment scenario, 2030

Table 27: Value-added decomposition for FC system for cars and light commercial vehicles by market deployment scenario, 2024 and 2030

Year	**2024**			**2030**		
Deployment scenario	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Total annual production (Thousand units)	95	352	645	304	1,062	1,796
Annual production rate of leading manufacturer (Thousand units)	57	211	387	182	637	1,077
System cost (Output price)	€ 10,800	€ 7,800	€ 6,800	€ 8,100	€ 6,100	€ 5,400
Total VA within system	€ 2,900	€ 1,800	€ 1,500	€ 1,900	€ 1,300	€ 1,100
Application VA as a share of total costs (VA / output price)	27%	23%	22%	23%	21%	20%
Rate of VA (VA / material & overhead costs)	37%	30%	28%	31%	27%	26%
Breakdown of VA by component or activity						
Total VA in system (excl. MEA and Stack)	**35%**	**45%**	**51%**	**44%**	**55%**	**61%**
FCEV system integration	10%	14%	17%	14%	19%	22%
Tank	13%	17%	19%	17%	21%	23%
Balance of Plant	12%	14%	15%	14%	16%	16%
Total VA in stack (excl. MEA)	**19%**	**21%**	**21%**	**21%**	**23%**	**24%**
FCEV Stack integration	14%	13%	13%	14%	13%	13%
Bipolar Plate	3%	5%	5%	4%	6%	7%
Balance of Stack	2%	3%	3%	3%	4%	4%
Total VA in MEA	**46%**	**34%**	**28%**	**35%**	**22%**	**15%**
ME Assembly	38%	26%	20%	27%	14%	8%
Gas Diffusion Layer	6%	5%	5%	5%	4%	4%
Membrane	2%	2%	2%	2%	2%	2%
Catalyst	0%	1%	1%	1%	1%	1%
Breakdown of total VA by cost category						
Labour cost	21%	26%	28%	25%	30%	33%
Capex cost	50%	43%	40%	45%	37%	33%
Margin	28%	31%	32%	30%	33%	34%
Total	100%	100%	100%	100%	100%	100%
Notes: numbers may not add up due to rounding of data						

Estimated value creation potential for FC systems for buses

The estimates of the breakdown of value-added for FC systems for buses under the low and high market scenarios for 2030 are presented in Figure 30 and Figure 31. Under the low scenario, the annual global production volume corresponds to 10 thousand vehicles, while 40 thousand buses would be produced under a high scenario. The breakdown of value-added creation for all three scenarios, for both 2024 and 2030, can be found in Table 28.

As with FCEVs, at low levels of production MEA activities capture the greatest share of total value-added generated in the supply chain of fuel cell systems for buses (37% of value-added generated in the low scenario for 2030), followed by hydrogen tanks (26% of value-added). At higher production volumes, the position of these two segments is reversed, with MEA activities capturing 26 percent of value-added and tanks capturing 33 percent in the high scenario for 2030. Given the relatively modest production levels, even under the high scenario, opportunities for reduction in costs arising from increased volumes of production of MEAs and associated sub-components are less pronounced than for FCEVs. Thus, the estimates show a more modest shift of value capture from upstream to downstream manufacturing with higher production volumes. Overall, system integration activities are estimated to represent only a modest part of overall value-added generated in the supply chain of fuel cell systems for buses, achieving only 6 percent in the high scenario for 2030.

In terms of the intensity of value-added creation of different production segments, this is highest for the balance of stack (70% under the low scenario and 67% under the high scenario for 2030), followed by MEA activities (50% and 41%) and the GDL (46% in both scenarios), although GDL accounts for only around 5 percent of total value-added generated in the supply chain of fuel cell systems for buses.

As with systems for FCEVs, under all deployment scenarios the annualised cost of capital (capex) represents the largest share of value-added when broken down by ‘production factor’. Capex is estimated to account for about half of value-added generated, with its share ranging from 54 percent in the low scenario for 2024 to 44 percent of value-added in the high scenario for 2030. Both the share of labour costs and the share of margins in total value-added are shown to rise modestly with increases in the volume of production. At the level of individual components and integration/assembly activities, the share of labour costs in total value-added is estimated to be relatively high for balance of plant (for system integration) and system integration, together with tanks and the gas diffusion layer (GDL). The share of capital costs in value-added is highest for membrane electrode assembly, bipolar plates and stack integration.

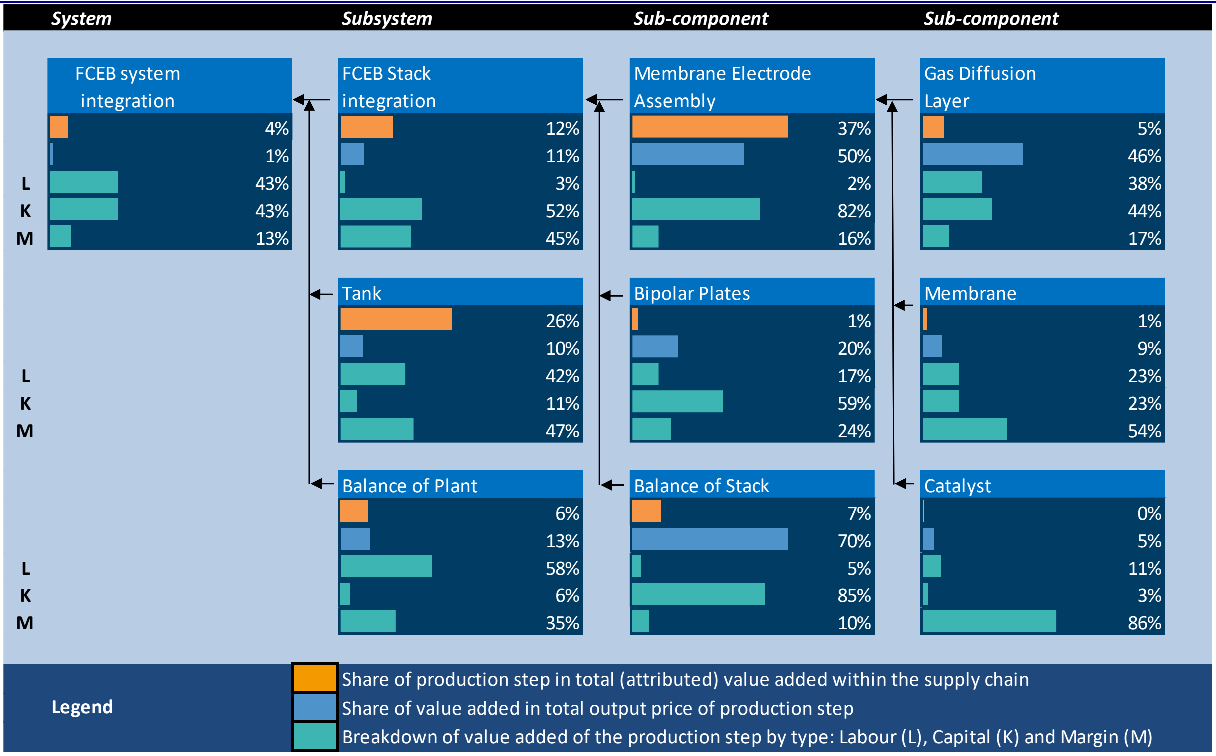


Figure 30: Value-added decomposition for FC system for buses, low market deployment scenario, 2030

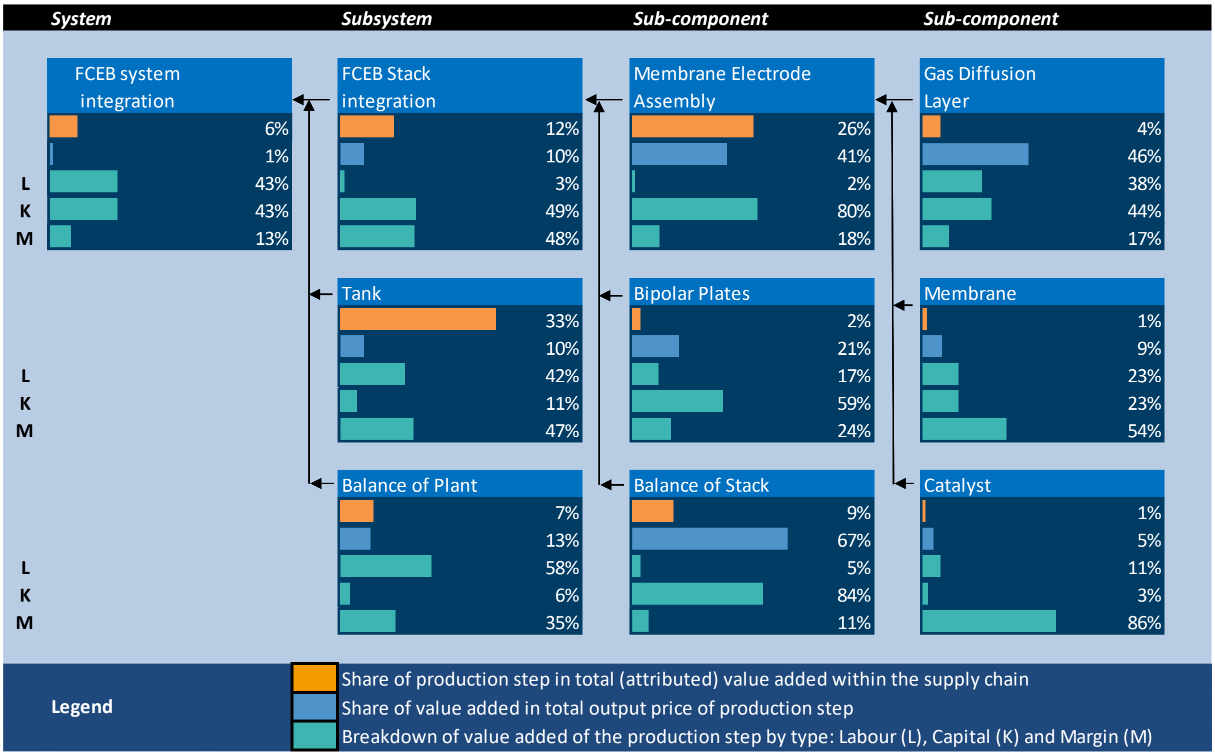


Figure 31: Value-added decomposition for FC system for buses, high market deployment scenario, 2030

Table 28: Value-added decomposition for FC system for buses by market deployment scenario, 2024 and 2030

Year	2024			2030		
Deployment scenario	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Total annual production (Thousand units)	4	8	10	10	23	40
Annual production rate of leading manufacturer (MW)	500	800	1,400	1,400	3,000	5,400
System cost (Output price)	€ 59,400	€ 52,300	€ 46,600	€ 46,900	€ 39,500	€ 34,900
Total VA within system	€ 15,400	€ 12,800	€ 10,600	€ 10,900	€ 8,400	€ 6,900
Application VA as a share of total costs (VA / output price)	26%	24%	23%	23%	21%	20%
Rate of VA (VA / material & overhead costs)	35%	32%	29%	30%	27%	25%
Breakdown of VA by component or activity						
Total VA in system (excl. MEA and Stack)	**31%**	**34%**	**38%**	**37%**	**42%**	**46%**
FCEB system integration	3%	4%	4%	4%	5%	6%
Tank	22%	24%	27%	26%	30%	33%
Balance of Plant	6%	6%	6%	6%	7%	7%
Total VA in stack (excl. MEA)	**19%**	**19%**	**20%**	**20%**	**21%**	**22%**
FCEB Stack integration	13%	12%	12%	12%	12%	12%
Bipolar Plate	1%	1%	1%	1%	2%	2%
Balance of Stack	5%	6%	7%	7%	8%	9%
Total VA in MEA	**50%**	**47%**	**43%**	**43%**	**37%**	**31%**
ME Assembly	44%	40%	36%	37%	31%	26%
Gas Diffusion Layer	6%	5%	5%	5%	4%	4%
Membrane	1%	1%	1%	1%	1%	1%
Catalyst	0%	0%	0%	0%	0%	1%
Breakdown of total VA by cost category						
Labour cost	18%	19%	20%	20%	22%	24%
Capex cost	54%	52%	50%	50%	47%	44%
Margin	28%	29%	30%	29%	31%	32%
Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
Notes: numbers may not add up due to rounding of data						

Estimated value creation potential for FC systems for HGVs

The estimates of the breakdown of value-added for FC system for HGVs under the low and high market scenarios for 2030 are presented in Figure 32 and Figure 33. Under the low scenario, the annual global production volume corresponds to 4 thousand vehicles, while 17 thousand fuel cell HGVs are produced under a high scenario. The breakdown of value-added creation for all three scenarios, for both 2024 and 2030, can be found in Table 29.

> **Note:** *As the underlying cost models assume that fuel cell production for buses, HGVs and trains is based on the same production technology and fuel cell component configuration (catalyst, GDL, MEA, bipolar plated, balance of stack and balance of plant), with overall production learning cost reduction factors reflecting a cumulative effect across these application types, the pattern of GVA creation and intensity is similar across the three application types. Differences arise because of the different size of stacks and tanks used for each application.*

MEA activities are estimated to generate the largest share of total value-added in the supply chain of fuel cell systems for HGVs. Although this share declines with increased production volumes – from 40% in the low scenario for 2030 to 29% in the high scenario HGVs – it remains greater than the value-added generated by production of tanks, which reaches 26 percent under the high scenario for 2030. Stack integration, which is steady at around 13 percent of total value-added, has the third largest share in the supply chain of FC system for HGVs.

Reflecting the common cost model used, the intensity of value-added creation in the supply chain for fuel cell systems for HGVs is essentially the same as for buses. Value-added intensity is highest for the balance of stack, followed by MEA activities and the GDL. Also, the breakdown of value-added generation by 'production factor' has the same pattern as for buses, with differences arising due to the relative share of the fuel cell stack, tank and balance of plant in the overall cost of the fuel cell system for different applications. Under all deployment scenarios the annualised cost of capital (capex) represents the largest share of value-added when broken down by 'production factor', ranging from 57 percent in the low scenario for 2024 to 48 percent of value-added in the high scenario for 2030. Both the share of labour costs and the share of margins in total value-added are shown to rise modestly with increases in the volume of production.

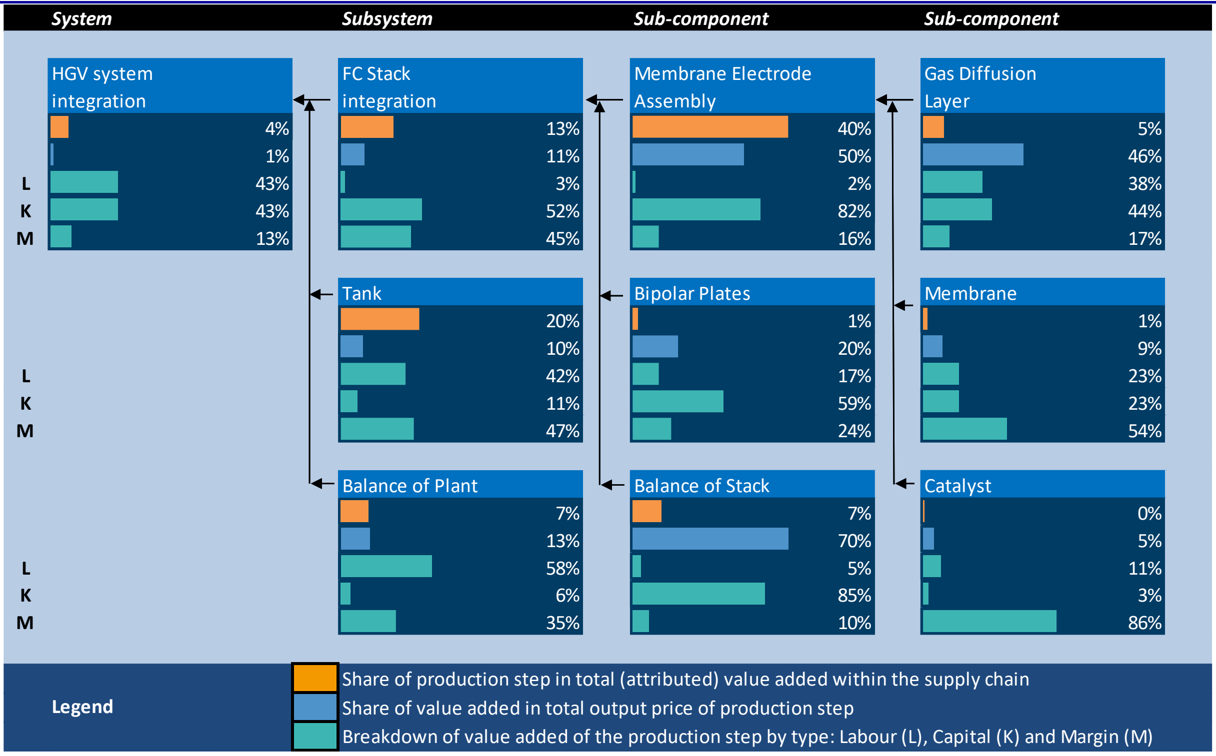


Figure 32: Value-added decomposition for FC system for HGVs, low market deployment scenario, 2030

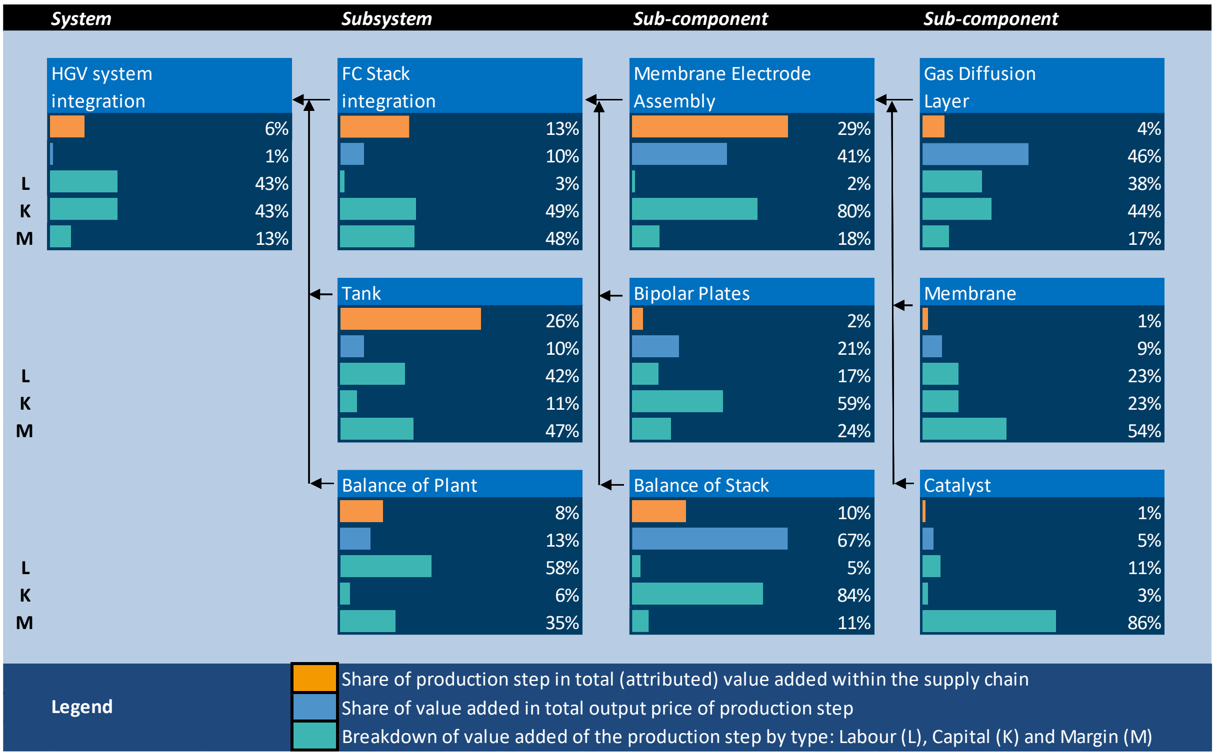


Figure 33: Value-added decomposition for FC system for HGVs, high market deployment scenario, 2030

Table 29: Value-added decomposition for FC system for HGVs by market deployment scenario, 2024 and 2030

Year	2024			2030		
Deployment scenario	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Total annual production (Thousand units)	1	2	4	4	9	17
Annual production rate of leading manufacturer (MW)	500	800	1,400	1,400	3,000	5,400
System cost (Output price)	€ 70,600	€ 61,600	€ 54,400	€ 54,700	€ 45,600	€ 40,000
Total VA within system	€ 20,600	€ 17,000	€ 14,000	€ 14,300	€ 10,900	€ 8,900
Application VA as a share of total costs (VA / output price)	29%	28%	26%	26%	24%	22%
Rate of VA (VA / material & overhead costs)	41%	38%	35%	35%	31%	29%
Breakdown of VA by component or activity						
Total VA in system (excl. MEA and Stack)	**26%**	**29%**	**32%**	**31%**	**36%**	**40%**
HGV system integration	3%	4%	5%	4%	6%	6%
Tank	16%	18%	20%	20%	23%	26%
Balance of Plant	6%	7%	7%	7%	7%	8%
Total VA in stack (excl. MEA)	**20%**	**21%**	**22%**	**22%**	**24%**	**25%**
HGV Stack integration	14%	13%	13%	13%	13%	13%
Bipolar Plate	1%	1%	1%	1%	2%	2%
Balance of Stack	5%	6%	7%	7%	9%	10%
Total VA in MEA	**54%**	**51%**	**46%**	**46%**	**40%**	**35%**
ME Assembly	47%	43%	40%	40%	34%	29%
Gas Diffusion Layer	6%	6%	5%	5%	5%	4%
Membrane	1%	1%	1%	1%	1%	1%
Catalyst	0%	0%	0%	0%	0%	1%
Breakdown of total VA by cost category						
Labour cost	16%	17%	19%	18%	20%	22%
Capex cost	57%	56%	53%	54%	51%	48%
Margin	26%	27%	28%	28%	29%	30%
Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
Notes: numbers may not add up due to rounding of data						

Estimated value creation potential for FC systems for trains and light rail

The estimates of the breakdown of value-added for FC systems for trains and light rail under the low and high market scenarios for 2030 are presented in Figure 34 and Figure 35. Under the low scenario, the annual global production volume corresponds to around 80 systems, while around 400 fuel cell systems for trains are produced under a high scenario. The breakdown of value-added creation for all three scenarios, for both 2024 and 2030, can be found in Table 30.

Note: *As the underlying cost models assume that fuel cell production for buses, HGVs and trains is based on the same production technology and fuel cell component configuration (catalyst, GDL, MEA, bipolar plated, balance of stack and balance of plant), with overall production learning cost reduction factors reflecting a cumulative effect across these application types, the pattern of GVA creation and intensity is similar across the three application types. Differences arise because of the different size of stacks and tanks used for each application.*

In contrast to road vehicles, hydrogen storage tanks are estimated to generate the largest share of total value-added in the supply chain of fuel cell systems for trains and light rail. This share, which reaches over half of total value-added under the high scenario for 2030, increases over time and at higher production levels. By contrast, the share of value-added generated from MEA activities and associated components (i.e. GDL, membranes and catalyst) decreases with increases in production volumes. Their combined share, which represents 41 percent of total value-added in the low scenario for 2024, is estimated at only 23 percent in the high scenario for 2030. These findings reflect differences in the underlying assumptions for opportunities for overall cost (output price) reductions at higher volumes of production, which are assumed greater for MEAs than for system integration and tanks.

Reflecting the common cost model used, the intensity of value-added creation in the supply chain for fuel cell systems for trains and light rail is essentially the same as for buses and HGVs. Value-added intensity is highest for the balance of stack (70% in the low scenario for 2030 and 67% in the high scenario), followed by MEA activities (50% and 41%) and the GDL (46% in both scenarios).

Although the general breakdown of value-added generation by ‘production factor’ has the same pattern as for buses and HGVs, the overall share of value-added attributable to capital (capex) is lower for fuel cell systems for trains and light rail. This finding is attributable to differences in the relative share of the fuel cell stack, tank and balance of plant in the overall cost of the fuel cell system for different applications. Specifically, this relates to the high share of tanks (and balance of plant) in overall system costs, which have low capital intensity and higher labour intensity compared to stack integration and MEA activities.

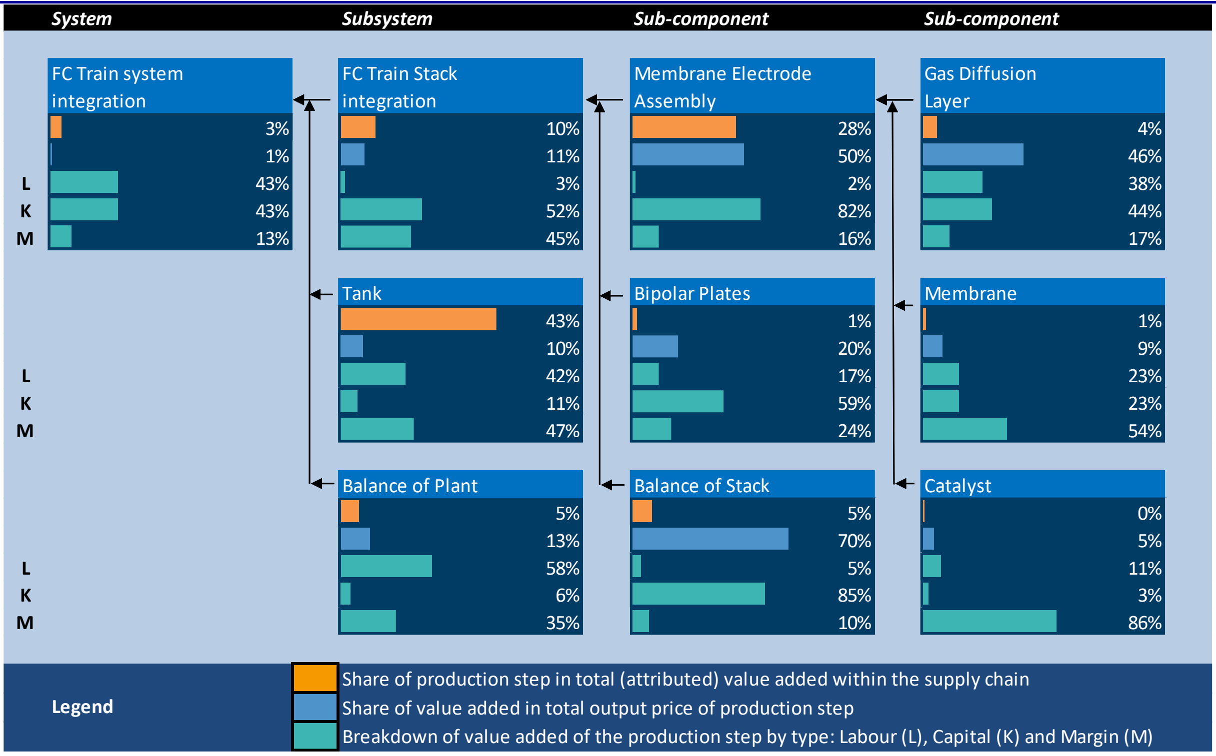


Figure 34: Value-added decomposition for FC system for trains and light rail, low market deployment scenario, 2030

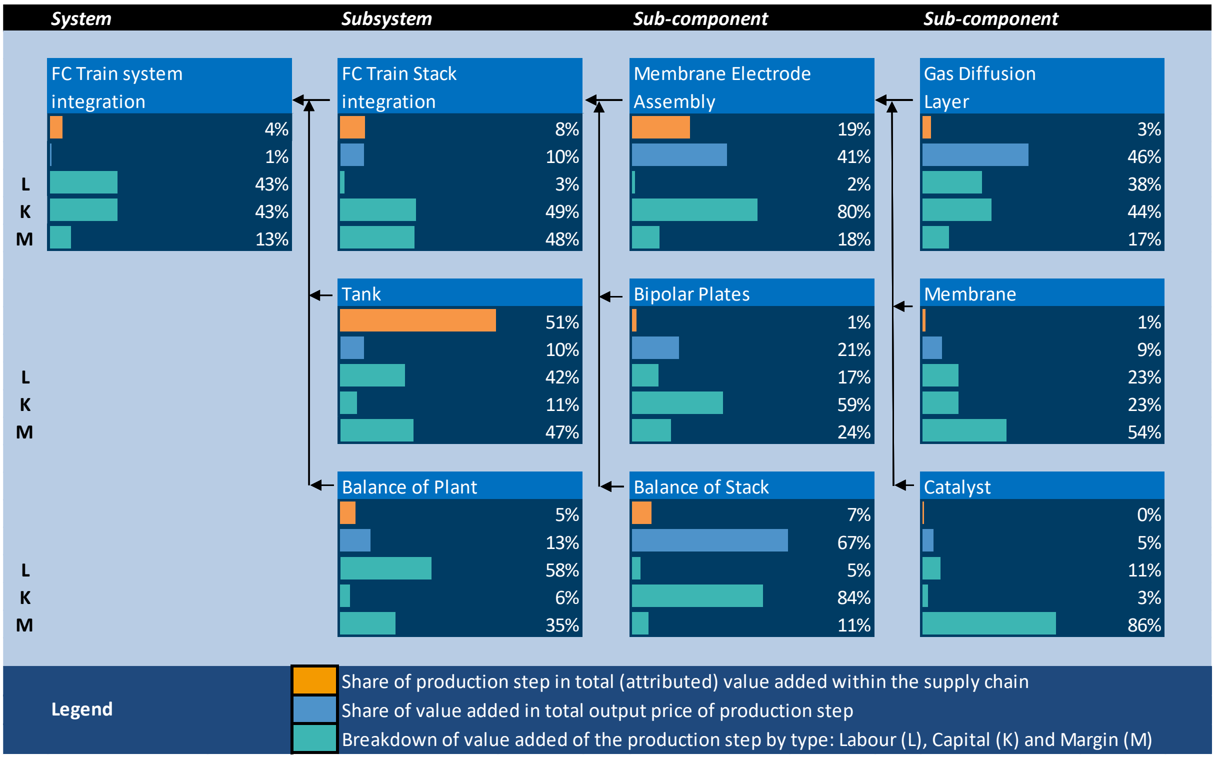


Figure 35: Value-added decomposition for FC system for trains and light rail, high market deployment scenario, 2030

Table 30: Value-added decomposition for FC system for trains and light rail by market deployment scenario, 2024 and 2030

Year	**2024**			**2030**		
Deployment scenario	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Total annual production (Units)	30	70	160	80	240	400
Annual production rate of leading manufacturer (MW)	500	800	1,400	1,400	3,000	5,400
System cost (Output price)	€ 206,000	€ 184,000	€ 167,000	€ 168,000	€ 144,000	€ 129,000
Total VA within system	€ 40,900	€ 34,600	€ 29,500	€ 30,100	€ 24,100	€ 20,400
Application VA as a share of total costs (VA / output price)	20%	19%	18%	18%	17%	16%
Rate of VA (VA / material & overhead costs)	25%	23%	21%	22%	20%	19%
Breakdown of VA by component or activity						
Total VA in system (excl. MEA and Stack)	**44%**	**48%**	**52%**	**51%**	**56%**	**61%**
FC Train system integration	3%	3%	3%	3%	4%	4%
Tank	37%	40%	44%	43%	47%	51%
Balance of Plant	5%	5%	5%	5%	5%	5%
Total VA in stack (excl. MEA)	**15%**	**15%**	**15%**	**16%**	**16%**	**16%**
FC Train Stack integration	10%	10%	9%	10%	9%	8%
Bipolar Plate	1%	1%	1%	1%	1%	1%
Balance of Stack	4%	5%	5%	5%	6%	7%
Total VA in MEA	**41%**	**37%**	**33%**	**33%**	**28%**	**23%**
ME Assembly	35%	32%	28%	28%	23%	19%
Gas Diffusion Layer	5%	4%	4%	4%	3%	3%
Membrane	1%	1%	1%	1%	1%	1%
Catalyst	0%	0%	0%	0%	0%	0%
Breakdown of total VA by cost category						
Labour cost	22%	24%	25%	25%	27%	29%
Capex cost	46%	44%	41%	41%	38%	35%
Margin	32%	33%	34%	33%	35%	36%
Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
Notes: numbers may not add up due to rounding of data						

Estimated value creation potential for FC systems for PEM micro-CHPs

The estimates of the breakdown of value-added for FC system for PEM micro-CHPs under the low and high market scenarios for 2030 are presented in Figure 36 and Figure 37. Under the low scenario, the annual global production volume corresponds to around 150 thousand systems, while around 500 thousand fuel cell systems are produced under a high scenario. The breakdown of value-added creation for all three scenarios, for both 2024 and 2030, can be found in Table 31.

A comparison of the low and high scenarios for 2030 reveals only small changes in the distribution of value-added generated within the supply chain, reflecting the fact that production volumes in both scenarios are substantial and scope for further cost reductions from economies of scale are limited. Approximately three-quarters of value-added is generated in the downstream segments of system integration and production of balance of plant items, with system integration representing around two-fifths of total value-added and balance of plant around one-third. There is some shifting of value-added from upstream to downstream supply chain segments, with both membrane assembly activities and the gas diffusion layer accounting for a declining share of total value-added at higher production volumes.

The intensity of value-added generation is highest for balance of stack – 71% in the low scenario for 2030 and 68% in the high scenario – followed by membrane electrode assembly activities (49% in the low scenario) and the gas diffusion layer (46%).

Within the supply chain for FC systems for PEM micro-CHPs, labour and capital (capex) inputs each account for around 40 percent of overall value-added creation. The share of labour is largely driven by production of balance of plant items for system integration and system integration activities themselves, with labour accounting for nearly 60 percent of value-added for balance of plant items and over 40 percent for system integration activities. The share of capital (capex) in value-added generation is highest for membrane assembly activities (85% in both the high and low scenarios for 2030) and balance of stack (84%).

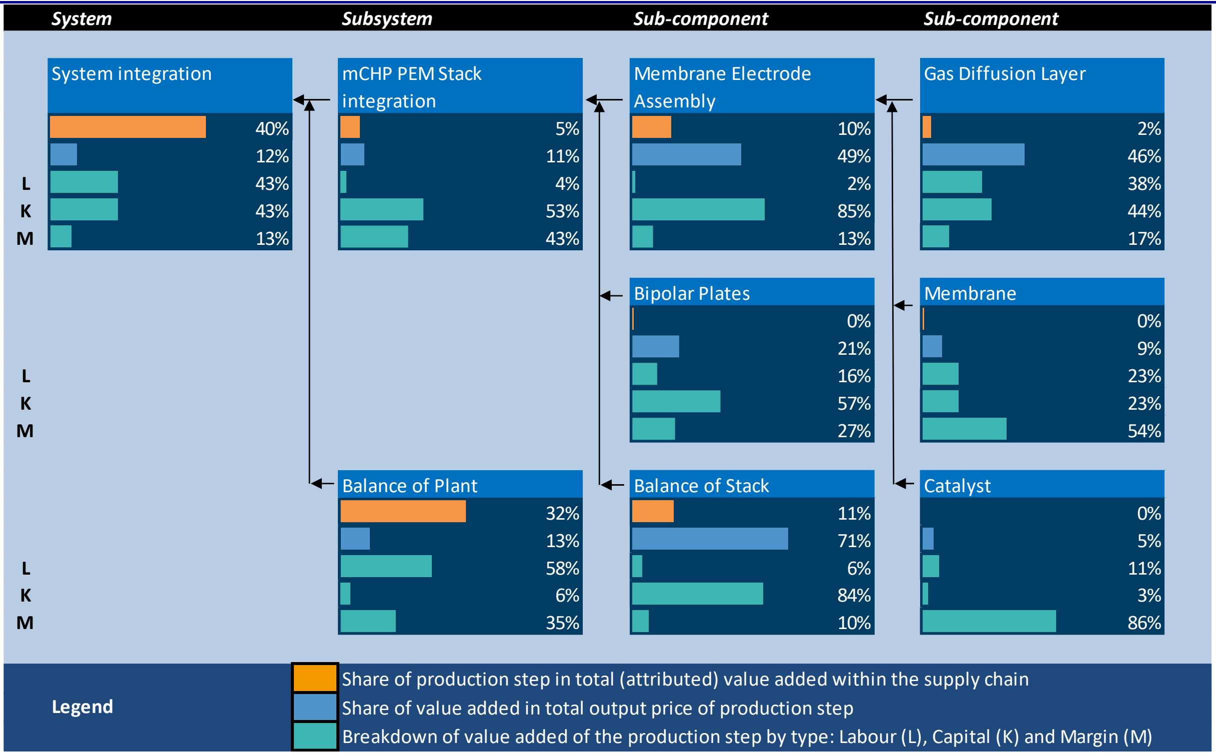


Figure 36: Value-added decomposition for FC system for PEM micro-CHPs, low market deployment scenario, 2030

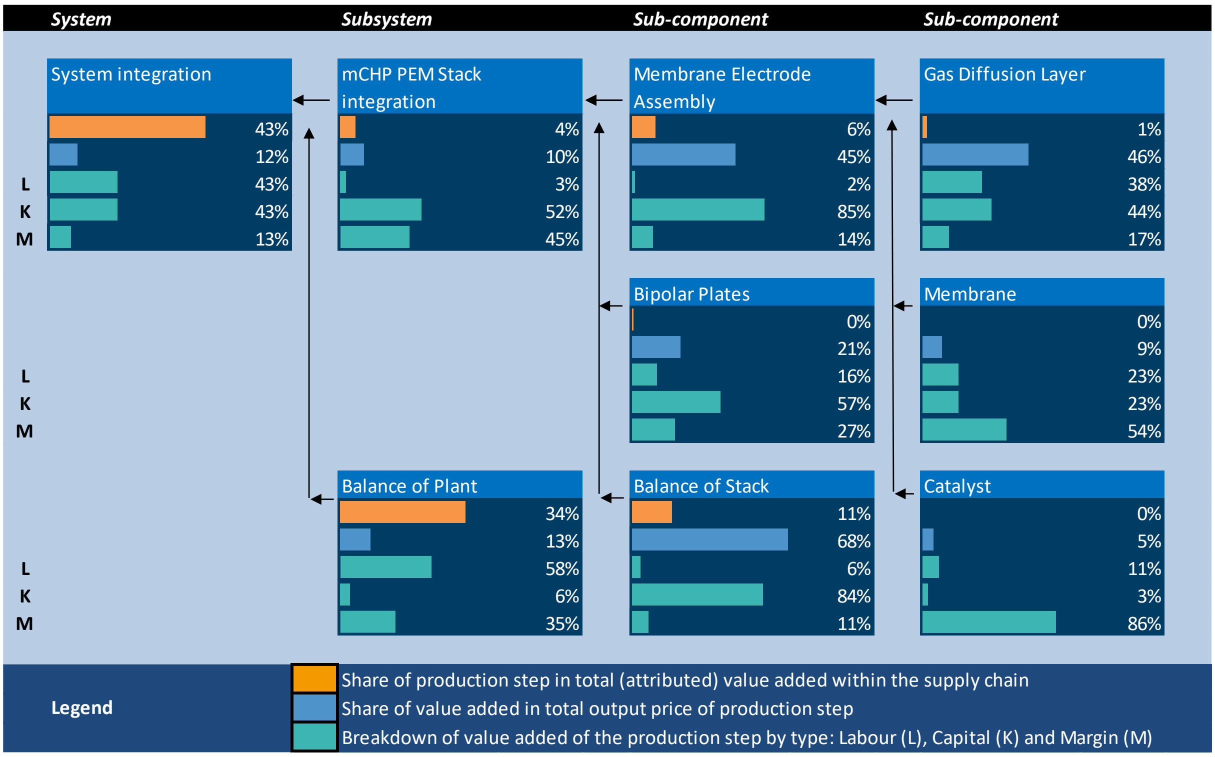


Figure 37: Value-added decomposition for FC system for PEM micro-CHPs, high market deployment scenario, 2030

Table 31: Value-added decomposition for FC system for PEM micro-CHPs by market deployment scenario, 2024 and 2030

Year	**2024**			**2030**		
Deployment scenario	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Total annual production (Thousand units)	47	130	169	151	308	505
Annual production rate of leading manufacturer (Thousand units)	28	78	101	91	185	303
System cost (Output price)	€ 2,700	€ 2,400	€ 2,300	€ 2,300	€ 2,200	€ 2,000
Total VA within system	€ 800	€ 700	€ 700	€ 700	€ 600	€ 600
Application VA as a share of total costs (VA / output price)	31%	30%	30%	30%	29%	29%
Rate of VA (VA / material & overhead costs)	46%	44%	43%	43%	42%	41%
Breakdown of VA by component or activity						
Total VA in system (excl. MEA and Stack)	**65%**	**70%**	**71%**	**72%**	**75%**	**77%**
PEM micro-CHP system integration	36%	39%	39%	40%	41%	43%
Balance of Plant	29%	31%	32%	32%	33%	34%
Total VA in stack (excl. MEA)	**16%**	**16%**	**16%**	**16%**	**15%**	**15%**
PEM micro-CHP stack integration	6%	5%	5%	5%	4%	4%
Bipolar Plate	0%	0%	0%	0%	0%	0%
Balance of Stack	10%	10%	10%	11%	11%	11%
Total VA in MEA	**19%**	**15%**	**13%**	**12%**	**10%**	**8%**
ME Assembly	15%	12%	11%	10%	8%	6%
Gas Diffusion Layer	4%	3%	2%	2%	2%	1%
Membrane	0%	0%	0%	0%	0%	0%
Catalyst	0%	0%	0%	0%	0%	0%
Breakdown of total VA by cost category						
Labour cost	35%	37%	38%	38%	39%	40%
Capex cost	44%	41%	41%	40%	39%	38%
Margin	21%	22%	22%	22%	22%	22%
Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
Notes: numbers may not add up due to rounding of data						

Estimated value creation potential for FC systems for PEM CHPs

The estimates of the breakdown of value-added for FC system for PEM CHPs under the low and high market scenarios for 2030 are presented in Figure 38 and Figure 39. Under the low scenario, the annual global production volume corresponds to around 3,300 systems, while around 21,000 thousand fuel cell systems are produced under a high scenario. The breakdown of value-added creation for all three scenarios, for both 2024 and 2030, can be found in Table 32.

The pattern of value-added generation is like that estimated for PEM micro-CHP systems, although the share of value-added generated by balance of stack items for large systems is minimal, whereas it is estimated at around 10% for micro systems. This is offset by an even higher share of value-added generated in the downstream segments, with system integration and production of balance of plant items reaching a combined share over 90 percent in both scenarios. System integration alone reaches half of total value-added generated in the supply chain.

The intensity of value-added creation is highest for membrane electrode assembly activities, together with balance of stack and the gas diffusion layer, though neither of the latter two segments make a measurable contribution to overall value-added creation in the supply chain.

Labour contributes around 45 percent of total value-added generated in the PEM CHP supply chain, which is higher than for PEM micro-CHPs. The capital (capex) share is around one third. As with micro-CHPs, the high share of labour is largely driven by production of balance of plant items for system integration and system integration activities themselves, with labour accounting for over half of value-added for balance of plant items and over 40 percent for system integration activities. The share of capital (capex) in value-added generation is highest for membrane assembly activities and balance of stack.

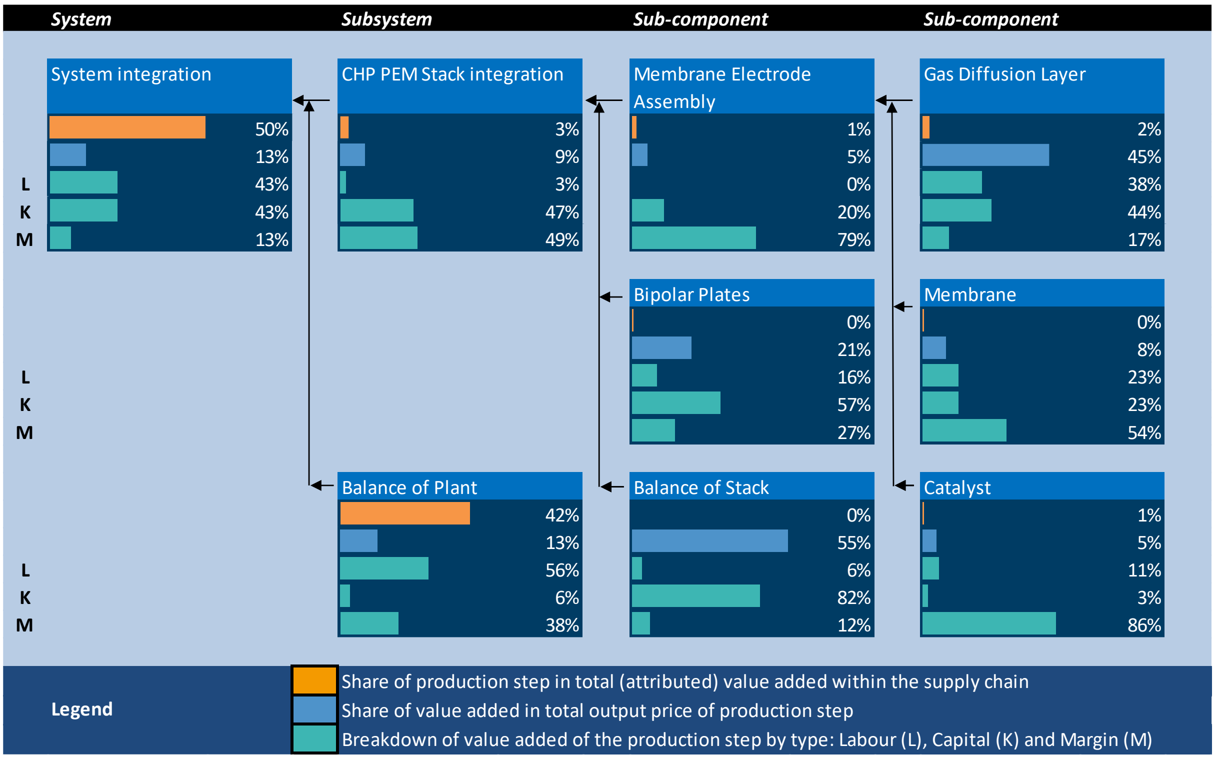


Figure 38: Value-added decomposition for FC system for PEM CHPs, low market deployment scenario, 2030

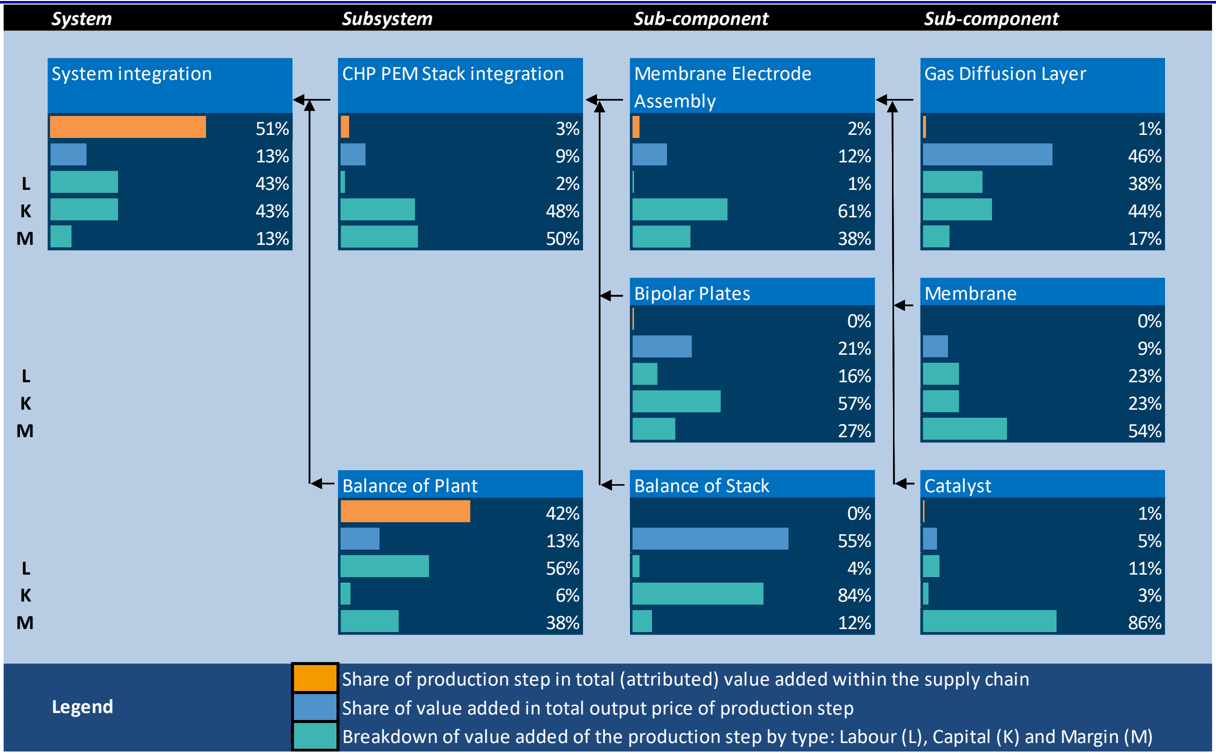


Figure 39: Value-added decomposition for FC system for PEM CHPs, high market deployment scenario, 2030

Table 32: Value-added decomposition for FC system for PEM CHPs by market deployment scenario, 2024 and 2030

Year	**2024**			**2030**		
Deployment scenario	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Total annual production (Units)	900	1,600	5,300	3,300	9,000	21,000
Annual production rate of leading manufacturer (Units)	500	900	3,200	2,000	5,400	12,600
System cost (Output price)	€ 214,000	€ 200,000	€ 178,000	€ 184,000	€ 170,000	€ 158,000
Total VA within system	€ 56,000	€ 51,000	€ 45,400	€ 45,600	€ 42,700	€ 39,700
Application VA as a share of total costs (VA / output price)	26%	26%	26%	25%	25%	25%
Rate of VA (VA / material & overhead costs)	35%	34%	34%	33%	34%	34%
Breakdown of VA by component or activity						
Total VA in system (excl. MEA and Stack)	**83%**	**88%**	**91%**	**93%**	**92%**	**93%**
PEM micro-CHP system integration	45%	48%	50%	50%	50%	51%
Balance of Plant	38%	40%	42%	42%	42%	42%
Total VA in stack (excl. MEA)	**5%**	**4%**	**3%**	**3%**	**3%**	**3%**
PEM micro-CHP stack integration	4%	4%	3%	3%	3%	3%
Bipolar Plate	0%	0%	0%	0%	0%	0%
Balance of Stack	0%	0%	0%	0%	0%	0%
Total VA in MEA	**12%**	**8%**	**5%**	**4%**	**5%**	**4%**
ME Assembly	8%	5%	3%	1%	3%	2%
Gas Diffusion Layer	4%	3%	2%	2%	1%	1%
Membrane	0%	0%	0%	0%	0%	0%
Catalyst	0%	1%	1%	1%	1%	1%
Breakdown of total VA by cost category						
Labour cost	43%	45%	46%	47%	46%	46%
Capex cost	32%	30%	28%	27%	28%	28%
Margin	25%	25%	26%	26%	25%	25%
Total	100%	100%	100%	100%	100%	100%
Notes: numbers may not add up due to rounding of data						

Estimated value creation potential for PEM electrolyser systems

The estimates of the breakdown of value-added for PEM electrolysers under the low and high market scenarios for 2030 are presented in Figure 40 and Figure 41. Under the low scenario, the annual global production volume corresponds to around 700 systems (900 MW), while the high scenario corresponds to annual production of around 3,200 systems (4,000 MW). The breakdown of value-added creation for all three scenarios, for both 2024 and 2030, is shown in Table 33.

The estimates indicate that the generation of value-added is concentrated in three downstream production segments, namely system integration at just below 50 percent of total value-added generated in the supply chain, balance of plant at just below 20 percent, and stack integration, at around 15 percent. Overall, these segments account for more than four-fifths of value-added generated in the supply chain. This pattern shows limited variation across the scenarios and when comparing 2024 and 2030 estimates.

In terms of the intensity of value-added generation, the highest rates are observed in more upstream segments, particularly balance of stack component – for which value-added is estimated at 54% of the cost price in 2030 for both the low and high scenarios – and porous layers (44%). However, these components represent, respectively, only 7% and 2% of the total value-added generated in the supply chain.

The share of value-added generation by each 'production factor' is relatively stable across time and scenarios. Labour inputs account for around a third of total value-added generation and capital inputs (capex) for just below 45 percent. For 2030, the share of labour in total value-added generation is highest in balance of plant for system integration (58%), system integration (43%) and the porous layer (40%). Conversely, the share of capital dominates for balance of stack components (84%), stack integration (62-64%) and membrane electrode assembly activities (61%).

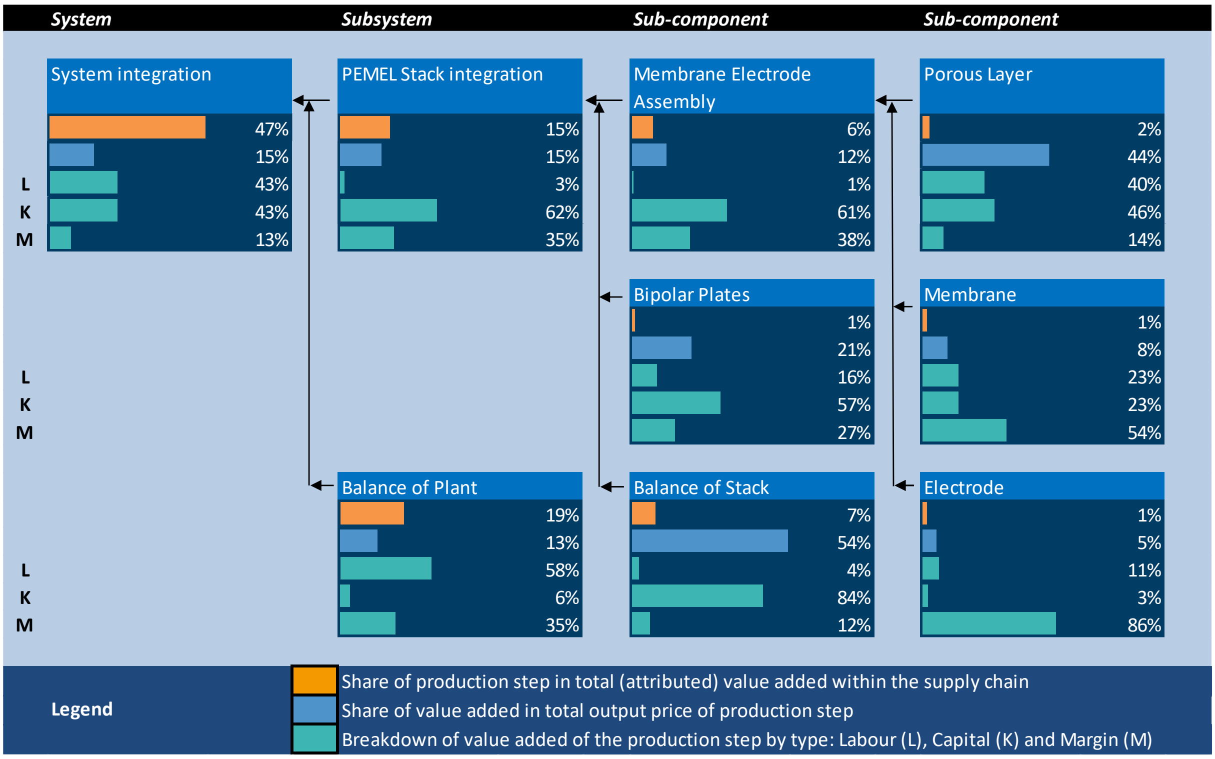


Figure 40: Value-added decomposition for PEM electrolyser systems, low market deployment scenario, 2030

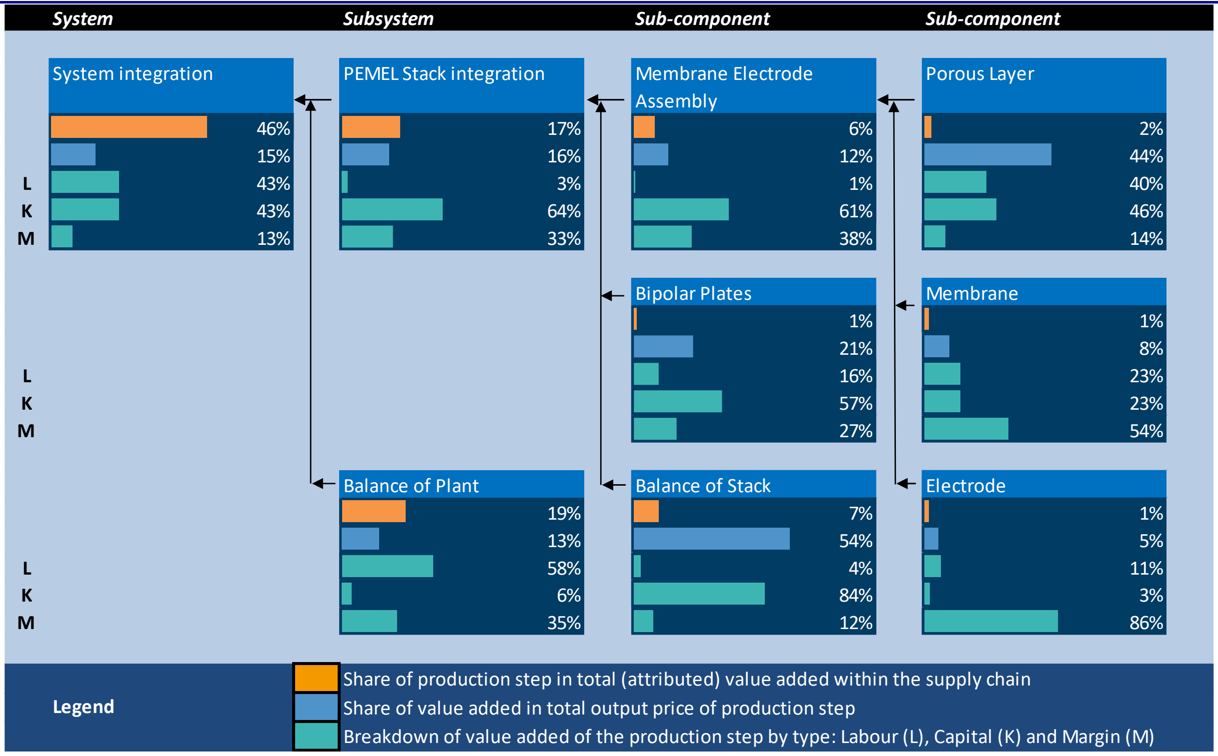


Figure 41: Value-added decomposition for PEM electrolyser systems, high market deployment scenario, 2030

Table 33: Value-added decomposition for PEM electrolyser systems by market deployment scenario, 2024 and 2030

Year	**2024**			**2030**		
Deployment scenario	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Total annual production (Units)	300	650	1,050	700	1,600	3,250
Annual production rate of leading manufacturer (Units)	200	400	650	450	950	1,950
System cost (Output price)	€ 335,000	€ 314,000	€ 303,000	€ 311,000	€ 295,000	€ 282,000
Total VA within system	€ 104,000	€ 103,000	€ 100,000	€ 102,000	€ 98,000	€ 94,000
Application VA as a share of total costs (VA / output price)	31%	33%	33%	33%	33%	33%
Rate of VA (VA / material & overhead costs)	45%	49%	49%	49%	49%	50%
Breakdown of VA by component or activity						
Total VA in system (excl. MEA and Stack)	**70%**	**67%**	**66%**	**67%**	**66%**	**64%**
PEMEL system integration	50%	47%	47%	47%	47%	46%
Balance of Plant	20%	19%	19%	19%	19%	19%
Total VA in stack (excl. MEA)	**17%**	**23%**	**24%**	**23%**	**24%**	**25%**
PEMEL Stack integration	8%	15%	16%	15%	16%	17%
BPP	1%	1%	1%	1%	1%	1%
Balance of Stack	8%	7%	7%	7%	7%	7%
Total VA in MEA	**14%**	**10%**	**10%**	**10%**	**10%**	**10%**
ME Assembly	8%	6%	6%	6%	6%	6%
GDL	3%	2%	2%	2%	2%	2%
Membrane	1%	1%	1%	1%	1%	1%
Catalyst	1%	1%	1%	1%	1%	1%
Breakdown of total VA by cost category						
Labour cost	36%	34%	34%	34%	33%	33%
Capex cost	39%	43%	43%	43%	43%	44%
Margin	25%	23%	23%	23%	23%	23%
Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
Notes: numbers may not add up due to rounding of data						

Estimated value creation potential for FC systems for SOFC micro-CHPs

The estimates of the breakdown of value-added for SOFC micro-CHP systems under the low and high market scenarios for 2030 are presented in Figure 42 and Figure 43. Under the low scenario, the annual global production volume corresponds to around 225 thousand systems, while the high scenario corresponds to annual production of around 760 thousand systems. The breakdown of value-added creation for all three scenarios, for both 2024 and 2030, is shown in Table 34.

A comparison of the low and high scenarios for 2030 reveals relatively small changes in the distribution of value-added generated within the supply chain. Most value-added is generated in the supply of balance of plant components for system integration, which accounts for 55 percent of value-added in the low scenario for 2030 and over 60 percent in the high scenario. Balance of stack items account for a further 15 percent of value-added generated in the supply chain under both scenarios. In contrast to PEM micro-CHP systems, system integration activities account for only a small proportion of value-added generated in the supply chain, falling to only 3 percent in the high scenario for 2030. The share of value-added generated though the production of cells (EEA, MEA) is estimated at just below 15 percent.

The intensity of value-added creation is highest for cells, balance of stack items, interconnectors and seals, reaching or exceeding 50 percent for all these segments. More than half of the VA generated in the supply chain of SOFC micro-CHP systems is attributed to labour inputs, with value-added attributed to capital (capex) is estimated in the range of 16 to 18 percent. Labour intensity is relatively high for many segments, for example, seals (86% in the high scenario for 2030), system integration (66%), porous layer (62%).

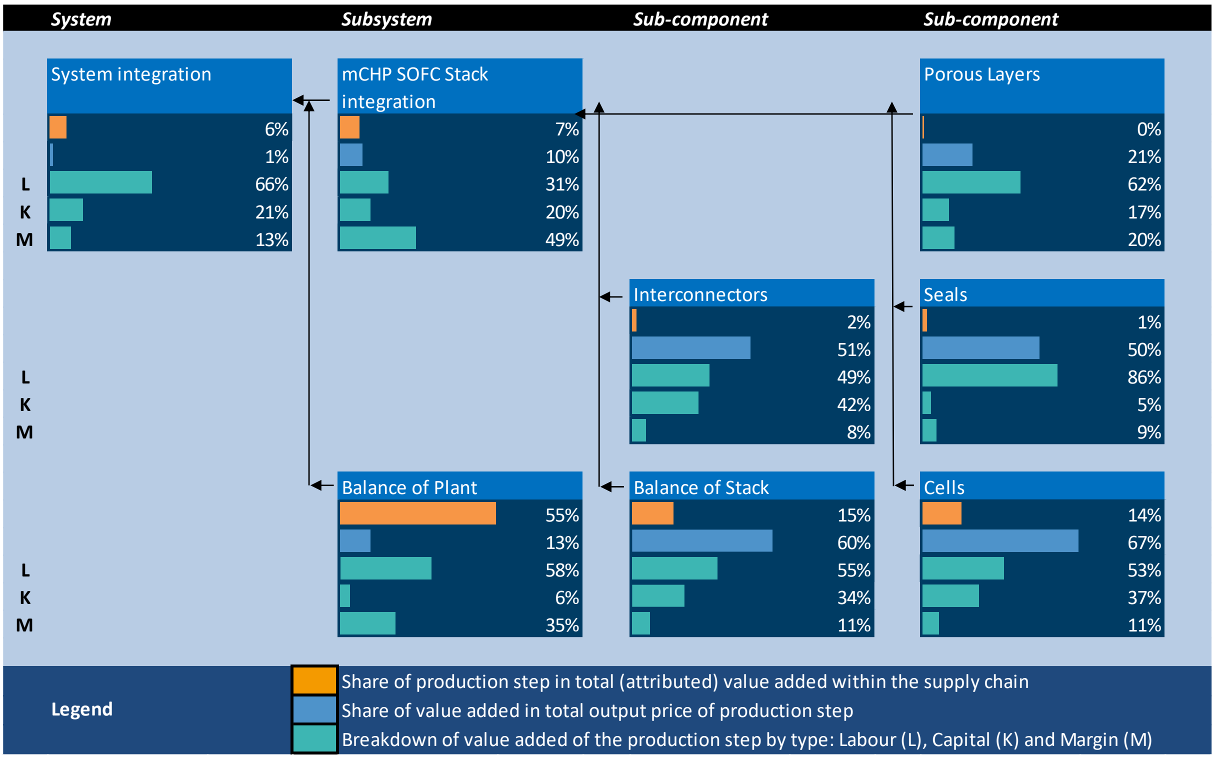


Figure 42: Value-added decomposition for FC system for SOFC micro-CHPs, low market deployment scenario, 2030

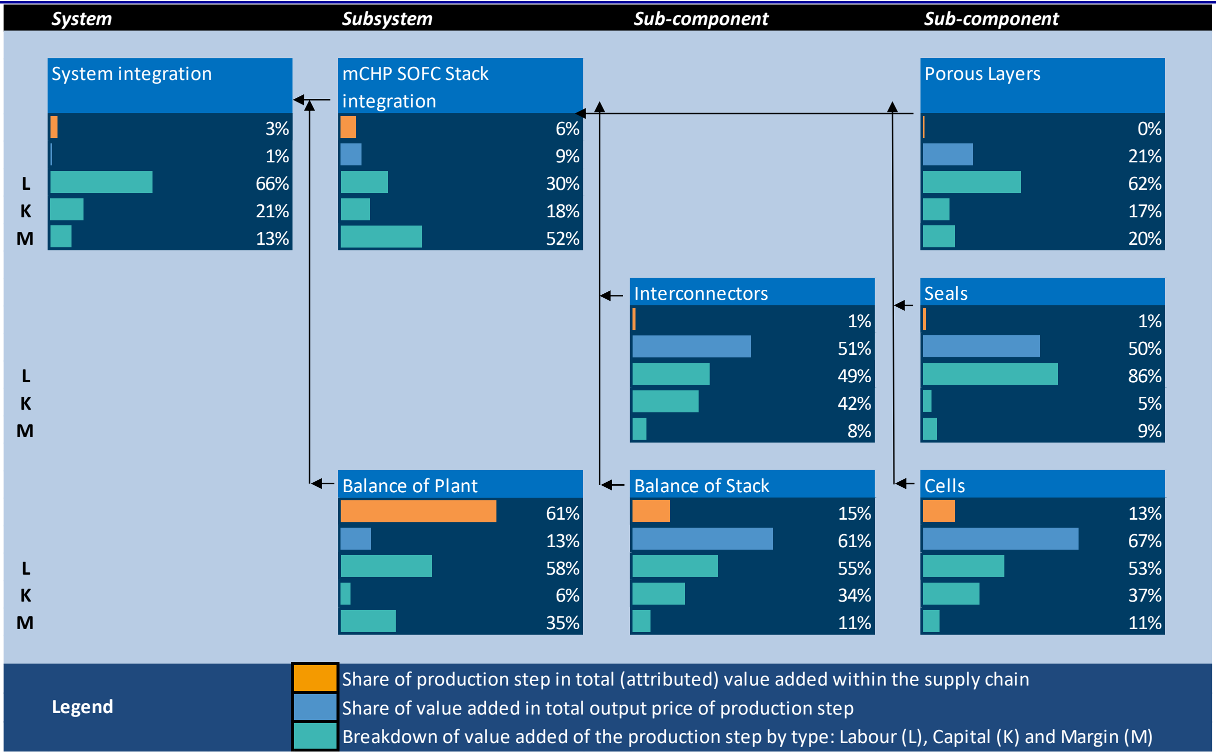


Figure 43: Value-added decomposition for FC system for SOFC micro-CHPs, high market deployment scenario, 2030

Table 34: Value-added decomposition for FC system for SOFC micro-CHPs by market deployment scenario, 2024 and 2030

Year	2024			2030		
Deployment scenario	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Total annual production (Thousand units)	70	195	255	225	460	760
Annual production rate of leading manufacturer (Thousand units)	45	115	150	135	275	455
System cost (Output price)	€ 3,800	€ 3,700	€ 3,600	€ 3,700	€ 3,500	€ 3,400
Total VA within system	€ 800	€ 700	€ 700	€ 700	€ 700	€ 700
Application VA as a share of total costs (VA / output price)	0%	0%	0%	0%	0%	0%
Rate of VA (VA / material & overhead costs)	26%	25%	25%	25%	23%	23%
Breakdown of VA by component or activity						
Total VA in system (excl. Stack)	**60%**	**61%**	**61%**	**61%**	**65%**	**64%**
SOFC micro-CHP system integration	7%	6%	5%	6%	4%	3%
Balance of Plant	53%	55%	56%	55%	61%	61%
Total VA in stack (excl. Cells)	**26%**	**25%**	**25%**	**25%**	**22%**	**23%**
SOFC micro-CHP stack integration	7%	7%	7%	7%	4%	6%
Porous Layer	1%	0%	0%	0%	0%	0%
Seals	1%	1%	1%	1%	1%	1%
Interconnectors	2%	2%	2%	2%	2%	1%
Balance of Stack	15%	15%	15%	15%	15%	15%
Cells (EEA, MEA)	**14%**	**14%**	**14%**	**14%**	**14%**	**13%**
Breakdown of total VA by cost category						
Labour cost	56%	56%	56%	56%	56%	56%
Capex cost	18%	17%	17%	17%	16%	16%
Margin	27%	27%	27%	27%	28%	28%
Total	100%	100%	100%	100%	100%	100%
Notes: numbers may not add up due to rounding of data						

Estimated value creation potential for FC systems for SOFC CHPs

The estimates of the breakdown of value-added for SOFC CHP systems under the low and high market scenarios for 2030 are presented in Figure 44 and Figure 45. Under the low scenario, the annual global production volume corresponds to around 3,300 systems, while the high scenario corresponds to annual production of around 21,000 systems. The breakdown of value-added creation for all three scenarios, for both 2024 and 2030, is shown in Table 35.

In contrast to SOFC micro-CHPs, the generation of value-added for larger CHP systems is more evenly distributed through the supply chain, with both upstream and downstream segments making a notable contribution. Cell production is estimated to account for around a quarter of value-added generation in all scenarios, for both 2024 and 2030. The second highest share of value-added is attributed to balance of plant items for system integration, at around a fifth of total value-added generated in the supply chain. The combined share of system integration and stack integration activities is just below 30 percent.

As is the case for the supply chain for SOFC micro-CHP systems, the intensity of value-added creation is highest for cells (65%), balance of stack items (59%), interconnectors (50%) and seals (49%), though interconnectors and seals generate only small shares of total value-added. Again, more than half of the VA generated in the supply chain is attributed to labour inputs, with value-added attributed to capital (capex) is estimated in just below a quarter.

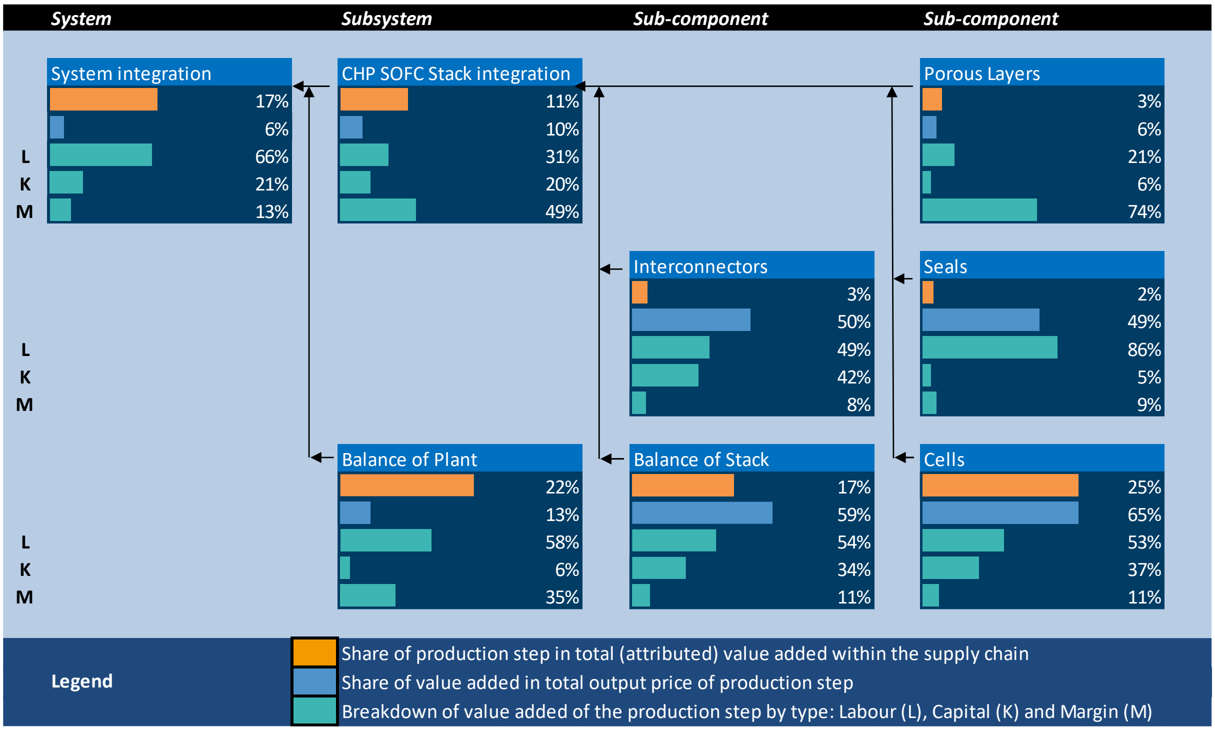


Figure 44: Value-added decomposition for FC system for SOFC CHPs, low market deployment scenario, 2030

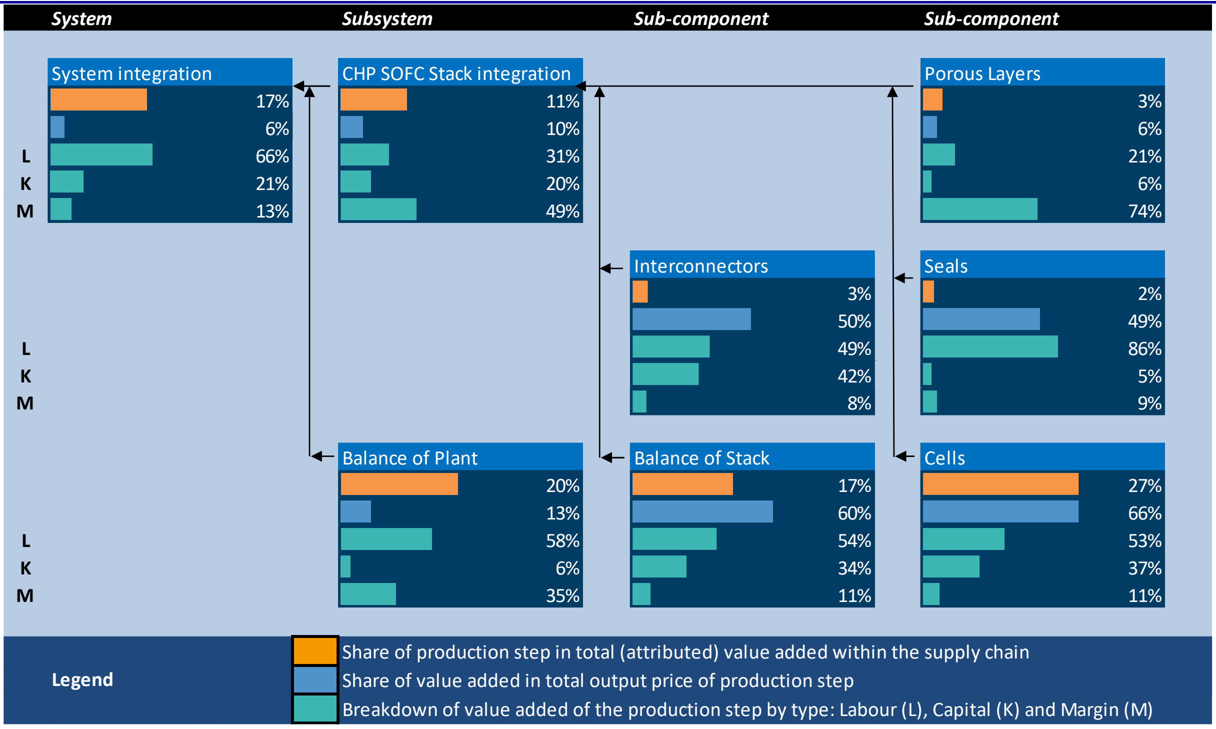


Figure 45: Value-added decomposition for FC system for SOFC CHPs, high market deployment scenario, 2030

Table 35: Value-added decomposition for FC system for SOFC CHPs by market deployment scenario, 2024 and 2030

Year	**2024**			**2030**		
Deployment scenario	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Total annual production (Units)	900	1,600	5,300	3,300	9,000	21,000
Annual production rate of leading manufacturer (Units)	500	900	3,200	2,000	5,400	12,600
System cost (Output price)	€ 131,000	€ 126,000	€ 118,000	€ 121,000	€ 115,000	€ 110,000
Total VA within system	€ 41,700	€ 40,600	€ 39,100	€ 39,700	€ 38,600	€ 37,700
Application VA as a share of total costs (VA / output price)	32%	32%	33%	33%	34%	34%
Rate of VA (VA / material & overhead costs)	47%	48%	50%	49%	50%	52%
Breakdown of VA by component or activity						
Total VA in system (excl. Stack)	**41%**	**40%**	**39%**	**39%**	**38%**	**37%**
SOFC CHP system integration	18%	18%	17%	17%	17%	17%
Balance of Plant	23%	23%	21%	22%	21%	20%
Total VA in stack (excl. Cells)	**34%**	**35%**	**35%**	**35%**	**36%**	**37%**
SOFC CHP stack integration	11%	11%	11%	11%	11%	11%
Porous Layer	3%	3%	3%	3%	3%	3%
Seals	2%	2%	2%	2%	2%	2%
Interconnectors	3%	3%	3%	3%	3%	3%
Balance of Stack	16%	16%	17%	17%	17%	17%
Cells (EEA, MEA)	**25%**	**25%**	**26%**	**25%**	**26%**	**27%**
Breakdown of total VA by cost category						
Labour cost	54%	54%	53%	53%	53%	53%
Capex cost	23%	23%	24%	24%	24%	24%
Margin	23%	23%	23%	23%	23%	23%
Total	100%	100%	100%	100%	100%	100%
Notes: numbers may not add up due to rounding of data						

Estimated value creation potential for Solid Oxide electrolyser systems

The estimates of the breakdown of value-added for Solid Oxide electrolysers (SOEL) under the low and high market scenarios for 2030 are presented in Figure 46 and Figure 47. Under the low scenario, the annual global production volume corresponds to around 90 systems (45 MW total capacity), while the high scenario corresponds to annual production of around 400 systems (200 MW total capacity). The breakdown of value-added creation for all three scenarios, for both 2024 and 2030, is shown in Table 36.

The estimates indicate a very stable pattern over time and across scenarios in the distribution of value-added generated in the supply chain for SO electrolysers, reflecting the fact that low production volumes offer limited scope for cost changes arising from economies of scale. In common with SOFC CHPs, the generation of value-added for SOEL systems is relatively evenly distributed across upstream and downstream supply chain segments. Cell production and balance of plant items for system integration are each estimated to account for around a quarter of value-added generation in all scenarios, for both 2024 and 2030. The combined share of system integration and stack integration activities is just below 30 percent, of which 20 percent coming from system integration and 10 percent from stack integration.

As is the case for the supply chain for SOFC CHP systems – both micro and large – the intensity of value-added creation is highest for cells, balance of stack items, interconnectors and seals. Again, more than half of the VA generated in the supply chain is attributed to labour inputs, with value-added attributed to capital (capex) is estimated in just below a quarter. The labour share in value-added is highest for seals, the porous layer, and system integration.

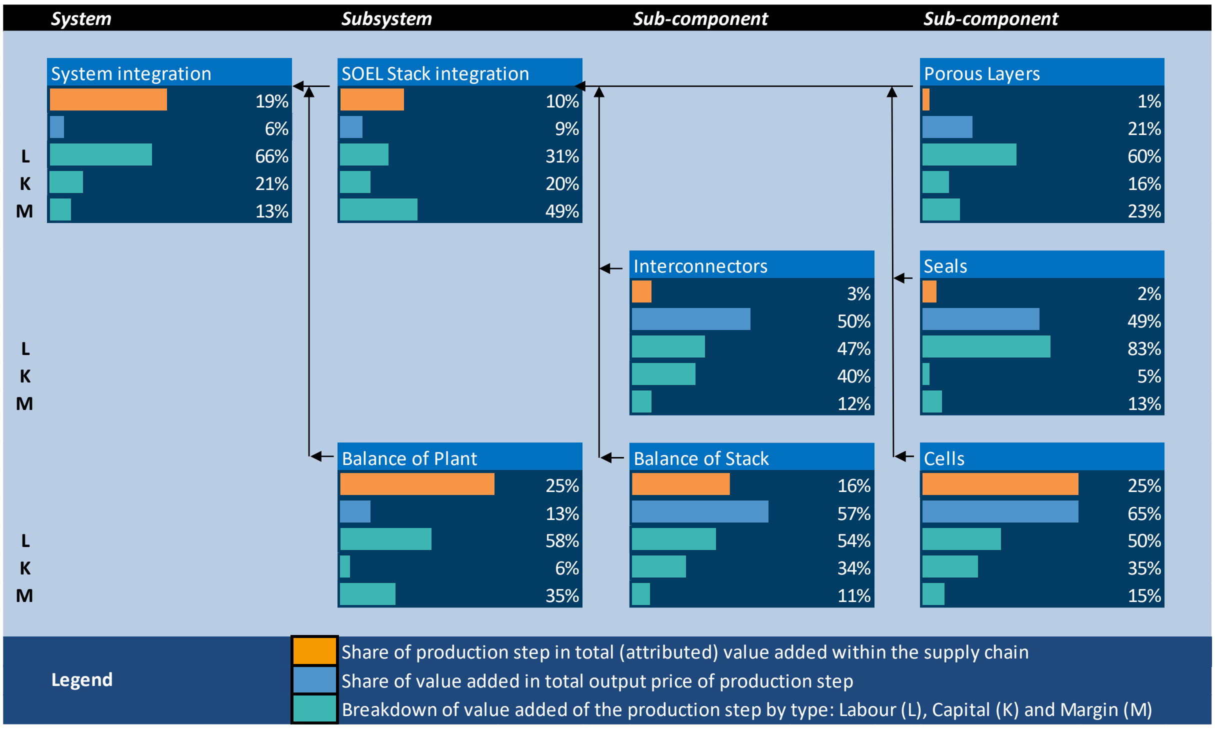


Figure 46: Value-added decomposition for Solid Oxide Electrolyser systems, low market deployment scenario, 2030

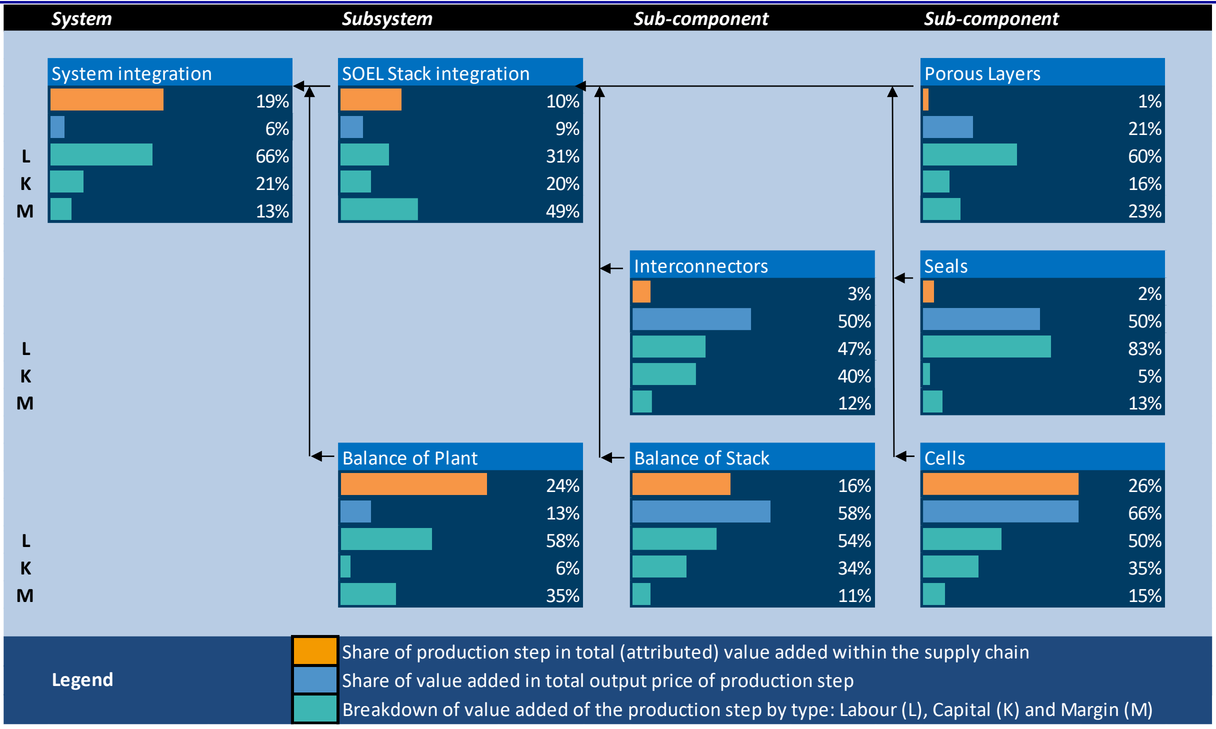


Figure 47 Value-added decomposition for Solid Oxide Electrolyser systems, high market deployment scenario, 2030

Table 36: Value-added decomposition for Solid Oxide Electrolyser systems by market deployment scenario, 2024 and 2030

Year	**2024**			**2030**		
Deployment scenario	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Total annual production (Units)	40	80	130	90	200	405
Annual production rate of leading manufacturer (Units)	25	50	80	55	120	245
System cost (Output price)	€ 802,000	€ 748,000	€ 719,000	€ 742,000	€ 698,000	€ 664,000
Total VA within system	€ 248,000	€ 232,000	€ 224,000	€ 230,000	€ 219,000	€ 211,000
Application VA as a share of total costs (VA / output price)	31%	31%	31%	31%	31%	32%
Rate of VA (VA / material & overhead costs)	45%	45%	45%	45%	46%	46%
Breakdown of VA by component or activity						
Total VA in system (excl. Stack)	**43%**	**43%**	**43%**	**43%**	**43%**	**43%**
SOEL system integration	18%	19%	19%	19%	19%	19%
Balance of Plant	24%	25%	25%	25%	24%	24%
Total VA in stack (excl. Cells)	**33%**	**32%**	**32%**	**32%**	**32%**	**32%**
SOEL stack integration	10%	10%	10%	10%	10%	10%
Porous Layer	1%	1%	1%	1%	1%	1%
Seals	3%	2%	2%	2%	2%	2%
Interconnectors	3%	3%	3%	3%	3%	3%
Balance of Stack	16%	16%	16%	16%	16%	16%
Cells (EEA, MEA)	**25%**	**25%**	**25%**	**25%**	**25%**	**26%**
Breakdown of total VA by cost category						
Labour cost	55%	55%	54%	55%	54%	54%
Capex cost	23%	23%	23%	23%	23%	23%
Margin	22%	22%	22%	22%	22%	22%
Total	100%	100%	100%	100%	100%	100%
Notes: numbers may not add up due to rounding of data						

Estimated value creation potential for hydrogen refuelling stations

The estimates of the breakdown of value-added for hydrogen refuelling stations (HRS) under the low and high market scenarios for 2030 are presented in Figure 48 and Figure 49. Under the low scenario, the annual global production volume corresponds to around 670 stations (520 t/day of new capacity), while the high scenario corresponds to annual production of around 3,700 stations (2,700 t/day of new capacity).

Note 1: *As opposed to all other applications covered in supply chain value-added estimates, which cover fuel cell systems only, the estimates for hydrogen refuelling stations cover the total costs and corresponding value-added for the installation of the station. This approach explains the predominance of station integration in the supply chain estimates for hydrogen refuelling stations.*

Note 2: *The estimates for the breakdown of value-added in the supply chain for hydrogen refuelling stations is based on an assumed typical configuration but in reality this will be influenced by the distribution of different sizes of stations (e.g. delivery capacity of hydrogen on a daily basis).*

For HRS, the major part of values-added is generated by station integration, which covers construction and equipment installation, estimated at around 70 percent of total value-added generated. In addition, balance of plant, covering non-specified equipment, accounts for above 10 of total value-added. The two specified items, namely dispensers and compression units are estimated to each generate between 8 to 10 percent of value-added associated to the development of HRS. Since materials and equipment inputs have a relatively low share in overall costs for the construction and installation of HRS, the station integration segment is associated with a high value-added intensity, of close to 90 percent. Each of the three component categories (dispensers, compression units and balance of plant) are estimated to have a high share of labour in generation of value-added, at between 55 to 60 percent.

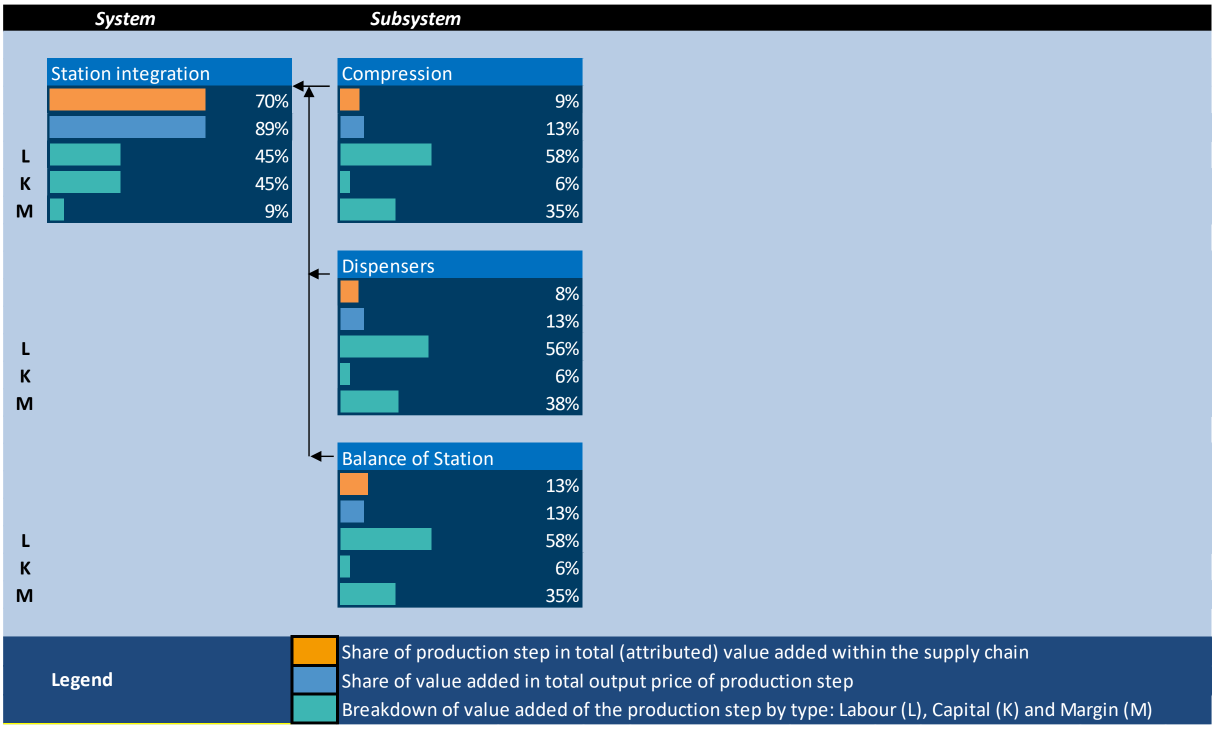


Figure 48: Value-added decomposition for hydrogen refuelling stations, low market deployment scenario, 2030

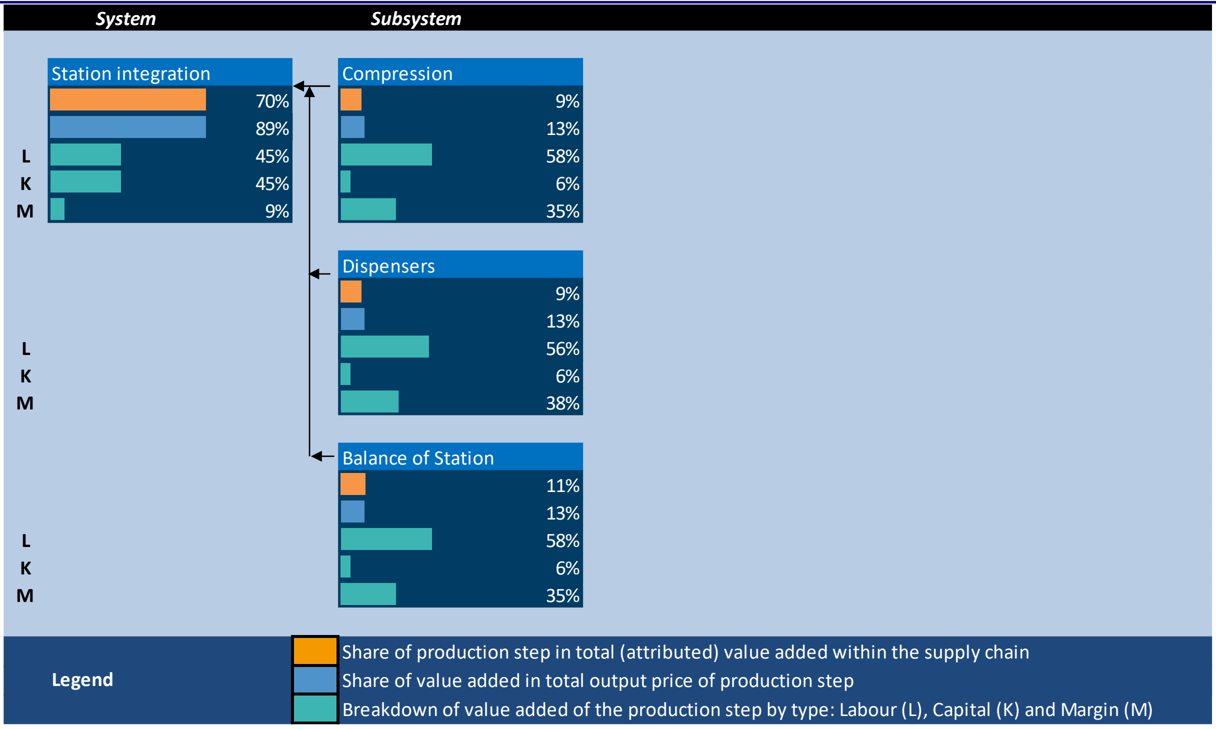


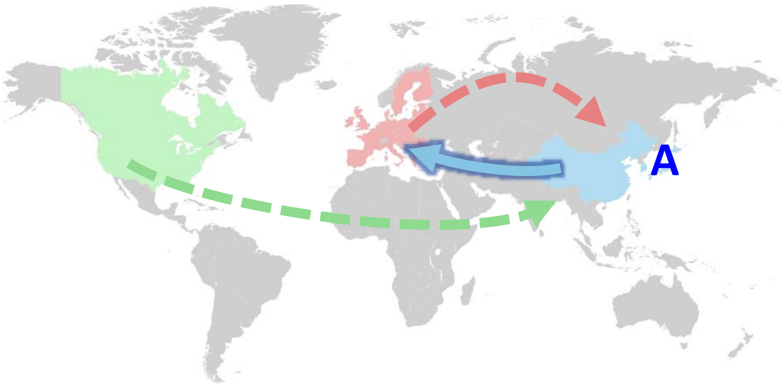
Figure 49: Value-added decomposition for hydrogen refuelling stations, high market deployment scenario, 2030

Appendix B Industry scenarios

Approach to describing the scenarios

For each application and scenario a snapshot of what the application-specific industry might look like in the 2020s and by 2030 is captured. This snapshot shows the location of system assembly focussing on the three key global regions of Europe, North America and Asia (primarily China, Japan and S. Korea). The snapshot also indicates what trade flows – in components, systems or both – would be expected at that time, in that scenario, for that specific application. The snapshots are accompanied by a bullet point description of key aspects and drivers of the industry for that application in that scenario in that timeframe. The snapshots focus on illustrating the situation of the relevant European industry so some flows, e.g., to N. America may have been omitted for clarity.

An example snapshot diagram along with a key is shown in Figure 50.



Regions

- 🟩 N America
- 🟥 EU
- 🟦 Asia

Trade flows

- ╍ Components
- ▭ Systems
- ━ Both

Flows colour coded by source region

System assembly

Key assembly locations shown with an 'A'

Size of 'A' indicates relative importance

Colour of 'A' reflects origin of actors

Black letter indicates actors from more than one region

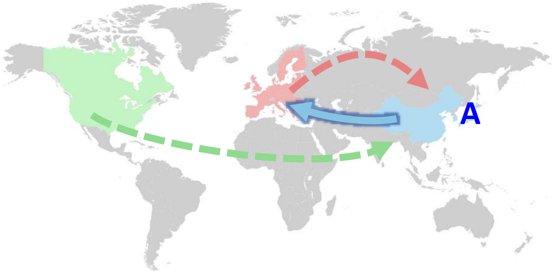
Figure 50: Example industry scenario snapshot diagram with key

FCEV industry scenarios

- Automotive OEMs are global actors and rely on a highly optimized global supply chain in which Tier 1 suppliers play a key role
- OEM production processes accommodate both low volume (1,000s to 10,000s per year) and mass market (100,000s per year) models
- OEMs ship vehicles internationally as well as putting in place local assembly capacity in other regions

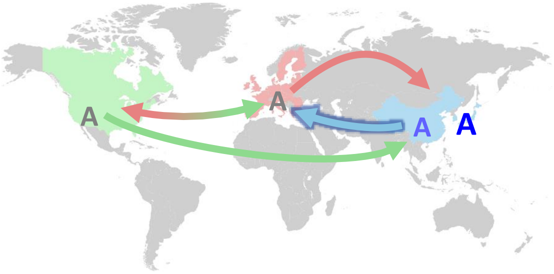
- For higher volume lines, suppliers will put in place local production capacity to support the assembly plant

Scenario A: 2020s



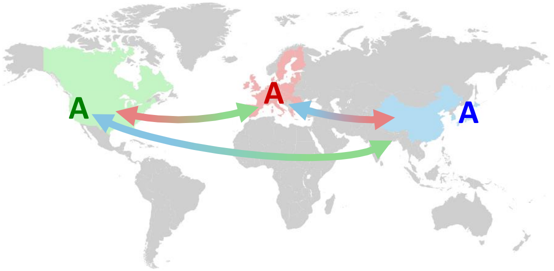
- Asian OEMs dominate
- Initial supply chain is global using available suppliers
- Some EU actors export components to Asian OEMs
- Vehicles are imported from Asian OEMs

Scenario A: By 2030



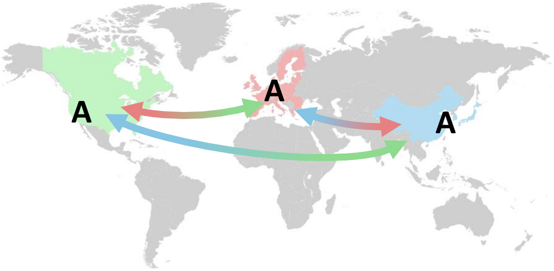
- Asian OEMs are starting to build manufacturing capacity in other regions
- EU and NA OEMs are still in early stages of developing capacity
- Regional supply chains in EU and N America are being put in place
- EU actors supply components primarily to local production but also to other regions

Scenario C: 2020s



- EU, Asian and NA OEMs all play a role
- Initial supply chain is global using available suppliers
- EU actors export and import components
- Vehicles are imported and exported

Scenario C: By 2030

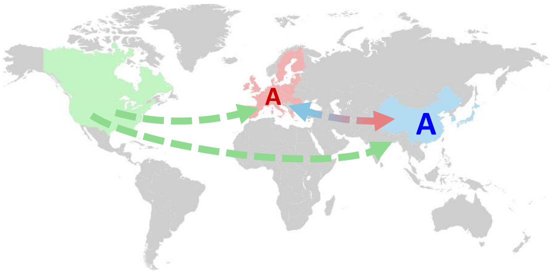


- Supply chain is starting to consolidate around Tier 1s rather than pure FC players
- Proportion of locally produced content increases
- Component suppliers (EU and global) build manufacturing capacity close to vehicle assembly
- EU actors export and import components
- Higher volume models are trending towards local assembly by global OEMs with locally produced parts from global suppliers

FC bus industry scenarios

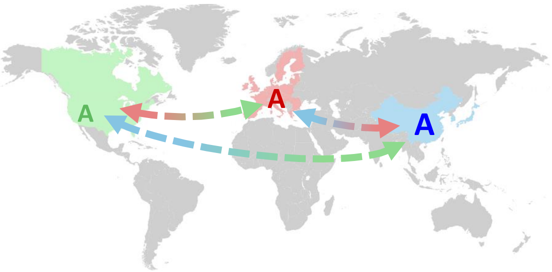
- City bus sector is historically fairly fragmented with small integrators supplying local markets
- Though the stacks are larger and have different requirements, FC buses will benefit from maturation of the PEMFC supply chain promoted by development of other PEMFC transport applications like the FC passenger car segment

Scenario A: 2020s



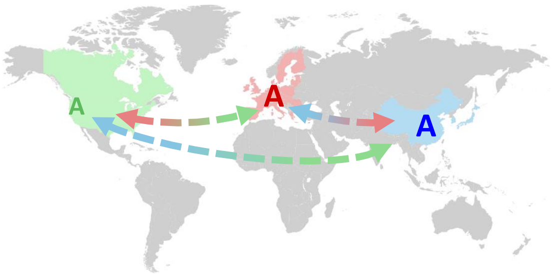
- Strongest deployment is in China
- Some deployment in EU
- Local integrators in China and EU
- Mixed local and global supply chain
- Stacks are sourced from N America and EU

Scenario A: By 2030



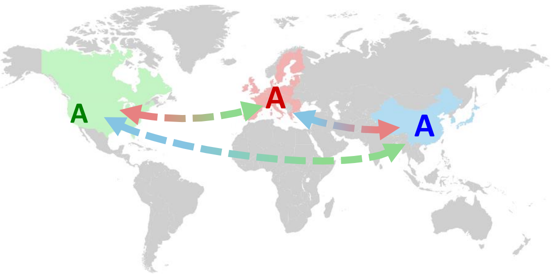
- EU component manufacturers supply integrators in other regions
- EU integrators import components from global suppliers
- EU bus stack manufacturers primarily serve the EU bus market
- Some deployment in N America using globally supplied components

Scenario C: 2020s



- Strong development in China and EU
- Some deployment in N America
- Local integrators in each region
- Mixture of global and local supply chain

Scenario C: By 2030



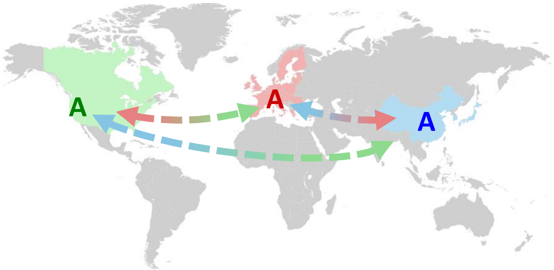
- EU component manufacturers supply integrators in other regions
- EU integrators import components from global suppliers
- EU bus stack manufacturers have a strong share of the EU bus market and are exporting stacks and subsystems

HGV industry scenarios

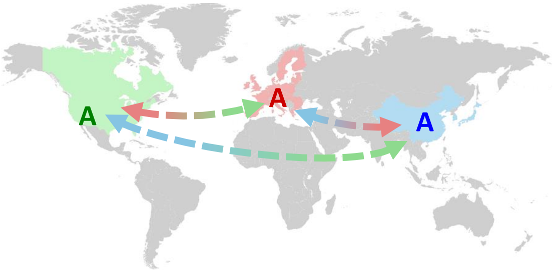
- Application covers trucks >3.5t
- Like passenger cars, HGV manufacturing is dominated by a few large actors with fairly integrated supply chains
- However, volumes are significantly lower than auto OEMs so supply chain is not as heavily optimised
- Though the stacks are larger and have different requirements, FC HGVs will benefit from maturation of the PEMFC supply chain promoted by development of other PEMFC transport applications like the FC passenger car segment

Scenario A: 2020s

Scenario A: By 2030

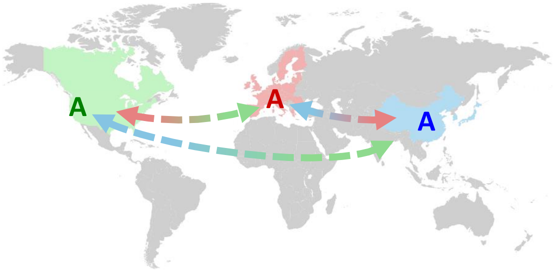


- A few OEMs in EU, Asia and N America
- Global supply chain based on available suppliers
- Stacks primarily sourced from established players outside EU
- EU stack manufacturers serve a share of the EU market



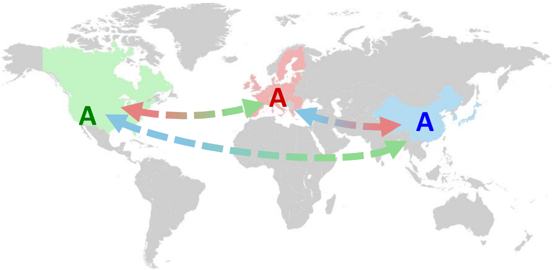
- EU component manufacturers supply integrators in other regions
- EU integrators import components from global suppliers
- EU stack manufacturers' share of the EU market is increasing

Scenario C: 2020s



- OEMs in EU, Asia and N America
- Global supply chain based on available suppliers
- Stacks sourced from established players outside and increasingly within the EU, as the EU technology matures

Scenario C: By 2030



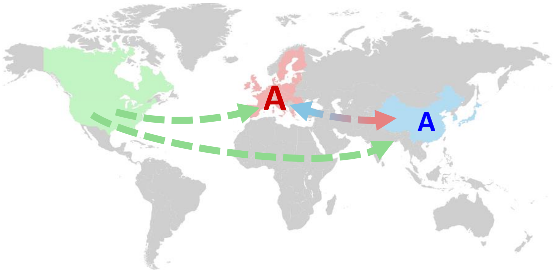
- Supply chains are starting to consolidate around Tier 1s
- Global suppliers developing capacity where assembly occurs
- EU stack manufacturers serve a significant share of the EU market and also serve other regions

Trains and light rail industry scenarios

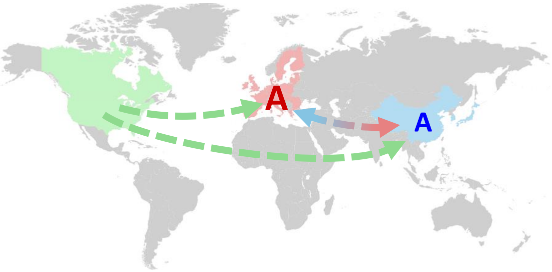
- Trains expected to be dominated by self-propelled carriages – so called multiple units (MU)
- FC trains can be
  - An approach to decarbonise and/or reduce emissions of non-electrified rail segments by replacing diesel units
  - An alternative to deploying light rail with different infrastructure requirements
    i. Overhead lines are costly and may require supporting electricity grid infrastructure
    ii. H_2 supply can be localized at depots potentially reducing overall infrastructure cost

Scenario A: 2020s

Scenario A: By 2030

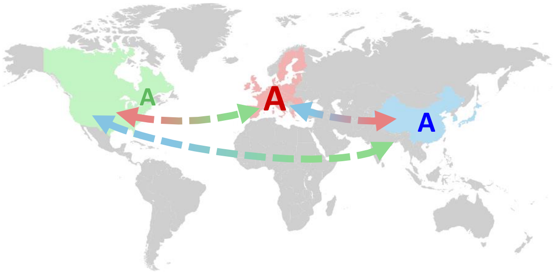


- Major deployment is in EU with some activity in China
- Integrators in EU and China
- Global supply chain based on available suppliers
- Stacks are primarily sourced outside EU



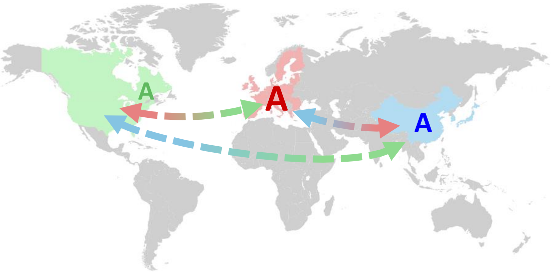
- EU component manufacturers supply integrators in EU and China
- EU integrators import some components
- EU stack manufacturers are starting to play a role, building on experience with HGVs

Scenario C: 2020s



- Strong activity in EU and China, some activity in Canada
- Main integrators in EU and China
- Global supply chain based on available suppliers
- Stacks are primarily sourced outside EU

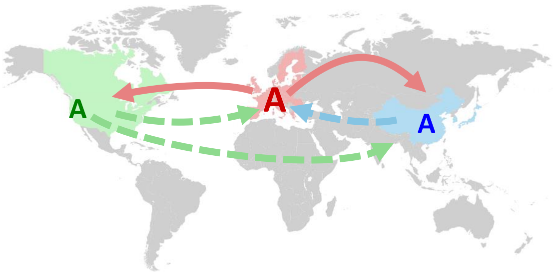
Scenario C: By 2030



- EU component manufacturers supply integrators in EU and China
- EU integrators import other components
- Benefitting from experience in FCEV / bus / HGV segments, supply chains are starting to mature
- EU stack manufacturers supply a share of the EU and global market

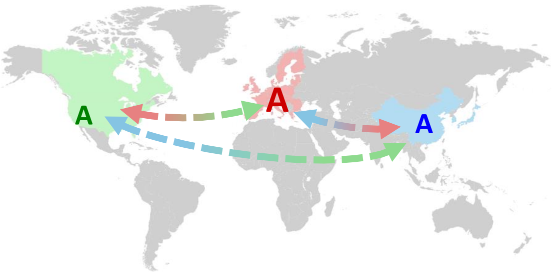
HRS industry scenarios

Scenario A: 2020s



- Deployment principally in California and Asia and some in EU
- EU takes leading supplier role given strength in HRS integration and electrolysis

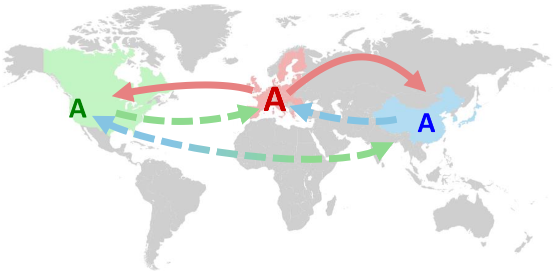
Scenario A: By 2030



- Integration takes place locally in each key region
- Exports shift down to predominantly subsystems and components

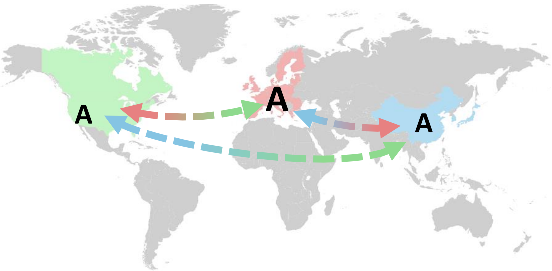
- Mix of local and global supply chain
- EU actors export systems, subsystems and components

Scenario C: 2020s



- Deployment in EU, Asia and N America
- EU takes leading supplier role given strength in HRS integration and electrolysis
- Mix of local and global supply chain
- EU actors export systems, subsystems and components

Scenario C: By 2030

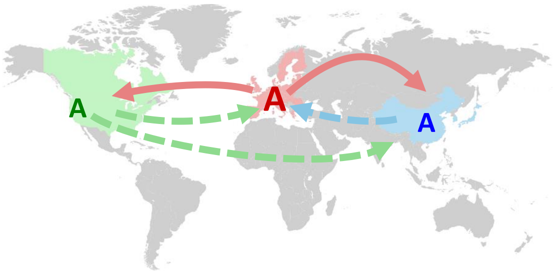


- Exports shift down to predominantly subsystems and components
- Strong system integrators in each region, some as joint ventures with EU actors
- EU and Asian actors have local system/subsystem integration capacity in each key market

Electrolyser industry scenarios

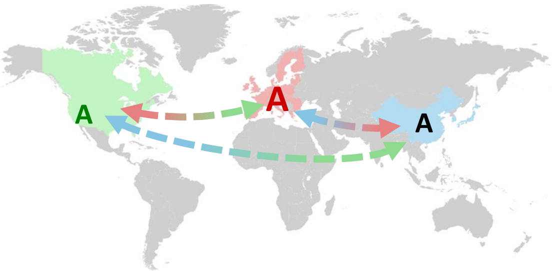
- Electrolysers can be used to
  - Provide potentially green H_2 for vehicle refuelling, refineries and industry
  - Support the integration of greater proportions of variable renewables into the grid
- Refinery and industrial applications – if they take off – could dominate the capacity deployment
- Units in refuelling stations will be lower capacity than industrial ones but will potentially be deployed in greater numbers

Scenario A: 2020s



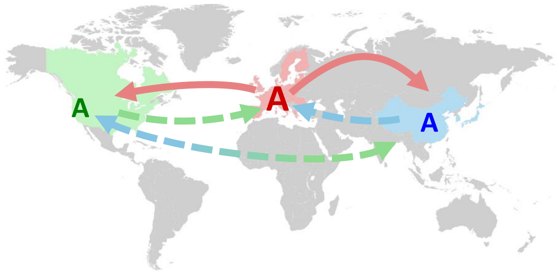
- Electrolyser *capacity* is mostly deployed for green H_2 demonstrations although more *units* are deployed in vehicle refuelling
- Electrolyser role in grid integration is small
- EU integrators play a central role and export electrolysers
- Global supply chain for components

Scenario A: By 2030



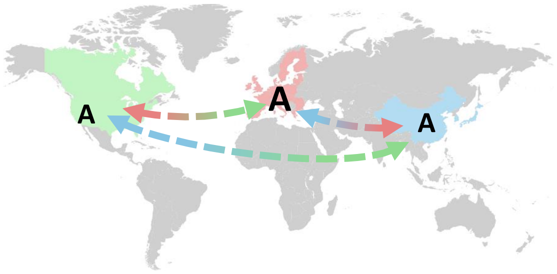
- Integrators have added some system production capacity in Asia to serve the rapidly growing FCEV market and to comply with 'local manufacturing' requirements

Scenario C: 2020s



- Electrolysers deployed for green H_2 in refineries / industry, vehicle refuelling and grid integration
- EU integrators play a central role and export electrolysers
- Some Asian integrators locate final assembly in Europe
- Global supply chain

Scenario C: By 2030

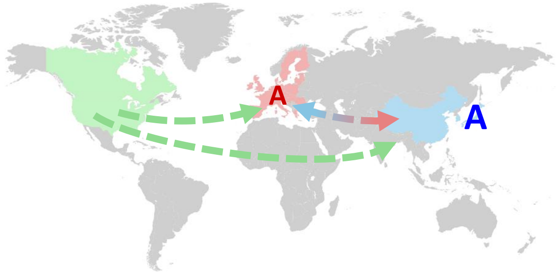


- Supply chains are being optimised with more local production in each region
- Imports and exports of components, with systems usually assembled locally
- EU integrators still lead and dominate EU market, but integrators from all regions serve all markets

Micro CHP industry scenarios

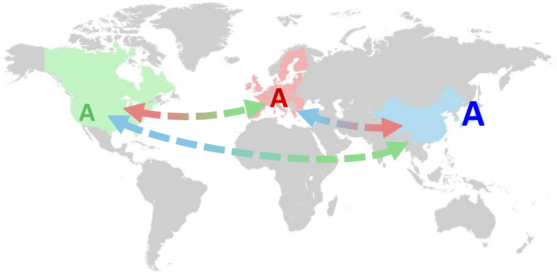
- Small CHP units for residential use (< 5kWe)
- Units expected to operate on natural gas with built in reformers
- SOFC and PEMFC chemistries are expected to be deployed
- Existing channels to client base mean micro-CHP will most likely be deployed by heating equipment manufacturers and/or utilities

Scenario A: 2020s



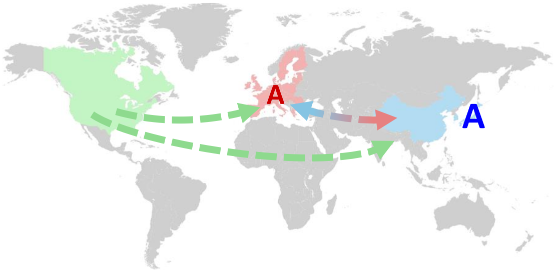
- Deployment remains concentrated in Japan
- Some EU deployment
- Supply chain is focused on Japanese market
- EU component manufacturers export specialized components to Japanese market

Scenario A: By 2030



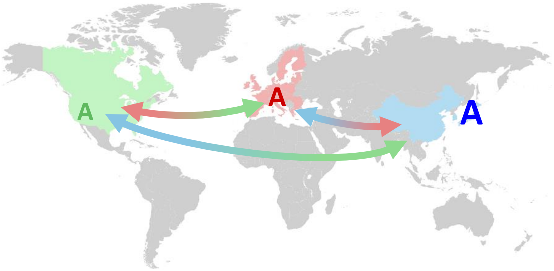
- Japanese market still dominates
- EU system integrators more active, but mostly selling within EU, some activity in N America
- Some EU system integrators import stacks and reformers

Scenario C: 2020s



- Strong deployment in Japan, South Korea and EU
- Integrators primarily supplying their local markets
- Global component supply chain with local integrators
- EU component manufacturers export to integrators in other regions

Scenario C: By 2030

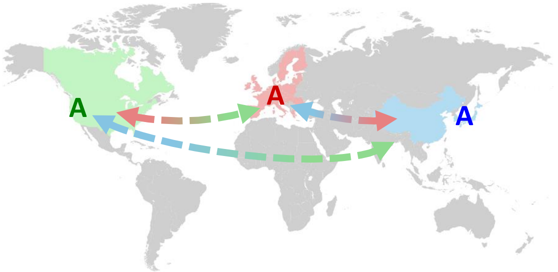


- EU component manufacturers export to integrators in other regions
- EU stack manufacturers supply EU market and export to system integrators in other regions
- EU system integrators export systems to other regions but also import stacks and components

Commercial CHP industry scenarios

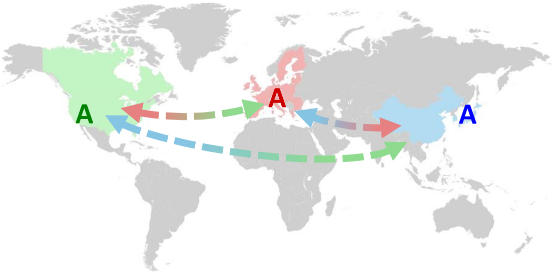
- CHP units for commercial / industrial use (5-100kWe)
- Units expected to operate on natural gas or biogas
- Application expected to be dominated by SOFC chemistry

Scenario A: 2020s



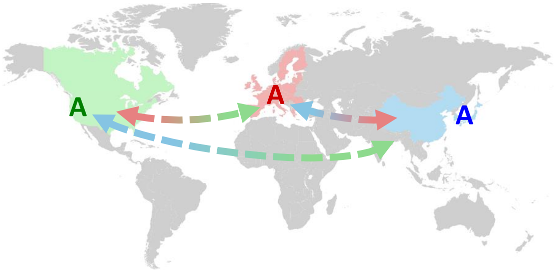
- Moderate deployment in Asia, EU and N America
- Local system integrators – heating equipment suppliers – supply local markets
- SOFC supply chain more vertically integrated than other chemistries so supplier ecosystem is smaller
- Global supply chain

Scenario A: By 2030



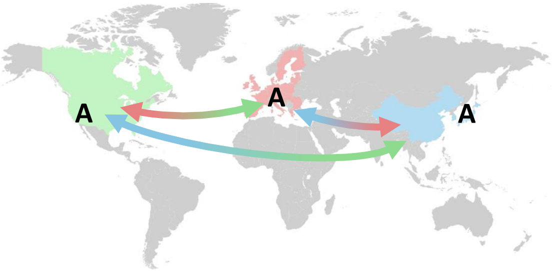
- Market grows but structure remains largely the same – though some specialist suppliers start to emerge
- EU component manufacturers export to system integrators in all regions

Scenario C: 2020s



- Strong deployment in Asia, EU and N America
- Local system integrators primarily supplying local markets
- Supply chain is global and somewhat vertically integrated by manufacturer though specialists are emerging

Scenario C: By 2030



- EU component manufacturers export to system integrators in all regions
- Stronger system integrators export to more than one region and develop local assembly capacity

Appendix C Nomenclature

AC	Alternating current
AEL	Alkaline electrolyser
AFC	Alkaline fuel cell
AIST	National Institute of Advanced Industrial Science and Technology, a Japanese research facility
ANL	Argonne National Laboratory, operated by the University of Chicago for the US Department of Energy
APU	Auxiliary power unit
BEV	Battery electric vehicle
bn	Billion
BOP	Balance of plant
CCS	Carbon capture and storage
CEA	French Alternative Energies and Atomic Energy Commission
CGS	Compressed Gas Storage
CHP	Combined heat and power
CNG	Compressed natural gas
CO	Carbon monoxide
Comm-CHP	Commercial CHP. Here defined as a CHP system with an electrical output capacity between 5 kW and 100 kW
CRRC	A Chinese publicly traded rolling stock manufacturer
DC	Direct current
DLR	German Aerospace Center
DoE	United States Department of Energy
DoT	United States Department of Transport
EEA	Electrode electrolyte assembly
ENEA	Italian National Agency for New Technologies, Energy and Sustainable Economic Development
EPFL	École polytechnique fédérale de Lausanne
EPS	Electro Power Systems S.A.
EU	European Union
FC	Fuel cell
FCEB	Fuel cell electric bus
FCEV	Fuel cell electric vehicle. Application covers passenger cars and light commercial vehicles
FCH	Fuel cell and hydrogen
FISIPE	Fibras Sinteticas de Portugal, S.A. operates as a subsidiary of SGL Carbon SE
fte	Full time equivalent
GDL	Gas diffusion layer
GHG	Greenhouse gas
GM	General Motors Company
GVA	Gross value added
GW	Gigawatt

HGV	Heavy goods vehicle. Truck weighing more than 3.5 t
HRS	Hydrogen refuelling station
HTEL	High temperature electrolyser
ICE	Internal combustion engine
IEA	International Energy Agency
IKTS	Fraunhofer Institute for Ceramic Technologies and Systems
IP	Intellectual Property
JARI	Japanese Automotive Research Institute
JGA	Japanese Gas Association
JM	Johnson Matthey
JSTRA	Japan Ship Technology Research Association
KBA	Knowledge-based actor, e.g. a University
kW	Kilowatt
LCV	Light commercial vehicle. Commercial vehicle such as a van or small truck weighing less than 3.5 t
LGFCS	LG Fuel Cell Systems Inc.
LIB	Lithium ion battery
LOHC	Liquid organic hydrogen carrier
MCFC	Molten-carbonate Fuel Cell
MEA	Membrane Electrode Assembly
METI	Ministry of Economy, Trade and Industry, a ministry of the Government of Japan
MTU	MTU Friedrichshafen GmbH, manufacturer of commercial internal combustion engines
MW	Megawatt
m	million
mCHP	Micro-CHP. Here defined as a CHP system with an electrical output of less than 5 kW
MW	Megawatt
m€	million Euros
NEDO	New Energy and Industrial Technology Development Organisation. Japan's largest public management organization promoting research and development as well as deployment of industrial, energy and environmental technologies.
NMRI	National Maritime Research Institute, Japan
NREL	National Renewable Energy Laboratory,
O&M	Operation and maintenance
OEM	Original equipment manufacturer, typically used to refer to car manufacturers
PACE	An FCHJU project : Pathway to a Competitive European Fuel Cell micro-Cogeneration Market
PAFC	Phosphoric acid fuel cell
PBI	Polybenzimidazole, a synthetic fiber with a very high melting point
PEM	Proton exchange membrane
PEMEL	Polymer electrolyte membrane electrolyser
PEMFC	Proton exchange membrane fuel cell
PSI	Paul Scherrer Institut, the largest research institute for natural and engineering sciences in Switzerland

PTFE	Polytetrafluoroethylene, a synthetic fluoropolymer of tetrafluoroethylene
R&D	Research and development
RIST	Research Institute of Science and Technology, Korea
RTD	Research and technology development
SAIC	SAIC Motor Corporation
SGL	SGL Carbon SE, german manufacturer of carbon-based products
SMR	Steam-methane reforming
SOEL	Solid oxide electrolyser
SOFC	Solid oxide fuel cell
SUV	Sports utility vehicle
SWOT	Strengths, weaknesses, opportunities, threats. A strategic planning technique.
t	tonne
THE	Tianjin Mainland Hydrogen Equipment Co. Ltd.
TRL	Technology readiness level
UNIST	Ulsan National Institute of Science and Technology, Korea
UPS	Uninterruptable power supply
VA	Value added
WP	Work package
xEV	Electric vehicle of any of the following types: hybrid electric vehicle (HEV), plug-in hybrid (PHEV) or battery electric vehicle (BEV)
ZBT	Zentrum für BrennstoffzellenTechnik GmbH