Endorsed by the Governing Board on 15 June 2018

FUEL CELLS and HYDROGEN 2 JOINT UNDERTAKING

(FCH 2 JU)

Addendum to the

Multi - Annual Work Plan
2014 - 2020

Not legally binding

Contents

1. Executive Summary

This document represents an addendum to the Multi-Annual Work Programme (MAWP) 2014-2020 (http://fch.europa.eu/page/multi-annual-work-plan) and revises the scope and the objectives of the research, technological development and demonstration activities, with an update of the technical objectives and key performance indicators (KPIs) at mid-term stage of the Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU) while reflecting its Governing Board strategic priorities for 2018-2020.

The update of the KPIs is based on a Joint Research Centre (JRC) methodology, which allows tracing the progress towards the FCH 2 JU specific objectives while enabling the comparison with conventional technologies. For obtaining a clear overview of the FCH 2 JU strategy, programme and actions the reader should refer to both documents MAWP 2014-2020 and this addendum 2018.

The Paris climate conference (COP21) in 2015 has set the global momentum towards low carbon innovation and put the European Union firmly on the pathway towards transforming all sectors (electricity, heating and cooling, transport, and industry) as part of a future low carbon economy, whilst decoupling economic growth from resource and energy use, increasing energy security, and maintaining a strong competitive global position[1].

In this context, the unique capability of FCH technologies to facilitate cross-sectoral integration to enhance the overall efficiency of the energy system and cut the GHG emissions of power, heat, transport and industrial processes in chemistry, steel and other energy and feedstock intensive industries in a synergetic manner is now being put in the spotlight. The 2015 IEA Hydrogen and Fuel Cells technology roadmap[2] concluded that hydrogen can help to: 1) achieve very low-carbon individual motorised transport; 2) integrate very high shares of variable renewable energy into the energy system; 3) contribute to the decarbonisation of the industry and the buildings sector. Furthermore, independent near to mid-term market projections worldwide indicate a substantial growth in the FCH sector with positive impacts on direct industry and associated supply-chain jobs.[3]

However, monetising the potential social and environmental benefits of FCH technologies in the short term remains extremely challenging. Important framework conditions required to foster widespread commercialisation of these technologies, such as the infrastructure to produce, distribute and store hydrogen sustainably and safely, end-user confidence and the availability of appropriate regulations, codes and standards have not yet been fully met.

Exploiting the full potential of FCH applications requires further system integration, costs decrease and enhanced focus on green hydrogen. In that sense, emphasis will continue to be placed through the FCH 2 JU's R&I programme on cross-sectorial hydrogen applications, showcasing the potential for sector-coupling while enhancing the feasibility and sustainability of the European hydrogen supply chain and the necessary trade-offs.

1 Communication COM(2009) 519 final
2 IEA Technology Roadmap Hydrogen and Fuel Cells, 2015
3 http://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-Scaling-up_Hydrogen-Council_2017.compressed.pdf

2. Objectives of the FCH 2 JU for 2018-2020

The strategic operational and techno-economic objectives of FCH 2 JU as defined in the founding Regulation[4] and consequently in the original MAWP 2014-2020 are still valid and are driving the strategy and consequently the content of its research and innovation programme.

The last phase of the FCH 2 JU under the Horizon 2020 should now build on the experience gained from the portfolio of clean and efficient solutions developed by the FCH 2 JU Research & Innovation programme in the period 2008-2017 as a vehicle to support the largest commercialisation of FCH technologies.

Therefore, the main focus of FCH 2 JU's support within the time frame of 2018-2020 should be on applications with significant market potential based on unique selling proposition against alternative options and with high policy importance, integrated under the hydrogen ecosystem that allows synergies between various applications and improves energy efficiency. In addition, driven by the target to decarbonise the transport and energy sectors and to go beyond the state-of-the-art, the programme should continue to focus on industry-led applied research, development and demonstration activities (including prototyping, piloting, testing) with particular emphasis on enabling/emerging technologies for next generation of products that could reach the market by 2020-2025. Cost reduction and strengthening of the European value chains should be considered a top priority. Where strategically important, lower TRL (2-3) research objectives will also be addressed .

The programme's achievement will be also dependent upon activities supporting research and innovation of the Member States, associated countries and regions, particularly in the current Paris Agreement context, which paves the way towards more active collaboration among states and regions in order to achieve the ultimate goal of limiting global warming. Consequently, the FCH 2 JU will need to coordinate its activities with relevant national or regional programmes, for example, in the field of H2 Mobility (including actions related to the implementation of the Alternative Fuels Infrastructure Directive (AFI) and supporting the Hydrogen Valleys concept within regions and/or cities.

Following the recommendations of the European Parliament[5], the FCH 2 JU needs to strengthen the communication with Union citizens by better highlighting the improvements and benefits achieved as a consequence of its work. Other complementary actions such as support to development of deployment strategies, communication, exploring additional funding sources and financial instruments, provision of inputs to policy making will allow to increase the impact of the programme.

The 2018-2020 budget for the Energy and Transport Pillars/activities as well as Cross-Cutting activities is agreed each year by the Governing Board. It is nevertheless expected that within the Energy pillar, most of the budget (approximately 75%) will be dedicated to areas of the highest relevance to the energy transition (such as integration of RES and energy storage). Limited budget (up to 10% of the total budget) might be allocated to low-TRL activities (starting from TRL 2) based on real industrial interest.

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4 http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:JOL_2014_169_R_0007&from=FR

5 Report on discharge in respect of the implementation of the budget of the Fuel Cells and Hydrogen 2 Joint Undertaking for the financial year 2016 (2017/2185(DEC))

FCH technologies constitute a very diverse and versatile portfolio, with applications in transportation, energy and industrial applications (H2 as industrial/chemical feedstock). In recent years, the FCH 2 JU has supported a significant number of projects (a few of them mentioned in the following sections) that are enabling a step change in the use of hydrogen for emissions reduction in different sectors, while at the same time setting the new standards for the State of the Art.

3. State of the Art

3.1 Transport applications

3.1.1. Road applications and hydrogen refuelling stations (HRS)

Passenger cars and buses:

Hydrogen and fuel cell technologies in the transport sector are at various stages of maturity, depending on the application. The most mature fuel cell (FC) systems for propulsion are found in vehicles for road transport, notably passenger cars and buses, with a significant number of FCEVs deployed in a range of demonstration projects throughout the world. The technological challenges which at the turn of the millennium were identified as critical for the successful implementation of FC in vehicles have all been resolved by now: start-up and operation at temperatures down to -30ºC has been demonstrated; the driving range of today's highest performing FCEVs is now close to 700 km for cars and 450 km for buses (compatible with a full day's service in urban applications); refueling times have been reduced to 3-4 minutes for passenger cars and ~10 minutes for buses. A range of developments over the last 20 years mean that FC cars are now very reliable, with availability of 98%[6], while buses have demonstrated values up to 94%[7], which is very close to market expectations. In terms of performance, these vehicles are at the threshold of market introduction. However, to become fully commercially viable, total cost of ownership, including price of the vehicle and fuel costs still need to be reduced while lifetime ratings need to be proven.

The present generation of FCEVs, including buses, benefit from developments that have been supported in several demonstration projects co-funded by FCH JU during 2008-2013. These projects aimed to deploy 220 cars (175 to date) and 67 buses (42 to date) and were followed up by FCH 2 JU projects that expanded these aims to approximately 1850 (360 to date) cars and 360 buses in total (47 to date). In particular, flagship demonstration projects such as H2ME and H2ME 2[8] have demonstrated light duty vehicles alongside the required hydrogen-refueling infrastructure while for buses, large fleets are currently deployed through JIVE 1 and JIVE 2 projects[9].

The majority of large car manufacturers throughout the world are working on further development and market establishment of fuel cell passenger cars, while multiple bus manufacturers are developing and deploying fuel cell electric buses (FCEBs). In the European context, Symbio is producing hydrogen kits which are integrated in the Renault Kangoo ZE converting the original car in a range extender (dual energy) vehicle. Symbio has already sold more than 200 FC range extender vehicles in Europe, while participating in FCH JU projects such as H2ME, H2ME 2 and BIG HIT[10]. Additionally, some smaller manufacturers have developed two-wheel and four-wheel FCEVs such as the Riversimple car deployed in the

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6 Availability of FCEVs (including Daimler's F-Cell and Hyundai's iX35) demonstrated in the FCH 2 JU supported project H2movesScandinavia (http://www.fch.europa.eu/proiect/h2moves-scandinavia) over more than a year.
7 Value achieved within HighVLOCIty (http://www.fch.europa.eu/proiect/cities-speeding-integration-hvdrogen-buses- public-fleets) in Antwerp over 69,000km in 2016.
8 https://h2me.eu/
9 http://www.fch.europa.eu/news/launch-proiect-iive-large-scale-deplovment-fuel-cell-buses-europe
10 http://www.fch.europa.eu/proiect/building-innovative-green-hvdrogen-svstems-isolated-territorv- pilot-europe

project SWARM[11].

Costs have fallen from more than a million Euro per fuel cell powered passenger car at the beginning of the millennium to prices close to 70,000 Euro in 2017, while lifetime has increased from a few hundred operating hours to numbers ranging between six and seven thousand *(6,000-7,000)* operating hours. A number of major car manufacturers are starting to offer early series-production vehicles, which are now comparable in performance with conventional internal combustion engine cars in terms of functionality[12].

For buses, the capital cost has been reduced by 72% already compared to the 2012 SoA and needs to be reduced further in order to provide a viable alternative to other low-emissions options; this is expected to be possible with increasing production (and demand) volumes, going from tens in earlier procurements moving to potentially 200 units per year. The challenge is also the competition with other local zero emission options, i.e. plug-in electric buses, although FCEBs present some net advantages such as 50% longer range, quick refilling and route flexibility.

Heavy-duty vehicles (HDV) are key targets for fuel cell applications as they have a higher torque coming from electric motors while they consume considerably more power compared to passenger vehicles. Fuel cell heavy-duty vehicles started recently their deployment at global scale. China will be demonstrating 500 FC trucks in the near term and in the US, the procurements reached the number of 800 trucks with further plans to expand the fleet. Toyota has recently built a prototype hydrogen FC truck taking advantage from the Mirai technology and is already developing its second iteration. In Europe, a fleet of 15 waste removal trucks is under procurement through the FCH 2 JU project REVIVE[13] while the EU project H2-Share[14] (co-funded by Interreg North-West Europe) is aiming to deploy a heavy-duty truck and mobile HRS at 6 locations in 4 European countries. The European number of heavy-duty vehicles is expected to increase further in 2018.

Integration of the fuel cell system and on-board hydrogen storage into a passenger car remains also a challenge, taking into account the competing requirements of long range, high performance (speed and acceleration), low weight, and minimal impact on the passenger and luggage space. The general approach for on-board storage in the last years has focused on high-pressure (700 bar) gaseous hydrogen storage, which offers large storage capacity while occupying less space. On-board H2 storage tanks remain a critical component and further reduction of prices by employing new materials, novel architectures, better manufacturing, and creation of a European value chain is needed for composite overwrapped pressure vessel (COPV) type IV and more fundamental research on COPV Type V, beyond the achievements of recently finished project COPERNIC[15].

Hydrogen refueling stations:

A European-wide network of hydrogen refueling stations (HRS) has yet to be established. The number of HRSs is growing significantly, and is currently approaching 140, plus more than 180

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11 http://swarm-project.eu/project-information.html

12 http://www.shell.com/energv-and-innovation/the-energy-future/future-transport/hydrogen/ jcr content/par/textimage 1062121309.stream/1496312627865/46fec8302a3871b190fed35fa8c09 e449f57bf73bdc35e0c8a34c8c5c53c5986/shell-h2-study-new.pdf

13 https://www.waterstofnet.eu/nl/nieuws/kick-off-meeting-revive-proiect-15-fuel-cell-refuse-trucks-at-7-sites-in-europe

14 https://www.waterstofnet.eu/en/projects-roadmaps/h2-share

15 http://www.fch.europa.eu/success-story/improved-hydrogen-tanks-fuel-cell-cars-future

HRS in planning/developing stage. However, there are still big areas in Europe (covering more than 1000 km) where there is no hydrogen refuelling station.

Refuelling interfaces have been successfully developed and refuelling times are competitive with liquid fuels, however further developments are necessary on compressors, metering and quality assurance. 99 HRS are receiving support from the FCH 2 JU: 41 HRSs are already deployed and 56 are in the planning or development stage. The CAPEX cost is declining, while reliability and lifetime are increasing. HRSs have been demonstrated in different sizes, from stations that supply small demonstration fleets, to HRSs that are capable of supplying busy public locations. The 700 bar refuelling technology is becoming established as the predominant refuelling pressure level for FC passenger cars, while 350 bar is used for buses (fewer constraints in the storage space, on the roof) and several range-extended plug-in electric vehicles. As regards the HRSs for forklifts, it is too early to recognise a proper trend, with 250 bar, 350 bar and even metal-hydride storage solutions being used in different projects.

With a standardised refuelling interface, the interoperability of emerging HRS networks is already advanced. The targeted refuelling time (3-4 minutes) has been reached by pre-cooling the fuel and applying infra-red communication between the vehicle and the filling station, according to the SAE J2601 standard. The next step should consider the development of stations for multiple uses (trucks, buses, cars, municipality vehicles, boats, trains etc.) as an integrated hydrogen ecosystem within a territory, enhancing the economies of scale in early deployment stages. Similarly, with the emergence of large hydrogen vehicles and an increasing hydrogen demand per refuelling station, there is a need to improve the compactness and footprint of future HRS solutions. There is also an associated need to develop refuelling protocols for vehicles other than cars and light duty vans.

The remaining major technological/standardisation issue for refuelling, the metering accuracy of dispensers. The current technology for metering hydrogen can achieve at best +/- 3% accuracy, while higher accuracies will be needed for public billing purposes (+/- 1% is required for dispensing natural gas). Additionally, hydrogen compressors are still a challenge being both expensive and insufficiently reliable. A portfolio of FCH 2 JU's projects[16] are investigating promising innovative compression technologies, which should deliver greater performance, durability, efficiency, and lifetime while lowering costs. At the same time, the FCEV customer experience around publicly accessible HRS should be improved, notably as regards the access to real-time information on the HRS status, availability of hydrogen at the HRS, access and payment methods, the ergonomics etc. Activities have already started in 2017 on HRS availability and hydrogen metering aspects.

Finally, hydrogen gas quality assurance at the nozzle also constitutes a challenge: the very stringent requirements for hydrogen maximum impurity levels for automotive fuel cell applications require complex and expensive instrumentation. A revision of the maximum impurity levels allowable should be considered and take into account the possible trade-off between cost, hydrogen purity, and the associated fuel cell lifetime expectancy.

3.1.2. Non-road transport applications

During the first half of the FCH 2 JU programme, the transport activities were focused mainly

16 Projects H2REF (http://www.fch.europa.eu/proiect/development-cost-effective-and-reliable-hvdrogen-fuel-cell-vehicle- refuelling-system) and COSMHYC (http://www.fch.europa.eu/proiect/combined-hvbrid-solution-multiple-hvdrogen- compressors-decentralised-energy-storage-and)

on road applications and their refueling infrastructure; due to the latest achievements in these applications, new sectors have shown increased interest such as maritime, rail or aviation sectors.

To understand the needs of these markets and the readiness of the technology, two dedicated workshops were organized in 2017 on maritime[17] and rail[18] applications.

Waterborne applications:

FC systems have been trialed for propulsion ranging from small passenger, and tourist/leisure vessels to submarines since 2002, with different types of fuel including hydrogen, methanol and diesel. Major technology demonstrators will be the two parallel Swiss and French boats touring the world from 2017[19] in full autonomy, taking their energy from solar panels and wind and storing excess energy in batteries or hydrogen produced through on-board electrolysis.

Strong interest is now for the use of high-power FC systems, powered either by pure hydrogen or LNG that could be applied for propulsion of naval vessels and be operated in CHP mode to provide heating and hotel power for cruise ships. For inland waterways, the focus is on sub-MW propulsion applications using pure hydrogen. Demonstration of these is being called already as part of the FCH 2 JU's 2018 activities/call for proposals.

FCH-based APUs are being evaluated for providing power (250 kW upwards) for in-port operations and 'hotel' loads in ferry and larger vessels, thereby reducing emissions and pollution at sea and in harbours from main engines operating on heavy fuel oil and marine diesel. The critical issues that need to be addressed for APUs are still reliability, lifetime and cost - with criteria largely similar to those of mid-sized stationary power generators with the additional concerns of weight reduction and volume minimisation.

Rail applications:

In rail applications, FCH systems have already been trialed for niche mining and shunting locomotive applications in South America, China, Japan, and the UK. More recently, a first successful trial of Alstom's Coradia iLint regional train in March 2017 has demonstrated the potential to exploit the FCH ("Hydrail") clean technologies to replace diesel on non-electrified railway lines and first passenger operations are expected in 2018 in Lower Saxony, Germany. Other FCH developments in rail applications include fuel-cell systems in electric tramways (and trolleybuses) to extend their routes beyond the electrified itineraries[20].

APU's (200kW+) in the rail sector are being considered an alternative for diesel-powered rail units to cover 'hotel' loads and eliminate main engine idling while in stations.

In order to clarify the best possible business cases in Europe (as the different rail applications might differ across Europe, different climates and/or different economic or geographical situations), and consequently the R&I priorities for the FCH 2 JU in this domain, a study[21] is jointly performed in 2018 with the Shift2Rail Joint Undertaking and rail industry.

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17 http://fch.europa.eu/event/workshop-maritime-and-port-applications
18 http://fch.europa.eu/event/hydrogen-trains-real-alternative-electrification
19 Race For water (catamaran, in navigation since April 2017) and Energy Explorer (catamaran, in navigation since June 2017)
20 Some national projects in Riga, Latvia, and Aruba
21 http://fch.europa.eu/news/fuel-cell-railway-fch-ju-shift2rail-ju-launch-new-study

Aeronautical applications:

Small manned airplanes have recently demonstrated the capability of hydrogen fuel cell propulsive power[22] while a 19-seater hybridised electric-hydrogen plane is in development[23]. The 2018 FCH 2 JU call for proposals will already support research efforts in the development and demonstration of modular propulsion system for small aerial platforms.

In parallel, FCH technologies are being widely evaluated for unmanned aerial vehicles (drones) outside FCH 2 JU's scope in civil applications, such as infrastructure maintenance, surveying, agriculture and other.

FCH Auxiliary Power Unit technologies can enable increased on-board power demands from more electric aircraft architectures (in view of substituting power demand from the main engines) and can also be used for 'hotel loads' on the ground and runway taxiing. Fuel cell systems are being evaluated to replace conventional tail cone APUs and/or as multi-functional systems providing ~200kW electric power, heat, water and oxygen. They are also being evaluated (<20kW) for replacement of mechanical Ram Air Turbine systems. Flight testing of representative systems is anticipated from 2018 onwards An ongoing FCH 2 JU project working towards the demonstration of such applications is HYCARUS[24], setting already the scene for designing a generic PEM fuel cell system for a single aisle aircraft tested and demonstrated in real flight conditions. Since there are no formal FCH system standards and requirements across the aviation sector for APU requirements yet, this project will extend the work already completed in the automotive sector and develop these for use in airborne installation and applications. There are still other critical issues that need to be addressed such as weight reduction, reliability, and on-board hydrogen or other fuel (e.g. LNG) storage.

Material Handling Vehicles (MHV):

With around 20.000 units deployed in North America MHVs constitute the most successful fuel cell application to date used in a number of different sites e.g. harbors, airports, industrial and logistic sites etc. Benefiting from the US success, forklifts in Europe are also approaching market introduction - some 250 units have been deployed through FCH 2 JU projects including a hydrogen refuelling network of 10 stations. .Given its limited contribution to decarbonisation, this application is not considered an immediate policy priority for the EU and hence will not be prioritised in the FCH 2 JU's activities 2018-2020, unless major developments are taking place in the short-term in the EU industry.

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22 Boeing demonstrator in 2008 on a Dimona 2-seater airplane in Austria, DLR Hy4 aircraft (4-seater) test flight in September 2016 in Germany, RX1E -based (2-seater) test flight in China in January 2017.

23 Pipistrel (Slovenia) in cooperation with Chinese partners

24 http://hycarus.eu/

3.2 Energy Applications

3.2.1. Hydrogen production from renewable electricity and other resources

In order to serve the goals of greenhouse gas abatement and overall reduction of emissions, hydrogen needs to be produced mainly from renewable energy, including wind and solar energy, biogas, but also waste streams and by recovery of surplus/waste hydrogen from industry processes. The increase of variable renewable energy feed into the electricity grids, such as solar and wind energy, will potentially create grid stability challenges in Europe's electricity infrastructure, calling for a greater use of energy storage amongst other flexibility measures. Hydrogen is one of the key solutions for large scale and long-term energy storage. Finally, it can contribute to the decarbonisation of the heating sector as an admixture to the natural gas grid.

Electrolyser systems are starting to be commercially available today with FCH 2 JU projects planning to demonstrate large scale installations such as H2FUTURE[25] deploying the largest PEM electrolyser in Europe (6MW) for steelmaking industry and REFHYNE[26] project which will demonstrate a 10MW electrolyser in a refinery environment. As regards their performances, the average energy consumption for electrolysers is currently estimated at approximately 60 kWh/kg while further improvement is still possible.

Polymer Exchange Membrane (PEM) electrolysis projects at MW-scale such as Hybalance[27] have started to demonstrate significant improvements in costs and mild improvements in efficiency. These improvements have however come at the expense of long-term stability and lifetime. The research projects on alkaline electrolysis have shown also progress in addressing the minimum operating load capabilities with innovative materials. Overall, the FCH 2 JU low-temperature (PEM and Alkaline technology) project portfolio results are competing with the SoA 2016 at a global scale and have provided the means to go beyond it. In that sense, the focus for the remaining period will still be resilient long-lasting multi-MW scale demonstrations, while looking at improving their performances through parallel research activities.

As regards high-temperature (solid-oxide) electrolysis, the portfolio of projects involve (since the beginning of FCH 2 JU) still a significant research dimension, with considerable performance progress, however, in a far smaller scale (tens or hundreds of kW) and lower TRL. Here the focus for the remaining period will be to scale-up to MW scale, while looking at other operational modes such as reversible or co-electrolysis as an interesting solution to reduce the capital cost of the electrolyser/fuel cell combination.

As regards alternative (renewable) hydrogen production pathways, the challenge is mainly to provide a reliable and low cost fuel. The potential pathways to be explored on a much-longer term might include high temperature water splitting, biogas/biomass reforming, photo-electrochemical water splitting, fermentation, biophotolysis, waste/biomass gasification, and purification of hydrogen-rich gas streams. The various pathways display different TRLs[28]. The most promising long-term pathways should be favoured, in order to be able to progress soon to an acceptable TRL (6-9).

25 http://www.fch.europa.eu/proiect/hvdrogen-meeting-future-needs-low-carbon-manufacturing-value-chains
26 http://www.fch.europa.eu/proiect/clean-refinerv-hvdrogen-europe
27 httpy/www.fch.europa.eu/project/hybalance
28 http://fch.europa.eu/publications/study-hydrogen-renewable-resources-eu

3.2.2. Hydrogen storage, handling and distribution: compressed gas, cryogenic liquid, solid or liquid carriers, pipelines

Large scale **storage** of gaseous hydrogen is feasible and has been in few cases commercially proven using an underground salt formation. However, a suitable business case has yet to be defined. The possibility to exploit the large scale storage capacity of the Natural Gas (NG) grid is also being considered; the first demonstrations of blending hydrogen with natural gas have already started[29], as well as producing synthetic natural gas (SNG) through co-electrolysis in Solid Oxide Cells.

Currently large-scale handling, storage and delivery of hydrogen are limited to locations connected by hydrogen pipelines. Extension of this infrastructure to cover even just a relevant part of Europe would cost many billions of Euro, an investment, which will only be feasible in a fully mature market (and falls outside the research and innovation programme of the FCH 2 JU).

In the short term, distribution of hydrogen can be achieved by expanding the existing merchant market for truck distribution. A capacity of 400 kg for compressed hydrogen trucks is standard for industrial applications, but demonstrations of higher pressure and higher capacity trailers have also started on Europe's roads.

Research on liquid hydrogen storage and distribution to be able to expand the area supplied by central hydrogen production sites and to make them commercially viable will be prioritised for the remaining period of the FCH 2 JU. The energy consumption of existing liquefaction plants is high, at 12 kWh/kg hydrogen and the FCH 2 JU IDEALHy[30] project concluded that it is possible to halve this. Liquid hydrogen is currently transported in trucks and containers of around 3,500 kg capacity.

Large-scale gas(es) compression is normally most efficiently done via turbo-machinery. This type of machinery, however, as well as other compression technologies, still needs to be adapted to hydrogen, as standard machinery is not optimised for the low molecular weight of hydrogen. There were no FCH 2 JU supported projects on this aspect until now.

Other forms of hydrogen storage and/or delivery, in particular via hydrogen carriers such as metal hydride storage or surface storage systems (sorbents) are still at an early stage of development, but can attain the required technology level in the near future and provide interesting performance compared to compressed gas and liquid hydrogen if up-scaled.

3.2.3 Fuel cell systems for CHP and other high efficiency conversions for industrial, commercial, residential scales and small applications

Stationary fuel cell systems present an interesting option for the conversion of hydrogen into electricity (and heat) as they allow achieving total efficiencies of above 90% when operated in cogeneration mode. With the increasing electrification of the heat sector, the heat and power peak demand are moving in the same direction. The potential for this heating demand needs to be considered in order to make best use of renewable energy generation and investments in the RES sector. In that respect, FC micro-CHP have proven[31] that they enable the development of other high efficiency applications in the commercial scale sector, providing

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29 https://www.telegraph.co.uk/business/2018/01/06/hydrogen/
http://www.voxeurop.eu/en/content/article/49521-possibilitv-gas-free-island
http://www.itm-power.com/news-item/iniection-of-hvdrogen-into-the-german-gas-distribution-grid
30 http://www.fch.europa.eu/proiect/integrated-design-efficient-advanced-liquefaction-hydrogen
31 Commercial units (5kW) demonstrated in ene.field

combined (cold) heat and power (C(C)HP) and other configurations of poly-generation into existing niches. While becoming established in early markets and offering reduced emissions, high efficiency and increasingly sufficient economic pay-back, these first successes in FC micro CHP applications will not require any further demonstration in the field in the remaining period of the FCH 2 JU.

Regarding the incumbent markets, fuel cells can offer three main advantages: significantly increased electrical system net efficiency (> 60%) compared with engine technology, operational flexibility while maintaining high efficiency at part load and longer operating hours. The FCH 2 JU projects have also proven that FCs are capable of converting a wide range of gasified waste streams such as from municipal, industrial and toxic waste, or wood into electricity & heat[32]. These organic-origin low-grade fuels can be exploited in the future as complementary to renewables for balancing the grid, to offer base load to compensate variable renewable production and therefore could play an important role in the future energy system based almost entirely on renewables. For this, a thorough evaluation of economic feasibility, technological durability, and identification of technological gaps are still to be completed.

Several European companies cover significant shares of the value chain and stimulate the creativity in approaches to technical solutions and to market entry. At the same time, there is an increasing interest for exporting components, sub-systems or complete systems from overseas markets. With several leading actors in this segment, EU could provide worldwide competitive technology and products. This will likely require a stronger focus of the individual companies in their activity to provide high added value at larger volumes.

The main technologies (PEMFC and SOFC) have opened already the path to commercialisation, however, further progress should be made to reduce costs, improve performance and durability as well as improve the manufacturing processes. Concerning durability, the minimum targets for commercialisation have been already reached but further enhancement will further reduce total cost of ownership (TCO). SOFC appear favorable since they can operate with various fuels and in particular methane (from natural gas, biogas, SNG) in addition to hydrogen. The pervasive natural gas network within Europe and the quickly evolving bio-gas industry focused on sustainable energy generation provide a natural pre-existing condition to valorise the advantages of SOFC based systems. In this case, the fuel flexibility and ability to simplify the balance of plant that is inherent to SOFC systems will permit widespread implementation of a cost effective and highly durable power source.

The residential market for micro CHP installations (0.3 - 5 kW), primarily for single family homes, but also multi-family homes and small buildings is very rapidly developing in Japan. More than 220,000 units had been installed by the end of 2017. In comparison, about 2,500 units have been installed in Europe as part of projects supported by both the FCH 2 JU[33] and Member States, such as in Germany where the technology has essentially entered an early deployment phase, since the KfW433 programme provides funding to end-users for the installation of approximately 60,000 units by the end of 2022[34]. As a consequence, a number of European manufacturers have started the scale-up process towards mass manufacturing. Within this power range a large market potential of hundreds of thousands of installations has

32 http://www.demosofc.eu/
33 Projects ene.field (http://www.fch.europa.eu/proiect/european-wide-field-trials-residential-fuel-cell-micro-chp) and PACE (http://www.fch.europa.eu/proiect/pathwav-competitive-european-fc-mchp-market-Q)
34 https://www.now-gmbh.de/en/news/press/more-fuel-cells-in-boiler-rooms

been identified by 2023[35]. Also, systematic research has been conducted on those topics with significant contributions from NELLHI[36] and INNO-SOFC[37] projects supported by FCH 2 JU, which contributed at stack and fuel cell system manufacturing.

Mid-sized installations (5 to 400 kW) for commercial and larger buildings are to date less mature due to a lack in upscaling of the current stacks available at increasingly lower cost and higher quality from other sectors such as micro CHP. A number of demonstrations have been however implemented across Europe such as Germany, the Netherlands, and several other locations in Switzerland, Italy, France, and UK[38], validating the technology as such. Following the base support to research and proof of concepts activities, first real life validation and demonstrations have started. This builds predominately on the experiences gained in the µ^P sector and on some more mature fuel cell stacks used in transport applications.

Likewise, the much larger market of centralised power generation has not yet properly developed due to the low electricity prices for large industrial customers in EU (the fuel cell industrial segment in Europe has struggled to find applications with viable business cases). There are however identified business opportunities for using European products in overseas territories or overseas markets that can serve as stepping stones for cost reduction and longer term strengthening of European industry. A number of projects around the world showcase large sized CHP installations such as the FCH 2 JU DEMCOPEM-2MW project[39] which deployed a 2 MW CHP system in China, the 1.4 MW project by E.ON and Fuel Cell Energy Solutions in Manheim[40], Germany and the 750 KW stationary system installed in New York, USA by Bloom Energy[41].

3.3 Cross Cutting Activities

Cross-cutting projects constitute an essential part of the overall FCH-JU project portfolio since they address challenges common to the energy and transport pillars. The latest developments in the fields of Pre-Normative Research (PNR) and Regulations Codes and Standards (RCS) have demonstrated improvements at European and international level, and currently contribute to developing an appropriate, fit-for-purpose regulatory framework for FCH technologies.

Considering the solid oxide cell/stack assembly, project SOCTESQA[42] has been able to develop, validate and submit to the relevant European and International Standardisation bodies industry-wide test procedures for performance characterization. Project HyPACTOR[43]

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35 European Parliament resolution on microgeneration - small-scale electricity and heat generation- http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML+MOTION+B7-2013-0388+0+DOC+PDF+V0//EN

36 http://www.fch.europa.eu/project/new-all-european-high-performance-stack-design-mass-production

37 http://www.fch.europa.eu/project/development-innovative-50-kw-sofc-system-and-related-value-chain

38 Projects DEMOSOFC (http://www.fch.europa.eu/proiect/demonstration-large-sofc-svstem-fed-biogas-wwtp). FITUP (http://www.fch.europa.eu/proiect/fuel-cell-field-test-demonstration-economic-and-environmental-viabilitv-portable-generators-)

39 http://www.fch.europa.eu/proiect/demonstration-combined-heat-and-power-2-mwe-pem-fuel-cell-generator-and-integration-existing

40 http://www.eon.com/en/media/news/press-releases/2017/2/8/radisson-blu-and-eon-form-partnership-for-a-low-emission-hotel-in-frankfurt.html

41 http://www.bloomenergy.com/newsroom/press-release-12-13-16/

42 http://www.fch.europa.eu/project/solid-oxide-cell-and-stack-testing-safety-and-quality-assurance

43 http://www.fch.europa.eu/project/pre-normative-research-resistance-mechanical-impact-composite-

contributed to the individual aspects of high pressure storage systems while project HyCora[44] worked on hydrogen fuel quality assurance, both providing a solid set of recommendations to be considered for present and future standardisation activities related to these topics.

Safety aspects are addressed through safety requirements in standards and regulations while incorporating findings from FCH JU projects such as: HySeA[45], HyPACTOR[46], KNOWHY[47] and HYRESPONSE[48]. Guidelines containing best practices for use of Computational Fluid-Dynamics modelling for safety analysis of FCH systems and infrastructures, including the related verification and validation procedures have been delivered by the project SUSANA[49]. The safe deployment of hydrogen installations in semi-confined spaces by introducing harmonized standard vent sizing requirements has also been tackled (project HySeA).

A set of educational and training tools has been made available to a broad range of audiences, from technician and professional operators, up to universities, regulators and public safety officials, including emergency responders has been developed through the cross-cutting FCH JU portfolio (KNOWHY, HYRESPONSE). This set of educational tools will be further completed by the recently launched project NET-Tool, which is focusing on e-learning.

Building upon the preparatory work of the project HyGUIDE[50] which analysed the hydrogen production routes, a European framework for guarantees of origin for green hydrogen has been proposed alongside a roadmap for its implementation in the EU (project CERTIFHY[51]). Future demonstration actions and advances in legislation for recycling and dismantling technologies, and strategies applied to the whole fuel cells and hydrogen technology chain are expected to be delivered by the project HYTECHCYCLING[52].

The FCH-JU Regulations, Codes and Standards Strategy Coordination Group (RCS SCG) identifies and prioritises items requiring further pre-normative research (section 5.2). In this context, the Joint Research Centre (JRC) has proposed a number of key cross-cutting areas and topics that need to be further addressed such as: safety provisions for the hydrogen fuel system, the high pressure tank and the electric high voltage component of the HFCV; safety for tunnels; safety issues associated with hydrogen/natural gas mixtures that have not been investigated yet. Additionally, a European repository on safety lesson learned for alternative fuels vehicles is required justified by the lack of awareness for such events, considering that with the end of the project HyResponse, no other activity on education and training of First Responders has been foreseen. Regarding liquid Hydrogen, the lack of experimental data and reliable validated models hampers progress in the safety dimension (this topic is currently examined by project PRESLHY[53]).

44 http://www.fch.europa.eu/project/hydrogen-contaminant-risk-assessment
45 http://www.fch.europa.eu/project/improving-hydrogen-safety-energy-applications-hysea-through-pre-normative-research-vented
46 http://www.fch.europa.eu/project/pre-normative-research-resistance-mechanical-impact-composite-overwrapped-pressure-vessels
47 http://www.fch.europa.eu/project/improving-knowledge-hydrogen-and-fuel-cell-technology-technicians-and-workers
48 http://www.fch.europa.eu/project/european-hydrogen-emergency-response-training-programme-first-responders
49 http://www.fch.europa.eu/project/support-safety-analysis-hydrogen-and-fuel-cell-technologies
50 http://www.fch.europa.eu/project/guidance-document-performing-lcas-hydrogen-and-fuel-cell-technologies
51 http://www.fch.europa.eu/project/developing-european-framework-generation-guarantees-origin-green-hydrogen
52 http://www.fch.europa.eu/project/new-technologies-and-strategies-fuel-cells-and-hydrogen-technologies-phase-recycling-and
53 http://www.fch.europa.eu/project/pre-normative-research-safe-use-liquid-hydrogen

4. Content of the Programme (2018-2020)

The implementation of the FCH2 JU programme of research & innovation for fuel cell and hydrogen technologies for the remaining period 2018 - 2020 continues to follow the two Pillars, dedicated respectively to Transport and Energy Systems. Overarching projects integrating both Transport and Energy technologies, and Cross-cutting activities will complement the two Pillars.

To allow a more flexible implementation of the Programme, priorities and budget-distribution among the various Pillars are agreed each year by the Governing Board. For 2018-2020 it is estimated that around EUR 236 million will be available for implementation of these activities (including call for proposals 2018 already published for EUR 73.2 million).

4.1 FCH Technologies for Transport Systems

Following agreement by the Governing Board on future strategy, for 2018-2020 the programme will mainly focus on the following topics[54]:

- **H2 local ecosystem**: demonstration of combination of various hydrogen applications for zero-emission transport solutions (e.g. larger vans, city delivery trucks (from 3.5 to 40 t), garbage truck, bikes, etc.) for clean urban/cities area (ecosystems) and across different transport modes.
- **Research on next generation of vehicles:**
    - stack, stack components and balance of plant, including tanks and on-board storage - cost reduction (including manufacturing, operation and maintenance, diagnostic and reduction of critical raw materials), increase efficiency and durability;
    - EU supply chain with the objective to create FC System stack European "Champions" including linkage between FC system integrators and OEMs of various transport applications;
    - improved certification for vehicles and components to ensure common technical specifications;
    - effective after-sales capability, ensuring rapid and effective interventions and minimising/facilitating maintenance and repair needs through improved designs of the entire FC system, including education and training;
    - next generation of vehicles (focus on buses) based on these learnings/EU developed components;
    - hybridisation aspects with batteries
- **Maritime sector applications:**
    - better understanding of market potential (and business cases/feasibility) and regulatory issues;

54 Material Handling Vehicles (outside the fork-lifts mentioned under port ecosystem/applications) could also be in the focus if strong evidence is brought that EU suppliers can catch-up with worldwide state-of-art or even displace the leading supplier

  - solid oxide fuel cells (SOFC) running directly on LNG, for auxiliary power units (APU) or propulsion applications as a transitional stage, with the aim of using pure hydrogen from renewable sources as a long-term fuel;
  - ports applications as FCH hubs with HRS producing H2 from renewables, with opportunities to create scale via deployment of hydrogen powered trucks, vans, fork-lifts, port machinery and possibly other transport vehicles ('multi-modal' approach);
  - inland waterways applications;
- **Rail and aviation:** better understanding of market potential (and business cases/feasibility) and regulatory issues before launching well targeted demonstration activities; viable FCH solutions should be developed for these transport modes across EU countries, keeping EU added value and synergies with Shift2Rail and Clean Sky in mind.
- **Hydrogen Refuelling Station (HRS) reliability and cost:**
  - reduce cost and increase reliability of the HRS;
  - mainly improving compression but also H2 supply optimisation;
  - onsite H2 production from electrolysis and coupling with HRS and liquefied H2 carriers;
  - common technical specifications and certification processes for both HRS and components;
  - development of: compact HRS for refuelling heavy vehicles (delivery of large quantity of hydrogen per day) & HRS with multimodal potential

As regards the research activities within the Transport Pillar, FCH 2 JU will continue to address fuel cell systems, hydrogen refuelling and on-board storage of hydrogen. Non-FC-specific electric drive train components, such as electric motors and batteries, as well as specifically electric drive train architectures fall outside the scope of the FCH 2 JU and should be addressed in coordination with the EGVI initiative to leverage and coordinate public investment. Nevertheless, issues specific to hybrid FC-battery configurations are important and are between priorities for 2018-2020.

Annex 1 shows the state-of-the-art in 2017 and the targets for the particular applications of FCH technologies in the Transport Pillar for 2020, 2024 and 2030.

4.1.1. Road applications

Scientific and technical progress has brought FCH technologies for transport systems to various levels of maturity (see previous chapter on SoA). These applications have proven their technology readiness in terms of performance, safety and reliability, and already meet public expectations for mobility whilst emphasis is required on the next generation vehicles. Nonetheless, achieving affordability still requires large scale production of vehicles and hydrogen refuelling stations, which in turn, necessitates substantial and sustained RD&D efforts to improve performance and reduce cost.

The after-sales market of FC transport applications including effective after-sales capability, ensuring rapid and effective interventions while facilitating and concurrently minimizing maintenance and repair needs is a complementary focus area which requires improved designs of the entire FC system, including education and training. This is an area identified to create employment as part of the supply chain.

Regarding refuelling infrastructure several demonstrations have been supported by the FCH 2 JU according to the specific needs of locations (i.e. close to the hydrogen production facility or to the point of use) and customers. However, efforts must be sustained to reduce capital costs and operational costs to reach the highest international levels in terms of modularity, refuelling time, reliability, safety and availability. These developments will be accompanied by limited demonstration activities where relevant and useful.

Although standardisation of the interface between FCEVs and the HRS as well as filling protocol standards are already agreed on the basis of applicable standards, such as those developed by SAE and ISO, it is still necessary improved certification for vehicles and components to ensure common technical specifications and in parallel to complete the standardisation work for HRS. Examples of this work include the purity of the hydrogen delivered by the HRS, refuelling protocols for heavy vehicles, the accuracy of the measurement of the amount of hydrogen dispensed to the FCEVs and its temperature level. This work will be crucial in safeguarding a rapid build-up of sufficient refuelling infrastructure network for hydrogen as envisaged in the Alternative Fuel Infrastructure Directive[55].

4.1.2. Non-road transport applications

Applications for maritime, inland waterways, port, rail, and aviation are prioritised; there fuel cells are likely to offer a unique selling proposition but will need significant additional research efforts to achieve competitiveness with incumbent technologies, given the need to urgently intensify efforts to reduce air pollution across Europe. Thus, development and adaptation of components and demonstration of fuel cell propulsion systems for non-road applications and related infrastructure, will be also prioritised across different transport modes.

The envisaged activities will hence prioritise main propulsion power supply for maritime ships and other maritime and inland waterway vessels, including use of solid oxide fuel cells (SOFC) running directly on hydrogen as well as LNG, SNG and LSNG as a transitional stage, with the aim of using pure hydrogen from renewable sources as a long-term fuel. The CHP functionality could be suitable for cruise ship hotel loads, and in-port machinery. In addition, ports applications as FCH hubs with HRS producing H2 from renewables create opportunities to increase scale via deployment of hydrogen powered trucks, vans, fork-lifts, port machinery and possibly other transport vehicles ('multi-modal' approach).

Depending on the results of the current joint study with Shift2Rail Joint Undertaking, traction power for trains on non-electrified tracks in sensitive locations (e.g. stations, suburban trains, and protected areas) might be supported. As regards aviation, the focus will be mainly on APUs for airplanes, without excluding propulsion options once the market potential matures. Increased use of FCH technologies in these non-road applications can stimulate and leverage additional economies of scale in adjacent supply chains for fuel cell and hydrogen infrastructure related components, and is hence important for the whole hydrogen sector.

Close links to other Transport and Energy activities for supply and storage of hydrogen and generic aspects related to fuel cell development (e.g. lifetime issues etc.) will be established to fully exploit the synergies between various applications and maximise the potential of hydrogen

55 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014L0094

as an energy vector in a sustainable energy system.

4.2 FCH technologies for Energy Systems

Following agreement by the Governing Board on future strategy, for 2018-2020 the programme will mainly focus on developing and demonstrating technologies that enable fuel cells and hydrogen to play a key role in the sectorial integration of the energy system, linking the power, gas, mobility, heating and industrial sectors. Alongside providing a renewable energy source for mobility, the use of renewable hydrogen for energy storage, to decarbonize the natural gas grid and its use in industry will be considered as matters of priority. In that respect, most of budget (around 75%) will be dedicated to the first two bullet-points below:

- **Next generation of electrolysers:** research on reducing cost (including manufacturing and reduction of critical raw materials) and improving electrolyser performance (increase efficiency) of all three electrolysis technologies (low and high temperature); this can include reversible operation and co-electrolysis but must demonstrate a clear path to commercial viability. Focus should be on EU supply chain and EU added value.

- **Large-scale H2 storage and distribution:**
    - large-scale storage of pure hydrogen (underground, aboveground, liquefied, gaseous, hydrogen carriers etc.) or as admixture of hydrogen into natural gas grid (including regulations aspects) and improved H2 distribution aspects (e.g. compression, purification, liquid hydrogen supply chain);
    - use of hydrogen storage as a reserve supporting grid services.

- **FC-CHP:**
    - demonstration in selected specific applications (poly-generation services and focus on very high total efficiency);
    - optimisation for enabling use of RES, resiliency (back-up capabilities), varying gas qualities and increased self-consumption own renewable electricity (enhanced features for µCHP);
    - research on next generation cell/stack for FC-CHP to reduce cost (including standardisation, manufacturing, diagnostic and reducing critical raw materials), increase efficiency, reliability and durability, and strengthen EU supply chain;

Annex 2 shows the state-of-the-art in 2017 and the targets for the particular applications of FCH technologies in the Energy Pillar for 2020, 2024 and 2030.

4.2.1. Hydrogen production from renewable electricity via electrolysis

Although the capital and fixed operational costs of electrolysers have been reduced considerably since 2012, additional improvements are needed. Especially when operated exclusively on renewable electricity, limited utilisation increases the impact of these two cost factors on commercial viability. The electrolyser KPI Tables (2.1-2.3) in Annex 2 specify the need for a further 50% cost reduction by 2030 compared to 2017 levels. The FCH 2 JU will contribute by calling for demonstration projects that enable cost reduction via further scale-up of the technology and via better integration with renewable electricity sources. Simultaneously, more fundamental research into improving current density, durability and the reduction of use of critical raw materials is required.

A second objective is to improve the efficiency of electrolyser systems to reduce cost and the electricity consumed. For low temperature electrolysis research activities are expected to enable improvements in next generation systems. This includes research into improved ways of connecting electrolysers to renewable sources, for example DC-DC coupling or other innovations in power electronics that lead to standardisation and cost reduction. Further scale-up and demonstration of high-temperature electrolysis will enable much lower electricity consumption especially in cases where waste steam is available from other processes.

Additional KPIs, like ramp-up times and idle power use, were included for grid balancing services with PEM electrolysis, as this technology is expected to deal with these variations more effectively. Similarly, an additional KPI for electrolyser system footprint has been added. Without a clear fixed KPI, the ability to run for short periods above the nominal capacity (over-capacity) for a specific use case may form part of future work. Specific topics will be formulated in a technology neutral way, so that different and especially new electrolyser technologies can compete.

The KPIs for high-temperature electrolysis (Annex 2) contain additional ones reflecting the current readiness level and capabilities of the technology. These include the KPI on downtime (already solved to satisfaction for low-temperature electrolysis) and capacity, as well as efficiency in reverse mode when it acts as a fuel cell producing power from hydrogen or methane.

In addition, some stack technologies, in particular those using solid oxide cells, are capable of operating reversibly, becoming regenerative energy storage devices. The development of regenerative energy storage systems, comprising an electrolyser and fuel cell that in one unique device can alternatively generate or store power (in the form of hydrogen or other chemical fuel), provides an interesting perspective in terms of simplicity, round-trip efficiency and integration into Europe's electricity and gas grids. They offer grid balancing and energy storage capabilities and can contribute to improve grid stability in the future with both positive and negative controllable load solutions and efficient the option for decentralized base load power production.

4.2.2. Hydrogen production from other renewable energy sources

The FCH2 JU will now focus on reducing cost and improving efficiency of hydrogen production from technologies that support the primary objectives of deployment and reduced carbon emissions (when compared to the state-of-the-art steam reforming of natural gas). Options for hydrogen production such as renewable high temperature water splitting, photo-electrochemical, and biological processes, will be addressed if considered strategic. Actions are expected to be mainly Research and Innovation, rather than Innovation.

Table 2.4 in Annex 2 contains KPIs related to the conversion of biogas to hydrogen, on which several topics were called in the past, and on high-temperature water splitting with already a topic in 2018 Call for Proposals for production of hydrogen directly from sunlight.

4.2.3. Hydrogen storage (including handling) and distribution

FCH 2 JU priorities will be based on the need to store hydrogen at a central production and/or to transport the hydrogen from the central production to its customers:

- Large-scale storage is required to deal with imbalances between supply and use of hydrogen, in particular those caused by fluctuations in availability of renewable electricity.

- Improved delivery concepts are needed to increase the area of potential customer base around central facilities; delivery encompasses those processes needed to transport hydrogen from a central or semi-central production facility to the final point of use.

The FCH2 JU will focus on gaseous truck transport and liquid delivery, including the preparation of hydrogen for these delivery methods. It is expected that permitting will be an essential aspect for all these technologies.

Research and Innovation activities into promising carrier options may also be supported, similar to the 2017 topic on liquid organic carriers, if the technology in question has reasonable likelihood of providing benefits when compared to gaseous or liquid delivery. Pure hydrogen pipeline transport is not in the scope of the FCH2 JU as the technology has little need for further development.

KPIs Table 2.5 in Annex 2 contains targets for hydrogen transport via tube trailers and large-scale hydrogen storage.

Beyond distribution, further ancillary technologies to be covered for hydrogen logistics include:

- Compression: required for most hydrogen systems, whether underground storage, gaseous truck distribution, liquefaction or pipeline injection. Actions on large-scale hydrogen compression would improve efficiency and cost effectiveness of compression of hydrogen to the various pressure stages required for commercial introduction.
- Purification: needed for all low-temperature fuel cell use cases and separation of hydrogen from the gas grid, to provide pure hydrogen and natural gas whereas separation from waste gas streams provides an additional source of low carbon hydrogen.

A special case is the injection of renewable hydrogen as an admixture into the natural gas grid, which increases the renewable energy content of the gas, thus integrating renewable electricity into the wider energy system. It also provides a way to match hydrogen production and demand, preventing for example, curtailment of the electrolyser at times when the hydrogen storage capacity is exhausted but there is a sustained availability of excess renewable electricity. Local demonstrations of gas grid injection in Europe are planned or on-going under separate programs. In the FCH 2 JU programme, gas grid injection may be included as an aspect of electrolysis demonstration.

Moreover, it is important to put in place a regulatory framework that will be conducive towards hydrogen injection into the natural gas grid. The FCH 2 JU will continue to work on defining the maximum concentration of hydrogen in the natural gas grid and removing the barriers towards higher concentrations. At the same time, the effects of using various hydrogen/natural gas mixtures in FCH 2 JU's research and demonstration projects will be monitored and fed-back to legislators. An additional topic may be called to support this work as long as it is complementary with the 2018 PNR related topic.

4.2.4. Fuel cell systems for CHP and other high efficiency conversions for industrial, commercial, residential scales and small applications

The main focus of this area will continue to be the reduction of primary energy use by efficient conversion of chemical energy (hydrogen, biogas, synthetic natural gas, and other renewable hydrocarbons, power to gas, industrial waste gases etc.) into power and other energy services, such as heat and cold production (CHP, CCHP, CH2P). In addition, the modularity of fuel cells which offers decentralised electricity and heat production, reducing efficiency losses from the transmission and distribution grids could also be addressed. In the short term, especially for the residential and commercial sectors, the main effect of FCs is realising savings by using natural gas more efficiently while simultaneously preparing the transition to increased hydrogen and renewable methane content in gas grids, and potentially pure hydrogen grids in the long run. With increased maturity of the technology, the focus of development will shift to both increased H2 content fuel mixtures and low-grade biomass derived fuels. High overall and electrical efficiency will continuously be pursued.

To increase the competitiveness of the European stationary fuel cell sector on the global scale and reduce the total cost of ownership (TCO in €/kWh), the establishment of a more efficient industrial structure is required. Priority will hence be given to actions that favour the emergence of specialised actors that generate higher added value in their specific segment. Offering those components to several integrators in terms of applications, product size and geographical scope will allow for volume scale effects across the whole industry.

Residential: micro CHP for single family homes and small buildings (0.3 - 5 kW)

While becoming established in early markets and offering reduced emissions, high efficiency and increasingly sufficient economic pay-back, micro CHP applications will not require any further demonstration in the field in the remaining period of the FCH 2 JU. The focus of FCH 2 JU for the remaining period will only be on building the European supply chain and developing next generation technologies that deliver decisive cost reductions, improvements in manufacturability and robustness, and other quantum changes in stack and system performance. Activities such as improved fuel flexibility dedicated research to further increase durability and performance of stack/systems, that can achieve considerable cost reduction, development of mass-manufacturing processes, building of a European supply chain, and development and validation of the next generation and breakthrough technologies for stacks and systems may be supported 2018 to 2020.

Commercial: Mid-sized installations for commercial and larger buildings (5 - 400 kW)

Continued support to selected demonstration activities in this segment is still meaningful to increase the maturity level of systems, in order to establish the confidence for end users and the finance community to recognise the investment opportunity of the energy savings. To this end, a modular approach with focus more on the design (rather than the actual large scale deployment of fuel cell systems), will enable them to address a wide range of innovative end-use applications, as well as various power levels. This could result in increased levels of competitiveness and strengthened volume effects visible on the supply chain of the other system components. Beyond the pure volume effects, such measures will also translate the increased core technology maturity and allowing them to benefit from next generation materials much easier as they can be validated in other segments.

Industrial: Large scale installations for industrial use and grid support and district use (1 - 30 MW)

With the technology used in current demonstration projects it is unlikely that the KPI's for the industrial large scale segment will be achieved with European technology within the frame of the FCH 2 JU programme. Therefore longer-term actions might be required to open this segment to European technology and value creation. In this regard, new research activities have started within the FCH JU aiming at developing the next-generation MW-size Fuel Cell Power Plant unit (FCPP) with reduced CAPEX and with grid services capabilities.

Against this background, the focus of this segment in 2018-2020 should be on considerations of strengthening the supply chain for all system components with other sectors, including electrolysis, to benefit from mass- volume cost reduction and increased technical maturity.

Other applications:

Other applications of fuel cells include off-grid and backup power applications. Following early demonstration projects, the next generation of products are currently being developed. Medium scale demonstrations will take place through FCH 2 JU's projects[56] in the next years including genset applications and power supply in remote locations. Cost reduction, improvement of components and system architecture in view of boosting the energy systems' resilience should be prioritized in those applications.

4.3 Low TRL, research-oriented challenges

The FCH 2 JU activity in this field aims at maintaining Europe's world-wide excellence in the technology in the long-term and is part of Europe's competitiveness vision. The major specific challenges in relation to the fuel cell and hydrogen core technology are identified, in order to establish the base for the next generation components.

The present fuel cell and hydrogen technologies for automotive and energy applications show limitations (performances, durability, production cost) which appear to be difficult to overcome by incremental improvement of each component or sub-system such as membrane, catalyst, MEA or stack. In order to reach the OEM's targets, to prepare the next generation of stack and components for both transport and energy applications, and in order for EU to stay competitive versus North America or Asia, new disruptive component and sub-system concepts are needed involving new component architecture, new materials, and new manufacturing processes. Next-generation products will be competitive thanks to solutions that are simple and integrated into the base components such as the cells and stacks, and allow reduction of the total cost of ownership.

These challenges are typically addressed by lower TRL solutions, moving e.g. from 2 to 5, even though the final product incorporating the outcomes may be already over TRL 7 or 8. The results should therefore be available to participating industry to allow it to pick up the relevant outcomes and integrate them into their existing products and so to progress to the next generation. In that respect, further research (R&I activities at low-TRL) on topics of strategic importance (e.g. reduction of critical raw materials) for next generation of products aiming at cost reduction, performance improvement and strengthening of the European value chain should be also considered (in particular, taking into account inputs from Scientific Committee).

An overview of the research-oriented challenges is defined here for transport and energy applications:

56 Project EVERYWH2ERE (http://www.fch.europa.eu/proiect/making-hvdrogen-affordable-sustainablv-operate-everywhere-european-cities)

For SOC (Solid Oxide Cells), the challenges are mainly to improve the system operation and efficiency while decreasing stack materials cost. The development of 'game changer' cells and electrode microstructures to improve durability as well as stack gas tightness increase, long-term tolerance to cycling conditions and increase of stack performance homogeneity will be therefore prioritised. These should also include decrease of stack raw materials cost by replacement of noble raw materials by more largely available ones (reduction of Cr by increase of Fe) or by the use of less pure raw materials (rare earths) requiring therefore a higher tolerance for impurities. Moreover, progress is required in developing low cost BoP components and increase fuel flexibility for methane/ hydrogen variable mixtures, biogas of differing quality, syngases etc. Finally, sulphur tolerance of both the reformer and stack and increase of stack robustness to fault conditions, including redox cycles is required. Other aspects that should be addressed from low TRL research are the improvement of reversible operation of a SOC stacks through dynamic operation and control and the performance in co-electrolysis (steam+CO2) operation, as well as the design and development of membranes for water purification and removal from hydrogen stream.

For PEFC/PEMFC the focus is on disruptive solutions, through 'game changer' MEA and stack in order to reach the very challenging 2030 KPI targets. The identification and understanding (including modelling) of the degradation mechanisms for 'game changer' solutions will be also prioritised. Topics around stack tightness and lower cost for BoP components, stack durability surface and volumetric power density, sulphur tolerance and reduction of CRM still remain crucial.

For alternative low-carbon hydrogen production pathways, the maturity of direct solar hydrogen generation is emphasized in parallel with filtering the most promising solutions while proposing upscaled, more efficient, more reliable geometries, materials, components and systems. 'Game changer' separation and cleaning solutions from hydrogen rich gases as well as research on waste-to-H2 and waste-to-energy processes might be also in focus.

For hydrogen storage, distribution and handling the challenges include development of novel solutions for large scale hydrogen storage and, scaling-up actual storage systems. In addition, emphasis should be placed on 'game changer' hydrogen carriers and storage materials and solutions to reach the 2030 targets in terms of performance and cost. The development of solid state hydrogen compressors using low and medium temperature hydrides as well as the development of new separation membranes still need to be addressed. In addition, the reduction of compressor and tank degradation, and the improvement of their lifetime and materials withstanding H2 embrittlement might be prioritised, too. Next generation of liquefaction and purification issues technologies related to purification with novel high temperature sorbents, lower energy losses for purification to near zero with H2 purity level 5N as well as purification with medium T and high T electrochemical processes and that are noble metal free still need to be addressed.

For on board hydrogen storage for transport the focus will be on technologies that will increase gravimetric density, enable fast refuelling and decrease production cost (carbon fibre substitution as well as on board production and game changer hydrogen tank (type V).

For component manufacturing the main focus will be on developing sensors/actuators and associated data processing for real time production quality controls including defect database establishment.

4.4 Overarching activities

Overarching projects will be supported by the FCH 2 JU to demonstrate interoperability and synergies between the two Pillars, in order to identify the best business-cases and showcase the value proposition of hydrogen with particular emphasis on sectoral-integration. Emphasis will be put on technology itself, rather than volume or size, in order to show an integrated system-level approach towards the production of hydrogen from renewable sources and its subsequent valorisation as energy vector in transport, industrial feedstock and electricity/gas grid.

As both a fuel and an energy carrier, hydrogen can mitigate the challenges posed by the variability of solar and wind energy. As the "gaseous form of electricity", it is an enabler for sectoral integration. Sectoral integration denotes the integration of the power sector with the transport, heating, cooling, and other energy system sectors via specific energy carriers to achieve European climate and energy goals. There are several examples of sectoral integration including the refuelling of FCEV with green hydrogen; the admixture of hydrogen to natural gas networks, while providing grid services to electricity networks; the use of fuel cell CHP systems to deliver heat and power; and the utilisation of green hydrogen as a feedstock for deriving chemicals such as methanol and ammonia, as well as in hydrogen consuming industry such as refineries and metallurgy. When one or more type of sectoral integration is applied in a region we have what is known as a 'hydrogen territory' or 'hydrogen valley' preferably with an overarching dimension (i.e. integrating transport and energy pillars). Sectoral integration faces overarching challenges involving a wide range of factors from technology to safety, education and social acceptance and the Overarching activities will aim at addressing these bottlenecks in an integrated and systematic manner.

The integrated energy chain from fuel production, storage (including large scale storage and power- to-gas) through distribution to end use by vehicles or stationary fuel cell systems in different Member States and Associated Countries should be considered by the FCH 2 JU in the 2018-2020 timeframe, including coordination and combination with national or regional projects. Specific business models in an industrial and commercial environment should also be addressed in order to verify and evaluate the suitability of current theoretical concepts and move the technology, including the business side, towards full-scale roll-out across Europe.

Consequently, such 'eco-system' activities will be supported concerning sectoral integration and 'hydrogen valley' approaches that are applicable to energy and transport. Such projects will include activities where hydrogen production from renewables is combined with FCEVs, distributed generation gas grid injection, industrial processes and selected consumer appliances into an integrated system. Field-testing FCH technologies showcasing their possibilities to the public will be pursued.

Research activities concerning both energy and transport technologies will be also supported as well as studies that look at a system-led rather than technology-led perspective of what hydrogen and sectoral integration must achieve in order to play a major role in decarbonising the EU economy.

4.5 Cross-cutting Activities

Cross-cutting activities will support and enable both the Transport and Energy Pillars and facilitate the **transition to market for FCH technologies.**

Education & Dissemination:

Information, education and dissemination activities are needed to build political support and societal acceptance for hydrogen and fuel cell technologies throughout the European Union. Information transfer will include descriptions of the benefits of fuel cell and hydrogen technologies, but also how possible risks have been addressed, and how any potential negative impacts should be mitigated.

Regulations, Codes and Standards:

With respect to regulations, codes and standards, the Cross-cutting pillar is supported by the FCH 2 JU RCS Strategy Coordination Group (see section 5.2). Priority will be given during 2018-2020 to activities such as green H2 certificates (CertifHy initiative)[57], safety aspects, RCS, training and education, PNR and input to European standardisation activities.

Safety:

Innovative safety strategies and safety solutions are of paramount importance for public acceptance and commercial deployment of FCH technologies. Special attention will be paid to the technology transfer from the professional community to the general public. This includes identifying best practices and guidelines for various emerging FCH applications and intervention techniques and procedures for first (and second) responders for different situations and different technologies (e.g use of H2 in heat & power, tunnels, parking spaces, fleet users (H2 vs. petrol / diesel), industrial uses, back-up power, drones and other early deployment areas; regulatory / permitting issues, etc.).

Emphasis will be put on technical safety, including but not limited to pre-normative research. Actions may include close of knowledge gaps in safety concerns, development of best practice guidelines, development of intervention techniques for first responders at an incident/accident scene etc.

Pre-Normative Research (PNR):

Building upon the work started in the FCH 2 JU this will among other actions include harmonisation of testing procedures and of reporting templates, as well as establishment of commonly agreed representative loading profiles (stressors) for different applications of FCH technologies, such as automotive and stationary fuel cells. Particular emphasis will be placed on admixture of hydrogen in the natural gas grid following conclusions of the European Committees Standardization and of Electronical Standardization[58] - Sector Forum 'Energy Management' on Hydrogen. In addition, other topics such as refuelling protocols, revising codes & standards for emerging new applications, standardisation of FCEV vehicle data and of critical component and investigation of materials compatibility as well as improvement of the hydrogen metering device will be also emphasized. In particular, alignment with international efforts in

57 http://www.fch.europa.eu/page/certifhy-designing-first-eu-wide-green-hydrogen-guarantee-origin-new-hydrogen-market

58 https://www.cen.eu/Pages/default.aspx & https://www.cenelec.eu/

this area e.g. USA and Japan will be prioritised as well as preparing the alignment of RCS for hydrogen and fuel cells across all Member States.

Cross-cutting activities might contain also public awareness, including educational and public outreach projects that will prepare the European citizens for the market introduction of FCH technologies. Another important initiative will be to map the EU FCH value-chain[59], including the supply-chain, with the aim to identify the main bottlenecks/and weaknesses and put in place well-targeted actions by the FCH JU in order to address those.

As various cross-cutting activities influence each other and cannot be taken as independent, activities in this domain should address more than only one subject to address a specific aim and should put emphasis on communication and dissemination of results in order to improve public awareness.

59 http://www.fch.europa.eu/page/FCH-value-chain

5. Other activities of the FCH 2 JU

5.1 Interface with EU policies and other programmes

Background:

Whereas the EU 2020 Strategy[60] with the priorities for smart, sustainable and inclusive growth was an important driver for the conception of the FCH 2 JU and still remains valid for the top-level EU policy objectives, in the meantime several global and EU policies and strategies have set the new scene for accelerating the energy transition.

On 25 February 2015, Commissioner Miguel Arias Cañete launched the Energy Union Framework Strategy[61] as one of the 10 Commission priorities to provide Europeans with energy which is secure, competitive and sustainable.

Few months later, at the Paris climate conference (COP21) in December 2015, 195 countries adopted the first-ever universal, legally binding global climate deal. The agreement sets out a global action plan to limit global warming to well below 2°C.

In November 2016 the EC adopted the "Clean Energy for All Europeans Package"[62] which includes legislative proposals for the post 2020 timeframe in the areas of energy efficiency, renewable energy, the design of the electricity market, security of electricity supply and governance rules for the Energy Union. As part of the Clean Energy Package, the EC adopted a revised Renewable Energy Directive. The role of renewable gases, including hydrogen, in achieving the ambitious decarbonisation targets is explicitly recognised in these proposals.

This was followed by the European Commission Staff Working Document on Energy Storage published as part of the "Second Report on the State of the Energy Union' on 01 February 2017, which emphasised the crucial role of energy storage in energy system with high shares of renewables. It also acknowledged that hydrogen storage solutions are uniquely placed to serve the strategic purpose of strengthening links between the energy and transport sectors and facilitate the transition of the EU toward a low-carbon society.

Finally, on 8th November 2017, the European Commission adopted the so-called 'Clean Mobility Package' which aims at accelerating the transition to low- and zero emission vehicles and towards the attainment of the 60% reduction of greenhouse gas emissions by 2050 with respect to 1990 levels. Fuel cell electric vehicles form an integral part of this strategy.

The level of ambition of the Paris Agreements and of the commitments Europe has made to comply with it, necessitate unprecedented levels of technological innovation in the field of energy. They put more spotlight on the European Research and Innovation Framework, including its various facets, such as the JTIs. These efforts go hand in hand with the new modernised SET Plan, which builds on an integrated approach that goes beyond technology silos. The upgraded SET Plan proposes 10 focused research and innovation actions[63] to accelerate the energy system's transformation and create jobs and growth, ensuring the European Union's leadership in the development and deployment of low-carbon energy

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60 https://ec.europa.eu/energv/en/topics/energv-strategv-and-energv-union/2020-energv-strategy
61 http://ec.europa.eu/priorities/energy-union/index en.htm
62 Clean Energy for All Europeans Package: https://ec.europa.eu/energy/en/news/commission-proposes-new-rules-

technologies. The FCH technologies are relevant for a number of actions defined in the SET Plan, and the FCH 2 JU will continue to actively support its work.

Actions:

Beyond the SET Plan Actions the FCH 2 JU will contribute and maintain regular contacts with other relevant EU initiatives such as Clean Sky 2, Sustainable Transport Forum, Gear 2030, Shift2Rail, Smart Cities and Communities, EERA, and KETs[64], the AFI Directive STRIA[65] teams, in order to explore potential synergies and provide FCH related inputs. In particular, a strong interface and coordination of strategies is needed with relevant EU level activities targeting electro-mobility, such as the European Green Vehicles Initiative (EGVI), given that many electric components and architectures are common between fully electric, plug-in hybrid, range extended and FCEVs.

With regard to the potential contribution of hydrogen to the decarbonisation of the transport sector, collaboration should be strengthened regarding the implementation of the directive on the deployment of alternative fuels infrastructure, and actions arising from the "European Strategy for Low-Emission Mobility[66] to ensure that hydrogen is well addressed. In parallel, coordination with Trans-European Networks for Transport needs to be pursued, as well as close collaboration with the Connecting Europe Facility (CEF) programme and its coordinated calls (CEF-transport and CEF-energy) in order to maximise the impact of EC co-funding. Finally yet importantly, efforts should continue to deliver solutions in support of the Transport White Paper's[67] objective to establish essentially CO2-free logistics in major urban centres by 2030.

A strong liaison should also be in place with the Joint Programme on Fuel Cells and Hydrogen within the European Energy Research Alliance (EERA), in order to pool resources and coordinate efforts throughout the supply chain, from fundamental research to product marketing towards strong and competitive EU FCH sector.

It will be critical that the results and achievements delivered by the FCH 2 JU projects to date are extracted and used to inform and support various European policies. To this end, the FCH 2 JU in cooperation with the relevant European Commission services, should continue to explore best ways for developing the necessary "interface mechanisms" between the JU and relevant EU initiatives and policies, particularly in key areas such as transport, energy, environment and industrial competitiveness. To this end, the FCH 2 JU will ensure presence in the relevant technical groups organised by the EC services such as the Sustainable Transport Forum (STF), the Clean Bus Deployment Initiative Expert Group, the SET Plan and the Alternative Renewable Transport Fuels Forum (ART Fuels).

Finally, at the end of 2015 the EC adopted a new Circular Economy Package to stimulate Europe's transition towards a circular economy. As part of this in 2017 the EC issued a Communication on the role of waste-to-energy in the circular economy. Innovative waste-to-energy solutions with fuel cells are being demonstrated as part of the FCH project portfolio. The FCH 2 JU will therefore strengthen collaboration with the different initiatives and funding

64 http://eur-lex.europa.eu/legal-content/EN/ALL/;isessionid=xg6vTG1f34nJVvqviJq9rvX0J3LzniQbVnzJl0JvKgrp5VG4Gvws!-1079227193?uri=CELEX:52012DC0341
65 http://ec.europa.eu/programmes/horizon2020/en/news/towards-strategic-transport-research-innovation-agenda-stria
66 COM(2016) 501 final
67 https://ec.europa.eu/transport/themes/strategies/2011_white_paper_en

programmes underpinning the implementation of the Circular Economy Action Plan such as The Circular Economy Stakeholder Platform[68] and will explore synergies with projects and initiatives supported under Horizon 2020 Societal Challenge 5 [69] as much as possible through the SRG.

5.2 Regulations, Codes and Standards (RCS) Strategy Coordination

The implementation of a Regulation Code and Standards Strategy Coordination (RCS SC) is crucial for the market deployment of FCH systems. Today, the lack of harmonized RCS and pre-normative research (PNR) to fill RCS knowledge gaps at EU (and world) level is still recognised as a major barrier for the commercialization of FCH products.

RCS activities target the development as well as the actual use of harmonised performance-based standards for FCH appliances and systems, together with their safety in energy and transport applications that can (a) facilitate access to the market and (b) can serve as mandatory references in regulatory documents at EU level.

The FCH 2 JU Strategy on RCS[43] therefore aims at *deploying the activities needed to enable meeting the interests of the European FCH-community*[44] in:

- Developing science-based, fit-for-purpose European and international standards that promote and enable market deployment by providing the technical requirements to achieve safety and build public confidence;
- Establishing compliance/certification criteria within the EC and UN regulatory framework
- Guiding authorities and other stakeholders in the application of RCS.

To enable coordinated implementation of the above tasks, industry-led regulations, codes and standards strategy coordination group (RCS SCG) has been created, composed of representatives of Hydrogen Europe and Hydrogen Europe Research assisted by JRC and with the support of the Programme Office. The RCS SCG is tasked with the following activities:

A. Identification of strategic themes for RCS development (of the inter alia RCS input from projects) and proposed follow-up,
B. Contribution to the definition of the consecutive FCH 2 JU Annual Work Plans to best address RCS needs
C. Transfer and ensuring actual use of PNR results in RCS developments
D. Establishing an approach to enhance European participation and influence in European and international RCS bodies, including inputs to Annual Union Work Plans for Standardisation

A practical implementation of the RCS SCG tasks A to D relying on the rationale, the inputs that need to be considered, the required actions, the resulting outputs and the follow-up to be performed by the PO will be continued to be developed.

The RCS and PNR identified priorities by the RCS Strategic Coordination Group will serve as reference for new topics to be processed in the Annual Working Plans. Any topic proposal related to RCS and/or PNR activities must be in explicit coherence with the set of priorities

68 http://circulareconomy.europa.eu/platform/
69 https://ec.europa.eu/easme/en/horizon-2020-societal-challenge-climate-action-environment-resource-efficiency-raw-materials

established by the RCS SCG.

5.3 Environment and sustainability

The complete fuel cell and hydrogen energy value chain needs to be evaluated in order to assess the social, economic and environmental impacts of these technologies so that emissions reduction and resource conservation can be targeted at all stages of the life-cycle. The main factors that affect the magnitude of the impacts are the hydrogen production pathways (i.e. renewable, fossil or nuclear), [70] [71] the availability of scarce materials, manufacturing processes for the production of components and systems, the types of operational applications involved, and the recycling and disposal of all the components and materials at the end of their useful life.

As a tool supporting progress related to this, the FCH 2 JU has defined a Life-Cycle Assessment (LCA) methodology to be applied to its projects and products[72]. Accordingly, it is expected that LCAs will be performed at both project and programme levels. The resulting Life Cycle Inventory (LCI) data sets will form a database, published as part of the ILCD (International Reference Life Cycle Data System), and maintained by the industry and research partners of the FCH 2 JU. The FCH 2 JU shall also establish an international exchange thus providing a globally consistent framework.

An inventory of the work performed in the various projects and in studies can provide the FCH 2 JU with an overview of the progress achieved so far in this field and allow for a gap analysis. This will be performed by JRC through a report mapping the LCA effort executed in the projects and studies to date generations, including a gap analysis and recommendations for future AWP's.

The LCA related activities will be properly interfaced with the Technology Monitoring Assessments (TMA) and with TRUST. Together, they will deliver the necessary quality data and scientific information required to assess, in a systematic and reliable way, the potential benefits and drawbacks of fuel cells and hydrogen technologies along the entire life-cycle, from energy source, raw material extraction, and processing to recycling and final disposal. This will facilitate a more effective technology evaluation and contribute to policy formulation.

5.4 Cooperation with JRC

For the Horizon 2020 period, a Framework Contract between FCH 2 JU and JRC was approved by the Governing Board on 23/12/2015. The scope of the Framework Contract does not cover the JRC participation to FCH 2 JU funded projects, but covers the activities that JRC will provide at the level of the FCH 2 JU programme free of charge and against payment from the FCH 2 JU operational budget. In line with the JRC mission, these support activities will primarily contribute to formulation and implementation of the FCH 2 JU strategy and activities in the areas of RCS, safety, technology monitoring and assessment. In addition, the Programme Office may call upon JRC to perform testing as a service to FCH 2 JU.

The JRC support activities to the FCH 2 JU programme covered by the Framework Contract are discussed and agreed on an annual basis (Annual Rolling Plans, part of FCH 2 JU Annual Working-Plans, AWPs) between the JRC and the Program Office, with involvement of a

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70 REGULATION (EU) No 1025/2012 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 October 2012 on European standardisation

71 Terms of Reference for the FCH 2 JU RCS Strategy Coordination Group (Final version 01.02.2016)

72 See project FC-HyGuide, http://www.fc-hvguide.eu/

representative of Hydrogen Europe Industry and of Hydrogen Europe Research.

5.5 Coordination with Member States, Associated Countries and Regions

It is a key objective of the FCH 2 JU to strengthen the alignment with and leverage additional innovation investments within Member States, Associated Countries and Regions. The FCH 2 JU has established coordination and cooperation mechanisms with its States Representative Group (SRG). Targeted cooperation and coordination, at programme and, when possible, at project level through appropriate co-funding schemes or via Joint Calls, can considerably expand the scope and impact of FCH 2 JU activities.

The FCH 2 JU will therefore collaborate with Regions involved in or planning significant fuel cells and hydrogen activities in order to align strategy and coordinate research and demonstration activities (for example, exploring opportunities for joint public outreach actions).

The FCH 2 JU is currently following a procurement for a study on development of business cases for fuel cells and hydrogen applications for European regions and cities[73] which will provide an overview of the relevant developments across Europe to allow for a smoother planning of new strategies and activities.

This in addition, close collaboration with the Smart Specialisation Platform[74], which can provide guidance to the countries and regions in designing and financing their research and innovation strategies to achieve maximum synergies regarding FCH activities, will be established. A path to be explored further might look at synergies with Structural Funds; these funds can be allocated at national or regional level to also cover research and innovation activities, thereby offering interesting opportunities.

5.6 European Hydrogen Safety Panel (EHSP)

The panel was established at the end of 2017 and will assist the FCH 2 JU at both programme and project level in ensuring that hydrogen safety is adequately handled. The EHSP[75] will provide the PO with a unique, practical and direct access to state-of-the-art expert judgment for all issues regarding hydrogen safety.

It is anticipated that this panel will collaborate with IPHE and similar global initiatives (e.g. US DoE safety panel) for more consistent, European and worldwide harmonized approach to hydrogen safety and an improved education, training and public outreach. One of the objectives of the EHSP is to coordinate a package of measures to avoid any accident by integrating safety learnings, expertise and planning into FCH 2 JU funded projects, by ensuring that all projects address and incorporate the state-of-the-art in hydrogen safety appropriately.

Besides answering urgent questions related to hydrogen safety in an independent, coordinated and consolidated way, the EHSP activities could include the offer of basic short introductions to hydrogen safety review of safety plans, laboratory visits to conduct site inspections and safety assessments and monitoring the appropriate safety performance of all relevant publicly co-funded projects.

One of the tasks foreseen for the EHSP is related to the analysis of existing events already

73 http://www.fch.europa.eu/page/about-initiative
74 http://s3platform.irc.ec.europa.eu/home
75 http://www.fch.europa.eu/page/european-hvdrogen-safetv-panel

introduced in the European hydrogen safety reference database (HELLEN[76]) and of new information from relevant mishaps, incidents or accidents. The EHSP will interpret these data together with the involved parties, derive lessons learned and provide further general recommendations to all stakeholders. A quality control mechanism will be developed to ensure the needed data quality.

Regarding public outreach and framed within the context of the intended broad information exchange, the EHSP will offer a newsletter and a regularly updated website, containing the lessons learned and links to other important safety related information. As an additional value proposition, the EHSP may contribute to the development of a comprehensive outreach, education and training programme for the safety component of FCH 2 JU projects to ensure complete and effective information dissemination from all FCH 2 JU demonstration projects.

5.7 Knowledge Management[77]

Technology monitoring will continue with data collection from projects on annual basis, in the internally developed database/data collection platform TRUST[78]. Following its successful development and first use in 2017 (to collect project data generated in 2016), projects will be requested similarly to provide their data every year concerning results generated in the previous year, allowing to benchmark projects' progress against the targets defined in the MAWP (and this addendum) and related AWPs.

Each project active in a certain year (previous year to the exercise) will thus be asked to complete one or several questionnaires concerning the research data generated within the activities foreseen in the description of action/work. An annual iteration of the data collection exercise will enable the development of a time-dependent database of FCH 2 JU project results.

Via the FCH 2 JU website, information on projects is already supplied to the general public. The web site will amongst others (such as EC CORDIS[79] or TRIMIS[80] and SETIS[81]) serve as a repository of the results obtained by projects (e.g. by giving access to public deliverables).

In parallel to this, JRC is supporting the PO with the international state-of-the-art, SoA figures for the various technologies, in order to allow a benchmarking of the FCH 2 JU activities and results of its projects within the global setting.

Through the forthcoming TIM[82] database (development started in 2017 also by JRC for FCH technologies) scientific publications will be mapped according to the authors' organisations; fuel cell and hydrogen universes will be defined (to isolate information on related literature only) from which to further tag and filter FCH 2 JU beneficiaries and publications related to FCH 2 JU projects. This should allow tracking developments in the FCH technologies and related impact of FCH 2 JU funding.

An internal database has also been developed starting in 2017 containing overview of

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76 Hydrogen Events and Lesson LEarNed (dedicated version of HIAD (Hydrogen Incident and Accident Database) for the FCH
JU)
77 http://www.fch.europa.eu/proiects/knowledge-management
78 http://www.fch.europa.eu/sites/default/files/TRUST ExplanationFile Draft 3.pdf
79 https://cordis.europa.eu/
80 https://trimis.ec.europa.eu/
81 https://setis.ec.europa.eu/
82 http://www.timanalytics.eu/

deployments in Europe; it will continue to be maintained and updated by the FCH 2 JU. This database is complementary to other relevant activities of the FCH 2 JU (for example HRS availability study[83]) and is fed with information from projects and from general/specific press concerning plans and deployments of FCH technologies, such as electrolysers, vehicles, hydrogen refuelling stations and stationary units, including detailed information on country, size, technology etc. Information for other parts of the world may also be included for benchmarking.

Finally, the core of the Knowledge Management activities will be the 'Fuel cells and hydrogen market and policy observatory, expected to start during the last quarter of 2018. The scope of this study/service contract will be to collect systematically, comprehensive and publicly available market statistics, including information on the policy framework at national level and at regional level when relevant coupled with data on jobs creation, employment and education needs of FCH industry, national and regional R&D programs supporting FCH technologies in Europe.
The development of the European Media Monitoring (EMM)[84] for FCH technologies is also expected to be launched during the second quarter or 2018 with support of JRC (mainly for communication purposes), and should provide a more comprehensive press screening mechanism and allow a more thorough capture of the relevant, mainly public, information in the future.

5.8 Funding and Financial Engineering

There are several funding and financing schemes for complimentary projects to the ones directly supported by the FCH 2 JU. Reaching out to alternative funding and financing sources leverages the impact of FCH 2 JU projects and enhances the achievement of its objectives. Supporting synergies between funding sources should deliver additional gains in terms of innovation results, closing the innovation gap in Europe and promoting economic growth.

With the aim of accelerating the market introduction and deployment of the technologies stemming from the projects FCH 2 JU supports, funding/financial engineering activities have been integrated recently into the FCH 2 JU, as also observed by the Independent Experts Group during the Interim Evaluation of the FCH 2 JU[85], working closely with the industry, academia and research, the European Commission, Member States, Regions and Cities, other EU bodies and Financial Institutions to create synergies between different funding and financing sources. The FCH 2 JU has been addressing these funding sources on a case-by-case basis[86] but it is now time to initiate a structured approach to it.

Learning from and leveraging upon past experiences, the FCH 2 JU shall now initiate a structured approach to this activity, namely by setting up a sub-webpage dedicated to funding and financial engineering. It will include the lessons learned from already supported projects benefiting from the combination of funds, highlighting specific requirements that potential beneficiaries must address to ensure EU funds' blending is fully compatibility with EU rules (e.g. compliance with the non-cumulative principle and the co-financing principle). The site will also provide web access to the IT funding tool that is being developed under the "Regions & Cities' initiative", allowing for detailed analysis of existing grant funding opportunities on a simple and user-friendly platform. While this tool is being designed to provide support for Regions and

83 E.g. the HRS availability study
84 http://emm.newsbrief.eu/overview.html
85 http://www.fch.europa.eu/news/publication-fch2-iu-interim-report
86 Example combined projects: JIVE/MEHRLIN

Cities to deploy FCH projects, the tool is expected to also benefit the beneficiaries of FCH 2 JU calls for proposals, enabling them to better navigate around the array of EU funds available in different regions and Member States. This site will be key to enhance visibility of activities the FCH 2 JU has been working on with several EIB departments and advisory services as well as other financial investors in view of defining the right structures (e.g. special purpose vehicles - SPV) to aggregate demand and raise the bankability of fuel cell and hydrogen technologies with higher TRLs. The aggregation of demand will enable the development of more market driven and aggressive business models for deploying technology directly related with demonstration projects receiving support from the FCH 2 JU, with preference given to replicable solutions for different technologies and OEMs at the same time and a wide inter-regional coverage perspective.

As mentioned previously (see sections 5.1 & 5.4), the FCH 2 JU is also working with other Joint Undertakings and the JRC to share previous experiences and best practices in terms of partnerships with countries and regions in view of developing better synergies with the European Structural and Investment Funds (ESIF) for optimising their Research and Innovation Strategies for Smart Specialisation (RIS3). A joint JUs workshop for sharing experiences was organised during the first quarter of 2018. The FCH 2 JU will leverage on the outcomes of the workshop to pursue the most viable paths for leveraging H2020 funds with the ESIF at regional level. The FCH 2 JU shall continue, to reinforce the collaboration with policy makers in the European Commission. This might include Executive Agencies in charge of managing other parts of H2020 and centrally managed EU funds, to better exploit synergies among funding programmes and under the guidance of the policy DGs. On the energy sector, the FCH 2 JU will seek further collaboration with EASME under the policy DGs guidance, to foster potential points of intersection, in particular in what concerns capacity building for public authorities in view of them embracing and deploying energy efficient and environmentally sustainable FCH technologies in the future.

The FCH 2 JU will also work with the FCH JU beneficiaries to explore and facilitate pathways for financing (and funding) their plans for industrial plant expansion on a case by case basis.

6. Definitions & Abbreviations

Term	Definition
AC	Associated Country (Countries)
AFC	Alkaline Fuel Cell
APU	Auxiliary Power Unit
AWP	Annual Work Plan
BEV	Battery Electric Vehicle
BoP	Balance of Plant
BR **Long-term and break-through oriented research**	Activities addressing basic scientific fundamentals related to critical barriers and/or open up new pathways for technology, product and manufacturing improvements in the long run
BTH	Biomass-to-hydrogen (reforming processes)
CAPEX	Capital Expenditure
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CHP	Combined Heat & Power
CCHP	Combined Cooling, Heat and Power
CH2P	Combined Hydrogen, Heat and Power
CO_2	Carbon Dioxide
CPT	Clean Power for Transport
CTS	Clean Transportation Systems
Demonstration	Activities for a given technology and/or infrastructure comprising all or some elements of: 1) Validation/field testing of prototype/pilot systems including feedback to RTD, proof of safety aspects, functional and endurance testing under real-life conditions. 2) Market preparation demonstrating relevant numbers of application ready products, aiming at infrastructure development and expansion, customer acceptance and development of RCS, economic assessment, attraction of capital investment and achieving target costs for commercial deployment
Deployment	Activities for a given technology and/or infrastructure from its market introduction to its widespread use
DSO	Distribution System Operator (in relation to electricity & gas grid)
EASME	The Executive Agency for Small and Medium-sized Enterprises. It has been set-up by the European Commission to manage on its behalf several EU programmes
EC	European Commission
EERA	European Energy Research Alliance
EGVI	European Green Vehicle Initiative
EGIA	European Industrial Gases Association

EIB	European Investment Bank
EII	European Industrial Initiative
EIT	European Institute of Innovation and Technology
eLCAr	e-Mobility Life Cycle Assessment Recommendations
ESIF	European Structural and Investment Funds
EU	European Union, also referred to as the Union
FCEB	Fuel Cell Electric Buses
FCEV	Fuel Cell Electric Vehicle. This includes passenger cars, buses as well as commercial vehicless and two-wheelers
FC	Fuel Cells/Fuel Cell
FCH	Fuel Cells & Hydrogen
FCH JU, FCH 2 JU, JU	The FCH Joint Undertaking: name used to refer to the legal entity established as the public & private partnership. It may also be referred to as the JTI. The FCH 2 JU refers to the second phase of FCH JU under the H2020 Research & Innovation Programme starting from 2014
FET	Future and Emerging Technologies
FP	Framework Programmes
GB	Governing Board
GHG	Green House Gas(es)
GW / GWh	GigaWatt / GigaWatt hours
H2	Hydrogen
H2 Mobility	Hydrogen Mobility
HHV	Higher Heating Value
Horizon 2020	EU Research and Innovation programme over 7 years for the period 2014 to 2020
HRS	Hydrogen Refuelling Station
HTFC	High Temperature Fuel Cells
HyER	Hydrogen Regions and Municipalities partnership
IA	Implementing Agreement
ICE	Internal Combustion Engine
IEA	International Energy Agency
IEC	International Electrotechnical Committee
IG	European Industry Grouping for a Hydrogen and Fuel Cells JTI also referred to as "Industry Grouping" or Hydrogen Europe (HE)
ILCD	International Reference Life Cycle Data System, set of technical guidance documents supporting good practice in Life Cycle Assessment
IP	Implementation Plan
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
IRENA	International Renewable Energy Agency
ISO	International Organization for Standardization
JRC	Joint Research Centre of the European Commission

JTI	Joint Technology Initiative - referring to the political research initiative introduced by the EC in the FP7. The Term JTI may also be used to referred to the legally established structure implementing the initiative (cf. above FCH JU)
KET	Key Enabling Technologies
kg	kilogram
KPI	Key Performance Indicator
kW	Kilowatt
LCA	Life-Cycle Assessment
LCI	Life Cycle Inventory
LCOE	Levelised cost of electricity
LNG	liquefied synthetic natural gas
LSNG, SNG	liquefied synthetic natural gas, synthetic natural gas
MAIP	Multi-Annual Implementation Plan
MAWP	Multi-Annual Work Program
MCFC	Molten Carbonate Fuel Cell
µOHP	micro Combined Heat and Power
Members	The term "members" refers to the founding members of the FCH JU (EC & HE) and the Research Grouping (HER), as the case may be.
MEA	Membrane Electrode Assembly
MS/ Member States	The "Member States" shall be understood as the EU-27 Members States. If not stated clearly in the document, the term "Member States" can also refer to countries associated to the Horizon 2020 (named "Associated Countries" in the current document). It may also be referred to as "MS"
MW/MWh	MegaWatt / MegaWatt hours
MTBF	Mean time between Failures
HYDROGEN EUROPE RESEARCH	Research Grouping for Hydrogen and Fuel Cells
NG	Natural Gas
NOx	Nitrous Oxides
O&M	Operation and Maintenance (costs)
OEM	Original Equipment Manufacturer(s)
OPEX	Operational Expenditure
PEM (FC)	Polymer Electrolyte Membrane (Fuel Cell)
PNR	Pre-normative Research, R&D work that addresses technical knowledge gaps in the development of RCS
PO	Programme Office
PSA	Pressure Swing Adsorption
RD&D	Research, development and demonstration
RIS3	Research and Innovation Strategies for Smart Specialisation
R&I	Research & innovation
RCS	Regulations, Codes and Standards

RCS SC	Regulations, Codes and Standards Strategy Coordination
RG	European Research Grouping for a Hydrogen & Fuel Cells JTI, also referred to as " Research Grouping" or "HYDROGEN EUROPE RESEARCH"
RTD Research and technological development	Activities that directly support the development, operation and commercialisation of products within the duration of the program
S/T Quality criteria	Scientific and technological quality criteria (to evaluate a proposal)
SAE	Society of Automotive Engineers
SC	Scientific Committee
SETIS	SET Plan Information System
SET Plan	Strategic Energy Technology Plan, see COM(2007) 723 Final
SF	Stakeholders Forum
SME	Small and Medium size Enterprise
SoA	State-of-the-art
SOC	Solid Oxide Cell
SOFC	Solid Oxide Fuel Cell
SOx	Sulphur Oxides
SRG	States Representative Group, advisory body of the FCH JU gathering representatives from Member States and Associated Countries
Stakeholders	The term "Stakeholders" embodies any public or private actors with interests in FCH activities from the MS or third countries. It shall not be understood as "partners" or "members" of the FCH JU
STRIA	Strategic Transport R&I Agenda
STTP	Strategic Transport Technology Plan
TCO	Total Cost of Ownership
TFEU	Treaty on the Functioning of the European Union
TMA	Technology Monitoring Assessment
TRL	Technology Readiness Levels: TRL 1 - basic principles observed TRL 2 - technology concept formulated TRL 3 - experimental proof of concept TRL 4 - technology validated in lab TRL 5 - technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies) TRL 6 - technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies) TRL 7 - system prototype demonstration in operational environment TRL 8 - system complete and qualified TRL 9 - actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space
TRIMIS	Transport Research and Innovation Monitoring and Information System
TSO	Transmission System Operator (in relation to the electricity grid)

UN	United Nations
UPS	Uninterruptible power supply
US / USA	United States / United States of America
SRG	States Representative Group, advisory body of the FCH JU gathering representatives from Member States and Associated Countries

Annex 1: Transport systems State-of-the-art and future targets (KPIs)

(No targets have been fixed at this time for maritime applications and heavy-duty vehicles)

<u>Table 1.1 State-of-the-art and future targets for **fuel cell light duty vehicles (including cars)**</u>

No.	Parameter	Unit	State of the art		FCH 2 JU target		
			SoA 2012	International SoA 2017*	Target 2020	Target 2024	Target 2030
1	Fuel cell system durability	h	2,500	4,000	5,000	6,000	7,000
2	Hydrogen consumption	kg/100	na	1.2	1.15	1,1	1
3	Availability	%	95	98	98	99	>99
4	Maintenance	EUR/km	na	0.04	0.03	0.02	0.01
5	Fuel cell system cost	EUR/kW	500	100	60	50	40
6	Areal power density	W/cm2	na	1.0	1.5	1.8	2.0
7	PGM loading	g/kW	na	0.4	0.17	0.08	0.05
8	Cell Volumetric power	kW/l	na	5.0	7.3	9.3	10.0

Notes:

1) *Durability of the fuel cell system until 10% power degradation. The typical vehicle lifetime requirement is 6,000-7,000 h of operation.*
2) *Hydrogen consumption for 100 km driven under real life operation using exclusively hydrogen feed.*
3) *Percent of time that the vehicle is able to operate versus the overall time that it is intended to operate, assuming only FC related technical issues.*
4) *Costs for spare parts and labour for the drivetrain maintenance per km travelled over the vehicle's complete lifetime of 6,000 to 7,000 hours.*
5) *Actual cost of the fuel cell system - excluding overheads and profits, assuming 100.000 systems/year as cost calculation basis.*
6) *Power per cell area @ 0,66V: Ratio of the operating power of the fuel cell to the active surface area of the fuel cell.*
7) *Overall loading in Platinum Group Metals at cathode + anode. (to be only used as guidance, not as a development target).*
8) *Power for single cell (cathode plate, MEA, anode plate) per unit volume, ref: Autostack-core Evo 2 dimensions: cell pitch 1,0mm and cell area: 595cm^2*

**for cost aspects, when relevant, the European SoA is indicated and labelled with an asterisk*

Table 1.2 State-of-the-art and future targets for **fuel cell electric buses** (e.g. non-articulated type of bus)

No.	Parameter	Unit	State of the art		FCH 2 JU target		
			SoA 2012	International SoA 2017*	Target 2020	Target 2024	Target 2030
1	Fuel cell system durability	h	10,000	16,000	20,000	24,000	28,000
2	Hydrogen consumption	kg/100 km	9	8.5	8.0	7.5	7.1
3	Availability	%	85	90	90	93	93
4	Yearly operation cost (including labour)	EUR/year	-	-	16,000	14,000	11,000
5	Fuel cell system cost	EUR/kW	3,500	1,500	900 (250 units)	750 (500 units)	600 (900 units)
6	Bus cost	thousand EUR	1,300	650	625 (150 units)	600 (250 units)	500 (300 units)

Notes:

1) *Durability of the fuel cell system subject to EoL criterion, fuel cell stack life 10% degradation in power or H2 leak rate as per SAE2578*
2) *Hydrogen consumption for 100 km driven under operations using exclusively hydrogen feed acc. to SORT 1 and 2 drive cycle*
3) *Percent amount of time that the bus is able to operate versus the overall time that it is intended to operate for a fleet availability same as diesel buses.*
4) *Costs for spare parts and man-hours of labour for the drivetrain maintenance*
5) *Actual cost of the fuel cell system - excluding overheads and profits subject to yearly overall fuel cell bus module volume as stated*
6) *Cost of manufacturing the vehicle. In case of buses for which a replacement of the fuel cell stack is foreseen, the cost of stack replacement is included in the calculation. Subject to yearly volumes per OEM as assumed in Roland Berger FC bus commercialisation study.*

**for cost aspects, when relevant, the European SoA is indicated and labelled with an asterisk*

Table 1.3 State-of-the-art and future targets for **fuel cell electric trains** (300 passengers, 150seated)

No.	Parameter	Unit	State of the art		FCH 2 JU target		
			2012	International SoA 2017*	2020	2024	2030
1	Fuel cell system durability	h	N/A	12,000	20,000	25,000	30,000
2	Hydrogen consumption	kg/100 km	N/A	24 - 34	22 - 32	21 - 30	20 - 28
3	Availability	%	N/A	87	94	97	>99

Notes:
No possibility at this time to estimate train cost, including fuel cell system cost and yearly operation costs targets.

1) *Durability of the fuel cell system subject to EoL criterion output voltage at maximum power*
2) *Hydrogen consumption for 100 km driven under operations using exclusively hydrogen feed*
3) *Percent amount of time that the train is able to operate versus the overall time that it is intended to operate*

**for cost aspects, when relevant, the European SoA is indicated and labelled with an asterisk*

Table 1.4 State-of-the-art and future targets for **fuel cell electric aircrafts**

No.	Parameter	Unit	State of the art		FCH 2 JU target		
			2012	International SoA 2017*	2020	2024	2030
1	Fuel cell system durability	h	2,000	5,000	10,000	15,000	20,000
2	Availability	%	-	-	60	75	90
3	Fuel cell system cost	EUR/kW	3,500	>20,000 >10,000 >15,000	20,000 10,000 15,000	6,000 3.000 5.000	3,000 1,500 3,000
4	Gravimetric Power density	kW/kg	-	2 5	2.5 6	3 7	3.5 8

Notes:
No possibility at this time to estimate aircraft production cost at an assumed up-scaled production level.

1) *Durability of the fuel cell system until 10% power degradation.*
2) *Percent amount of time that the aircraft is able to operate versus the overall time that it is intended to operate.*
3) *Actual cost of the fuel cell system - excluding overheads and profits for mass production volumes.*
    a) *Ram air turbine - emergency system replacement (RAT) (15-50 kW)*
    b) *Propulsion (40 kW)*
    c) *Cabin Loads - APU (5-20 kW)*
4) *FC Stack & Power converter.*

**for cost aspects, when relevant, the European SoA is indicated and labelled with an asterisk*

Table 1.5 State-of-the-art and future targets for **fuel cell forklifts**

No.	Parameter	Unit	State of the art		FCH 2 JU target		
			2012	International SoA 2017*	2020	2024	2030
1	Vehicle lifetime	h	na	-	20,000	20,000	20,000
2	Hydrogen consumption	kg/h	na	-	6.67	6.3	6.0
3	System electrical efficiency	%	45	-	50	53	55
4	Availability	%	90	-	98	98	98
5	Mean time between failures (MTBF)	h	na	-	750	1,000	1,250
6	Cost of spare parts	EUR/h	na	-	7	5	4
7	Labour	personh/kh	na	-	10	7	5
8	Fuel cell system cost (10 kW)	EUR/kW	4,000	-	2,500	1,250	450
9	*Est. FC system cost @ mass prod.*	EUR/kW	*na*	-	-	1,250	*450*

Notes:
1) Total number of hours of vehicle operation until end of life (assuming >98% availability in the fleet in heavy duty 3/7 or 3/5 shift operation).
2) Hydrogen consumption for h of operations using exclusively hydrogen feed for Class 1 forklift load cycle @ 10kW avg. system power output (Begin-of-Life)
3) Percentage (%) of electricity generated by the fuel cell vs. energy contained in the hydrogen delivered to fuel cell (LHV) for Class 1 forklift load cycle @ 10kW avg. system power output (Begin-of-Life)
4) Percent amount of time that the forklift is able to operate versus the overall time that it is intended to operate.
5) Average time between successive failures leading to downtime (MTBF in the fleet in heavy duty 3/7 or 3/5 shift operation).
6) Costs for spare parts for the system maintenance as percentage of system investment over the vehicle's complete lifetime.
7) Man-hours of labour for the system maintenance per 1000 h of operations over the vehicle complete lifetime.
8) Actual cost of the fuel cell system - excluding overheads and profits.
9) Estimated fuel cell system cost at an assumed up-scaled production level of 2024: 20,000 units/production & 2030: FC cost level benefits from automotive, bus and truck volumes.
**for cost aspects, when relevant, the European SoA is indicated and labelled with an asterisk*

Table 1.6 State-of-the-art and future targets for **on-board gaseous hydrogen storage tank**

No.	Parameter	Unit	State of the art		FCH 2 JU target		
			2012	International SoA 2017*	2020	2024	2030
1	CAPEX - Storage tank	EUR/kg H2	3,000	1,000	500	400	300
2	Volumetric capacity (at tank system level)	kg/l	0.02	0.023	0.03	0.033	0.035
3	Gravimetric capacity (at tank system level)	%	4	5	5,3	5,7	6

Notes:
1) Total cost of the storage tank, including one end-plug, INCLUDING the in-tank valve injector assembly assuming 100.000 parts/year.
2) Weight of hydrogen that can be stored over the volume of the tank (including in-tank valve injector assembly, tank walls, bosses, plug and the volume for the hydrogen itself).

**for cost aspects, when relevant, the European SoA is indicated and labelled with an asterisk*

Table 1.7 State-of-the-art and future targets for **Hydrogen Refuelling Stations (HRS)**

No.	Parameter	Unit	State of the art		FCH 2 JU target		
			2012	International SoA 2017*	2020	2024	2030
1	Lifetime	years	na	10	12	15	20
2	Durability	years	na	-	5	10	15
3	Energy consumption	kWh/kg	na	10	5	4	3
4	Availability	%	na	95	96	98	99
5	Mean time between failures (MTBF)	days	na	20	48	72	168
6	Annual maintenance cost	euros/kg	na	-	1.0	0.5	0.3
7	Labour	Person h/kh	na	-	70	28	16
8	CAPEX for the HRS	Thousand EUR/ (kg/day)	7,5	7	4-2,1	3-1,6	2,4-1,3
9	Cost of renewable hydrogen	EUR/kg	13	12*	11	9	6

Notes:

1) Total number of hours of station operation.

2) Time that the HRS without its major components/parts (storage, compressor, pump) being replaced, is able to operate (storage shall be changed when the number of cycle reaches the regulatory limit. Replacement of hydraulic compressor is forecasted between 10 to 15 years).

3) Station energy consumption per kg of hydrogen dispensed when station is loaded at 80% of its daily capacity - For HRS which stores H2 in gaseous form, at ambient temperature, and dispense H2 at 700bar in GH2 from a source of >30 bar hydrogen.

4) Percent amount of hours that the hydrogen refuelling station is able to operate versus the total number of hours that it is intended to be able to operate (consider any amount of time for maintenance or upgrades as time at which the station should have been operational).

5) Parts and labour based on a 200kg/day throughput of the HRS. Includes also local maintenance infrastructure. Does not include the costs of the remote and central operating and maintenance centre.

6) Person -hours of labour for the system maintenance per 1,000 h of operations over the station complete lifetime.

7) Total costs incurred for the construction or acquisition of the hydrogen refuelling station, including on-site storage. Exclude land cost & excluding the hydrogen production unit. Target ranges refer to a 200 kg/day station and a 1000kg/day station.

8) Cost for the hydrogen dispensed (at the pump), considering OPEX and CAPEX according to the operator's business model.

**for cost aspects, when relevant, the European SoA is indicated and labelled with an asterisk*

Annex 2: Energy systems State-of-the-art and future targets (KPIs)

Table 2.1 State-of-the-art and future targets for hydrogen production from renewable electricity for energy storage and grid balancing using **alkaline electrolysers**

No.	Parameter	Unit	State of the art		FCH 2 JU target		
			2012	2017	2020	2024	2030
Generic system*							
1	Electricity consumption @nominal capacity	kWh/kg	57	51	50	49	48
2	Capital cost	€/(kg/d) (€/kW)	8,000 (~3,000)	1,600 (750)	1,250 (600)	1,000 (480)	800 (400)
3	O&M cost	€/(kg/d)/yr	160	32	26	20	16
Stack							
4	Degradation	%/1000hrs	-	0.13	0.12	0.11	0.10
5	Current density	A/cm^2	0.3	0.5	0.7	0.7	0.8
6	Use of critical raw materials as catalysts	mg/W	8.9	7.3	3.4	2.1	0.7

Notes:

**Standard boundary conditions that apply to all system KPIs: input of 6kV AC power and tap water; output of hydrogen meeting ISO 14687-2 at a pressure of 30 bar. Correction factors may be applied if actual boundary conditions are different.*

2) Capital cost are based on 100MW production volume for a single company and on a 10-year system lifetime running in steady state operation, whereby end of life is defined as 10% increase in energy required for production of hydrogen. Stack replacements are not included in capital cost. Cost are for installation on a pre-prepared site (fundament/building and necessary connections are available). Transformers and rectifiers are to be included in the capital cost.

3) Operation and maintenance cost averaged over the first 10 years of the system. Potential stack replacements are included in O&M cost. Electricity cost are not included in O&M cost.

4) Stack degradation defined as percentage efficiency loss when run at nominal capacity. For example, 0.125%/1000h results in 10% increase in energy consumption over a 10 year lifespan with 8000 operating hours per year

5) The critical raw material considered here is Cobalt. Other materials can be used as the anode or cathode catalysts for alkaline electrolysers. 7.3 mg/W derives from a cell potential of 1,7 V and a current density of 0,5 A/cm2, equivalent to 6.2 mg/cm2.

Table 2.2. State-of-the-art and future targets for hydrogen production from renewable electricity for energy storage and grid balancing using **PEM electrolysers**

No.	Parameter	Unit	State of the art		FCH 2 JU target		
			2012	2017	2020	2024	2030
Generic system							
1	Electricity consumption @nominal capacity	kWh/kg	60	58	55	52	50
2	Capital cost	€/(kg/d) (€/kW)	8,000 (~3,000)	2,900 (1,200)	2,000 (900)	1,500 (700)	1,000 (500)
3	O&M cost	€/(kg/d)/yr	160	58	41	30	21
Specific system							
4	Hot idle ramp time	sec	60	10	2	1	1
5	Cold start ramp time	sec	300	120	30	10	10
6	Footprint	m2/MW	-	120	100	80	45
Stack							
7	Degradation	%/1000hrs	0.375	0.250	0.190	0.125	0.12
8	Current density PEM	A/cm2	1.7	2.0	2.2	2.4	2.5
9	Use of critical raw materials as catalysts PGM	mg/W	-	5.0	2.7	1.25	0.4
10	Use of critical raw materials as catalysts Pt	mg/W	-	1.0	0.7	0.4	0.1

Notes:
Availability is fixed at 98% (value from the electrolysis study).
1) to 3) and 7) similar conditions as for alkaline technology (previous table)
2) The time from hot idle to nominal power production, whereby hot idle means readiness of the system for immediate ramp-up. Power consumption at hot idle as percentage of nominal power, measured at 15°C outside temperature.
3) The time from cold start from -20°C to nominal power
9) This is mainly including ruthenium and iridium as the anode catalyst and platinum as the cathode catalyst (2,0 mg/cm2 at the anode and 0,5 mg/cm2 at the cathode). The reduction of critical raw materials content is reported feasible reducing the catalysts at a nano-scale.

Table 2.3. State-of-the-art and future targets for Hydrogen production from renewable electricity for energy storage and grid balancing using **high-temperature SOE**

No.	Parameter	Unit	State of the art		FCH 2 JU target		
			2012	2017	2020	2024	2030
Generic system*							
1	Electricity consumption @rated capacity	kWh/kg	na	41	40	39	37
2	Availability	%	na	na	95%	98%	99%
3	Capital cost	€/(kg/d)	na	12,000	4,500	2,400	1,500
4	O&M cost	€/(kg/d)/yr	na	600	225	120	75
Specific system							
5	Reversible efficiency	%	na	50%	54%	57%	60%
6	Reversible capacity	%	na	20%	25%	30%	40%
Stack							
7	Production loss rate	%/1000hrs	na	2.8	1.9	1.2	0.5

Notes:
**Standard boundary conditions that apply to all system KPIs: input of AC power and tap water; output of hydrogen meeting ISO 14687-2 at atmospheric pressure. Correction factors may be applied if actual boundary conditions are different.*

From 3) and 4) please refer to table 2.1 (similar conditions as for alkaline technology)
5) Reversible efficiency is defined as the electricity generated in reversible mode of the electrolyser, divided by the lower heating value of hydrogen consumed.
6) Reversible capacity is defined as a percentage of the electric capacity in fuel cellmode in relation to the electrolyser mode
7) Degradation at thermo-neutral conditions in percent loss of production-rate (hydrogen power output) at constant efficiency. Note this is a different definition as for low temperature electrolysis, reflecting the difference in technology.

Table 2.4 State-of-the-art and future targets for **Hydrogen production with low carbon footprint from other resources**

No.	Parameter	Unit	State of the art		FCH 2 JU target		
			2012	2017	2020	2024	2030
Hydrogen from raw biogas*							
1	System energy use	kWh/kg	62	56	56	55	53
2	System capital cost	€/(kg/d)	4,200	3,800	3,100	2,500	1,500
High temp. water splitting*							
1	System energy use	kWh/kg	120	110	100	94	88
2	System capital cost	€/(kg/d)	4,000	3,500	2,500	1,700	1,400
3	System lifetime	years	0.5	1	2	10	10
Biological H2 production**							
1	System hydrogen yield	H2/C	0.60	0.62	0.64	0.65	0.65
2	Reactor production rate	kg/m3 reactor	2	10	40	100	200
3	Reactor scale	m3	0.05	0.5	1	10	10

Notes:

**The system energy use values include the energy required for heat generation and for producing hydrogen at 30 bar output pressure to meet ISO 14687-2. Correction factors may be applied if the actual boundary conditions are different.*

*** Concerning Microorganisms e.g. Algae*

Table 2.5 State-of-the-art and future targets for **hydrogen storage and large scale storage**

No.	Parameter	Unit	State of the art		FCH 2 JU target		
			2012	2017	2020	2024	2030
Compressed gas tube trailers							
1	Capacity	kg	400	850	1000	1000	1000
2	Capital cost	€/kg	550	400	350	350	350
Large scale H2 storage*							
1	Chain efficiency	%	-	60	67	70	72
2	Release energy use	kWh/kg	-	13.3	11	10	9.3
3	System capital cost	€/kg	1.2	1.1	1.0	0.8	0.6

Notes:

**Storage of at least 10 tones of hydrogen for at least 48 hours, including all necessary conversion steps from clean H2 input to clean H2 output at 30 bar. Correction factors may be applied if actual boundary conditions are different.*

Tables 2.6 State-of-the-art and future targets **fuel cell systems for CHP and power only for** stationary applications

Table 2.6.1 State-of-the-art and future targets residential **micro CHP** for single family homes and small buildings **(0.3 - 5 kW)**

No.	**Parameter**	**Unit**	**State of the art**		**FCH 2 JU target**		
			2012	**2017**	**2020**	**2024**	**2030**
1	CAPEX	€/kW	16,000	13,000	10,000	5,500	3,500
2	Lifetime	years of appliance operation	10	12	13	14	15
3	Availability	% of the appliance	97	97	97	97	98
4	Durability of key component (stack)	hrs	25,000	40,000	50,000	60,000	80,000
5	Reliability	MTBF (hrs)	10,000	30,000	50,000	75,000	100,000
6	Electrical efficiency	% LHV	30-60	33-60	35-60	37-63	39-65
7	Thermal efficiency	% LHV	25-55	25-55	30-55	30-55	30-55
8	Maintenance costs	€ Ct/kWh	40	20	5	3.5	2.5
9	Tolerated H2 content in NG	% (Volume)	5%	5%	100%	100%	100%
10	Installation volume/unit	l/kW	330	240	230	225	220

Notes:

1) *Cost of manufacturing (labour, materials, utilities) of the m-CHP unit at current production levels (exclude monetary costs, e.g. overheads, profits, rebates, grants, VAT, insurances, taxes, land).*
2) *Lifetime (years) that the m-CHP unit, with its major components/parts being replaced, e.g stack, is able to operate until the End-of-Life.*
3) *Ratio of the time that the FC module was able to operate minus downtime divided by the time that was expected to operate. Downtime is the time that the FC is not able to operate-includes time for (un)scheduled maintenance, repairs, overhaul etc*
4) *Time that a maintained fuel cell stack is able to operate until End-of-Life criterion - as specified by the OEM.*
5) *Mean time between failure of the FC that render the system inoperable without maintenance or average time between successive failures leading to downtime: time that the FC is not able to operate includes (un)scheduled maintenance, repairs, overhaul etc*
6) *Electrical efficiency at rated capacity for the FC module as % of electrical output vs energetic content of fuel - Low Heating Value (LHV).*
7) *Thermal efficiency at rated capacity for the FC module as % of electrical output vs energetic content of fuel - LHV.*
8) *Operation and maintenance costs per kWh of electricity produced - Including running, overhaul, repair, maintenance labour costs and costs of stack replacement; excluding: fuel cost, insurances, taxes, etc.*
9) *Percent amount of hydrogen that can blended into the hydrocarbon feed (usually natural gas) allowing normal functioning of the fuel cell module.*
10) *Volume of fuel cell module as is available for installation in its basic configuration, in l/kWe.*

Table 2.6.2 State-of-the-art and future targets **mid-sized** installations for commercial and larger buildings **(5 - 400 kW)**

No.	Parameter	Unit	State of the art		FCH 2 JU target		
			2012	2017	2020	2024	2030
1	CAPEX	€/kW	6,000 - 10,000	5,000 - 8,500	4.500 - 7.500	3.500 - 6.500	1,500 - 4,000
2	Lifetime	years of plant operation	2 - 20	6 - 20	8 - 20	8 - 20	15-20
3	Availability	% of the plant	97	97	97	97	98
4	Durability of key component (stack)	khrs	25	30x	50	60	80
5	Reliability	MTBF (hrs)	10,000	20,000	30,000	50,00 0	80,000
6	Electrical efficiency	% LHV	40-45	41-55	42-60	42-62	50-65
7	Thermal efficiency	% LHV	24-40	24-41	24-42	24-42	30-50
8	Maintenance costs	€ Ct/kWh	8.6	7.6	2.3	1.8	1.2
9	Tolerated H2 content in NG	% (Volume)	50%	50%	100%	100%	100%
10	Land use/ footprint	m2/kW	0.25	0.15	0.08	0.07	0.06

Notes:
From 1) to 9) please refer to the definitions of table 2.6.1
10) Base surface (width x depth) occupied by the stationary fuel cell module per unit of rated electrical capacity.

Table 2.6.3 State-of-the-art and future targets **large scale** FC installations, converting hydrogen and renewable methane into power in various applications **(0.4 - 30 MW)**

No.	**Parameter**	**Unit**	**SoA**		**FCH 2 JU target**		
			2012	**2017**	**2020**	**2024**	**2030**
1	CAPEX	€/kW	3,000 4,000	3,000 - 3,500	2,000 - 3,000	1.500 - 2.500	1,200 1,750
2	Lifetime	years of plant operation	n/a	15	25	25	25
3	Availability	% of the plant	98	98	98	98	98
4	Durability of key component (stack)	khrs	15	20-60	20-60	20-60	25-60
5	Reliability	MTBF (hrs)	n/a	n/a*	25,000	30,000	75,000
6	Electrical efficiency	% LHV	45	45	45	45	50
7	Thermal efficiency	% LHV	20	20-40	22-40	22-40	22-40
8	Maintenance costs	€ Ct/kWh	n/a	2.8-5	3	3	2
9	Start/Stop characteristics	-	-	4 hrs 0-100%	-	100%/1 min	-

Notes:
**insufficient number of units installed to get statistically supported figure*

From 1) to 8) please refer to the definitions of table 2.6.2
9) Time required to reach the nominal fuel cell rated output when starting the system from shut-down mode (at ambient temperature).