



Value Added of the Hydrogen and Fuel Cell Sector in Europe

Supporting European growth and
competitiveness

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

Summary report

September 2019

The 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 economic and industrial benefits from a strong FCH supply chain in Europe, and the opportunities for initiatives to support new energy supply chains, FCH 2 JU commissioned a study to evaluate for the first time the value added that the fuel cell and hydrogen sector can bring to Europe by 2030.

The outputs of this study are divided into three reports:

- A 'Summary' report that provides a synthetic overview of the full study;
- a '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.

This report is a summary of the work and findings included in the 'findings' and 'evidence' reports produced as part of this study. All reports are available at the FCH JU website <https://www.fch.europa.eu/page/FCH-value-chain>

The study behind this report was undertaken by E4tech for FCH 2 JU in partnership with Ecorys and Strategic Analysis Inc. The research underpinning the study was undertaken between January to October 2018

PDF ISBN: 978-92-9246-339-7 doi: 10.2843/065017 EG-01-20-046-EN-N

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1. Introduction

Fuel cells and hydrogen could bring significant environmental and socio-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 globally¹, while national governments and independent agencies are supporting their role in the energy systems transition².

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 2018³ (Figure 1). Much of the 2018 increase was in fuel cell cars, but stationary applications also saw increased volumes. While deployment of water electrolyzers 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 campaigns³. 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.

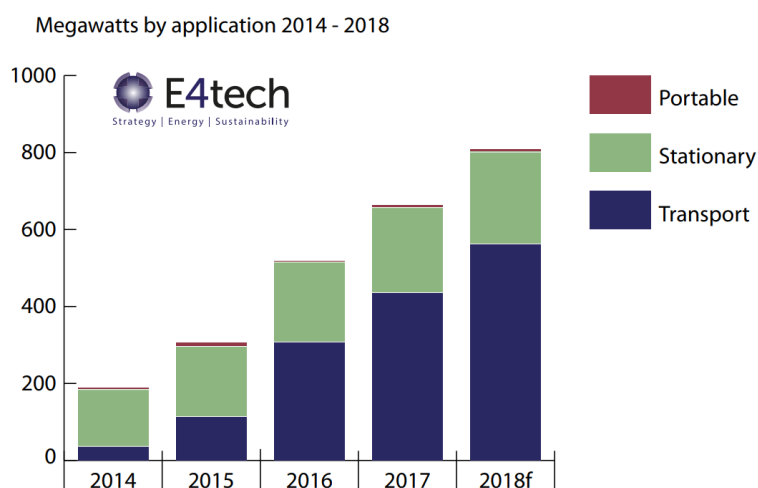


Figure 1: Growth in MW of fuel cells shipped, 2014-2018

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.

Scope of the study

The Value Chain study summarised in this document complements the Hydrogen Roadmap for Europe⁴, recently published by the FCH 2 JU. This lays out a pathway for the large-scale deployment of hydrogen and fuel cells to 2050 in order to achieve a 2-degree climate scenario. This study also quantified socio-economic and environmental benefits, but with important differences in scope between the two studies (Figure 2).

The Hydrogen Roadmap for Europe looked at the wider energy picture, quantifying the scale of FCH roll-out needed to meet the 2-degree scenario objectives. It assessed the socio-economic impacts of a sector of that scale, looking top-down at the *entire* FCH value chain. The Value Chain study presented here is a much narrower and more detailed bottom-up assessment of the value-added in *manufacturing activities* and the *immediate ecosystem of suppliers* that this is likely to create. The scope and boundaries of both studies are illustrated in Figure 2 below. This difference of scope means that the socio-economic impacts estimated in the two studies also differ.

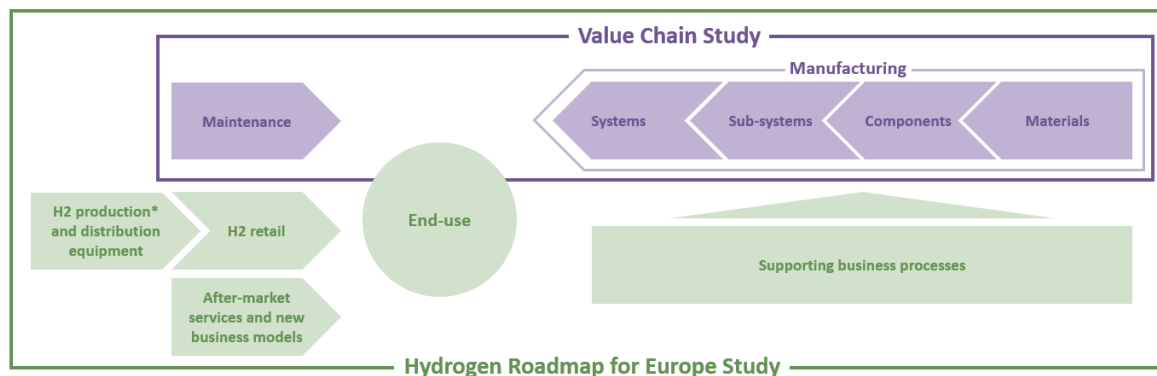


Figure 2: Scope of the Value Chain and Hydrogen Roadmap for Europe studies

⁴ Hydrogen Roadmap for Europe: A sustainable pathway for the European Energy Transition. January 2019. Report was prepared for the Fuel Cells and Hydrogen 2 Joint Undertaking <https://www.fch.europa.eu/news/hydrogen-roadmap-europe-sustainable-pathway-european-energy-transition>

* In terms of hydrogen production pathways, the Value Chain study focused on electrolysis whereas the Hydrogen Roadmap for Europe study focused on hydrogen production from steam methane reforming (with and without CCS) from both natural gas and biogas.

2. Methodology

Overall approach

At the beginning of the Value Chain study, data on sector actors were gathered through an actor questionnaire on FCH-related activities, a survey on EU competitiveness in FCH, and desk-based research. This data helped in the first instance to create a detailed database of European FCH supply chain actors⁵.

Data were gathered on the 13 applications listed below, for which detailed supply chain maps and an analysis of EU strengths, weaknesses, opportunities and threats was developed.

Transport applications

- Passenger cars and LCVs
- Buses
- HGVs
- Trains and light rail
- Forklifts
- Boats

Energy applications

- HRS
- Electrolysers
- Micro-CHP
- Commercial CHP / prime power
- Large scale CHP / prime power
- Back-up power / gensets
- Fuel processing / reforming

The overall project flow is illustrated in Figure 3 below.

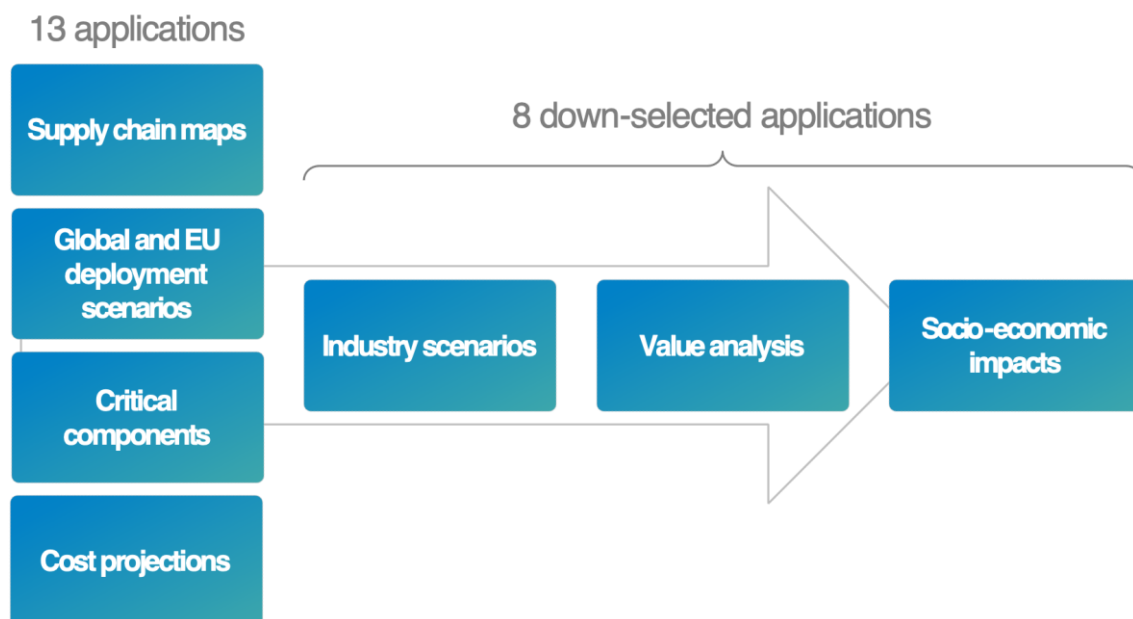


Figure 3: Overall methodology followed in the Value Chain Study

⁵ Online map showing in European FCH value chains <https://www.fch.europa.eu/page/FCH-value-chain>

Detailed supply chain maps for hydrogen and fuel cell applications have been created

The supply chain maps enabled a methodical and suitably comprehensive approach to be taken to develop the analyses in the study (Figure 4). All applications contain a large number of components, some of which are not unique to FCH, and some of which are already manufactured in large quantities. To focus on 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 assessed in detail; areas with European supply chain strength were prioritised; and only a subset of components was analysed in depth.

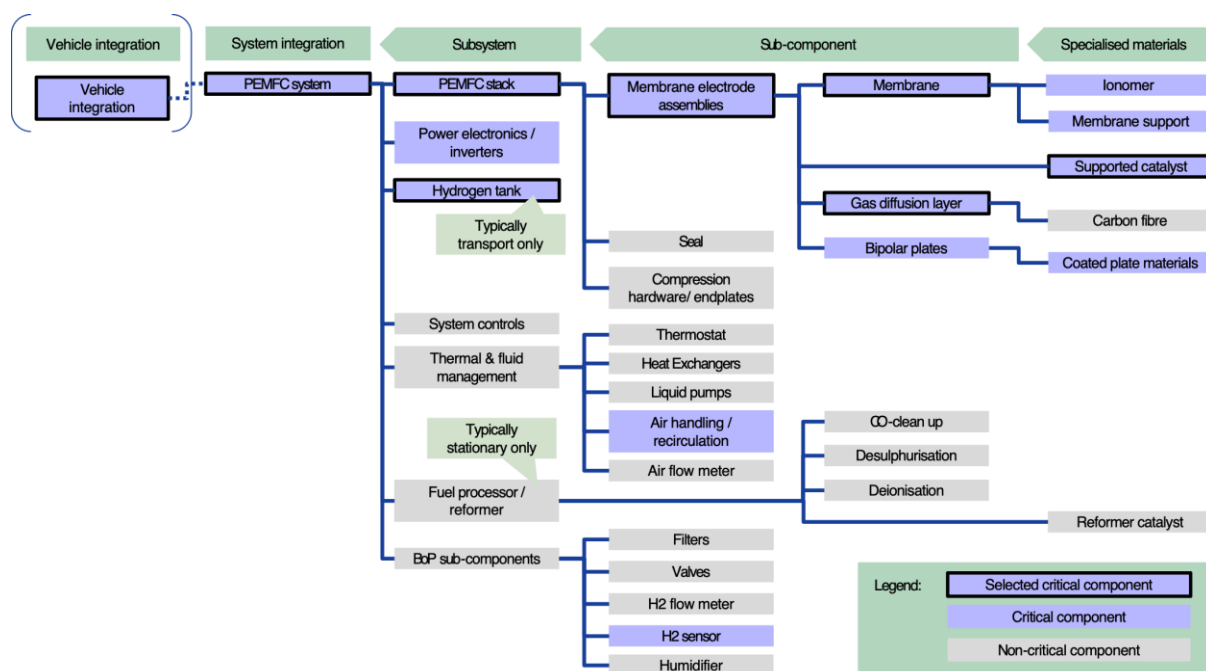


Figure 4: Generic PEMFC supply chain structure in both transport and stationary applications.

Global and European deployment scenarios have been developed

Global and EU market deployment scenarios were developed to 2024 and 2030 for the 13 applications initially selected. High, medium and low deployment scenarios were developed. These deployments 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. The deployment scenarios are not intended to be forecasts, but rather to capture a range of reasonable outcomes if the various applications were to begin to be deployed commercially (Table 1).

Table 1: Global and European deployment scenarios

Application	Comments	Units	2024		2030	
			Global	European	Global	European

FCEV	Passenger cars and light commercial vehicles (LCV)	millions	1.8	0.48	10	2.6
FC Buses		thousands	35	3.0	190	16
HGV		thousands	10	2.20	80	17
FC Forklifts		thousands	93	4.7	230	11
Trains and light rail		units	490	180	2,400	870
Maritime and inland boats		units	110	11	520	52
HRS		thousands	3.9	0.99	20	5
Micro CHP	1-5 kW _e	millions	1.7	0.18	7.0	0.77
Commercial CHP	5-100 kW _e	thousands	26	3.5	200	27
Large CHP	> 100 kW _e	thousands	27	2.2	97	10
Back-up power and gensets		thousands	75	5.2	230	16
Electrolysers	Not applicable as stack sizes vary significantly	GW	4.5	0.91	21	4.3

System cost breakdowns were developed and mapped to the production volumes in the deployment scenarios

System cost projections drawn from publicly available sources were mapped to the deployment scenarios to provide cost estimates in 2024 and 2030 for each scenario. The costs were broken down to capture selected components that make up the system. For each component or system, the contributions of upstream components, added labour, added material and the recovery of the capital cost of manufacturing equipment were estimated. These additional cost elements informed the value-added and socio-economic analyses described below.

Global turnover for each application has been estimated based on the deployment scenarios and cost breakdowns

Based on the global deployment scenarios and the cost breakdowns, the range of global turnover associated with each of the 13 applications was estimated. 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. These turnover estimates were one of the factors considered in down-selecting 8 applications for detailed value-added analysis.

Industry scenarios lay out possible futures of the European FCH value chain

Industry scenarios were developed for each of the 8 down-selected applications. These laid out possible futures of the European FCH value chain, exploring what could happen in the future, and the implications of the possible futures. Two key parameters were varied: 1) the extent of deployment of FCH technologies globally (over which the EU has limited control), and 2) the share of FCH production

captured by EU actors (over which more control can be exerted). This enabled the impact of different policies and sector approaches to be assessed. Industry narratives were produced to accompany the scenarios, and validated in a workshop with industry stakeholders. The scenarios are shown graphically in Figure 5 below.

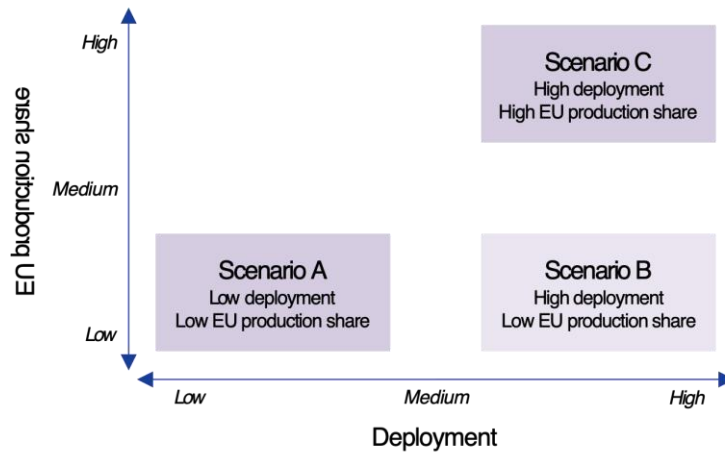


Figure 5: Industry scenario summary

The scenarios were designed to identify options and influences regarding Europe’s role. EU deployment shares came directly from the initial deployment scenarios, adjusted to give EU production shares in light of the industry scenario narratives. The scenarios served as a framework for assessing the socio-economic impacts of possible futures with more – or less – developed European FCH value chains. 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. In Scenario C, EU actors capture a higher share of production, including a more significant role in system integration for some applications.

Value-added analysis was conducted to track value creation throughout the supply chain

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 6). In the study, the value-added comprises the cost of labour, the recovery of the capital cost (capex) of manufacturing equipment, and the margin – captured as separate elements.

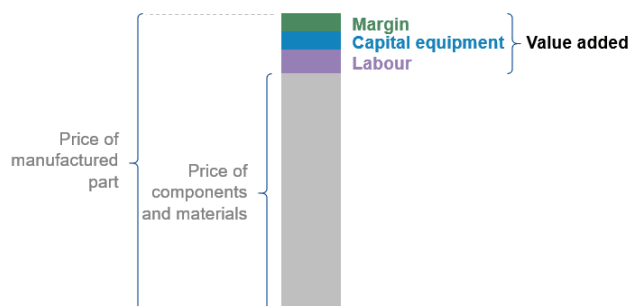


Figure 6: Definition of value-added

It is important to understand that 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. By tracking the value added for key components as well as for the system, the study was able to provide information into which parts of the supply chain have the potential to create the biggest economic benefits.

The detailed value-added analysis captured the labour, capex and margin value-added contribution for each component included in the application cost breakdown, for each of the industry scenarios.

Directly relevant socio-economic impacts in Europe were estimated based on the value-added analysis and cost breakdowns

The cost breakdowns and the detailed value-added analysis were used to estimate the socio-economic impacts in Europe in the following categories:

- **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.
- **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.

3. European supply chain strengths and opportunities

Europe has world class component and product providers and knowledge-based actors 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.

4. Socio-economic impacts and value added

Main findings: 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 7 below:

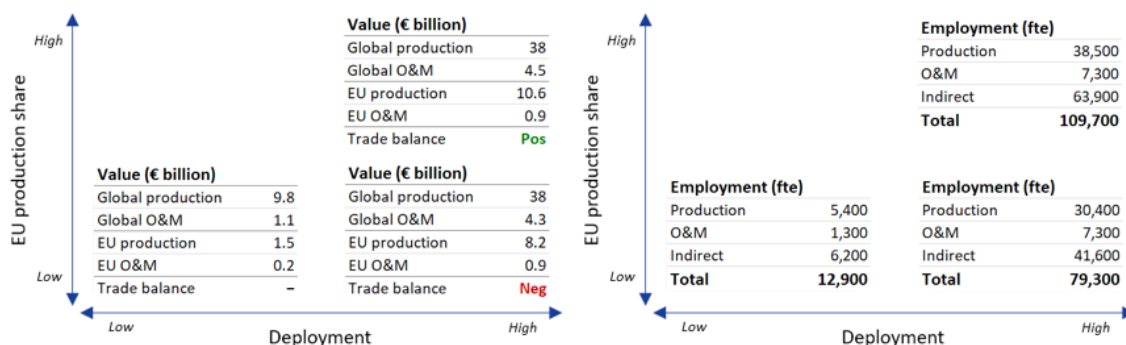


Figure 7: Sector-level socio-economic indicators

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 2 and Figure 9), with value added of €500 m and €3.5 bn respectively (Table 2 and Figure 10). 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 2 and Figure 8).

Table 2: 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

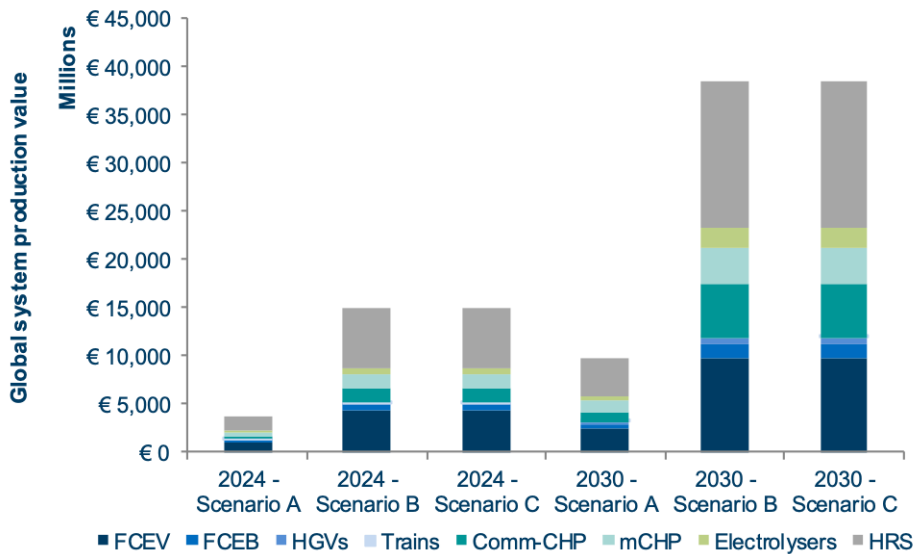


Figure 8: Global system production value for the selected applications by industry scenario (2024 and 2030)

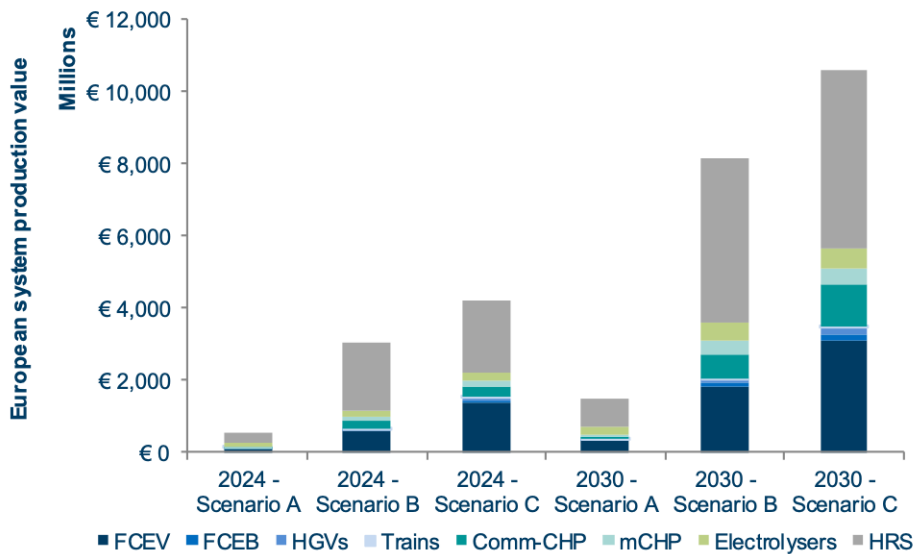


Figure 9: European system production value for the selected applications by industry scenario (2024 and 2030)

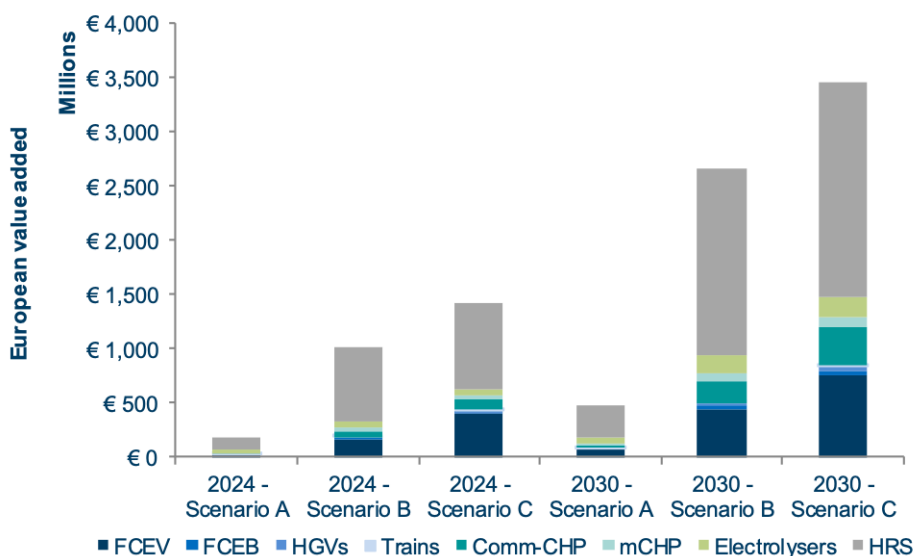


Figure 10: European value added for the selected applications by industry scenario (2024 and 2030)

- **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 2 and Figure 13).
- **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 2 and Figure 11). 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.

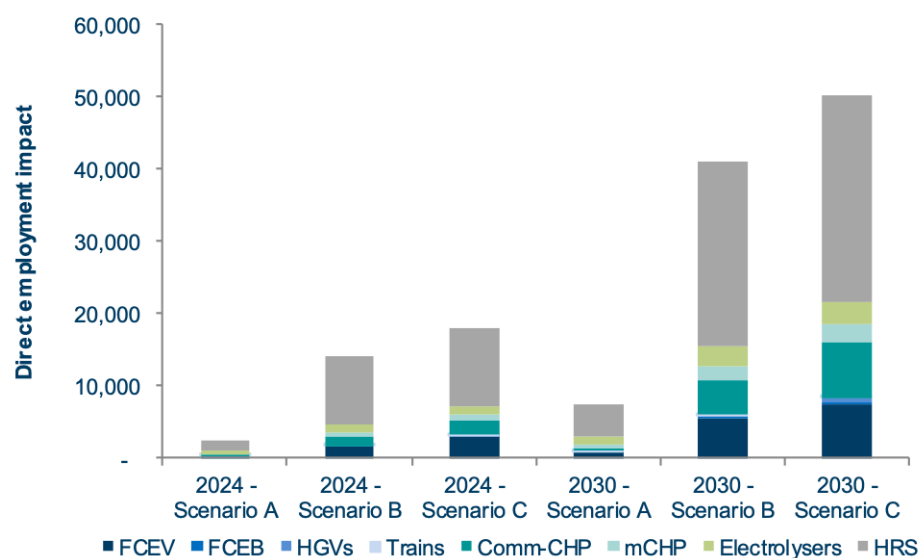


Figure 11: European direct employment for the selected applications by industry scenario (2024 and 2030)

- 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 2 and Figure 12). 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.

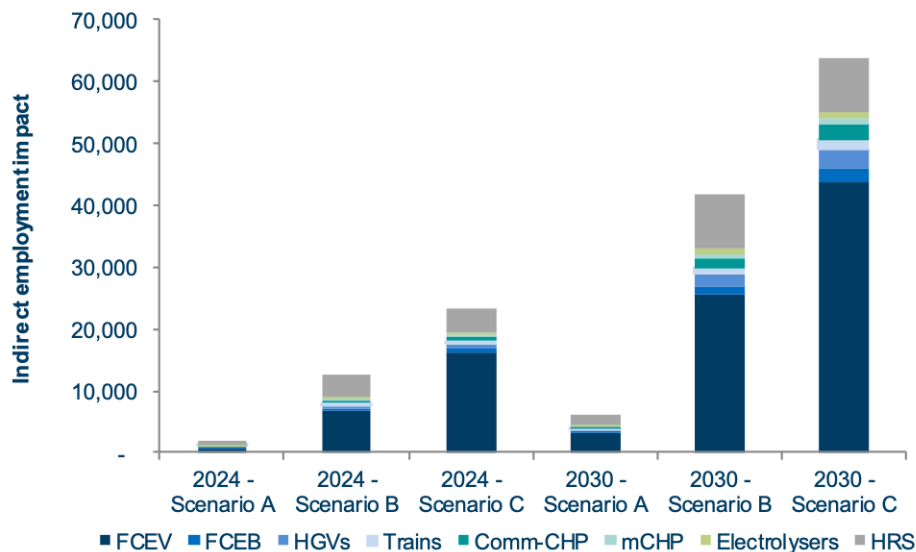


Figure 12: European indirect employment for the selected applications by industry scenario (2024 and 2030)

- 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.

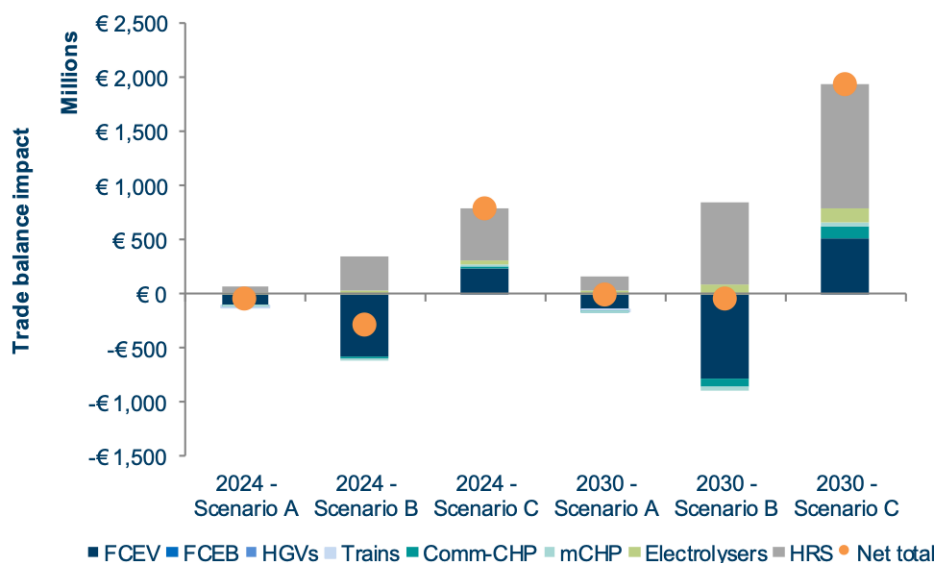


Figure 13: Trade balance impact for the selected applications by industry scenario (2024 and 2030)

- 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 2 and Figure 13).
- 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.

5. Capitalising on Europe's Opportunities Requires Action

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 only if it is 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 CO₂ 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.

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

FCH technologies can act as a strong complement to other 'clean' technologies and help provide a system solution which improves performance across a very wide range of sectors, meeting a range of policy objectives. Multiple indicators suggest that the FCH sector is starting to grow, and poised to grow fast. In fact, this growth must be relatively rapid to create both the size of industry and the 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.

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.

Nomenclature

APU	Auxiliary power unit
bn	Billion
CHP	Combined heat and power
Comm-CHP	Commercial CHP, here defined as a CHP system with an electrical output capacity between 5 kW and 100 kW
FC	Fuel cell
FCEB	Fuel cell electric bus
FCEV	Fuel cell electric vehicle
FCH	Fuel cells and hydrogen
fte	Full time equivalent
HGV	Heavy goods vehicle, here defined as any vehicle >3.5t
HRS	Hydrogen refuelling station
kW	Kilowatt
LCV	Light commercial vehicle (<3.5t)
m	Million
mCHP	Micro-CHP. Here defined as a CHP system with an electrical output of less than 5 kW
MW	Megawatt
O&M	Operation and maintenance
OEM	Original equipment manufacturer
PEM	Proton exchange membrane
RTD	Research and technology development
SOFC	Solid oxide fuel cell
t	Tonne