REPORT TO THE EUROPEAN PARLIAMENT ON THE SOCIO-ECONOMIC IMPACT OF THE FCH JU ACTIVITIES

EXECUTIVE SUMMARY

The Fuel Cell and Hydrogen Joint Undertaking (FCH JU) was established in 2008 to accelerate the commercialisation of Fuel Cell and Hydrogen technologies (FCH) in Europe, comprising:

- Hydrogen – a versatile energy carrier, which can be stored when not required, and which can be clean and carbon free when produced using Renewable Energy Sources (RES).
- Fuel Cells – highly efficient, fuel flexible and very low/zero emission energy conversion technologies that can be used in the Transport and Energy sectors.

These FCH technologies are both directly and indirectly relevant to the range of high-level EU policy initiatives that were introduced in the recent years. In particular the Energy Union Package referencing the 2030 Framework lays out the headline targets for climate and energy policies that will enable Europe to move towards a low or zero carbon, sustainable and innovative economy.

The 2030 Framework is a major policy driver for the uptake of fuel cells and hydrogen because these technologies offer low or zero carbon emissions (the extent of the reduction depending on the fuel), increased energy efficiency and have the capacity to facilitate greater integration of RES.

The FCH JU has worked with its partners to develop and demonstrate FCH technologies to the point where early-market deployment by 2020 will stimulate market growth and deliver substantial socio-economic benefits for Europe through to 2030 and beyond. These socio economic benefits include:

- Green House Gas (GHG) reductions – the roll-out of Fuel Cell Electric Vehicles, including cars and buses, will deliver GHG emissions reductions in the European transport sector, in the order of hundreds of millions of tonnes by 2050. At the same time, stationary fuel cells across residential, commercial and industrial sectors will cater for GHG emissions saving in power and heat generation, contributing to Europe's 80% to 95% reduction target.

- Localized air quality improvement – the substitution of conventional internal combustion engine applications by fuel cells in Europe's towns, cities and other sensitive zones will lower current levels of noxious emissions such as Particulate Matter (PM), NOx and SOx benefiting human health and reducing early deaths. Such local improvements will also benefit from the replacement of conventional heating technologies by stationary fuel cells which emit little/no Particulate Matter, nitrogen- and solid oxides.

- Increasing the share of renewable energy–generation of hydrogen from RES and storage of this will enable a higher penetration of intermittent RES into Europe's energy systems, with the hydrogen available for use in the gas grid, for power and heat and in transport (lowering the carbon intensity of these sectors) and even re-electrification.

- Energy security benefits– hydrogen generated using indigenous European RES for use in the transport system will reduce Europe's carbon fossil fuel imports, whilst also reducing the cost of the EU fuel bill for cars.

- Energy efficiency: as a distributed generation technology fuel cell systems exhibit particularly high energy efficiencies (electrical efficiency of up to 60%, combined efficiency in cogeneration of more than 90%), thereby attaining considerable primary energy savings whilst avoiding transmission losses. This can lead to a reduction of the energy bill of an individual household by an average of €1000/year[1].

- Safeguarding and creating Jobs – a strong indigenous European FCH industry will create high skilled, high value jobs amongst SMEs and larger businesses, simultaneously safeguarding jobs in the entire value chain of key European automotive and engineering industries.

- Boosting investment – the business opportunities created in the FCH industry are attracting substantial private sector investment from within and outside Europe as part of the shift to low-carbon economy strengthened by the COP21 (United Nations Conference on Climate Change, Paris 2015) conclusions.

- Revitalizing research and development – FCH technologies require a range of advanced, highly technical skills, capabilities and knowledge which is creating a talent pool directly relevant to Europe's automotive and engineering industries, and future longer term technology challenges.

FCH JU's activities comprise research & innovation activities in the Transport and Energy sectors, but also include specific market preparation activities such as actions to establish the framework conditions for market uptake of FCH technologies. To this end the FCH JU has acted, as a catalyst for commercialisation. It has brought together a range of stakeholders focused on FCH technologies, forged consensus among diverse industries that don't normally work with one another and built up a critical mass for achieving successful commercial deployment. It is with the mass roll-out of FCH technologies in the transport and energy sectors that the substantial socio-economic benefits will be realised.

[1] Projects CALLUX and ENEFIELD

1. INTRODUCTION

The Fuel Cell and Hydrogen Joint Undertaking (FCH JU) began operations in 2008 to accelerate the commercialisation of Fuel Cell and Hydrogen (FCH) technologies in Europe. Recognising the potential contribution to Europe's energy challenges (through Green House Gases (GHG) and other emissions reductions, higher energy efficiencies, improved energy security and increased use of renewables) the European institutions established the FCH JU as an innovative public-private partnership with the mandate to act as a catalyst for commercialisation[2]. This was succeeded by the current second phase when the mandate was renewed in 2014[3] as part of the Horizon 2020 programme.

Over the past eight years the FCH JU has worked with the public and private sectors across Europe to advance FCH technologies to the status where their early market deployment is achievable by 2020. This deployment will lead to viable commercialisation of FCH technologies at large scale for everyday use in the personal/consumer, commercial and industrial markets bringing with it significant benefits for Europe's communities.

In contrast to other European JU's with mandates for developing technologies for homogenous industries and markets, the task of the FCH JU has been to achieve a common vision, strategy and action plan for a sector that is dispersed across a range of activity areas (transport, energy, consumer etc.), actors and markets: FC technologies can be used in applications from units for charging mobile phones through systems providing clean power for transport e.g. cars and buses, to power plants of tens of megawatts of electrical power, whilst hydrogen can be used as a storage medium for excess renewable electricity. Forging a consensus among a range of industries that don't normally work with each other and building up a critical mass to initiate the technology deployment has been one of the FCH JU's primary achievements to date.

2. CONTEXT

2.1 Europe's Energy Ambitions and Challenges

In 2014 the European decision makers set ambitious targets[4] for Europe's 2030 energy system:

- 40% cut in GHG emissions relative to 1990 levels, (with 80-95% by 2050);
- A minimum of 27% of energy to come from Renewable Energy Sources (RES);
- At least 27% increase in energy efficiency.

In this context a shift towards greater use of indigenous energy resources and higher efficiencies will also positively impact European energy security, an issue of growing concern in recent years. Europe relies upon imports for more than 50% of its energy needs; yet the figure is over 90% for oil, critical for the current road transport system, and 66% for natural gas.

[2] Council Regulation (EC) 521/2008
[3] Council Regulation (EC) 559/2014
[4] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A policy framework for climate and energy in the period from 2020 to 2030, January 2014

At the end of 2015 the COP21 conclusions confirmed the need to reduce GHG emissions with the aim of limiting an increase in global temperatures to 2^{o} C overall and 1.5^{o} C by the end of the century.[5] The EU was one of 196 signatories to this agreement.

These GHG ambitions were reiterated in the Energy Union Package[6] of 2015. It sets out the vision of a secure, affordable and sustainable energy economy and is to be underpinned by innovative and competitive European businesses providing technology solutions and an engaged citizenship benefitting from socio-economic aspects of the energy transition. Thus jobs and skills, research and innovation and better fuel affordability are central to the Energy Union concept.

Achieving these ambitious targets will require substantial efforts from European households and businesses, both in the transport and energy sectors. For example, the 2013 GHG emissions from the European transport sector are estimated to have grown by over 19% from the 1990 level. The European Climate Foundation[7] estimates that reductions of 95% for road transport and a similar figure for buildings and the power sector will be necessary by 2050 to achieve Europe's 80 - 95% GHG reduction target.

Changes to Europe's energy system, both in terms of the consumption of energy and its supply/generation, will be necessary to hit the reduction targets. Such changes will include more efficient use of power and heat and an increase in RES, and the adoption of innovative energy technologies and fuels. The FCH technologies could be an essential part of the solution to the de-carbonization challenge. This is confirmed by the International Energy Agency, according to which, eliminating fossil fuels in transport and industry without resorting to hydrogen in the very long term will be hard to achieve[8].

2.2 FCH Technologies

Fuel Cells and Hydrogen are innovative technologies with the potential to make a substantial contribution to Europe's climate and energy policy goals and for enabling the transition towards low-carbon transport and energy systems where:

- Hydrogen is a versatile energy carrier which can be produced from a range of feedstocks, including renewable solar and wind power using electrolysis, and which can be stored when not required. Hydrogen from RES is a clean, carbon free fuel.
- Fuel Cells are near silent and modular electrical generators that use a range of fuels, and can be used in transport and energy applications for power and heat

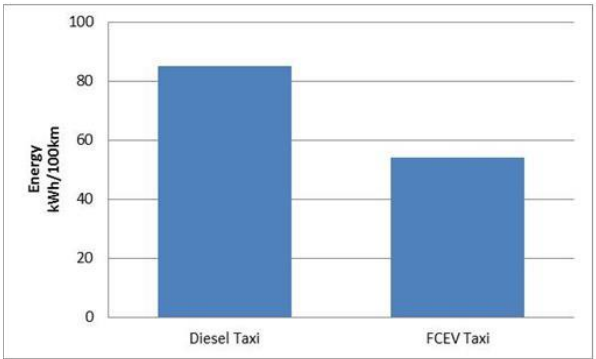
Fuel Cells have significant attributes:

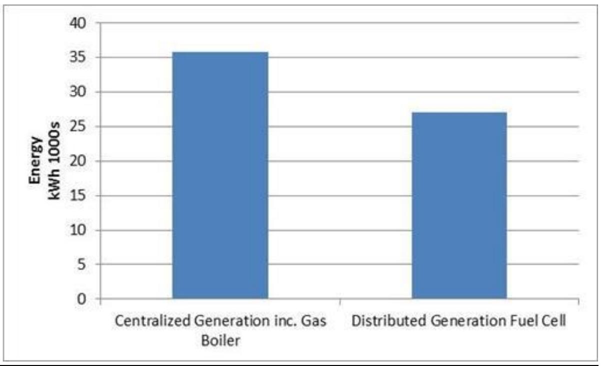
[5] United Nations Framework Convention on Climate Change, Adoption of the Paris Agreement Dec 2015.
[6] Energy Union Package: A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy COM (2015) 80 Final.
[7] European Climate Foundation, Roadmap 2050, www.roadmap2050.eu.
[8] IEA Energy Technology Perspectives 2012; Pathways to a Clean Energy System.

- Highly Efficient – fuel cells are capable of 95% efficiencies when used in Combined Heat and Power (CHP) mode[9], and even in power only mode are usually more efficient than conventional technologies with Solid Oxide Fuel Cells capable of 60% plus electrical efficiency.
- Fuel flexible – fuel cells can operate using a variety of fuels including hydrogen from RES, as well as bio-derived fuels and conventional fuels, all of which can be derived from European sources improving energy security.
- Very Low Emissions –fuel cells emit no harmful emissions when using hydrogen produced with RES, and have much lower carbon and other emissions (e.g. PM, NOx and SOx) than conventional technologies when using carbon containing fuels;

Examples of superior fuel cell efficiencies are shown below in Figure 1 on the basis of energy consumption in kWh/100km for taxis and energy demand in kWh for meeting the annual power and heat needs of a typical European home using different technologies.

Figure 1 - Comparison of Fuel Efficiency of Fuel Cells for Transport and Energy





Source: HyTEC Project and Advancing Europe's Energy Systems study [10]

The attributes and versatility of FCH technologies are recognised in the European Strategic Energy Technology Plan (SET Plan)[11]. This identifies FCH technologies as one of eight key technologies with a role in a future sustainable European energy system, suitable for use in both energy and transport systems.

2.3 FCH JU – Catalyst for Commercialisation

Since 2008 FCH JU has successfully acted with its partners as the catalyst in Europe for the development, demonstration and early market deployment of hydrogen and fuel cells. The FCH JU committed Euro 1 billion in phase 1, with plans to mobilise a further Euro 1.3 billion through its successor, the FCH 2 JU, to address fundamental weaknesses and accelerate FCH technology commercialisation.

[9] Advancing Europe's Energy Systems: Stationary Fuel Cells in Distributed Generation, Roland Berger strategy consultants, 2015; Panasonic and Toshiba commercial fuel cell information.
[10] Advancing Europe's Energy Systems: Stationary Fuel Cells in Distributed Generation, Roland Berger strategy consultants, 2015
[11] A European Strategic Energy Technology Plan (SET Plan) – Towards a Low Carbon Future [COM (2007) 723]

Whereas prior to 2008 the FCH industry suffered from fragmentation with no common vision and strategy, lacked critical mass and long term financial commitment, and had weak political backing at all levels in Europe, since its inception the FCH JU has:

- Brought together a range of stakeholders from across Europe's public and private sectors to create critical mass in terms of Research and Development capabilities, whilst leveraging financial resources from the private and public sectors;
- Created a common vision and strategy with Hydrogen Europe (formerly NEW-IG) and N.ERGHY[12], together with the European Commission, for the transport (including refuelling) and energy sectors (including hydrogen production, distribution and infrastructure);
- Raised awareness of FCH technologies in Europe especially amongst key decision and policy makers, and critically amongst regions and Member States, providing input to policies and strategies;
- Supported the development of European technology and commercial capabilities to be competitive with other lead other regions of the world.

Together the FCH JU's activities have generated increasing confidence throughout the stakeholder community; amongst researchers, developers and manufacturers, domestic and commercial end users, and policy and decision makers. The long term commitment from the private and public sector in the form of the FCH JU has created the conditions necessary to build investor confidence in the market opportunities and boosted commercialisation activities.

[12] Hydrogen Europe and N.ERGHY are the associations for Europe's industry and research and academic institutions respectively.

3. SOCIO-ECONOMIC IMPACTS

3.1 Key benefits

The successful commercialisation of FCH technologies in part due to the activity of the FCH JU will have a range of beneficial impacts for Europe. The key benefits are shown in Figure 2.

Figure 2 - Key Benefits for Europe of Commercialisation of Fuel Cells and Hydrogen technologies

Sustainability

Solutions

A radical reduction in harmful emissions can be achieved through the deployment of zero emission vehicles and the use of fuel cells for decentralized power production and heating of buildings.

Proof point

CO2 could be cut by between 64 per cent and 97 per cent in 2050

Energy security

Solutions

As hydrogen can be produced from a range of primary energy sources, its availability is almost limitless, thus allowing Europe to enjoy energy security and independence.

Proof point

Cut fuel consumption would deliver between €58 and €83 billion a year in fuel savings for the EU economy by 2030

Competitiveness

Solutions

Hydrogen is an extremely flexible energy carrier that can be used in all fields of the industry, with markets worth billions of euros across numerous applications.

Proof point

Europe could improve its growth prospects and create 500,000 to 1.1 million net additional jobs in 2030 through auto sector innovation

Data based on the report "Fuelling Europe's Future" by Cambridge Econometrics (CE), in collaboration with Ricardo-AEA (2013). It considers the economic impact of a series of forward looking scenarios that encompass alternative visions of Europe's future vehicle fleet.[4]

*Source: Hydrogen Europe (formerly New Energy World Industry Grouping (NEW-IG)), factsheets 2015

More specific benefits arising from commercialisation of FCH technologies in transport and the energy fields include:

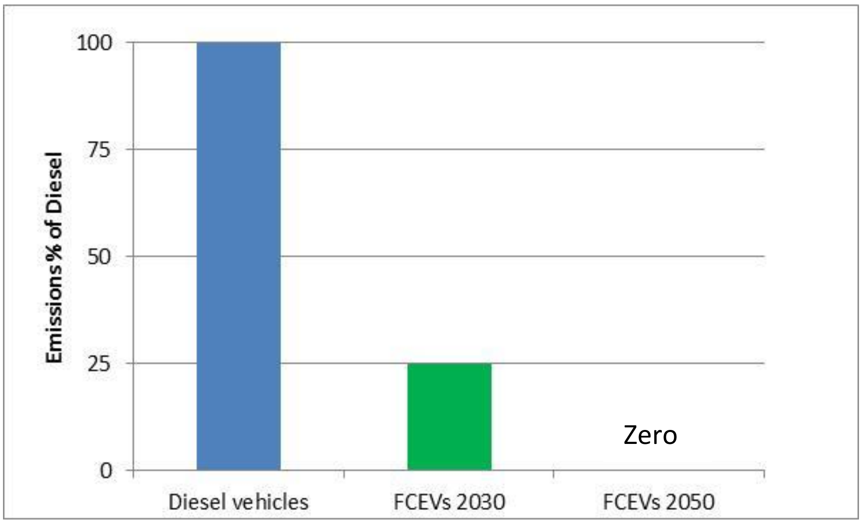
3.2 GHG emissions reductions

The roll-out of FCEVs displacing conventional internal combustion engine (ICE) vehicles and the deployment of stationary fuel cells will reduce Europe's Green House Gas emissions.

The UK H2 Mobility Phase 1[13] report shows that FCEVs would generate 75% fewer emissions than diesel vehicles by 2030 and zero by 2050 when all hydrogen fuel would be RES based. Overall it is estimated that the introduction of FCEVs into the UK vehicle fleet would reduce well-to -wheel CO_2 emissions by 3m tonnes annually by 2030 (1.6m FCEVs), and by up to 32m tonnes by 2050 (17m FCEVs, 50% of UK fleet). A similar reduction could be replicated in other EU countries. The new FCH JU financed bus study[14] indicates that over 2million tonnes of CO_2 could be saved annually in Europe through the deployment of about 2,500 buses by the 45 participating bus operators.

[13] UK H2 Mobility Phase 1 results April 2013, quoting DECC 2050 Pathways Analysis
[14] Fuel Cell Electric Buses – Potential for sustainable public transport in Europe 2015

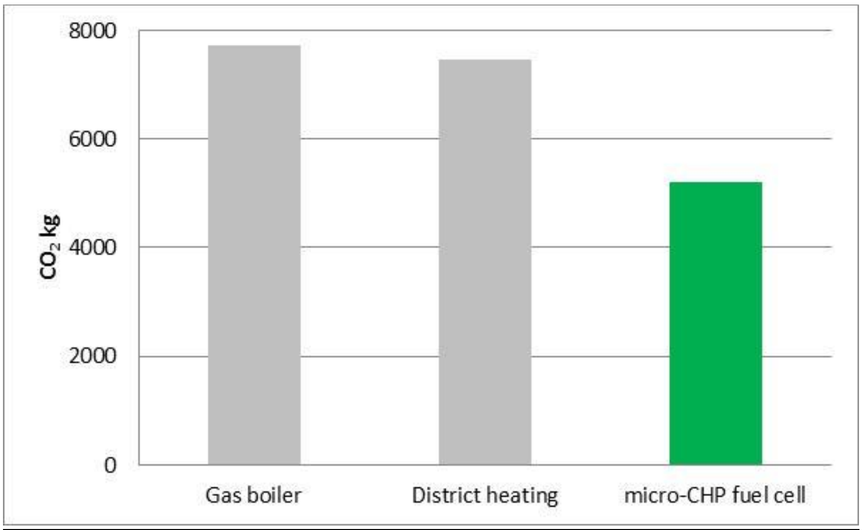
Figure 3 - Emissions from FCEVs 2030 and 2050 when compared with Diesels



Source: Based on UK H2 Mobility findings; assumes FCEVs in 2050 are fuelled with 'green' hydrogen from RES.

The FCH JU financed study "Advancing Europe's Energy Systems" estimates that a micro-CHP fuel cell unit for a typical 1-2 family house in Germany produces up to 25-30% less CO_2than incumbent solutions (a gas boiler or district heating system). These are significant emissions reductions which if replicated across Europe would have a substantial impact on Europe's overall GHG emissions.

Figure 4 - CO_2 emissions by technology for a typical German 1-2 family house



Source: Advancing Europe's Energy Systems, Stationary Fuel Cells in Distributed Generation, Roland Berger strategy consultants, 2015.

3.3 Localised air emissions reductions

Localized air emissions would also be reduced in Europe's cities especially in terms of vehicle pollution through use of FCEVs. ICE vehicles and diesels in particular, be these cars, vans, buses or taxis, contribute heavily to urban pollution. High levels of CO and CO_2, NOx, SOx and PM adversely affect human health leading to premature deaths; in London 9,400 early deaths per year are believed to be caused by NOx and PM[15]. At the European level it is estimated that long term exposure to PM and NOx in 2012 is responsible for 403,000 and 72,000 early deaths respectively in the EU-28[16]. In London it has been reported[17] that the famous 'Black Cabs' account for 25 % of vehicle derived PM pollution whilst comprising only 1% of the public transport capacity. As such all new 'Black Cabs' licenced after 1st January 2018 must be zero-emission capable[18]. These taxis, and vehicle fleets in general, are particularly well suited for early adoption of fuel cell technology on the basis of their predictable operation patterns.

It is clear that cutting transport sourced noxious emissions will benefit human health. The UK H2 Mobility study noted that UK Government estimates of the cost benefits of reduced localised emissions arising from the introduction of FCEVs into the UK vehicle fleet would be £14m a year by 2030 and much greater by 2050. This benefit would be multiplied many times if all of Europe's cities introduced FCEVs. Indeed, the recent diesel emissions scandal has emphasized the urgency of in putting in place low- and zero emission solutions, such as fuel cell and battery powered electric vehicles.

It is also the case that emissions of pollutants such as NO_x or SO_x as well as particulates can be virtually eliminated when a stationary fuel cell replaces conventional heating technologies, particularly important in sensitive or densely populated areas.

3.4 RES impact

The further integration of RES, notably solar and wind, into European energy systems is conditional upon increased system flexibility, mainly through energy storage to balance between the periods of fluctuating supply. Hydrogen storage where RES is used to generate zero carbon hydrogen (through electrolysis) emerges as an interesting option because of high energy density, response times as well as potential for deployment at large-scale and over long time periods. The hydrogen produced could then either be mixed into the natural gas grid or stored until it is needed for power, mobility or industry, thereby contributing to the decarbonisation of these sectors.

3.5 Energy Security

The use of indigenous RES to produce hydrogen which is then available for use as fuel for the European transport and other sectors would reduce the volume and value of energy imports, as well as lead to savings in the average life time cost of vehicles. The European Climate Foundation

[15] The Guardian newspaper July 2015, quoting King's College London Study
[16] European Environment Agency 2015, Air Quality Report.
[17] www.autocar.co.uk/car-news/green-car/londons-electric-cab-goes-live
[18] Transport for London announcement, October 2015.

estimates[19] that a rapid rate of introduction of advanced electric vehicles[20] could lead to annual fuel cost savings for motorists in the range of € 500 per vehicle in 2050 or some € 180-190 billion in the EU fuel bill (for cars only). The money saved by cutting fossil fuel imports would be enough to pay for both the additional vehicle technology and the new energy infrastructure. Reducing European citizens' bills at the fuel pump through electrification and shifting spending towards other, more labour intensive areas of the European economy would induce net job creation and reduce the dependency on imported oil.

3.6 Energy efficiency and distributed generation

As near silent, modular power and heat generation systems stationary fuel cells are ideally suited to Distributed Generation (DG) where generation is located at or near to the point of end user consumption. DG technologies benefit from the reduction in energy losses apparent in the transmission grids, which adds to the overall system efficiencies. Thus stationary fuel cell systems exhibit particularly high energy efficiencies: 60% plus for power only units and more than 90% when used in a co-generation e.g. CHP mode. Stationary fuel cells using natural gas could provide power and heat to every building with a connection to the natural gas grid.

Stationary fuel cells could play a significant part in the development of energy systems for Smart Grids and Cities in Europe. Low emissions and noise make them ideal for location in sensitive areas. They also offer the opportunity for end-users to own and operate their own energy systems providing independence from centralised grid power, and increased choice, with the potential additional benefit of lower costs. In Germany, the total number of businesses with more than 20 full-time employees that produce their own electricity on site has more than doubled from 2008 to 2012.

3.7 Job Creation

Europe is currently the location of some 33% of the companies working in the global fuel cell supply chain. Germany has the majority of these, at 11% of the world total, and the UK hosts an impressive 8% of all companies working in the global fuel cell supply chain. This means that Europe is very well positioned to develop a strong and competitive FCH sector, tapping into the relevant benefits when the technology is fully commercialised.

Current efforts in R&D for FCH technology already involve a significant number of high value-added, high-technology jobs across Europe. Employment estimates for the FCH sector from a survey in 2012 commissioned by the FCH JU[21] showed a job growth rate of 6% between 2008 and 2012, compared to a European average of -0.3% over the same period. This growth can, in part, be attributed to the activities generated by the FCH JU, and is expected to have continued in recent years.

[19] As outlined in "Fuelling Europe's Future", 2013
[20] where all new vehicles sold are FCEVs and Battery Electric by 2050, roughly accounting for 50% of sales each
[21] Report commissioned by the FCH JU 'Trends in investments, jobs and turnover in the Fuel cells and Hydrogen sector', 2013

It is clear that the deployment of FCH technologies will lead to more intensive job creation throughout the FCH value chain in Europe. Europe's largest FCH dedicated businesses employ over 300 people e.g. Intelligent Energy of the UK, and these numbers can be expected to grow as the businesses themselves grow. These will include more manufacturing jobs: factories operating in the USA and Korea manufacturing Molten Carbonate Fuel Cell Systems have in the region of 300 employees each[22]. Further employment growth will be expected in the automotive and engineering sectors, building FCEVs and stationary fuel cells.

In the wider value chain jobs will be created and/or safeguarded, from development and design, through supply of components and sub-systems to distribution, installation and maintenance. In particular, it is of strategic importance due to its potential knock-on effect on the European automotive industry. Given that Europe excels in auto technology, the increased spending on FCEV components would help secure technological leadership, create supply-chain jobs domestically and even create opportunities to develop an export market in fuel cell vehicle technologies.

Further, the benefits arising from the substitution of fossil fuel imports, as noted in the European Climate Foundation work above, would also lead to the creation of substantial numbers of jobs (850,000 net additional jobs by 2030, and some 2 million by 2050).

3.8 Investment

The formation of the FCH JU was driven in part by the expectation that European funds would leverage further private and public sector investments for R&D and deployment. Industry committed prior to the launch of the FCH JU that it would invest significantly in FCH technologies; over the period 2005 to 2010 it is estimated that this private expenditure totalled Euro2.5 billion[23].

The FCH JU survey[24] undertaken in 2012 found that about 60% out of 150 organisations (FCH industry players) increased their R&D expenditures/budgets in FCH technologies following the formation of the FCH JU.

Further indirect benefits have also accrued as private sector investment into FCH businesses. The most obvious form of this has been FCH businesses raising funds on the private and public markets. For example Intelligent Energy floated on the London Stock Exchange in 2014 raising £55m; in 2015 EPS of Italy raised Euro14m on the French Bourse; also in 2015 ITM Power of the UK received an investment of £4.9m from JCB, a global construction equipment business located in the UK. These are all classified as SME businesses, an indication of growing confidence in the technology and the business opportunities that these businesses are set to exploit.

Another indication of the commitment of the industry and research stems from the level of the matching achieved so far under the FCH-FP 7 programme: for the closed projects as of 31 December 2015, the industry and research beneficiaries contributed 1.2 euro into the project for each euro

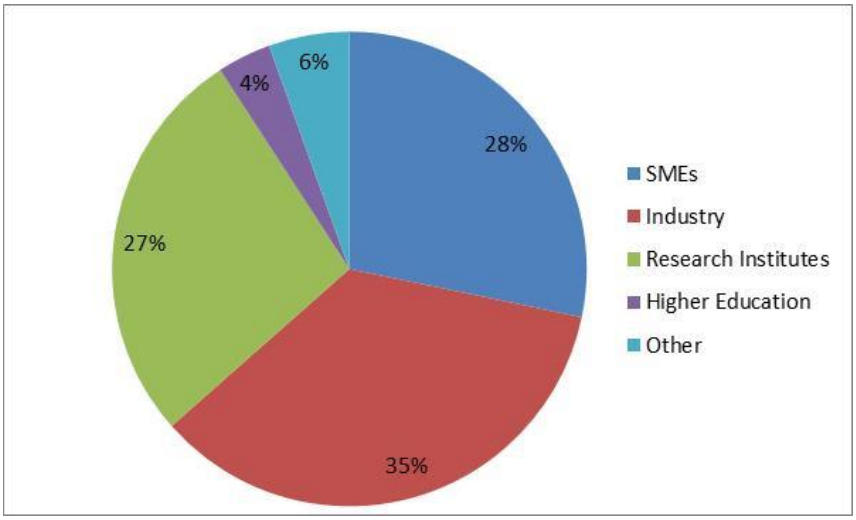
[22] Annual and other reports from Fuel Cell Energy Inc.
[23] FCH JU Trends in Investments, Jobs and Turnover in the Fuel Cell and Hydrogen Sector, February 2013
[24] FCH JU Trends in Investments, Jobs and Turnover in the Fuel Cell and Hydrogen Sector, February 2013

provided by the FCH JU (20% more than the matching requirement provided in the Council Regulation) .

3.9 Europe's research and development community

Through the activity of the FCH JU the European FCH R&D community has benefited from additional investment in R&D and the stimulus to collaboration across a range of entities, large industrial businesses, SMEs and academic research institutions. An increasing number of businesses has been attracted into the sector and membership of Hydrogen Europe almost doubled from 53 businesses in 2008 to 93 in 2015. The association maintains a diverse mix of large companies (such as Air Liquide, Daimler, Siemens and Linde) and SMEs (more than 50% of membership). At the same time the membership of N.ERGHY grew from 42 to 65 entities. Overall the sector is diverse, vibrant and extremely capable.

Figure 5 -Project Beneficiaries in FCH JU supported grants (2014)



Source: FCH JU, 2014 Project Review Days

Numbers of beneficiaries of FCH JU supported projects stands at 545, including 346 private businesses and 169 research centres and higher education institutes, and 30 others. The FCH JU has been especially successful in attracting SMEs, with 28% of beneficiaries classified as SMEs compared to 18% average in FP7.

3.10 Knowledge creation and dissemination

Investment in R&D is promoting the generation of knowledge and its dissemination across a range of key fields: electro-chemistry, electrical and mechanical engineering, computer modelling and simulations, systems integration as well as diagnostics and control solutions, plus installation and operations and maintenance. The generation and education of a workforce talent pool within Europe with these capabilities complements Europe's scientific and engineering capabilities. Indeed the R&D is directly relevant to the future of the automotive industry in Europe and to the energy engineering industry and others, benefiting the span of businesses from multinationals to SMEs and micro-enterprises.

The FCH community experienced a growth of 16% in patent numbers between 2008 and 2012[25], whilst the European industry rate was only 1.5% per annum. Both industry and research are disseminating the knowledge and know-how as shown in Table 1 below.

Table 1 Indicators of Knowledge Generation in FCH JU Projects

Indicator	**2013**	**2014**	**2015**
Projects with publications in peer reviewed journals	9	21	42
Publications in peer reviewed journals	70	115	244
Projects generating one or more patents	4	6	15
Number of patent applications	12	14	31

Source: FCH JU Annual Activity Reports

[25] FHC JU 2013 Trends in Investments, Jobs and Turnover in the Fuel Cell and Hydrogen Sector

4. DIRECT PROGRAMME COMMERCIALISATION IMPACTS

In terms of programme impacts on commercialisation of FCH technologies the FCH JU has been critical in three key areas: emission free mobility in the Transport sector, highly efficient power and heat for energy applications and energy storage (through hydrogen) for increased penetration of RES in the Energy sector.

4.1 Transport

In the transport sector the FCH JU has been instrumental in advancing the case for the deployment of hydrogen and fuel cells in cars and public transport in Europe. It has triggered and provided support for key demonstration projects across Member States, worked with these Member States to develop coherent and complementary strategies and, with a range of stakeholders, assessed and developed the business and environmental case for FCH technologies in transport applications in Europe.

4.1.1 Passenger Cars and other Light Vehicles

The FCH JU has been active in developing the technology, notably in terms of operational performance and cost reductions, proving the readiness of the technologies.

Demonstrations – The FCH JU has supported a series of increasingly ambitious projects to demonstrate the readiness of Fuel Cell Electric Vehicles (FCEVs), primarily passenger cars, (in terms of driving experience, reliability, driving range, refuelling) as well as advance public awareness of FCEVs and the social acceptance of hydrogen as a fuel. Thus:

- H2Moves project , demonstrated 19 FCEVs in Scandinavia and supported 1 HRS (Hydrogen Refuelling Stations);
- HyTEC project , has supported the deployment of 27 vehicles and four HRS in London and Copenhagen;
- HyFive project, in UK, Germany and Italy 110 FCEVs have been introduced alongside the development of 6 HRS;
- H2ME (Hydrogen Mobility in Europe) project– has started operations across Germany France, Scandinavia and the UK to deploy 325 FCEVs, and install 29 HRS;
- A further project is expected to be added in 2016, complementary to the existing ones, with even greater numbers of cars FCEVs and adding more HRSs.

The majority of FCEVs deployed in these projects come from European OEMs, e.g. Daimler and Symbio/Renault.

Through these projects, FCEVs have demonstrated that they can effectively compete with Internal Combustion Engine (ICE) vehicles, with very clear advantages in terms of no local emissions (GHG, NOx, SOx and particulate matter), and low noise. When using hydrogen produced with solar or wind power there are no emissions whatsoever. Whilst current costs are higher than ICEs, FCEV costs can be expected to fall sharply once production numbers increase. However, roll-out of low cost FCEVs will require the appropriate framework conditions in Europe, e.g. financial incentives, environmental targets and the associated political decisions; decisions which are already being made in Japan, Korea and California.

In addition the location of HRS in these projects is a key part of the development of a viable and coherent HRS network across Europe, involving other European initiatives and those of the Member States. The realisation of these HRS would represent the world's only multi-country HRS network, which itself is a major achievement given the need work across borders with multiple stakeholders.

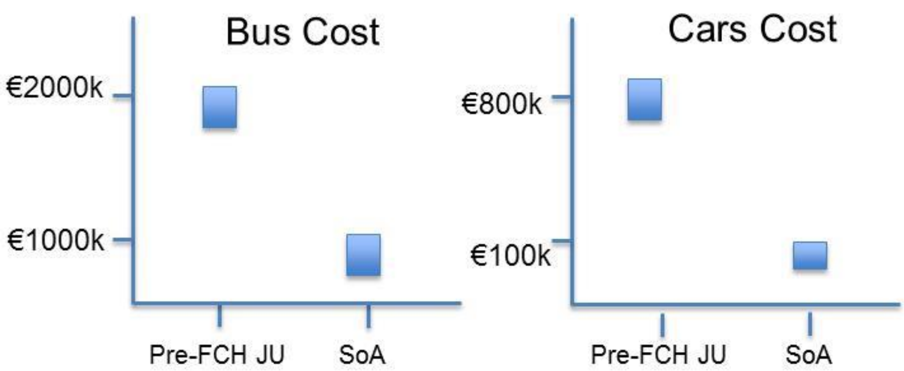
Strategy development – The FCH JU has worked with the industry and Member States in the development of strategies to roll-out FCEVs and HRS across Europe; these include the German, UK, Scandinavian and French mobility initiatives. The involvement of the FCH JU in these strategies, and the demonstrations in the relevant Member States, has ensured that together the initiatives create a coherent and comprehensive plan for the European deployment of vehicles and infrastructure, rather than a series of parallel fragmented initiatives.

Technology progress - The FCH JU has supported research and development projects to improve performance and reduce costs. Most notable of these has been the reduction in platinum use. A critical part of the catalyst used in PEM fuel cell, platinum can account for up to a third of the cost of a fuel cell and the latter is about one third of the cost of a FCEV. Preliminary results from FCH JU projects show a 75% reduction in platinum use for fuel cells used in transport compared to the 2008 state-of-the-art, and hence a substantial cost reduction. This is a significant achievement contributing to making FCEV's a price-competitive option.

Further technology development in the area of automotive fuel cell systems has focused on increasing performance and lowering cost for other stack components such as membranes, gas diffusion layers and bipolar plates e.g. STAMPEM, IMPACT , stack design e.g. AUTOSTACK CORE and modelling, PUMAMIND.

A European market – Allied with the initiatives of the Member States and working with industry a credible and compelling case for FCEVs in Europe has been produced. This has provided the confidence that has underpinned increasing private and public investment in FCEV demonstrations and refuelling infrastructure, which in turn has laid the foundations of a globally viable and attractive early market for automotive OEMs from within and beyond Europe. Hydrogen Europe has set a target of 100,000 FCEVs by 2020 deployed in Europe, using a network of 250 HRS. At an average of Euro 50,000/vehicle this equates to a potential market of Euro 5billion through to 2020, with another Euro 350m for the HRS.

Figure 6 - Costs of Fuel Cell Buses and Cars pre-FCH JU and State-of-the-Art 2014/5



Source: FCH JU

4.1.2 Buses

The development of the case for fuel cell buses in Europe has been largely driven by the FCH JU in cooperation with industry and end users. Whereas prior to the FCH JU real interest in fuel cell buses by end users was unclear, work led by the FCH JU over the past eight years has identified a clear and compelling case for the use of fuel cell buses by public transport authorities.

Demonstrations – The FCH JU is supporting four projects to demonstrate the viability of fuel cell buses for operation by public transit authorities and others in European cities and other localities. CHIC, HyTransit, HiVLoCity and 3Emotion are deploying 67 buses with public transport operators in European cities and localities including London, Aberdeen, Antwerp, Milan, Bolzano, with others to follow in Rome, Cherbourg amongst others. Consequently Europe currently has the world's largest fleet of fuel cell buses while two-thirds of the world's existing fuel cell buses fleet was produced in Europe.

Technology progress - The demonstrations have generated technical and operational information providing bus suppliers and operators with a realistic understanding of the pros and cons of fuel cell buses whilst identifying issues that need to be resolved. FCH JU supported projects have achieved:

- Fuel consumption reductions by about 50% when compared with earlier versions;
- Cost reductions to circa Euro 650k per unit today from Euro 1.5m at the FCH JU's inception;
- Refuelling times of less than 10minutes, with high availability of HRS (typically > 98%).

As such fuel cell buses are now perceived as a real alternative to conventional diesel buses: they are more energy efficient, have none of the emissions, are low noise and are just as flexible for daily operations.

Fuel cell bus consortium – In 2011/12 the FCH JU brought together a consortium of European bus manufacturers, hydrogen suppliers and bus operators, including regions and municipalities, to determine the business case for fuel cell buses[26]. By working together over the past several years under FCH JU leadership the consortium has created a shared fact-base upon which a common understanding has been developed about what users require and suppliers can deliver, with positive benefits for investment by suppliers and commitments by operators.

Further the FCH JU has been a key player in the development of Letters of Understanding (LoU) between operators and suppliers. The first was signed in November 2014 between operators in London and Hamburg and five European bus manufacturers (Daimler/Evobus, Van Hool, MAN, Solaris and VDL). This was followed up in June 2015 when a further 33 bus operators from across Europe signed a similar LoU in Riga, presenting it to Violeta Bulc, the European Commissioner for Transport. Over 45 bus operators throughout Europe are now considering the introduction of over 500 fuel cell buses by 2020.

[26] Urban buses: alternative power trains for Europe, 2012

A European Market – Following from the above the consortium has identified[27] the developments necessary to operate large scale fuel cell bus fleets, and estimated a potential minimum market size through to 2020 of about Euro 1billion. This value is based on the views of operators in the current FCH JU study, but could be much greater with the recruitment of further operators. As such there is now a real opportunity for the commercialisation of fuel cell buses over the next five to ten years. Such commercialisation would place Europe at the forefront of bus deployment, bringing with it substantial environmental and economic benefits.

4.1.3 Other Transport Applications

FCH technologies can be applied to other transport modes be this rail, marine or air, with the same environmental benefits as evident in FCEVs and buses. The FCH JU has supported a range of projects to further develop FCH technologies for these applications and to prove the environmental benefits. In the case of maritime and air fuel cells would be used as Auxiliary Power Units (APUs) providing power for ships when in harbour or aeroplanes at airports. The FCH JU held a joint workshop with the Clean Sky JU on the aeronautical application of fuel cells, demonstrating its outward looking approach to the commercialisation challenge.

[27] https://www.fch.europa.eu/sites/default/files/150909 FINAL Bus study Report

4.2 Energy

The FCH JU has been a driving force in Europe in developing the case for stationary fuel cell systems for power only and CHP in distributed generation mode, for domestic, commercial and industrial use. Further the FCH JU has been at the forefront of assessing the case for hydrogen as a storage medium and the use of FCH technologies, notably electrolysis, but also other pathways, to allow increasing penetration of RES into the European energy system.

4.2.1 Stationary Fuel Cells

In the stationary fuel cell sector the FCH JU has, through a series or projects and studies, undertaken the following activities:

Demonstrations – supported leading demonstration projects across Europe for micro-Combined Heat and Power (CHP) fuel cells for domestic use as well as larger units for commercial and industrial use. The Ene.Field and SOFC-Pact projects have fielded 400 micro-CHP units across ten Member States and others to date, with another 500 contracted. These projects have complemented national initiatives and provided data points for product performance and reliability:

- High energy efficiency – micro-CHP fuel cell units are, for example, 24% more efficient than conventional centralised generation in Germany[28], due to the very high total efficiencies of 90%, and reduction of electrical grid distribution losses through the use of decentralised generation; (this figure varies between Member State depending on the energy mix);
- Lower emissions – micro-CHP fuel cell units produce up to 80% less CO2 than centralised generation, and no particulate matter, NOx and SOx; and these same units are relatively quiet in operation;
- Good customer satisfaction – 75% of customers were either extremely or very satisfied with the units installed in their homes, with quietness and reliability being the most positive aspects.

A follow-on project to Ene.Field which will support even greater numbers of micro-CHP fuel cell units is expected to be supported by the FCH JU, starting in 2016. The numbers of units envisaged (3,000) will provide the increasing volumes necessary to initiate the drive down the production cost curve, leading to more cost effective products; a 40% cost reduction is achievable. The project will also explore different routes to market and possible European business models. Market specific demonstrations of larger fuel cell units have or are being supported by the FCH JU.

Technology progress – funded a range of research and development projects which aim to improve fuel cell performance and reduce cost. The FITUP project for the demonstration of stationary fuel cells for back-up power for remote power applications achieved reliability levels of 99.4% amongst its systems. Other projects have sought to reduce costs and increase lifetimes of components of stationary fuel cell systems: the FLUMABACK project successfully improved the lifetime of some system components.

Further projects have sought to better understand cell performances and lifetimes e.g. PREMIUM ACT, SOFC LIFE, reduce component cost and materials e.g. MMLRC=SOFC, SECOND ACT and improve

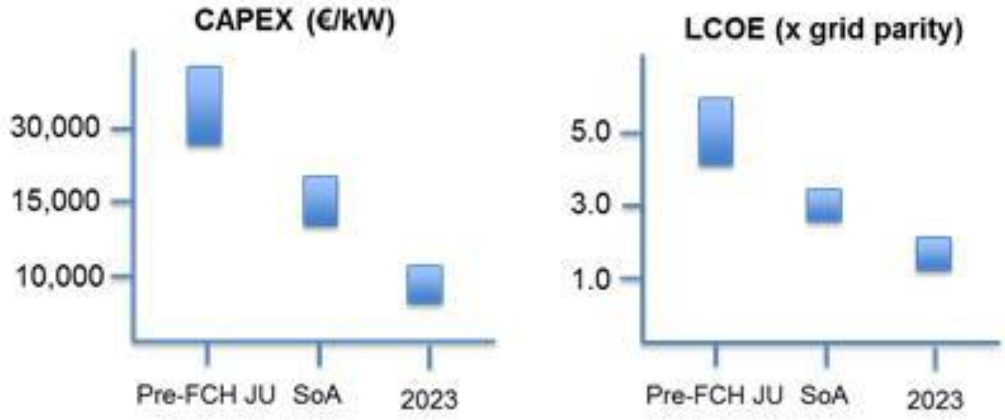
[28] Advancing Europe's Energy Systems: Stationary Fuel Cells in Distributed Generation, 2015

cell and stack design for higher performance and longer lives e.g. METSAPP, DEMSTACK. These projects support different fuel cells types, including high fuel efficient SOFC where Europe has a competitive position

Commercialisation Strategy and European Market Opportunity – brought together a consortium of over 30 stakeholders, including product developers, fuel businesses, utilities and others to undertake a study[29] of the case for fuel cells in Europe. This consortium produced an agreed fact-base for stationary fuel cell units in distributed generation applications, comparing these to other technologies, and also conventional centralized generation. This 'first of a kind' public document identifies the operational, environmental and business cases for micro-CHP and larger fuel cell units.

The study also noted that the annual market for various fuel cell types in the study countries was substantial: 2.5million micro-CHP units per annum in Germany, UK, Italy and Poland; 1.4GWe of large scale prime power fuel cell units annually and 5.6GWe of large scale fuel cell CHP systems every year. Further it showed that these units can have a positive impact on emissions of GHG and other pollutants, be more energy efficient than current centralised generation and will be cost competitive over the medium term.

Figure 7 - Changes in micro-CHP fuel cells pre-FCH JU and State-of-the-art and for 2023.



Source: FCH JU, note LCOE = (Levelized cost of electricity, refers to cost per unit of electricity produced. In the above chart units of electricity produced by micro-CHP fuel cells are shown as a multiple of the grid cost, i.e. pre-FCH JU this costs was five times the cost of grid electricity, by 2023 the cost will be close to parity.)

Awareness of Stationary Fuel Cells – raised awareness of the case for stationary fuel cells at a time when Member States' initiatives in the sector have largely been quiescent. Indeed support for stationary fuel cell demonstrations amongst Member States has been largely focused on Germany, where the Callux programme has operated. Thus the activity of the FCH JU has been invaluable when businesses have debated the merits of stationary fuel cells with Member States in terms of operational performance, readiness and cost competitiveness.

[29] Advancing Europe's Energy Systems: Stationary Fuel Cells in Distributed Generation, 2015

4.2.2 Renewable Energy Storage

The FCH JU has taken a lead in Europe in developing the technology necessary to couple RES with FCH technologies. The emphasis to date has been on developing technologies, such as electrolysis and undertaking proof-of-concept activities, and developing the business and environmental case. To this end the FCH JU supported work:

Assessing opportunities – the FCH JU commissioned a study on the Commercialisation of Energy Storage[30] which explored the role of hydrogen in maximising the penetration of RES. A consortium of over thirty businesses, gas businesses, utilities, FCH technology developers, plus others assessed the role and commercial viability of energy storage in the development of European power systems to 2030 and beyond. This compared hydrogen with other storage technologies including batteries, which showed that hydrogen is capable of storing very high energy volumes over long duration periods, months to years.

It also identified cases where such storage would benefit the power system in terms of allowing higher penetration of RES and lowering the requirement for carbon fuelled back-up technologies. The potential market in Germany alone was estimated at 170GW[31] by 2050. Using hydrogen as a storage medium would allow excess RES to be stored and then injected into the gas grid, or re-converted to power or used as a fuel for FCEVs.

Technology progress– provided grants to projects to support the technology for hydrogen production, distribution and storage. A number of pathways for the production of 'green' hydrogen have been supported, most notably through water electrolysis using RES, but also include bio- fuel and bio mass options.

Projects have improved the performance of PEM[32] electrolysis e.g. ELECTORHYPEM, and laid the foundations for increasing the power range from kW to MW, critical to large scale use of RES e.g. NOVEL. In the field of SOEC[33] electrolysers Europe is a world leader, holding the world record for continuous operation under the ADEL project. European projects are currently leaders in the integration of electrolysers with fluctuating renewable power sources. These technologies will provide an alternative to conventional hydrogen production from carbon containing natural gas.

Demonstrations – supported projects demonstrating the integration FCH technology and RES; for example the Don Quichote project focused on the application of water electrolysis powered by 'surplus' RES to produce hydrogen which is then available for use either to power forklifts in a warehouse or for reconverting back to power for the warehouse's own electrical needs, thus reducing dependence upon the electrical grid supply.

[30] Commercialisation of Energy Storage in Europe 2015
[31] GW GigaWatt, as with kW and MW, a measure of electrical power. (1 billion watts, 1,000 MW)
[32] PEM, Proton Exchange Membrane, one of several electrolytes used in electrolysers;
[33] SOEC, Solid Oxide Electrolyse Cell, another type of electrolyte used in electrolysers.

4.3 Market Preparation

The development and demonstration of FCH technologies is supported by the FCH JU's role in preparing the market for these. Through Coordination and Support Activities (CSA) a range of projects have been supported which have the objective of readying the market for introduction, deployment, and mass roll-out of FCH products and services. Referred to as Cross-cutting projects these include the following critical actions:

- Regulations, Codes and Standards (RCS) – the development of common standards etc. across Europe for FCH technologies to ease introduction and deployment of FCH technologies on a common basis. This is considered to be a major barrier to commercialization. With the willingness to contribute to Standardization Developing Organizations like CEN/CENELEC, the FCH JU's main activity in this sense is carried out through Pre-Normative Research (PNR) projects.

  PNR projects focus on filling gaps in basic knowledge, mainly on key safety issues such as on-board storage, use of hydrogen in confined spaces, hydrogen refuelling, etc. These strengthen the EU industry and research sectors and reinforce the confidence of end users. With a clear focus on improving standards they are one of several activities that further develop RCS at European and International levels. Additional FCH JU efforts in this area includes an industry led RCS Group set up within the JU to act as a platform to define and express needs, and to determine a strategy for the whole European FCH sector, in consultation with all European stakeholders.

- Safety related issues – developing frameworks for ensuring the safe deployment and operation of FCH technologies and contributing to the safe dispersion of these technologies across Europe.

- Education and training – human resource development projects to develop FCH focused training and education for current and future FCH workforce, as well as research and development professionals, alongside stakeholders such as first responders, regulators and safety officials;

- Socio-economic research – activities to better understand the public perception of FCH technologies and the awareness of the benefits and social acceptance of these to understand barriers and challenges to market adoption and developing effective communication strategies.

- Sustainability– supporting the development of specific tools for the sustainability assessment of FCH technologies, like Life Cycle Analysis (LCA) methods, and addressing the issues related to its recycling, but also defining frameworks at EU level with regards to green hydrogen and disseminating these outcomes to projects and stakeholders across the industry to ensure the highest possible impact;

Projects include: FIRECOMP and HYTRANSFER focused on improving the knowledge on the behaviour of pressure vessels when exposed to fire, and the optimization of fast hydrogen refuelling at refuelling stations; H2SENSE, dealing with cost effective and reliable hydrogen sensors; TRAINHY-PROF HYRESPONSE have addressed the development of education and training programmes for young technical researchers and first responders; HYACINTH and HY4ALL addressing issues of awareness and social acceptance of FCH technologies amongst Europe's citizens to drive a step-change in awareness around FCH; and CERTIFHY focused on developing a European Framework for generating guarantees of origin for green hydrogen.

The FCH JU has also worked on building the financing case for FCH technologies. This recognises that the magnitude of the financial commitment required to develop infrastructures and support early markets is beyond the budget of individual businesses, and Governments, and that a co-ordinated approach is necessary to leverage and align investments from the range of stakeholders, including the European Investment Bank and European funds. This has been most apparent in the Road Map for Financing Hydrogen Refuelling Networks.[34]

[34] A roadmap for financing hydrogen refuelling networks – Creating prerequisites for H2-based mobility 2103

5. CONCLUSIONS

The FCH JU has, with its industry and research partners, worked since 2008 to develop and demonstrate FCH technologies, along with development of the various business and environmental cases to the point where early market deployment is feasible and achievable in the period to 2020. This has involved a programme of increasingly ambitious demonstrations projects, a consistent approach to research and development actions and a long term policy commitment.

As importantly the FCH JU has led stakeholder coalitions in both the Transport and Energy sectors that have established the necessary fact bases for the market opportunities, forged consensus and developed shared strategies on the way forward. Confidence in a future for FCH technologies has been essential.

Creating the business and environmental cases for FCH technologies has created an increasingly compelling vision appealing to a range of stakeholders: to FCH technology businesses themselves assured by the long term commitment of the FCH JU, to end users in terms of cost and operational performance potential, and as critically to increasing numbers of policy and decision makers attracted by the substantial socio-economic benefits.

The socio-economic benefits of these FCH technologies will follow the mass roll-out of FCEVs and stationary fuel cells, as well as coupling hydrogen with the RES. The early market development through to 2020 lays the foundations for the substantial benefits of GHG reductions, air quality improvements, increased energy efficiencies and enhanced energy security, plus higher levels of RES to be realised through to 2030 and beyond, contributing to the 2030 and 2050 energy goals.

As critically the success of FCH technologies will impact the Energy Union Package ambitions for safeguarding and creating jobs in Europe's automotive and engineering and other sectors, and contribute to the social objectives of lowering energy bills and addressing fuel poverty.

The FCH JU will work with its partners through to 2020, and to the end of the project portfolio in 2023 to ensure that confidence is maintained and progress is continued to realise the opportunities for FCH technologies in Europe.

Acronyms

CHP – Combined Heat and Power

CSA – Co-ordinated Support Actions

CO_2 – Carbon Dioxide

FCH JU – Fuel Cells and Hydrogen Joint Undertaking

FCH technologies – Fuel Cell and Hydrogen technologies

FCEVs – Fuel Cell Electric Vehicles

GHG – Green House Gas (Emissions)

HRS – Hydrogen Refuelling Station

IEA – International Energy Agency

LCA – Life Cycle Analysis

NOx – Oxides of Nitrogen

PEM - Proton Exchange Membrane

PM – Particulate Matter

PNR – Pre-Normative Research

RCS – Regulation Codes and Standards

RES – Renewable Energy Sources

SET Plan – European Strategic Energy Technology Plan

SME – Small and Medium Enterprises

SOEC- Solid Oxide Electrolyser Cell

SOx – Oxides of Sulphur

kW, MW and GW – Units of electrical power or energy, often expressed on a per hour basis, i.e. kWh, kilowatts per hour.