

**HYDROGEN,
ENABLING A ZERO
EMISSION EUROPE**

**STRATEGIC PLAN
2020-2030**

Hydrogen Europe represents the European hydrogen and fuel cell sector with more than 115 companies, 65 research organisations and 10 national associations as members.

We partner with the European Commission in the innovation programme Fuel Cells and Hydrogen Joint Undertaking (FCH JU).

We promote hydrogen as the enabler of a zero-emission society.

INDUSTRY



RESEARCH ORGANISATIONS



NATIONAL ASSOCIATIONS



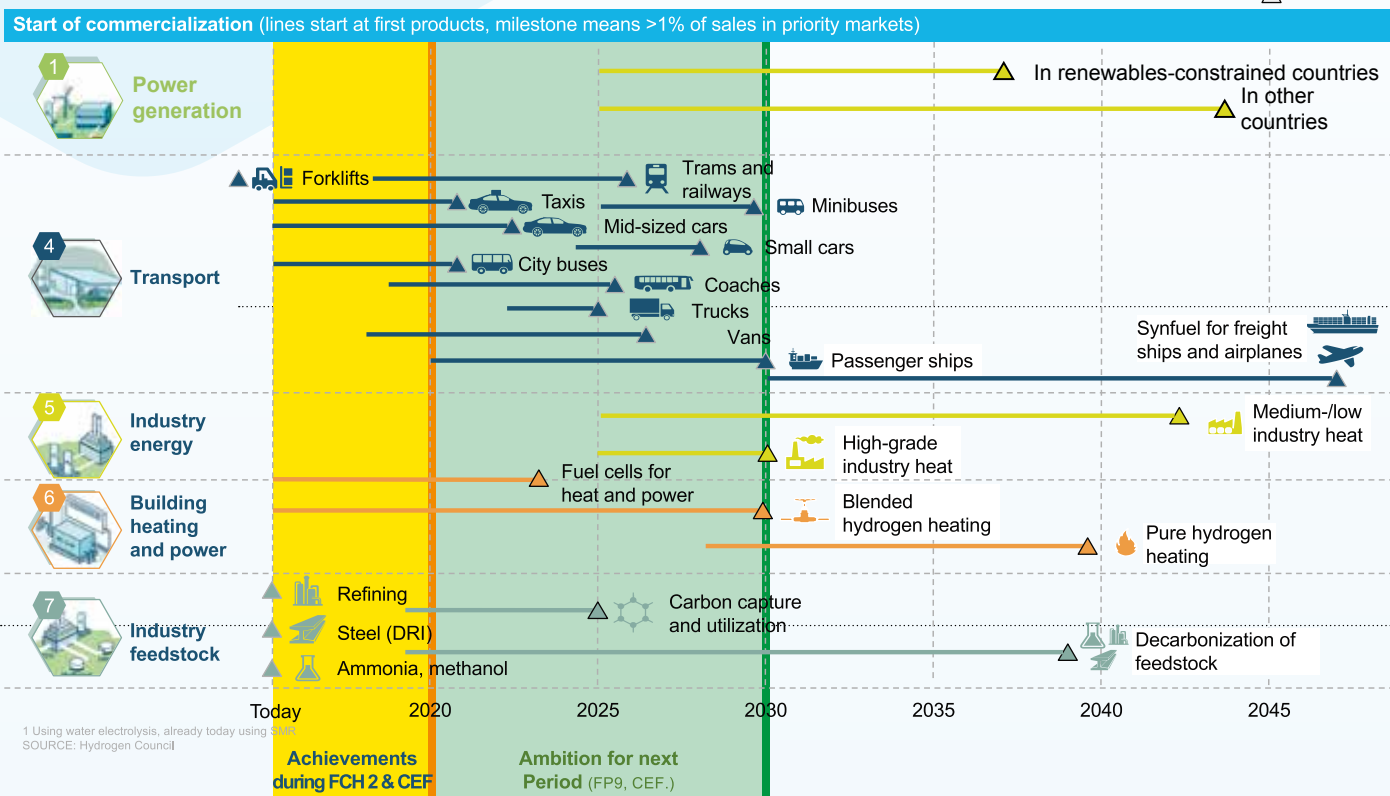
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EXECUTIVE SUMMARY

The hydrogen sector has steadily grown over the last few years, and has initiated the commercialisation of first generation of applications¹. With the progress of the technology and the growing push for decarbonising new applications are being developed across all sectors.

Realising this new market (worth an estimated 52B€ in investments and accounting for an estimated 850,000 jobs by 2030)² will require strong collaboration between the private and public sectors. This document lays out the vision of Hydrogen Europe for the road ahead and proposes a specific programme under the umbrella of an institutional public-private partnership (iPPP), as an evolution from the current programme ending in 2020.

Demonstration projects and first products already exist in many segments, with commercialization ramping up



HYDROGEN, ESSENTIAL TO DECARBONISE EUROPE

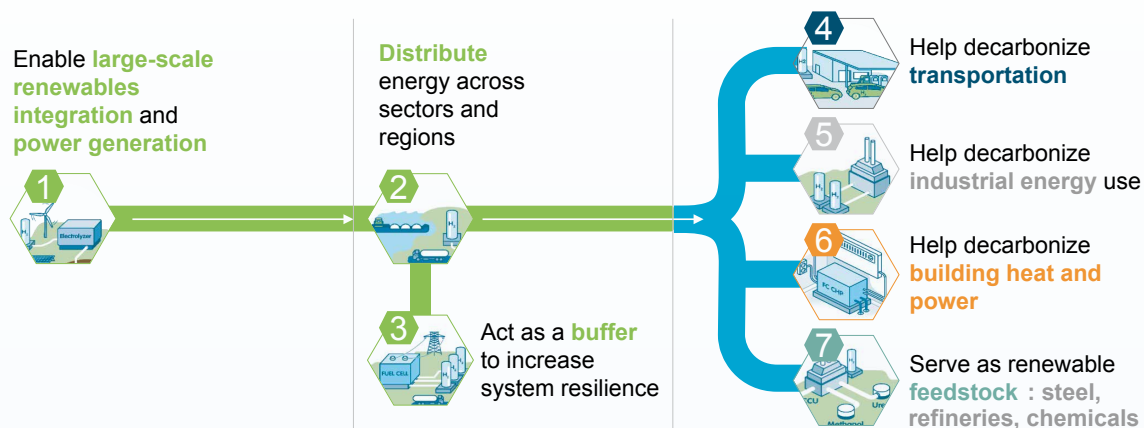
Transferring green electrons produced from renewable energy sources to final uses requires hydrogen as a flexible and practical energy carrier, as electricity alone cannot achieve this for all applications and its long-term storage in batteries at scale remains an issue. For this reason, hydrogen is an element *sine qua non* the energy transition cannot successfully achieve ambitious decarbonisation targets. **Hydrogen enables the electrification and decarbonisation of all major sectors in the economy, while supporting the sector integration** needed for the energy system transition (see graph below).³ In addition, it holds great potential to place Europe at the forefront of energy innovation technologies, helping cities improve air quality and creating new high skill jobs.

¹ Adapted from "Hydrogen: Scaling Up", November 2017. Available at: hydrogencouncil.com

² ibid

³ ibid

Enable the renewable energy system → Decarbonize end uses



SOURCE: Hydrogen Council

LARGE POTENTIAL FOR HYDROGEN, BUT POLICY SUPPORT IS ESSENTIAL

Achieving European targets for reductions of greenhouse gas emissions requires decisive policies that drive market entry of zero emission solutions, hydrogen and fuel cells being amongst the main ones. With the proper policies supporting this vision, the **demand for hydrogen will see a substantial increase**. Projections for Europe⁴ indicate that 5 million vehicles and 13 million households could be using hydrogen by 2030, while a further 600kt of hydrogen could be used to provide high grade heat for industrial uses. In this scenario, hydrogen would be **abating 80Mt CO₂** and account for an accumulated overall investment of \$62B (52B€) and 850,000 new jobs.

THE HYDROGEN ECONOMY SHOULD BE DRIVEN BY EUROPEAN COMPANIES.

Europe has much to gain by ensuring that its existing skills are promoted and expanded. The existing EU supply chain of over 100 SMEs⁵ and other large industrial players must be strengthened over the coming years, as otherwise significant investments being made abroad will result in loss of competitiveness. As an example, **over the last year China has invested an estimated 1.4B€⁶**, most of it in production lines for hydrogen and fuel cell products. **Japan is investing a total of almost 300M€ in 2017 alone**, following a pattern of sustained and increased investments in this technology the last few years. Against this background, European companies are successfully positioning themselves and exporting technology outside Europe.^{7,8} Europe has recently lost its leadership in solar PV and battery technologies. It cannot lose its chance to lead the hydrogen economy. Specific actions must be taken to ensure and enhance the competitiveness of European industry in this key field.

⁴ Ibid, p.4.

⁵ A preliminary internal study (Study on Supply Chain for Hydrogen and Fuel Cells Technologies, February 2017) by the FCH 2 JU identified nearly 200 companies in the FCH sector, 110 of them SMEs.

⁶ "To develop the hydrogen in China industriously", Dr. Zongqiang Mao, ICEF 4th annual meeting, 4-5 October 2017, Tokyo

⁷ First hydrogen fueling station with Nel technology opens in Japan:

<http://nelhydrogen.com/news/first-hydrogen-fueling-station-with-nel-technology-opens-in-japan/>

⁸ Powercell appointed as fuel cell stack supplier to Nikola Motor Company: <http://investor.powercell.se/en/news/powercell-appointed-as-fuel-cell-stack-supplier-to-nikola-mo-61935>

HYDROGEN EUROPE: PROPOSAL FOR A 8.2B€ PUBLIC-PRIVATE PROGRAMME

To realise such figures requires **coordinated action at European level to tackle remaining challenges** for the sector to fulfil its promise. While hydrogen and fuel cell technologies are very close to commercialisation, there remains a cost gap with conventional technologies and additional improvements in technology readiness must be pursued further. In addition, the European supply chain needs support in order to keep high-value added jobs in Europe. Changes to the regulatory and policy framework that recognise the contribution of hydrogen to the European decarbonisation goals and discourage the continued use of polluting conventional solutions are also essential.

Therefore, **Hydrogen Europe requests a 8.2B€ collaborative programme** involving main actors in the public and private sectors, including the following aspects:

- **R&D&D:** a 2.4B€ programme, comprising the main elements that are required to bring hydrogen and fuel cell technologies to the next step in evolution. Industry and research representatives have developed a preliminary portfolio of actions at various stages of development (early stage, development and demonstration) for a wide range of relevant applications. Normally this part of the programme would come under the umbrella of FP9.
- **Market Activation:** a 5.4B€ scheme that provides a simple and effective way to partially cover the existing cost premium for commercially ready products. This should take the form of direct funding of hydrogen and fuel cell products to kick-start the market. The main products targeted would be: (i) green hydrogen production; (ii) in transport (cars, buses, trucks, forklifts and trains); and (iii) fuel cells for combined heat and power.
- **Supply Chain:** a 400M€ scheme of support for the industrialisation of systems and components in Europe linked to key aspects of the supply chain for hydrogen and fuel cell products. Today, Europe has world-class components and product suppliers across the supply chain, amongst them a growing and promising number of small and medium enterprises in this sector.⁹ Focused investments in key components and products will keep EU industry competitive in this emerging market.

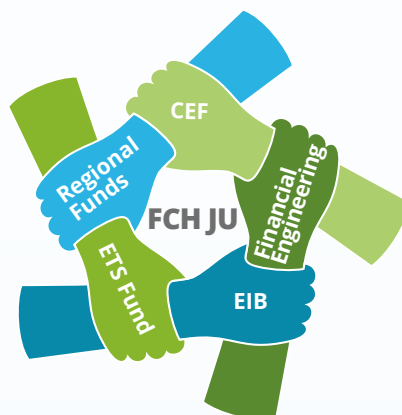
The industrial commitment will increase in this programme from current levels, covering 5.3B€ from the 8.2B€ budget, leaving the net EC contribution requested at 2.9B€. The leverage effect is thus 1.83 within the programme itself; considering broader industrial commitments to realise the 52B€ forecast through 2030, the leverage effect is estimated at nearly 17, or ten times greater than that of the programme itself.

	Total costs (B€)	Industry contribution (B€)	Public Contribution (B€)
R&D&D	2.4	0.8	1.6
Market Activation	5.4	4.2	1.2
Supply Chain	0.4	0.3	0.1
Total	8.2	5.3	2.9

EC/Industry contribution, estimation based on H2020 funding rates

⁹ Ibid, p.5.

Care should be taken that these support schemes (in particular, R&D and market activation) have the necessary flexibility to support the demonstration of the sector coupling capabilities of hydrogen, through Hydrogen Valleys. This linkage should become one of the focal points of the programme. **Hydrogen Europe calls for an evolution and expansion of the institutional Public Private Partnership (iPPP)**



To date, the FCH JU has served as the main instrument for the implementation of the iPPP model. Independent assessments¹⁰ have confirmed that **the FCH JU is an adequate mechanism for support**, ensuring that public funds are invested properly, while also aligned with the main objectives set out by industry in collaboration with the research community and agreed with the Commission. Thanks to key flagship innovation projects bringing applications closer to commercialisation (CHIC, JIVE, H2ME, ene.field, PACE, BIG HIT,...), and coordinated sectoral initiatives, Europe is at the forefront of hydrogen and fuel cell technologies worldwide. In addition, EC programmes such as **CEF** have given increasing relevance in the form of funding for a number of projects supporting the deployment of hydrogen infrastructure (COHRS, MEHRLIN, H2Nodes, Zero Emission Valley,...) and vehicles.

Against this backdrop of a successful programme, it is essential to ensure its natural evolution. While the current partnership model remains valid, **Hydrogen Europe sees the need to expand its scope and capabilities**. Thus, it should **coordinate the various support schemes**, i.e. R&D, market activation and supply chain.

It should further be able to expand coordination activities to initiate needed collaboration with **other industrial sectors** (e.g. iron and steel, refineries, renewable energy as well as the power and gas grids).

A programme that shows the evolution of the European hydrogen and fuel cell community, integrating again the private and public sectors, and expanding its scope, will bring in further participation from other sectors of civil society. Most critically, **the public investment of 2.9B€ from such a programme will catalyse an additional 50B€ through 2030**, placing Europe at the forefront of the energy transition and in line to achieve its ambitious 2050 goals on decarbonisation.

¹⁰ Latest interim report is available at: http://www.fch.europa.eu/sites/default/files/Interim_Evaluation_FCH2JU.pdf

WHY EUROPE NEEDS H2

1.1 AN OVERARCHING MISSION: A ZERO EMISSION EUROPE

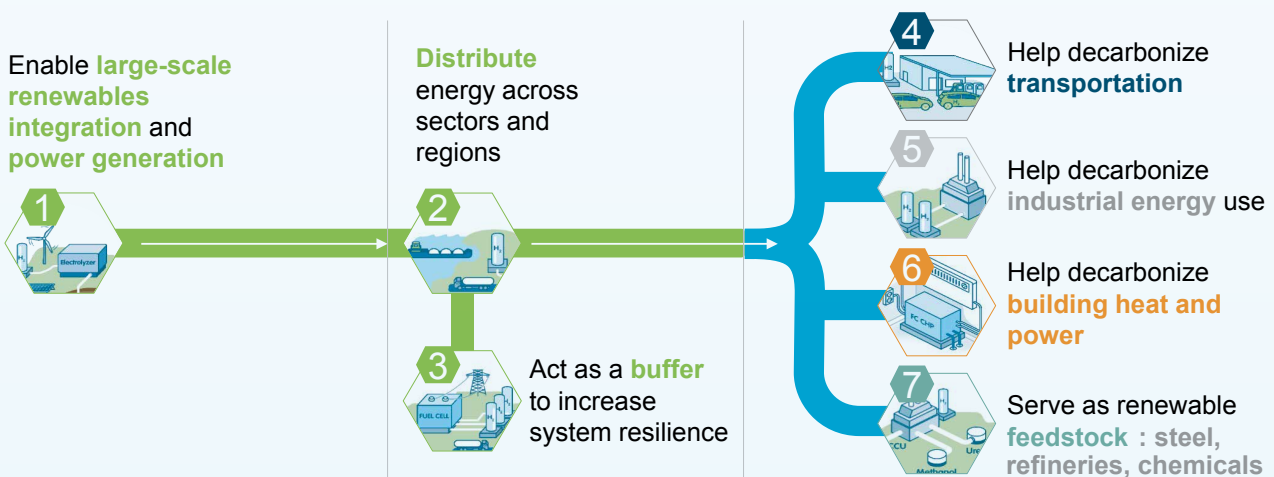
Europe is undergoing the early stages of an enormous energy transition in order to decarbonise all aspects of our daily lives in a short time. This shift is underpinned by three main elements: energy efficiency, increased use of renewable sources to provide a clean grid, and a switch to other energy carriers. **The overarching mission to enable this shift is clear: towards a zero-emission, carbon-neutral Europe.**

This new energy system will require a major contribution from hydrogen in order to be successful. Alongside electricity, hydrogen will become the main energy vector that enables a zero-emission Europe. The overarching reason for this is straightforward: in an energy system dominated by the use of renewable power from wind and solar, using these clean electrons to power whole sectors of the economy poses insurmountable challenges if not complemented by hydrogen. Hydrogen will play a necessary role in integrating large amounts of renewable power in the transport and heating and cooling sectors, which are today hard to decarbonise.

As shown in the figure below, hydrogen can:

- serve as an ideal energy vector, linking renewable energy sources with a number of final uses
- have a zero carbon footprint, when produced from electrolysis or natural gas (using SMR) + CCS
- be transported over long distances, allowing distribution of energy between countries
- store energy for long periods of time, serving as a needed system buffer and providing resilience, e.g. in underground storage
- decarbonize a wide range of final uses, providing clean power and/or heat to transport and stationary applications

Enable the renewable energy system —————> Decarbonize end uses



SOURCE: Hydrogen Council

Hydrogen is not simply a potential contributor to solving all of the challenges posed by the energy system transition, offering a future solution with a number of advantages, particularly when used in fuel cells. **Hydrogen is a solution *sine qua non* Europe cannot achieve its 2050 goals on GHG emissions reduction.**¹¹

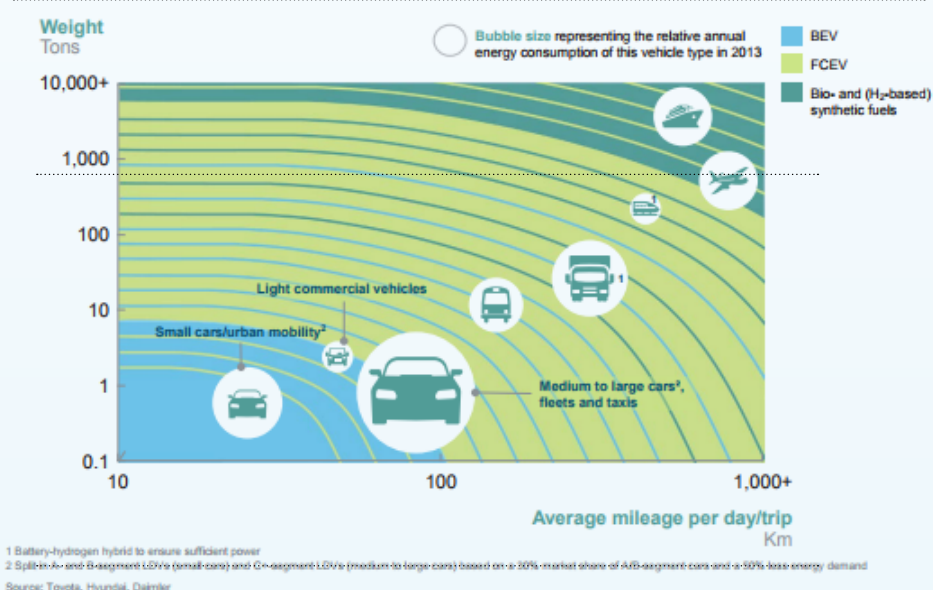
While other scenarios have been published that do not take into account a critical role of hydrogen into the future energy mix, they overwhelmingly neglect practical limitations of the other technology solutions, such as those presented next. These are absolutely crucial to ensure customer convenience and solid market uptake. Furthermore, the growth of renewable power sources may be hampered if investors are not assured of returns on their investments, which is the potential situation with new wind and solar farms with high degrees of curtailed and wasted electricity. The integration of hydrogen facilitates the long term storage and final use of this green electricity and its transfer to a host of final uses, and will thus enable the expansion of renewable energy sources.

A. MISSION : DECARBONISATION OF ELECTRICITY

The decarbonisation of the electric grid does not in itself require hydrogen since it is in itself an energy vector, rather than a supply of primary energy. However, the ability to absorb large quantities of renewable power and to store energy for long periods of time remains crucial; today, a reserve capacity of ca. 15% exists as a means to store energy. As the percentage of RES penetration increases, so does the need for long-term storage, since this clean electricity may not be needed when it is being produced and would otherwise be wasted. The use of hydrogen as a means to store renewable electricity coming from RES is not only the best solution to the issue of long-term storage, but furthermore the way to enable the decarbonisation of transport and heat: it enables the transfer of clean energy from the point of production to its final use. This is how energy and transport are linked in a **zero emission** world – see illustration below showing the roles of hydrogen in this scenario.¹²

B. MISSION: ZERO EMISSION TRANSPORT

Decarbonising transport to the levels required must go through a huge conversion to electromobility, where hydrogen fuel cells and batteries co-exist as the major complementary contributors. While many studies focus exclusively on the use of batteries, their limitations must be recognised. Rather than range, their main constraint is the recharging time and its effect on infrastructure needs. By way of illustration, imagine a highway service station where each customer takes 30' to go through any one dispenser. Besides the lack of customer convenience, there is



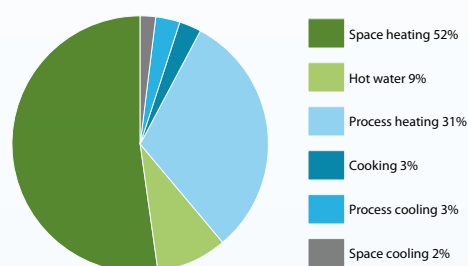
11 Important note: the reflections in this document do not imply that other technology solutions cannot/should not contribute to these decarbonisation goals. Rather, they point out inherent deficiencies that pose constraints to such solutions becoming enough on their own to achieve these objectives.

12 From: How hydrogen empowers the energy transition, Hydrogen Council, January 2017

the question of the requirements on an electrical installation based on how many dispensers the operator would need and how much space they would take. For long-distance travel it would clearly pose major issues intrinsic to the technology (e.g. imagine the situation on peak days during summer holidays). The automotive industry already is aware of these limitations: 62% of automotive executives believe that BEVs will fail due to infrastructure challenges, while 78% believe FCEVs will be the real breakthrough in electric mobility¹³. Therefore, it is clear that **hydrogen must complement batteries** as the fuels of choice in zero emission electromobility.

Due to the intrinsic technology constraints, the heavier the vehicles and the longer they need to travel, the better the case for H2 (see graph¹⁴ below). This argument also can be transposed to other modes of transport (maritime, rail and aviation), though for very large vehicles biofuels may also be a good option.

C. MISSION: DECARBONISATION OF HEATING FOR BUILDINGS AND INDUSTRY

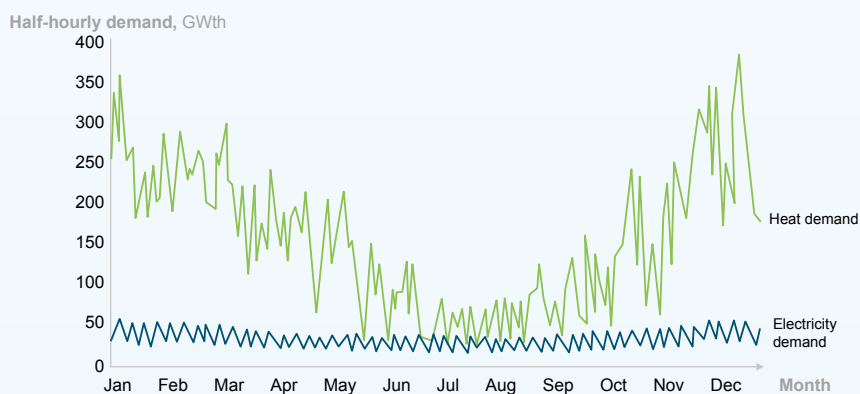


The decarbonisation of heat also follows a similar logic. Unless a massive undertaking sweeps through Europe in the next 20-30 years to convert all buildings (residential, commercial, industrial) to become essentially passive, the primary energy source to provide space heating requirements must be zero emission and carbon-neutral. In addition, since process heat also accounts for a substantial share of the final energy use, it must be decarbonized as well – see graph¹⁵ below.

Against this challenge, and besides the absolute need to support energy efficiency measures, there are three main options:

- Biomass/biogas: this is a viable option, working already in several locations across Europe (more in Northern countries in district heating mode). However, district heating is clearly not a workable solution everywhere in Europe and biomass is considered not perfectly suitable for all heat-intensive industries in Europe, due to its known lack of efficiency vs other solutions and the open question on its sustainability.
- Electricity: It already accounts for 11% of the overall mix of fuels for heating and cooling¹⁶; however, extending this practice poses a major strain to the grid in winter, which in turn requires a massive investment in overcapacity¹⁷ (peak heating demand is many times higher than peak electricity demand, as illustrated in the graph below¹⁸ showing the situation in the UK in 2010).

Synthesized half-hourly heat and electricity demand, 2010, UK



SOURCE: Reproduced from Sansom (2014)

¹³ Global Automotive Executive Survey, KPMG 2017.

¹⁴ Ibid, p.8

¹⁵ Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on an EU Strategy for Heating and Cooling (COM(2016) 51 final), p.6

¹⁶ From heatroadmap.eu

¹⁷ "Switching 80% of homes to heat pumps would require an additional 105GWs of electricity generation capacity (175% above current peak demand)", from 'Too Hot to Handle?', Policy Exchange, 2016. Available at: policyexchange.org.uk

¹⁸ Robert Sansom, Imperial College: Decarbonising Low Grade Heat for a Low Carbon Future, October 2014

Conversely, for process heat, the use of electrical boilers and heat exchangers in energy-intensive industries may fulfil their needs in a number of cases; however, high heat grades are not efficiently reached through electricity. To compound the issue, RES tend to supply less energy in winter than during summer months, so long term storage must be taken into account¹⁹.

- Progressive use of hydrogen as a carbon-free substitute for natural gas. Like natural gas, it can be easily transported everywhere and provides alternative means of seasonal storage. The technical feasibility is proven (there are existing H₂ pipelines in Europe even today), although it would require investment in its own infrastructure if taken to scale. In parallel, progressive injection of hydrogen into the existing natural gas grid is also possible, although legal limits vary from country to country up to 20%. Last, it can be obtained from RES, making it zero emission and providing the cross-sector coupling needed in the future.

An important consideration is that nearly all stationary applications (residential, commercial and industrial) require not only heat but also power on a constant or near-constant basis. Consequently, the best use of hydrogen is through a fuel cell, rather than an alternative combustion technology. This is due to the considerably higher efficiency of fuel cells, particularly at lower power levels and for lower grade heat (<500C). As a result, fuel cells should be at the core of future support efforts, while some room for other means of using hydrogen may also be warranted (e.g. turbines).

D. MISSION: DECARBONISING INDUSTRY THROUGH THE USE OF H₂ AS FEEDSTOCK (STEEL, REFINERIES AND CHEMICALS)

Steel: One of the most promising applications for H₂ is through its use as feedstock. For example, hydrogen can directly replace coal in the manufacturing process for steel through DRI (direct-reduced iron). In this way, its environmental impact is maximised, by substituting a fossil fuel such as coal for a clean one such as hydrogen, in an industry that is known as a large contributor to GHG emissions (it accounts for about a quarter of all industry emissions).

Chemical industries and refineries: Currently, the main use of H₂ is in the chemicals industry, mostly in refineries and for the production of ammonia and methanol. The primary method of production is through the reformation of natural gas. Because of the increasing pressure on these industries to lower their CO₂ emissions, they are considering the potential decarbonisation of the hydrogen feedstock. In this regard, the use of green hydrogen produced from renewable energy sources and low carbon hydrogen hold an enormous potential, all the more so if we consider the increasing demand for these chemical products worldwide over the next few decades.



¹⁹ As an example, there were 54 days in 2002 when there was little wind power available in Denmark. From: «Why wind power works for Denmark». Civil Engineering, 158, pp.66-72 (2005).

1.2 AIR QUALITY

According to the EEA, large percentages of the EU urban population are exposed to high levels of pollutant concentrations (see graph below).²⁰ As a result, every year about 600,000 EU citizens die prematurely due to air quality issues. At worldwide level, it amounts to 6.5 million deaths a year, with 36% of deaths due to lung cancer and 34% by “ACV” (accident cardio vasculaire) linked to air pollution.²¹ Beyond this enormous cost in lives, health issues affecting millions carry a concomitant cost in economic terms that have been estimated by the WHO at \$1.6Trillion annually.²²

These significant impacts are spurring a call to action in major European cities. Initiatives to curb the use of fossil fuels, for instance by cutting the access of diesel and gasoline-powered vehicles to city centres, and the announcements issued recently by cities and even national governments regarding bans of sales of vehicles with combustion engines, all give an indication of the size of the problem and the need to find workable solutions as soon as possible.

Table ES. 1 Percentage of the urban population in the EU-28 exposed to air pollutant concentrations above certain EU and WHO reference concentrations (minimum and maximum observed between 2013 and 2015)

Pollutant	EU reference value ^(a)	Exposure estimate (%)	WHO AQG ^(a)	Exposure estimate (%)
PM _{2.5}	Year (25)	7-8	Year (10)	82-85
PM ₁₀	Day (50)	16-20	Year (20)	50-62
O ₃	8-hour (120)	7-30	8-hour (100)	95-98
NO ₂	Year (40)	7-9	Year (40)	7-9
BaP	Year (1)	20-25	Year (0.12) RL	85-91
SO ₂	Day (125)	< 1	Day (20)	20-38
Key	< 5 %	5-50 %	50-75 %	> 75 %

Notes: (*) In µg/m³; except BaP, in ng/m³.
The reference concentrations include EU limit or target values, WHO air-quality guidelines (AQGs) and an estimated reference level (RL).
For some pollutants, EU legislation allows a limited number of exceedances. This aspect is considered in the compilation of exposure in relation to EU air-quality limit and target values.
The comparison is made for the most stringent EU limit or target values set for the protection of human health. For PM₁₀, the most stringent limit value is for the 24-hour mean concentration and for NO₂ is the annual mean limit value.
The estimated exposure range refers to the maximum and minimum values observed in a recent 3-year period (2013-2015) and includes variations attributable to meteorology, as dispersion and atmospheric conditions differ from year to year.
As the WHO has not set AQGs for BaP, the reference level in the table was estimated assuming WHO unit risk for lung cancer for PAH mixtures and an acceptable risk of additional lifetime cancer risk of approximately 1 in 100 000.

Source: EEA, 2017d.



20 <https://www.eea.europa.eu/publications/air-quality-in-europe-2017>

21 OMS – 2017 -

22 “Economic cost of the health impact of air pollution in Europe: Clean air, health and wealth”, World Health Organization, 2015. Available at: <http://www.euro.who.int>

1.3 OTHER BENEFITS

A. JOB CREATION AND ECONOMIC GROWTH

The European industry has made great strides and is poised to take the next step and achieve significant levels of commercialisation. This will enable significant economic growth to take place primarily within Europe, keeping high value-added jobs, and creating a supply chain of EU companies around a new suite of products based on hydrogen and fuel cell technologies.

This situation may be put in contrast to past and present experiences in other innovative technologies. For example, it is widely acknowledged that Asian manufacturers have won the race on PV panels and now have an overwhelming share of the market. Similarly, the batteries being used in BEVs are largely made in Asia. European OEMs in these market segments are not able to compete, due to steps taken at policy and investment levels in previous years that have led to the current situation

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.

European companies have become increasingly established as leaders in their respective fields. This is illustrated in the chart below, showing the relative position of EU actors in the supply chain with respect to competitors outside Europe.²³ [Note: Each score is out of 15, so the highest could be 30. A score of 9 for either factor denotes that Europe is on par with other world regions, a score above 9 means that Europe is leading the technology race.

	Fuel cell cars (FCEV)	Fuel cell buses	Fuel cell forklifts	Micro CHP	Large fuel cell CHP and Primary Power	Fuel cell APUs for trucks	Electrolysers	Hydrogen storage	Hydrogen Refuelling Stations
Strength	9	10	7	9	8	8	13	9	11
Growth	10	12	8	9	7	11	11	11	9
Overall	19	22	15	18	15	19	24	20	20

Europe has much to gain by ensuring that its existing skills are promoted and expanded. This EU supply chain must be strengthened over the coming years, as otherwise significant investments being made abroad will result in loss of competitiveness. As an example, over the last year China has invested an estimated 1.4B€²⁴, most of it in production lines for hydrogen and fuel cell products. Japan is investing a total of almost 300M€ in 2017 alone, following a pattern of sustained and increased investments in this technology the last few years. Decisive actions must be taken to ensure competitiveness of European industry in this key field.

The set-up of a competitive European manufacturing supply chain on FCH technologies and critical components or systems will effectively contribute to the EU economic recovery and sustainable growth - one of the pillars of Europe's Energy Union - by creating thousands of new jobs in a knowledge-based society, and will undoubtedly sustain the increasing demand of these products, supporting concurrently serial production capacities and low cost products based

²³ From: Study on Supply Chain for Hydrogen and Fuel Cells Technologies, internal study commissioned by the FCH 2 JU, February 2017

²⁴ "To develop the hydrogen in China industriously", Dr. Zonqiang Mao, ICEF 4th annual meeting, 4-5 October 2017, Tokyo

in Europe. Indeed, similar initiatives have been put in place worldwide, such as the ones already initiated in Asia (Japan, Korea) and in the USA (New Clean Energy Manufacturing Initiative). Based on these and other experiences around the globe, it is reasonable to believe that the deployment of the European industrial offer may start focusing on key enabling components or sub-systems with associated pilot lines.

As an example of the potential, data obtained from the recent study commissioned by the Hydrogen Council²⁵ indicate that realising the vision laid out in this document (see section 2) would contribute over 850,000 jobs in Europe by 2030. These jobs are distributed as follows:

	Revenues	Multiplier	Job creation
Transport	34B€	11.4 ¹	450,000
Residential heat and power	3.4B€	13.4 ²	54,000
Industrial heat	1.7B€	13.4 ²	27,000
Hydrogen as feedstock	13.5B€	12.6 ³	202,000
Power and energy storage	8.4B€	12.6	126,000
Total	61B€		859,000

1 Automotive and parts industry

2 Machinery and equipment industry

3 Average multiplier for hydrogen production (60% of total price; multiplier for machinery and equipment: 13.4), distribution (30% of total price, multiplier for industrial gases and gas utilities: 9.3), storage (10% of total price, multiplier for civil engineering: 16.6)

B. SECURITY OF ENERGY SUPPLY

Hydrogen contributes to secure a supply of energy in the EU in the future in line with European policy. This is a key aspect, as today Europe imports a large share of its primary energy needs (mostly natural gas and oil - Europe imports over 1B€ worth *per day*), and to a large degree from geographic areas that do not exhibit the desired level of stability. This is why locally produced hydrogen from renewable energy sources (wind, solar,...) available in Europe provides an excellent complement to these sources, as it displaces these fossil fuels coming from beyond our borders. Achieving high levels of this displacement can have additional indirect benefits (e.g. improved health of citizens, less investments needed in defense, potential decrease in terrorism that is financed from 'petrodollars', additional business opportunities for exporting of technology and hydrogen fuel to other areas of the world, etc.).



²⁵ "Hydrogen: Scaling Up", November 2017. Available at: hydrogencouncil.com. Calculated using McKinsey Input-Output Model (Germany; base data: Destatis); TAB (2012);

WHAT EUROPE HAS ACHIEVED SO FAR AND NEEDS TO ACHIEVE IN THE FUTURE

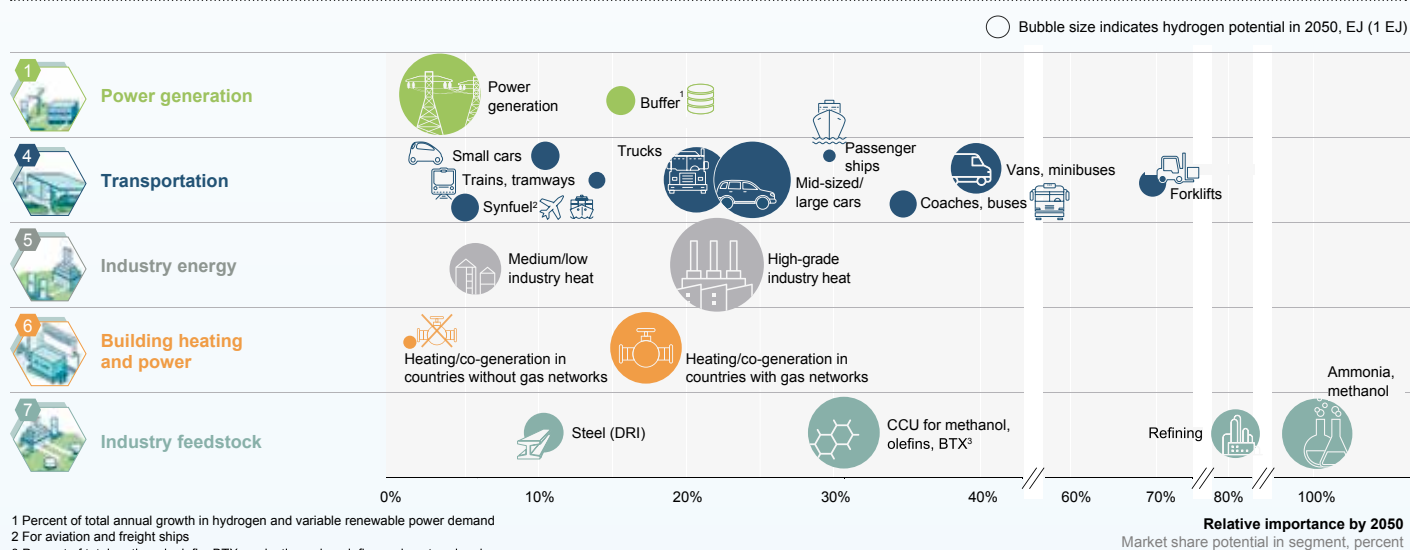
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Europe is in an excellent position to achieve a significant level of penetration of hydrogen and fuel cell technologies over the next decade, at a level that can: (a) prove that hydrogen can fulfil a key role as a central player in the decarbonisation of everyday activities, and (b) positively impact the economy thanks to a broad and competitive supply chain that keeps Europe in a leading position and creates a new wave of high skill jobs.

2.1 GROWING HYDROGEN DEMAND

A recent study by the Hydrogen Council²⁶ has evaluated the impact of hydrogen in the overall energy system by 2050 and the relative contributions in the various sectors in the economy. It further proposes a roadmap to achieve this vision. The global impact of this new energy vector can hardly be overstated. **By 2050**, hydrogen will account for:

- 18% of final energy demand
- 6 Gt of annual CO₂ abatement
- \$2500 B in annual sales of hydrogen and equipment
- 30 million jobs created



1 Percent of total annual growth in hydrogen and variable renewable power demand
2 For aviation and freight ships
3 Percent of total methanol, olefin, BTX production using olefins and captured carbon
SOURCE: Hydrogen Council

By 2030, projections for Europe include:

- over **5 million vehicles** could be on the road, including private cars, taxis, vans, and light commercial vehicles
- **5.5 Mt of hydrogen** demand in Europe, of which 600 kt for high-grade heat in first large scale projects
- **13 million households** connected to a network safely blending hydrogen and natural gas
- a cumulative **52B€ invested**, with annual revenues estimated at 60B€
- **80 Mt CO₂** abated

Beyond these figures, hydrogen will have proven its ability to link different sectors, using excess renewable electricity to be stored as hydrogen for long periods, and to provide heat and/or power in the residential, commercial, industrial sectors and transport, as well as carbon-free chemical feedstock.

26 Hydrogen: Scaling Up. Available at: hydrogencouncil.com

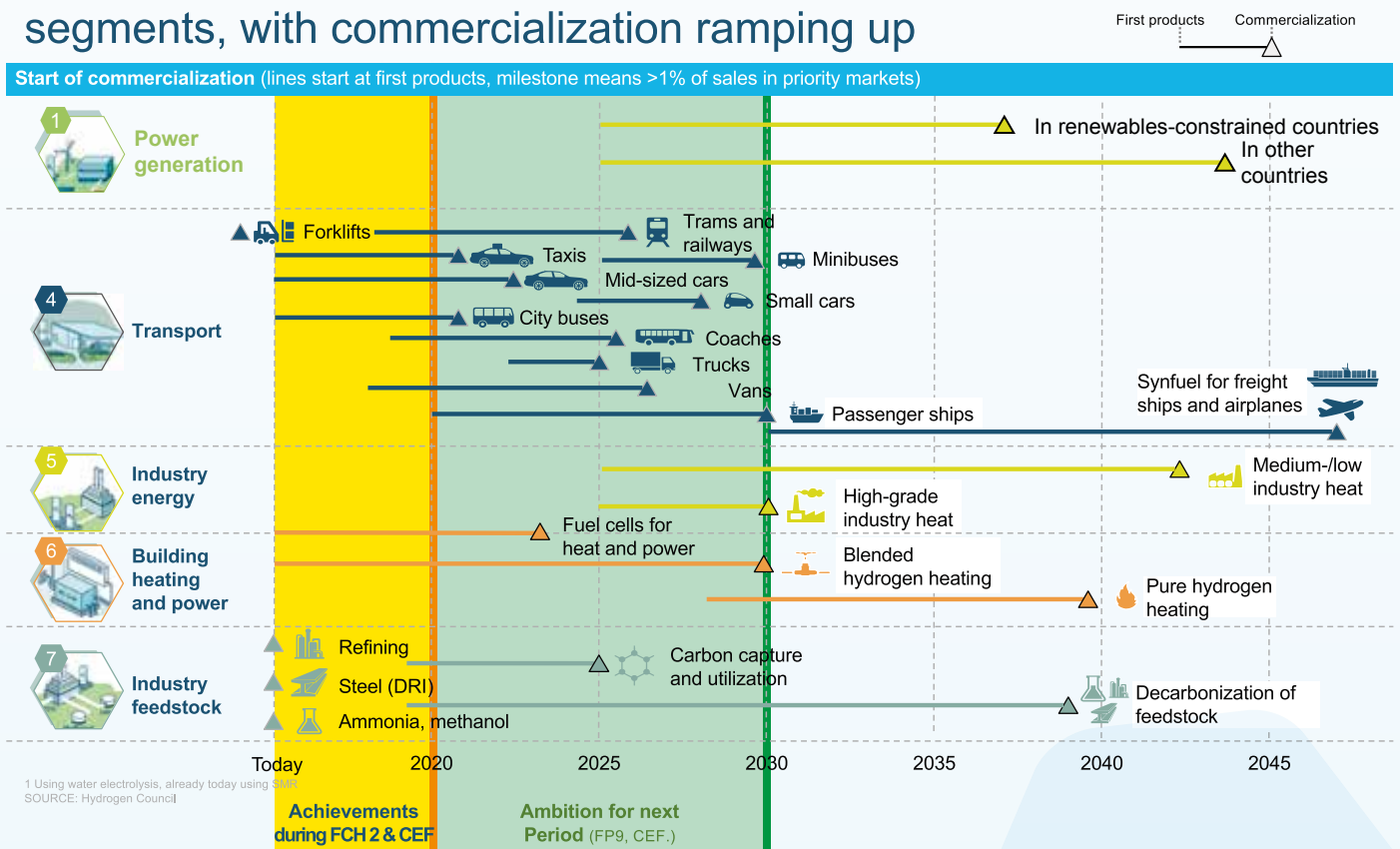
In Europe, it will be critical to ensure that this large emerging market is taken up by European companies, creating economic growth along the way to creating a new economy in which there is a strong backing from all stakeholders to heavily decarbonise our economy. Envisioning the energy transition and supporting it properly will create a new wave of high value-added jobs and business opportunities in Europe and abroad, to the tune of an estimated 850,000 jobs by 2030. Such jobs will come from the value chain in the development (R&D, product development), manufacturing and sales of new products that use this new energy vector for a myriad of uses.

2.2. OUTLOOK FOR APPLICATIONS

The technical readiness of FCH applications has increased greatly over the last few years. A preliminary assessment is shown in the figure below.²⁷

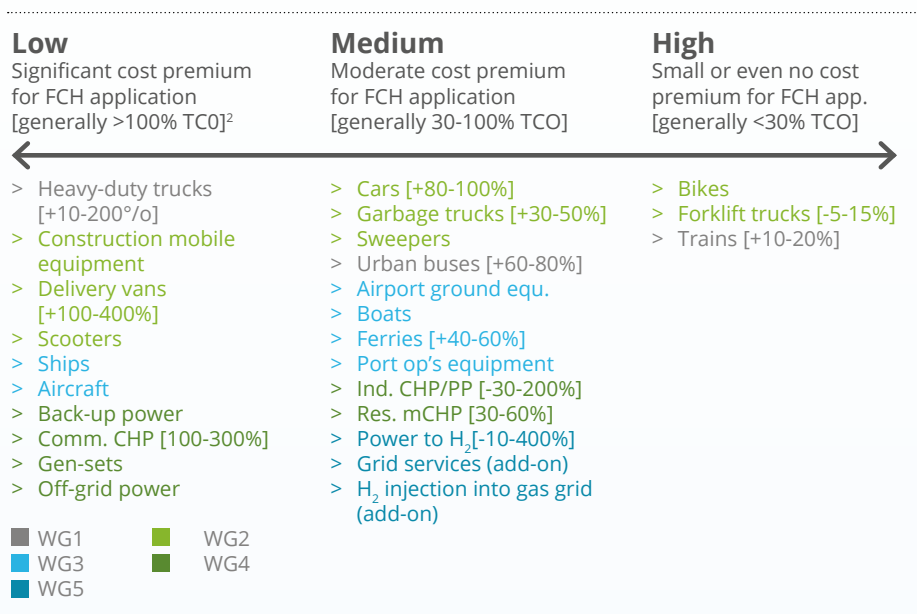
However, this status should not be mistaken for market readiness, since market conditions may make it difficult for technologically ready products to be successful due to their cost premiums. A preliminary assessment of the market readiness of the same applications is shown below.²⁸

Demonstration projects and first products already exist in many segments, with commercialization ramping up



²⁷ Hydrogen: Scaling Up. Available at: hydrogencouncil.com

²⁸ Obtained as part of the ongoing study funded by the FCH JU with regional and municipal authorities



The cost premium still presents a significant barrier to market entry, given that market conditions do not currently distinguish between polluting and non-polluting products, except in very few cases. More detail on the current status and outlook of applications within sectors is given next.



A. ELECTRICITY: STORING ENERGY AND ENABLING RES PENETRATION

The ability of hydrogen to become an effective method of storing energy from renewable energy sources goes through necessary cost reductions in the cost of electrolyzers used in the production of hydrogen from electricity. Great advancements have been made in electrolyser technology over the last few years, both in terms of cost and scale. The sector has moved from hundreds of kilowatts to the multi-megawatt scale, with projects installing >10 MW in the pipeline and concepts for >100 MW also being proposed. Alongside this increase in scale, costs have been reduced to below 1,000€/kW, depending on the scale.²⁹ Access to low-cost electricity within a favourable regulatory framework that recognises and values the use of hydrogen from clean sources remains an obstacle.

By 2020, a number of projects will be showcasing the ability of hydrogen to interact with the grid to further enable RES penetration, as well as using the generated hydrogen for other uses. Large scale storage, for example in salt caverns, may be used in some cases.

By 2030, electrolysis is expected to become mainstream and fully commercial. More importantly, the ability of hydrogen to perform this function of long-term energy storage will be widely accepted and will enable further deployment of RE power plants.

B. TRANSPORT

With increasing CO₂ emissions and a tougher regulatory framework, the transport sector is expected to start its conversion towards larger shares of low or zero emission systems. Albeit slowly, this shifting landscape is starting to create more favourable market conditions for the introduction of hydrogen-powered vehicles across the entire spectrum of applications.

Due to these factors, **applications such as cars, buses and forklifts have already achieved a good level of maturity**, as the results from a portfolio of demonstration projects funded by the FCH JU show, and are commercially available today. Where technical issues remain, they refer mostly to the integration of the components or the lack of a reliable supply chain for certain subcomponents, rather than the fuel cell stack itself.

²⁹ See for example: Study on early business cases for H₂ in energy storage and more broadly power to H₂ applications. Available at: http://www.fch.europa.eu/sites/default/files/P2H_Full_Study_FCHJU.pdf

A more mature market with an established supply chain is expected to solve these issues in the short to medium term as the number of units increases. A cost premium is expected to remain until volumes increase substantially.

Other applications such as trains, heavy-duty trucks and maritime are starting to see the first wave of demonstration projects. They must go through additional efforts on technology development in order to optimise systems and reduce capital and operating costs. While trains in particular have not undergone large scale trials, the economics look quite promising as a viable alternative to diesel locomotives (see chart on previous page). Heavy-duty trucks and maritime applications are heavily influenced by the regulatory environment and will benefit from commercialisation of other applications. They are also influenced by the characteristics of the specific use cases, as these are rather varied (e.g. cruise vs cargo ships, short haul delivery trucks vs long haul 44t trucks, etc...).

In economic terms, hydrogen can already lower the total cost of ownership of trains and forklifts, and we expect all transportation segments to be within a 10% range by 2030. These cost reductions require a significant scale-up of manufacturing capacities. If realized, FCEVs would have lower investment costs than BEVs in long-range segments.

The next five years will see the introduction of more models in medium-sized and large cars, buses, trucks, vans, and trains, and it is likely that additional segments such as smaller cars, minibuses and aviation will follow until 2030.

C. HEAT IN BUILDINGS AND INDUSTRY

The use of hydrogen to provide space and process heating is a relatively new concept. Highly efficient fuel cells producing heat and power have been developed and are now starting to be commercialised, particularly for residential and commercial applications, bringing economic as well as environmental benefits to users.

A number of studies have taken a closer look at the possibility of using hydrogen as a carbon-free substitute for the use of natural gas in the long term, particularly for providing space heating, both in environmental and economic terms. A recent study by KPMG looking at decarbonising the UK gas networks by 2050 concluded that the conversion of such networks to hydrogen was the most cost-effective and practical way.³⁰ The city of Leeds also commissioned a study³¹ that similarly concluded that the use of hydrogen was the best way to decarbonise its gas grid. It is now taking the first steps to implement this vision.

Intermediate steps involve using hydrogen from renewable energy sources and injecting it into the gas grid. While today the regulatory framework does not favour such a solution, it can help decarbonise the gas grid, and at the same time provide an additional source of income to hydrogen production plants where there is a different primary use of hydrogen.

By 2030, it is expected that hydrogen in low concentrations will be blended into natural gas networks with limited infrastructure upgrades. Alternatively, entire cities (or ecosystems) could be converted to pure hydrogen, following the Leeds example. As stated above, both processes have already started and could start scaling up around 2030, with the equivalent of more than five million households connected to a gas network with blended or pure hydrogen.

³⁰ "2050 Energy Scenarios - The UK Gas Networks role in a 2050 whole energy system", July 2016.

³¹ The Leeds City Gate project.

These households will be using 100% hydrogen appliances. Those where hydrogen is being blended into the natural gas networks will have advanced, fuel flexible appliances.

In addition, fuel cells operating on natural gas, hydrogen or any mixtures thereof, will become a widespread and fully commercial choice for the provision of heat and power for a range of residential and commercial applications.

D. HYDROGEN AS FEEDSTOCK IN INDUSTRY

By 2020, there will be installations using hydrogen from green energy sources (renewable energy) and low carbon hydrogen at large scale proving the viability of this process to decarbonise the use of hydrogen as chemical feedstock, such as in refineries or steelmaking. Such trial projects will also validate a number of studies that point to the technical and economic suitability of clean hydrogen to contribute to the decarbonisation goals in these industrial settings. In economic terms, access to low-cost electricity remains perhaps the largest challenge, though a price in the range of 40-50€/MWh or below can be accessed and may trigger attractive business cases³².

Such studies and trials are prompting a high level of interest from various industrial sectors, given the increased pressure to decarbonise industrial processes, both from regulators and society. The expectation is that hydrogen production from electrolysis using renewable power is being implemented at scale in a number of industrial applications by 2030. Some examples include:

- Steel
- Refineries
- Production of ammonia (fertilisers)
- Production of iron and steel
- Use of H₂ and captured CO₂ (CCU) replacing syngas for production of methanol, olefins, BTX, etc.)
- An additional possibility may be for the chemical process industry to demonstrate benefits from electrolysis integration by using e.g. oxygen and heat generated.

E. HYDROGEN VALLEYS

One of the main selling points for hydrogen is its ability to link different sectors, taking the electrons produced from renewable sources to a broad array of final uses. In this regard, it serves as an energy vector and holds a similar potential to electricity. To date, however, this ability to link various sectors within the same ecosystem is only being implemented at small scale.³³

A number of regions/cities have expressed a strong interest to implement these concepts at larger scale, and by 2030 we expect that these ecosystems or 'H₂ valleys', as they are commonly known, will be proven. They will gather elements from the previous applications covered in the previous sections and will certainly include hydrogen generation from renewable sources, its distribution and storage and final use in a variety of applications. This concept will be implemented in different ways depending on local needs.

³² See for example: Study on early business cases for H₂ in energy storage and more broadly power to H₂ applications. Available at: http://www.fch.europa.eu/sites/default/files/P2H_Full_Study_FCHJU.pdf

³³ See project BIG HIT (www.bighit.eu and <http://www.fch.europa.eu/project/building-innovative-green-hydrogen-systems-isolated-territory-pilot-europe>)

3

AN EFFECTIVE PROGRAMME FOR THE NEXT 10 YEARS

3.1 GOALS

In this next phase from 2020, the European industry sees these as the **main goals** in the necessary strategy:

A. PROVE SECTOR INTEGRATION USING H₂ AS FLEXIBLE ENERGY VECTOR:

One of the main advantages of the use of hydrogen in the energy transition is its ability to act as an energy vector linking sectors (e.g. from clean primary energy supply to final uses in transport and stationary applications). Therefore, it is essential that the next programme proves the technical and economic readiness of a hydrogen ecosystem, including production, distribution and storage, and final use in transport and stationary applications. This should be done in increasing steps in scale and complexity over time.

B. STRENGTHEN FCH TECHNOLOGY BASE THROUGH INNOVATION AND THE SUPPLY CHAIN:

With the increased level of awareness of hydrogen and fuel cell technologies, advanced countries such as **Japan, China, Korea and the US** are investing heavily. This puts pressure on EU companies to keep up their level of investments in order to establish themselves as leaders in their respective fields. Overall, EU companies fare quite well in the level of technology development vs the rest of the world. It is also clear that additional investments are needed to strengthen this technology base and the EU supply chain, with special attention to SMEs. This will help our economic competitiveness and the creation of high value-added jobs in Europe. A specific area of interest should therefore be the support for manufacturing capabilities in Europe.

At the same time, a strong and focused R&D&D programme is required to sustain the push for innovation and the level of technology leadership existing in the EU. This will support the development of the next generation of products across a portfolio of applications. It should cover a number of areas, including but not limited to: new and advanced materials for fuel cell systems (cell, stacks and balance of plant); hydrogen production, distribution and storage; and refuelling stations. It must address key areas such as lifetime, cost reduction and reliability of components, among others. A strong, sustained level of investment in R&D in these technologies will be a decisive factor in ensuring that Europe enhances its leadership in this field and trains highly qualified manpower and excellent scientists.

C. ENHANCE MARKET COMMERCIALISATION OF MATURE PRODUCTS:

The next programme must provide support for the market entry of a number of fuel cell applications entering the commercial marketplace. While this has been partly achieved in the current FCH 2 JU through demonstration projects focusing on innovation aspects, a more focused and simplified market activation mechanism is necessary. Such a mechanism would provide a percentage or **lump sum** (e.g. x€/unit or x€/kW) for every unit installed under commercial terms. Some potential examples of commercially available products that can benefit from this scheme may include cogeneration units at various scales (from residential to industrial), urban buses, passenger cars, hydrogen refuelling stations, trains, electrolyzers and trucks. This should be done at European scale, rather than leave it to individual Member States to decide on their own structures (although such complementary efforts would be very beneficial), in order to ensure that the size of the potential market is as large and as uniform as possible throughout Europe.



D. EXPAND APPLICATIONS REACHING COMMERCIALISATION:

A number of applications have attained advanced TRLs, but have not quite achieved the level of technology development and deployment desired. For these, additional actions to increase their state of readiness are required. These actions may include applied R&D and demonstration projects, as well as R&D projects at lower TRLs (2-5) that provide the improvements needed for technology development. Applications or technologies that may fall within this scope include maritime and port operations, airborne applications, advanced/alternative methods of clean hydrogen production, and improved methods to store and distribute hydrogen, amongst others.

E. COORDINATE KEY ACTIONS AT EU LEVEL:

Industry believes that the pace of innovation achieved in hydrogen and fuel cell technologies over the last decade can be characterised as a clear success. One of the main reasons for this success is the increased cooperation amongst industry, research and the European Commission, through the FCH JU. This body, created initially for the management of an R&D programme within FP7 and continued in H2020, has also taken on this role of coordination on a number of levels, and has been instrumental in ensuring the success of the main applications entering the market today. The ability of this body to catalyse certain key actions, bringing together the necessary actors around a common table to form de facto coalitions that work together around a common goal, has enabled certain applications to accelerate their commercialisation. It has also worked with other stakeholders to trigger additional or complementary co-financing for FCH applications, including some Member States. These types of actions are seen as key components of the European strategy necessary to achieve success and must be enhanced.

3.2 AREAS OF SUPPORT

Hydrogen must play a central role in the decarbonisation of everyday activities and European companies can take the lead at a worldwide level, but it is necessary to take decisive action. Three main areas require support:

A. A CONTINUED STRONG, FOCUSED R&D&D PROGRAMME

One of the main tools in the coming years must be a set of research and innovation activities that maintain state of the art technologies and keep European players at the forefront of H₂ technologies while improving market readiness across a number of specific applications. Normally within the framework of the upcoming FP9, this next phase should follow on the achievements of the previous FP7 and H2020 programmes and enhance the level of cooperation amongst the main actors (industry, research and the EC). An industry-led programme will ensure the correct links between early stage research projects and late stage prototyping, trials and commercialisation in a structured way and shorten time to market.

Early phase, low TRL (2-3) research is seen as a necessary component in this scheme. Development of new materials or architectures to be integrated into the next generation of products will place Europe at the forefront in this technology. Mid-level development stage R&D (TRL 4-6) allows the next level of development to take place, for example carrying out system integration and prototyping at the lab scale or with small numbers of units in the field, establishing the requirements for subsequent commercialisation by suppliers and fine-tuning balance of plant components.

Beyond these R&D actions, demonstration projects (TRL 7-9) will also be required. They are instrumental in providing confidence in the technical and commercial



readiness of the products, both for consumers and for suppliers, testing different business models and finding out which work best for future ramp-up. These are clearly application-specific, i.e. cars, buses, energy storage, FC-based CHP, etc.

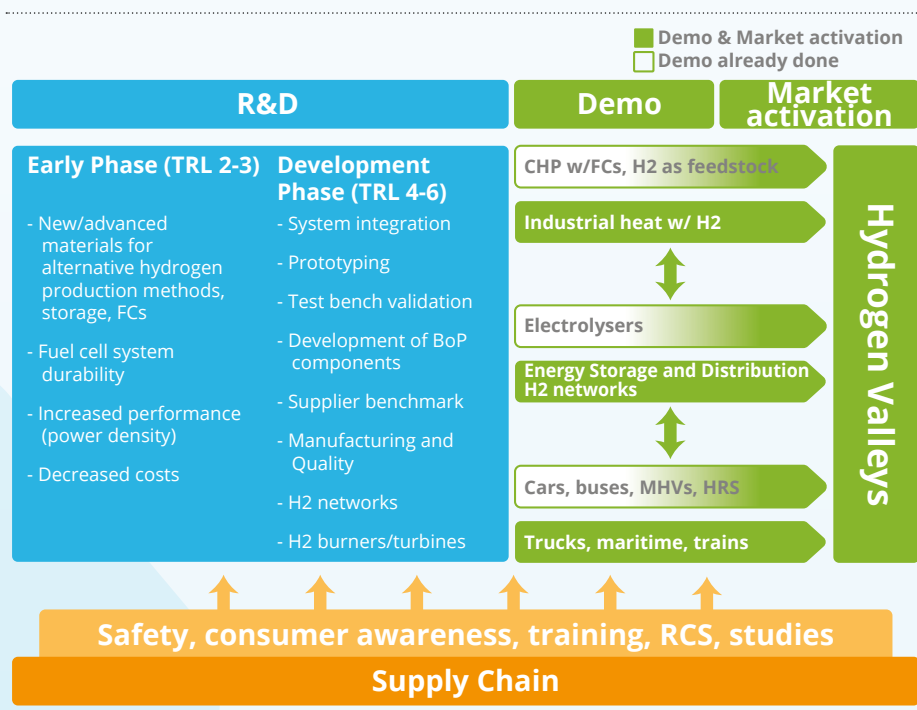
Conversely, the outputs in many of these projects further serve to fine-tune the next wave of deployments within the same family, by finding out what technology pathways do not work as well and which modifications are needed and should be explored in future projects.

B. A MARKET ACTIVATION SCHEME

Once rollout trials take on larger volumes, they bridge the gap towards commercialisation and gradually step outside the normal scope of an R&D framework programme as they start entering the marketplace. This is where simplified, product-specific **market activation** schemes become necessary. Such a market entry mechanism for advanced hydrogen and fuel cell products allows them to realise further cost reductions, recognizes their environmental advantages and sets them on the pathway to competitiveness with conventional, fossil fuel-based solutions. These can take on various forms but generally would involve covering part of the cost of a product (i.e. x€/kW or x€/unit). As an example, one can imagine an amount of 100,000€ for each fuel cell bus sold, helping to bridge the gap with conventional solutions (diesel and diesel-hybrid) and increasing the volumes to catalyse further needed cost reductions. In all cases, the number of products benefitting from such a scheme should be capped. This has been successfully tested for some products in FCH 2 JU flagship projects³⁴ with Horizon 2020 funds. It could be largely expanded with FP9 and CEF funds and with simplified rules (lump sum and/or unit of costs).

C. STRENGTHENING THE EU VALUE CHAIN

All of these efforts will fail to have the desired impact if Europe does not decisively support the European supply chain. Though not exclusively, this supply chain has a strong component of SMEs, which are best placed to take advantage of the opportunities offered by these new technologies and grow by creating new jobs requiring advanced skills.



³⁴ A flagship project that is big enough to trigger the commercialisation of a product with an impact on the costs and the credibility of the technology. Typically, it will involve an industrial investment of ~€100M for a public funding of ~€25M.



Besides the R&D activities laid out earlier, specific support to bring up the manufacturing capacity with a high degree of reliability and quality control and assurance will clearly have a strong multiplier effect in these SMEs. While this is typically the job of private investors, the environment in Europe for these types of investments is less favourable than in the US or China. Such an investment programme in the manufacturing capacities of companies that are ready to take the next step in commercialisation of their components will assist in the efforts to produce high quality, reliable products and ensure that European companies enhance their competitiveness worldwide, avoiding the failures made in other innovative technologies.

Lacking any one of these single elements will greatly hamper the efforts in Europe to benefit from the advances achieved over the last few years and those to come in the near future. The reason is that a number of FCH products are entering the marketplace now after having achieved a high level of technical maturity; without decisive focused support, there is a risk they may suffer from the well-known 'valley of death' that afflicts many companies when launching new and innovative products and which ultimately leads to their failure. This is particularly true in markets where regulations do not yet recognise the added value of these low or zero emission, highly efficient products. To avoid this situation and strengthen European industry, schemes that provide the right kind of assistance to the commercialisation of these early products is crucial and can play a key role in enabling the public to have confidence in these technologies. For the same reason, a healthy well-developed European-based supply chain that can provide top of the line components to OEMs in a competitive environment is also a critical element. It will further allow Europe to attain a level of leadership in this key field, attract top talent and create jobs requiring a new set of skills that can be supported and developed in Europe.

Industry sees limited need for demonstration projects for those applications that have reached a high level of technical maturity and are gradually entering the marketplace. These require more assistance in the market activation phase than in the demonstration phase. Examples include: electrolyzers, fuel cells for co-generation, cars, buses, material handling vehicles and refuelling stations.

D. HYDROGEN VALLEYS

There is a further specific need to show the sector coupling capability of the hydrogen energy vector in the complete value chain through hydrogen valleys. Such level of ambitious projects will ultimately demonstrate to key stakeholders that hydrogen and fuel cells can indeed act as key enabling technologies in a unique way. However, it is not clear that the funding mechanisms likely to be found within the FP9 programme will be the right fit to enable these projects, both in type and scale. For this reason, industry stresses the need for flexibility in the tools proposed above in order to ensure support for these Hydrogen Valleys: showing their feasibility is a must in the near future.

Last, there is still a clear need for support for a host of projects that address **cross-cutting issues**, such as regulations, codes and standards, education and training, safety, pre-normative research and consumer awareness, among others.

3.3 BUDGET AND FUNDING REQUEST

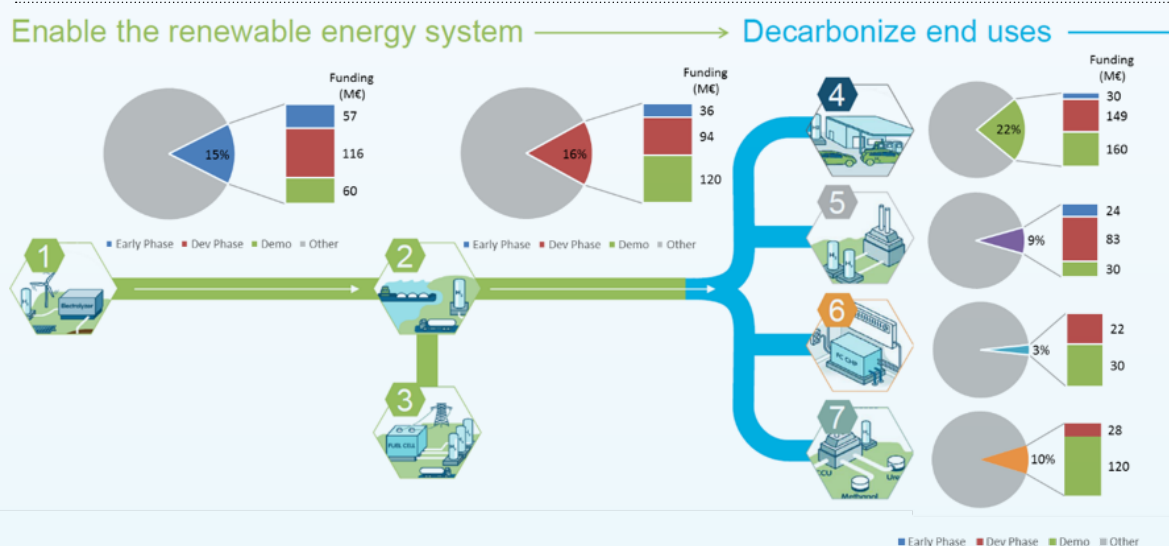
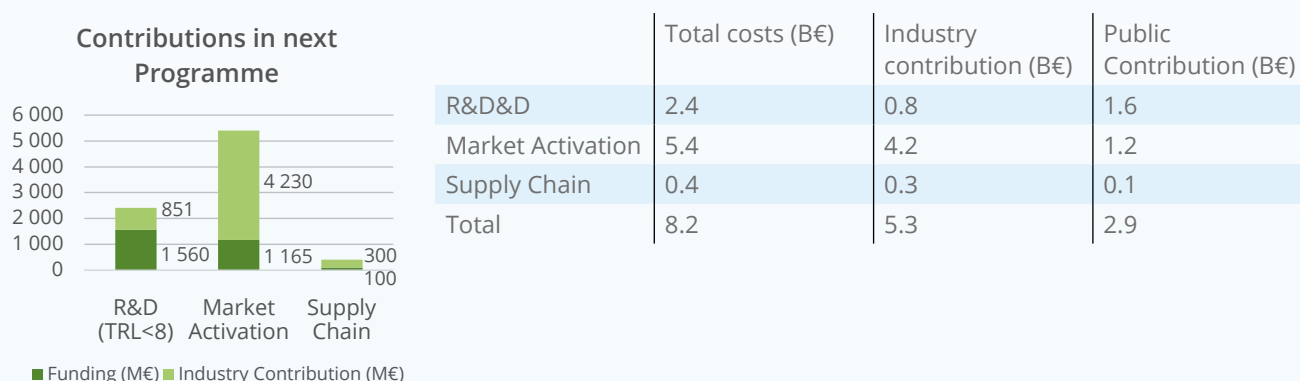
Overall, the costs estimated for the actions proposed and the contributions of industry and the iPPP are shown in the table below.

The industry and research community have worked on the development of a bottom-up list of areas for support. This preliminary list has been built at each development stage (i.e. basic, applied R&D and demonstration) for each of the main areas: production, distribution and storage, transport, use as source of heat and power in buildings and industry, and use as chemical feedstock. It has estimated different levels of funding depending on the development stage, being higher at the earlier R&D stages and progressively lower as TRL increases.

R&D&D

As a result, over 250 projects have been identified as needed in **the R&D&D part of the programme**, with an overall estimated budget of 2.4B€ and a funding request of about 1.6B€.

The proposed allocation of this funding with respect to the roles of hydrogen laid out earlier is depicted in the figure below. **A more detailed breakdown of these figures is provided in the Annex.**



MARKET ENTRY MECHANISM

Similarly, it has estimated a scope of support for **the market entry mechanism**, as well as investments in **the supply chain**, as outlined above. The table below summarises the market entry aspect.

Application	#units to be funded	Average cost (€/unit)	Total cost (M€)	Total funding (M€)	Public funding basis
from iPPP					
HRS	1000	1,000,000	€ 1,000	€ 250	25% iPPP
Cars	10000	50,000	€ 500	€ 75	10,000€/ 1st 5,000 cars, 5,000€/ 2nd 5,000 cars
Buses	1000	500,000	€ 500	€ 100	100,000€/bus
Trucks	500	500,000	€ 250	€ 50	100,000€/truck
Forklifts	10000	1,500 €/kW	€ 45	€ 15	500€/kW
Trains	100	5,000,000	€ 500	€ 100	1,000,000€/unit
Ships	100	1,000,000	€ 100	€ 25	25% iPPP
Electrolysers	1 GW	1,000 €/kW	€ 1,000	€ 250	25% iPPP
CHP	100MW	10,000 €/kW	€ 1,000	€ 200	2,000€/kW
		Total	€ 5,395	€ 1,165	

The table shows numbers of units to be financed through the iPPP, rather than overall figures to be deployed in Europe. It is expected that these investments will trigger additional deployments through actions at MS, regional and local levels, contributing to achieving the broader goals by 2030.

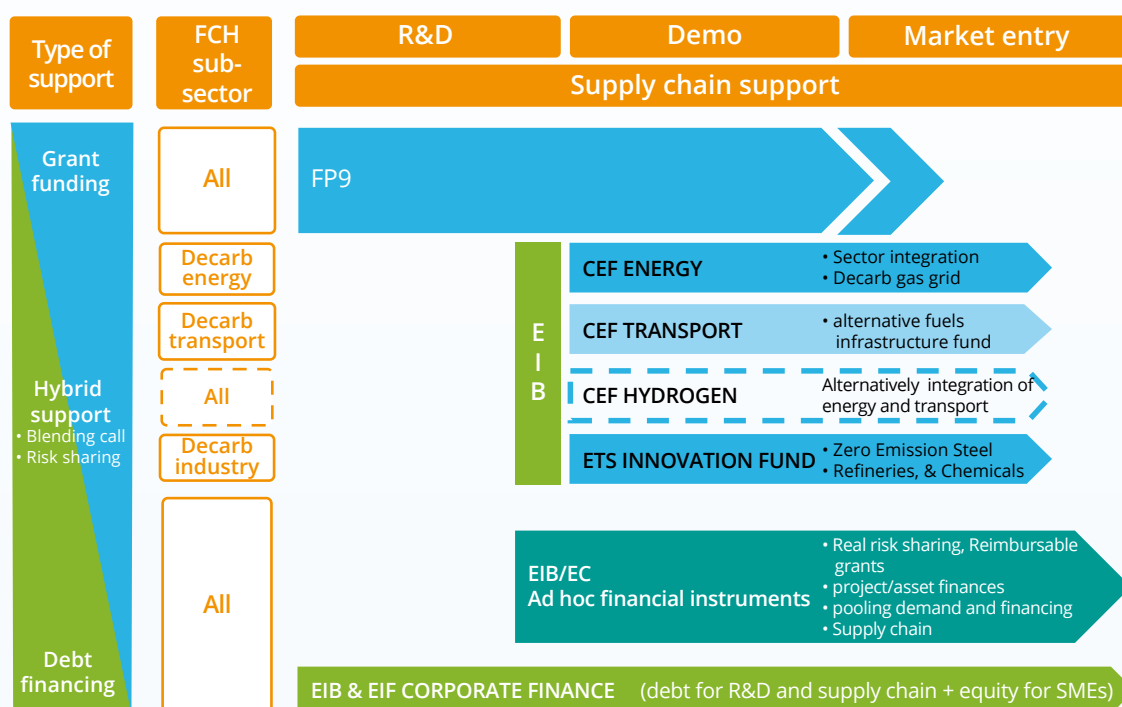
SUPPLY CHAIN

Regarding the supply chain, we forecast up to 20 companies benefitting from such a scheme. These SMEs would be in a position to invest in production lines in components considered of strategic importance for the EU industry. An average investment of 20M€ per company is forecast, bringing the total investment up to 400M€ over the duration of the programme. A 25% public funding by the iPPP is estimated, equal to 100M€, to be leveraged by private investments. Industry is ready to discuss with public European institutions in more detail the right approach to make this happen through any one of the tools available now or in the future (EIB,...).

The proposed comprehensive 8.2B€ programme would trigger a cascade effect, indicating to the broad public and the investment community that Europe is serious about taking the necessary steps to making hydrogen a reality through 2030 and beyond. It would catalyse the necessary actions to realise the vision outlined earlier, which by 2030 estimates a cumulative investment of \$62B (52B€). Taking into consideration only the public funding contribution of 2.9B€ within the iPPP, the leverage effect is 1.83 within the programme itself. Considering broader commitments to realise the 52B€ forecast through 2030, the leverage effect is estimated at nearly 17, or almost ten times greater than that of the programme itself.

3.4 FUNDING SOURCES

This ambitious programme cannot rely on a single funding source. It requires coordination of several funding and financing streams to cover the areas of support outlined earlier. Current programmes from the EC already offer elements that can be leveraged for this purpose.



1. RESEARCH AND DEVELOPMENT AND DEMONSTRATION

a. R&D

The Ninth Framework Programme (FP9) is the adequate funding source to set up an ambitious R&D programme to improve the performance and reduce the costs in advanced components of the first wave of products (e.g. cars, forklifts, buses, mCHP, electrolyzers,...) and prepare a second wave of products (e.g. large-scale energy storage, trucks, ships, harbour applications,...).

b. Demonstration and Innovation

We envisage that FP9 will also be suited for flagship demonstration projects. The FCH 2 JU already demonstrated that such projects with a large budget and high leverage of public funding (i.e. 100M+€ of investment with a funding of ~25M€) have the capacity to demonstrate to the public a new product.

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2. MARKET ENTRY

Europe often faces the challenge of converting its technology leadership into a market leadership. Too often Europe is overtaken by Asia and North America, which are more focused in supporting market entry. This is partly due to the reluctance of using Europe R&I instruments for supporting a real market activation. Hydrogen is a perfect example of this challenge.

Market entry is often regarded as a competence of Member States rather than of the EU. While support from Member States will be key, it is essential to realise that EU funding plays a role of vanguard indicating the direction to take and crowding in progressively support from Member States.

This support at national level often takes the form of subsidies or rebates on the purchase of a piece of equipment. A parallel can be drawn to the use of lump sums already existing in EU programmes. This is the reason why Hydrogen Europe suggests to take advantage of the redefinition of instruments like the framework programme, Connecting Europe Facility and the ETS Innovation Fund to solve this.

- **FP9:** While FP traditionally focus on R&D&D, it can play a role in market entry in industry-led initiatives. A number of flagship demonstration projects initiated by the FCH 2 JU under Horizon 2020, were very close to a market entry support.³⁵ The success of these flagship projects could be further increased and simplified with the use of lump sum for each unit of the demonstrated products.
- **The Connecting Europe facilities** are natural candidates for market entry support in the transport and energy fields:
 - **CEF Hydrogen** The size of the investment in the Hydrogen economy is so large that it could justify the existence of a dedicated hydrogen line ("CEF hydrogen") in the next CEF combining transport and energy. Such a scheme would further exploit existing synergies and sector coupling capabilities of hydrogen. It would also presumably become the ideal vehicle for the support of Hydrogen Valleys as described earlier. Otherwise, CEF Transport and Energy can be used.
 - **Transport applications: Connecting Europe Facility (CEF)** should naturally focus its effort in realising the deployment of the alternative fuels infrastructure in line with the AFI directive. CEF transport should however not be limited to infrastructure for cars, but instead be open to other transports means (trucks, train, ships, ports, airports) and enable a combined support of the infrastructure and a minimum number of vehicles. Here also a simplified market entry mechanism must be considered with a lump sum for each refuelling stations or vehicle deployed.
 - **Energy applications: CEF energy.** So far CEF energy has supported pre-identified extensions of the power and gas grids without connecting the two. As we progress in the energy transition, it appears indispensable to connect the two grids through power to gas installation, where clearly hydrogen comes in. Similarly, the continued existence of the gas grid depends on its capacity to be progressively decarbonised through the use of biogas and hydrogen. Connecting the power grid to the gas grid and decarbonising the gas grid should be at the core of the renewed CEF energy.
- **Industry applications: the ETS Innovation Fund** targets large scale projects in the fields of integration of renewable, carbon capture and storage (CCS) and carbon and capture and utilisation (CCU) in the highly emitting industries with the objective to prevent carbon leakage.



³⁵ This has been already tested for products like, buses, refuelling stations, fuel cells used as residential combined heat and power units.

Hydrogen has the unique characteristic of being the common enabler of the integration of renewable, CCS and CCU at industrial scale. This was largely documented in all the innovation fund preparatory workshops organised by the Commission³⁶. The size of the investment (easily in the hundreds of millions) required for decarbonising energy intensive industries matches well with the nature of the ETS Innovation Fund.

3. SUPPLY CHAIN SUPPORT

The FCH sector includes a series of highly successful SMEs that have developed products and are eager to move to large scale manufacturing to enable cost reductions and market penetration. This requires typically investments between €10-40 million. When they turned to private European investors, these SMEs face hesitation and risk aversion and too often they turn themselves towards Asian, North American or even Russian investors. Private European investments could be facilitated by a combination of EU grants and debt. This does not require huge amounts of money: as an example, a series of 5 million-euro grants (i.e. 25% funding) on the basis of 20M€ investments would be in line with the objective of the framework programme, the recommendation of the Lamy report (the so-called “FAB” dimension) and in line with the discussions around the Innovation Council, which aim at supporting technology development along the complete innovation chain from R&D to market.

Ad hoc financial instruments for both market entry and support of supply chain

Public funding is scarce and cannot cope with the size of the €52 billion required investment in fuel cells and hydrogen. It is necessary to attract private finance. Private finance is however limited by the level of risk associated with new technologies, the underutilisation of the infrastructure in the first years, the parcelling of demand, etc. To overcome scarcity of public funding and the risk aversion of private finance, tailored risk sharing mechanisms should be developed. Valuable progress in that direction are made by the Commission and the European Investment Bank (EIB) notably under the European Fund for Strategic Investment (EFSI or “Juncker fund”). Unfortunately, the institutional division between grant funding (Commission) and debt financing (EIB) has so far hindered the development of real risk sharing tools like reimbursable advances or similar mechanisms.

Financial instruments are horizontal tools that can support both market entry and supply chain and manufacturing.

3. 5 OTHER FACTORS

Support by the public sector in the form of a programme will be a significant step in the right direction to ensure the achievement of the goals by 2030. However, a number of other critical factors at a broader level must be addressed as well:

- Enforce the principle of technology neutrality between BEV and FCEV in all directives and regulations
- Policy support for hydrogen must be enhanced significantly at all levels (EU, national,...)
- A regulatory framework that recognizes the advantages of hydrogen and fuel cell technologies in the decarbonisation challenge
- A large scale, long-term communication campaign is required to reach out to EU civil society and key stakeholders.
- The investment community must be engaged, so that investments follow, both from the public and private sides.



³⁶ 17 February 2017: Workshop 1 «Ferrous and non-ferrous metals»; 23 March 2017: Workshop 2 «Oil refining, Chemicals & bio-based, Paper & pulp»; 06 April 2017: Workshop 3 «Cement & lime, Glass & ceramics»; 06 April 2017: Workshop 4 «Renewables and energy storage» see https://ec.europa.eu/clima/events/articles/0115_en

WHY EUROPE NEEDS AN INDUSTRY-LED PUBLIC-PRIVATE PARTNERSHIP

Previous sections of this document outline the vision put forth by industry on the necessary steps, primarily on the R&D and commercialisation sides, and funding mechanisms to realise this vision up to 2030, as well as certain necessary steps.

In deciding to support the fuel cells and hydrogen (FCH) sector through a Joint Technology Initiative (JTIs) or institutional public private partnership (iPPP), the EU made a major choice with long lasting impact. It is the view of industry that the JTI is responsible for having achieved a level of innovation faster than otherwise would have been the case. It sees the continuation of this model as a key component of any future efforts, both in light of the successes obtained so far and the challenges that lie ahead.

The JTIs or iPPPs have mainly three characteristics:

- They provide a ring-fenced budget over long periods, enabling the development and implementation of long-term strategies
- They bring all industry and all research actors together and enable them to define and implement long term strategies as a coordinated group.
- They create a continuous EU-Industry-research dialogue which ensures the relevance of the innovation strategy and its alignment with the EU policy goals.

Regarding the specific field of hydrogen and fuel cell technologies, the combination of all these factors has been critical, and it is undeniable that the FCH JU has literally created a sector. Before the creation of the JTI, industrial actors developing FCH technologies coming from different sectors used to work in isolation. In contrast, as hydrogen and fuel cells are truly cross-sectoral technologies, the creation of the FCH JU enabled them to work together, creating an association and becoming a real economic sector, which continues to grow with a good mix of SMEs, large firms and research organisations. Some figures back this up:

- Membership in Hydrogen Europe has increased from 53 in 2008 to 112 today, while at the same time the Research Grouping has increased its members from 42 to 68.
- In H2020 calls, a total of 413 unique participants receive funding; about 2/3 of those are not members of the FCH JU (through the industry or research associations)

In the latest interim report on the performance of the FCH JU in H2020³⁷, an independent review panel remarked that this instrument continues to demonstrate strengths and remains relevant as a funding instrument, ensuring good alignment with policy and industrial initiatives. Not only has the FCH JU performed very well in the indicators relevant to the implementation of the R&I programme, but is also finding a high degree of satisfaction in project participants. This has been achieved with a rather lean structure: each of the operational staff members of the PO manages eighteen projects and a budget of over 41M€, both quite high values when compared with other similar programmes.



hEAT BlueGEN
Duechting



Wrightbus FCB with mayor
London © EE_CTE

³⁷ Available at: http://www.fch.europa.eu/sites/default/files/Interim_Evaluation_FCH2JU.pdf

Successful technical results have also been recognised. As Clara de la Torre, Director for Transport in DG RTD recently remarked at the Hydrogen for Clean Transport conference (22 October 2017), “our investment in the Fuel Cells and Hydrogen Joint Undertaking starts paying off as first excellent results begin to emerge (...). I was particularly impressed by the progress of the European fuel cell buses [and...] am also aware of some excellent research results on hydrogen tanks and fuel cell stack manufacturing.” These results refer to projects COPERNIC³⁸ and Auto-Stack CORE,³⁹ and serve as illustrations of the success of the programme.

Perhaps more important are the economic benefits to society. First of all, SMEs are finding a higher degree of support through the JTI than H2020. To date, 27.6% of the funding goes to SMEs in FCH JU projects, while in H2020 only 15.9% does. Similarly, 26.5% of beneficiaries in FCH JU projects are SMEs, while in H2020 only 19.6% are. Secondly, the overall leverage achieved in the FCH JU to date stands at 1.96,⁴⁰ compared to 1.09 during the FP7 programme. This leverage effect is forecast to rise to 3.0.⁴¹



4.1 SECTORAL COORDINATION BY THE FCH JU: BEYOND THE ORIGINAL PLAN

Beyond the institutional cooperation between the EC, Industry and Research, and the benefits enumerated above normally expected from an R&D programme (leverage, support to SMEs, effective implementation of a programme with a set of common goals), the creation of a coordination partnership like the FCH JU has led to many additional coordination efforts.

1. **H2 mobility initiatives:** these national initiatives have brought together vehicle manufacturers, H2 infrastructure providers and public authorities to plan a synchronised deployment of vehicles and refuelling infrastructure. These plans are now the basis of the national policy frameworks that Member States submitted to the Commission as part of the Alternative Fuels Infrastructure directive (AFID). The FCH JU has been working with the major ones (Germany, France, the UK, Scandinavia), providing input and ensuring cohesiveness, resulting in a European roadmap for the deployment of vehicles and infrastructure.

2. **When supply meets demand:** Technology readiness is not sufficient to ensure commercialisation. Without coordination, one ends up with a series of isolated manufacturers that are hesitant to make large investments and a handful of interested customers hesitant to order as they wait for the costs to come down.

The FCH JU has been very successful in creating coalitions of manufacturers developing a common commercialisation strategy and coalitions of customers to aggregate demands, and triggering large scale production and joint procurement exercises.

3. **Regions and cities** are key actors in the energy transition and frontrunners to experiment ambitious regulations and test new technologies. 90+ regions and cities accounting for over a quarter of European population and GDP⁴² have signed a MoU with the FCH JU to support them in implementing a hydrogen strategy.

4. **Informal partnership and co-funding with other EU programmes.** The Germany H2 mobility initiative mentioned above as well as the deployment of H2 buses have been jointly funded by the FCH JU (vehicles) and CEF (infrastructure)

38 For more information, see: <http://www.fch.europa.eu/project/cost-performances-improvement-cgh2-composite-tanks>

39 For more information, see: <http://www.fch.europa.eu/project/automotive-fuel-cell-stack-cluster-initiative-europe-ii>

40 Leverage is calculated as the sum of in-kind contributions from beneficiaries within signed projects in calls 2014-2017 + certified additional activities from members through 21/12/2017 / sum of FCH JU contributions in signed projects funded under calls 2014-2016. Figure as of 21/12/2017

41 Uses the same calculation but using forecast figures for additional activities of members through 2018 (to be certified).

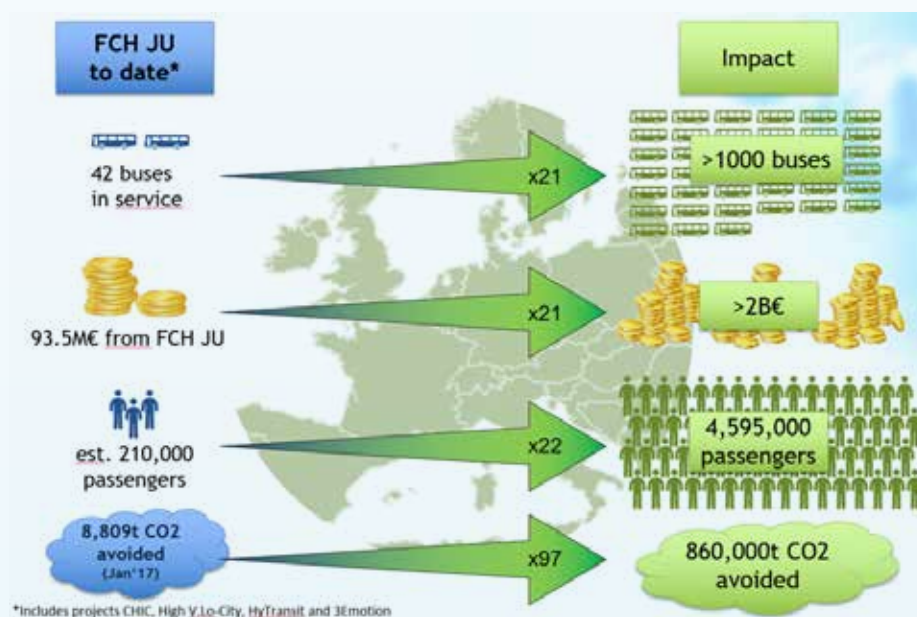
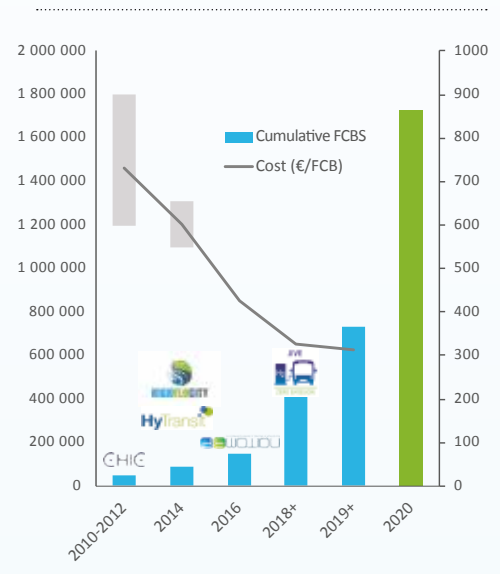
42 They account for 143 million people and a combined GDP of €4.5 trillion

as well as hydrogen regional clusters such as Normandy and zero emission valley in Auvergne Rhone Alpes both in France. Additional activities have been co-financed by structural funds (ERDF and Interreg).

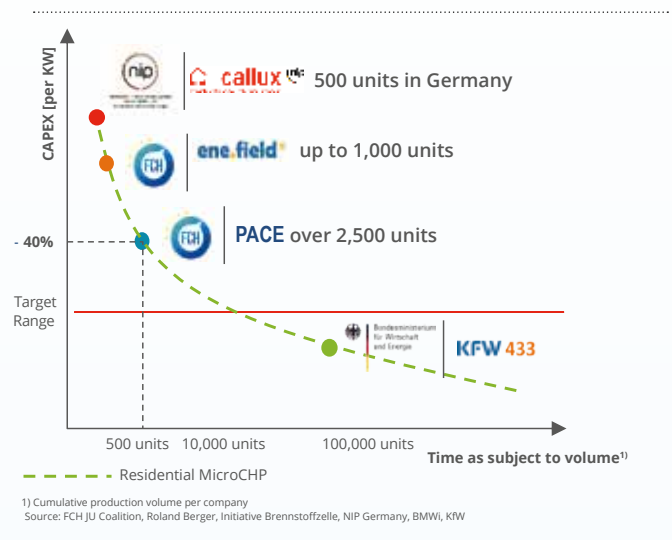
5. Coordinated funding with **Member States**: The FCH JU established good cooperation with several Member States with several cases of ambitious co-funding of projects.
6. Informal partnership with EIB: the FCH JU has been instrumental in establishing contacts between EIB and industrial actors in order to finance early commercialisation and convince commercial banks to finance the new technologies.

The ability of the FCH JU to have a significant impact can best be shown by two illustrative examples, dealing with different applications: buses and residential micro-cogeneration.

In 2010, when the FCH JU was starting its operations, there were only a few fuel cell buses in operation and the technology had yet to address the main question of whether it could become commercial. Following a string of FCH JU-funded projects (CHIC, High V.Lo-City, HyTransit, 3Emotion, and JIVE – all except CHIC still active today), the overall fleet of buses in everyday operations should surpass 200 by 2019; currently, these buses are proving their technical readiness to serve as drop-in replacements for diesel buses and have exhibited a sharp decline in their costs. To trigger a true degree of market entry, the FCH JU formed a coalition of 84 bus operators, OEMs (suppliers of buses and hydrogen) and technology providers to aggregate demand and agree on a common roadmap. As a result, the current level of appetite identified from European bus operators is over 1000 buses until 2020. To put this in context, the figure represents a total projected investment of over 2B€, triggered by an original investment of 93.5M€ from the FCH JU. The overall impact of these efforts goes beyond pure investment by bus operators, and can also be measured by the number of citizens using clean buses in European cities or the level of CO₂ abatement from realising these deployments, as depicted below.



Stationary fuel cells, which can use natural gas much more efficiently than conventional alternatives and produce both heat and power, have undergone a tremendous period of growth, largely due to the activities of the FCH JU. Supported by a portfolio of R&D and especially demonstration projects such as ene.field and PACE (a total of over 3500 units throughout Europe are being deployed), the technical readiness of micro-cogeneration (mCHP) units for the supply of residential heat and electricity is now proven. Beyond the impact of these projects, the FCH JU further commissioned studies supporting a coalition of dedicated OEMs in finding a suitable pathway to commercialisation of these products. Following these efforts, a number of national programmes (notably in Germany, UK and France) supporting commercial sales of mCHP are being implemented. The goal is to deploy around 100,000 in the coming years, representing an investment of 1B€.

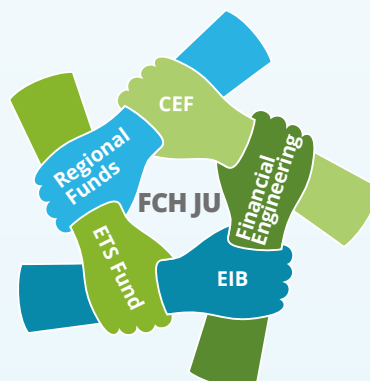


4.2 NEXT STEPS: COORDINATION EFFORTS MUST EVOLVE

The added value of these coordination efforts is hard to quantify, but they have undeniably contributed to the consolidation of the sector and the increasing visibility of hydrogen in a number of different fields (e.g. use as energy storage medium in the energy transition, means to decarbonise industrial processes, sustainable urban mobility). They can serve as blueprints for future activities that are necessary to achieve the deployment of hydrogen technologies in the coming years.

For these reasons, they must be expanded. This is especially true for **the cooperation with Member States, regions and cities**. While the EU and the FCH JU can develop market-ready applications, the massive commercialisation will very much depend on the efforts of Member States, regions and cities and their capacity to developed coordinated deployment.

The need for reinforced cooperation is also true for **other EU Programmes**. The deployment of an H₂ infrastructure in accordance with the Alternative Fuel Infrastructure Directive (AFID) will require an even bigger push from the Connecting Europe Facility (CEF). The decarbonisation of heavy industries fits particularly well with the mission of the ETS Innovation Fund.



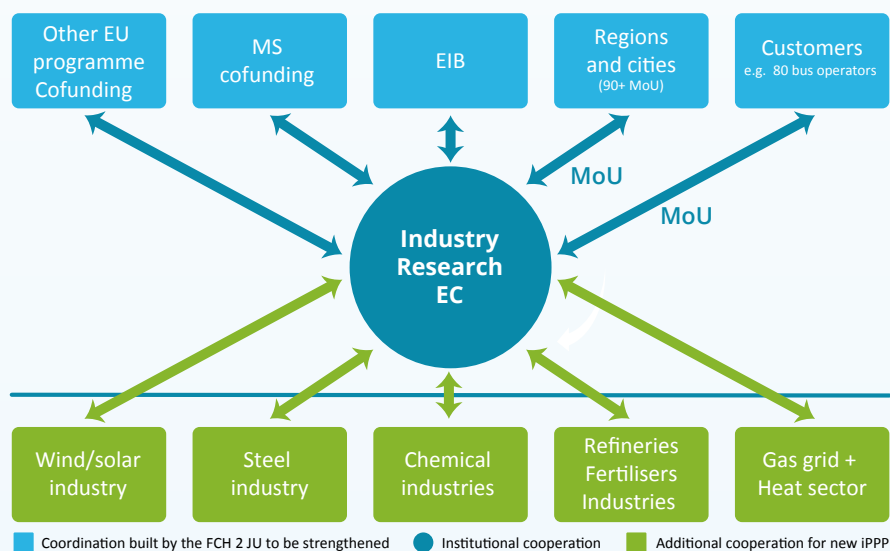
More broadly, we envisage additional forms of cooperation with **other sectors**. By their nature, hydrogen and fuel cells are cross-sectoral technologies. As explained above hydrogen is key for the integration of renewables in all parts of our energy systems and to decarbonise all major final uses, such as transport, heat and power for buildings, and industry as a source of heat and as feedstock.

First, this requires a structured cooperation with **the renewable sector** (wind and solar) which can increase their penetration thanks to hydrogen. Indeed, in a number of European Regions renewables are reaching their limits, can no longer be absorbed by the grid and end up being curtailed.⁴³ Turning renewable electricity into hydrogen enables a larger integration of renewables in the electricity grid but also in the other sectors, transport, heat and industry.

Second, it requires intense cooperation with **the industries** that can be decarbonised through hydrogen: iron and steel, chemicals, refineries and fertilisers and all industries that require large quantities of high-grade heat that are hard to electrify. As an illustration, it is possible to decarbonise the steel production by replacing coke by hydrogen both as a heat source and a reducing agent. This requires major innovation and investment from both the hydrogen and the **steel industry**. This cannot be done without intense coordination.

Thirdly, a similar intense cooperation is also necessary with **the heat and gas industries**. Through “Power to gas”, hydrogen links the electricity and the gas grids and contributes to the integration of renewables and to the decarbonisation of the gas grid and therefore also the heat sector.

On **transport**, the coordination is already well established. Many industrial actors are member of HE, the FCH JU has created coalition of users (cities, regions, bus operators, ports, airports). Similar links with the logistic (trucks), rail, maritime and aeronautic sectors will be necessary as hydrogen enters these fields.



This growing coordination effect of an institutional public private partnership can be illustrated as shown above. The dark blue shows the ongoing institutional cooperation created by the current legal framework, representing the founding members of the FCH JU. The light blue shows the additional cooperation which have been built by the FCH JU and that should be strengthened. The green part shows the additional cooperation with industrial sectors that will benefit from hydrogen.

While Hydrogen Europe industry and research are very keen to remain at the centre of the partnership and further develop their partnership with the European Commission, they are clearly open to develop strong links with these user sectors, and see the need to do so.

43 For instance, in 2015 in Germany 4,7 TWh of electricity were lost. This is the equivalent of the annual energy consumption of 300,000 households or of 700,000 hydrogen electric cars.

ANNEX: DETAIL OF THE R&D&D BUDGET ESTIMATES

The budget estimation in the report are the results of a bottom up exercise sector by sector, application by application, and by TRL level, with funding rates inspired by H2020 and decreasing as TRL increases.

These budget estimates are subject to further analysis and discussion with funding authorities

	Early Phase (TRL 2-3)		Development Phase (TRL 4-6)		Demo Phase (TRL 7-8)		Market Activation (TRL 8-9)		TOTAL		
	Overall budget (M€)	Funding (M€)	Overall budget (M€)	Funding (M€)	Overall budget (M€)	Funding (M€)	Overall budget (M)	"Funding (M€)"	Overall budget (M€)	"Funding (M€)"	private contribution
1. Hydrogen production	57	57	147	116	120	60	500	125	824	358	467
2. H2 infrastructure: storage & distribution & h2 stations	36	36	119	94	240	120	1.000	250	1.395	500	896
3. Clean transport (vehicles)	30	30	189	149	320	160	1.895	365	2.434	704	1.731
4. Decarbonising power, heat and cold in buildings	24	24	105	83	60	30	1.000	200	1.189	337	853
5. Decarbonising industry (h2 for heat and power)	0	0	28	22	60	30	500	100	588	152	436
6. Decarbonising industry (h2 as a feedstock)	0	0	35	28	240	120	500	125	775	273	503
7. Cross-cutting	24	24	147	116	0	0	0	0	171	140	32
8. Equipment value chain	24	24	98	77	240	120	400	100	762	321	441
Total funding (m€)	201	201	889	699	1.320	660	5.795	1.265	8.205	2.825	5.356
# Projects supported	71		127		65						



NOTES

LIST OF ACRONYMS

AFID: Alternative Fuel Infrastructure Directive

BEV: Battery Electric Vehicle

BOP: Balance of Plant

CCS/CCU: Carbon Capture and Storage/Use

CEF: Connecting Europe Facility

CHP: Combined Heat and Power

EIB: European Investment Bank

FCEV: Fuel Cell Electric Vehicle

FCH JU: Fuel Cells and Hydrogen Joint Undertaking

FP7: Seventh Framework Programme

GDP: Gross Domestic Product

H2020: Horizon 2020 (Framework Programme)

HE: Hydrogen Europe

iPPP: Institutional Public-Private Partnership

JTI: Joint Technology Initiative

MHV: Material Handling Vehicle

NIP: National Innovation Programme (Germany)

OEM: Original Equipment Manufacturer

PO: The FCH JU Programme Office

PP: Prime Power

R&D&D: Research, Development and Demonstration

RCS: Regulations, Codes and Standards

RES: Renewable Energy Sources

SMR: Steam Methane Reforming

TCO: Total Cost of Ownership



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