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Fuel Cell and Hydrogen technologies in Europe

Financial and technology outlook on the European sector ambition 2014- 2020

New Energy World IG

fuel cells & hydrogen for sustainability

Fuel Cell and Hydrogen technologies in Europe

Financial and technology outlook on the European sector ambition 2014- 2020


Vestas
H2 Logic
H2 Forklifter

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FOREWORD FROM THE NEW IG BOARD

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Sustainable, secure and competitive energy supply and transport services are at the heart of the EU2020 strategy towards a low carbon and inclusive economy, geared towards a reduction of 80% of CO_2 emissions by 2050. This objective has been endorsed by the European Institutions and Member States. It is widely recognised that a technological shift and the deployment of new clean technologies are critical for a successful transition to such a new sustainable economy. Furthermore, in addition to bringing a healthier environment and securing energy supply, innovation will provide huge opportunities for the European economy.

At the NEW IG board, we believe that it is possible to achieve the objectives set by the European Union and we are committed to contributing to reaching these. We believe that hydrogen and fuel cell technologies are vital components of this low carbon economy and therefore play a significant role in Europe's new energy and transport systems. The increase of the renewable share in the European energy mix, as part of the EU2020 ambition, is progressively going to shift our energy system management from a purely demand-driven system to a more complex demand and supply-driven system, with storage capacities and smart grids as key enablers for energy network management. In parallel, transport will shift from a purely oil-driven sector into a more diversified low carbon sector with a progressive increase in electric drive trains – including fuel cell electric power-trains. As a clean energy carrier, and combined with fuel cell technology, hydrogen is relevant to all energy sectors, transportation, buildings, utilities and industry.

However, this paradigm shift will not be purely driven by the market. A strong and determined commitment of public institutions and the private sector together are necessary to support the European political ambition. This is the common task of the stakeholders involved in the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) – the European Commission, Industry (NEW-IG) and the Research community (N.ERGHY) - together with the European Regions (HyRaMP) and the European Hydrogen Association (EHA).

The period 2014-2020 will be critical to ensure that the necessary investments are realized to support the EU2020 vision. In terms of hydrogen and fuel cell technologies, significant investments are required for (a) transportation for scaling up the car fleet and building up of refuelling infrastructure needs, (b) hydrogen production technologies to integrate renewable intermittent power sources to the electrical grid (wind and solar), (c) stationary

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fuel cell applications, with large demonstration projects in several European cities and (d) identified early markets (material handling vehicles, back-up power systems) to allow for volume developments and decrease of system-costs.

The fuel cell and hydrogen industry – gathered within the NEW-IG – has compiled this report in coordination with the other key stakeholders (EHA, HyRaMP and N.ERGHY). The Report summarizes the sector's financial ambition to reach Europe's objectives in 2020. **The estimated investments are split into traditional R&D and Demonstration efforts, totalling around €6.4 bn and a newer effort to take place in relation to market introduction investments, estimated at around €11.5 bn.** The role and responsibility of Industry will increase with increased proximity to the market. The respective contemplated roles of Member States and the European Union and other supporting financial institutions are explored in detail in this document.

Public private cooperation and European alignment are of critical importance when approaching these huge challenges. The FCH JU's scope, flexibility and ability to grow must be reinforced and further extended on the basis of efficient governance, shared between Industry, the European Commission and the research sector.

We do hope sincerely that this document will receive the attention it needs. In order to effectively achieve Europe's ambitions, a joint effort is required from all stakeholders. Industry is ready for it. Let's build Europe's sustainable, secure and competitive future together and now.

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EXECUTIVE SUMMARY

Sustainable, secure and competitive energy supply and transport services are at the heart of the EU2020 strategy for a low carbon economy. Innovation and deployment of new clean technologies are essential for a successful transition to a new sustainable economy as there is no silver bullet technology available to progressively replace fossil energy sources. In addition to creating a healthier environment and securing energy supply, innovation further provides huge opportunities for the European economy.

1 Fuel cell and hydrogen technology is vital for the future European economy

Fuel cells and hydrogen (FCH) technologies are among the key innovations that Europe will have to rely on in order to reach its ambition of a low carbon economy. Hydrogen is an energy carrier like electricity but with the unequalled advantage of being storable in various forms and transportable in various modes [(1)]. In tandem with a fuel cell, hydrogen provides the opportunity for a safe, carbon-free energy provision pathway, allowing flexible and decentralised power generation in multiple applications, with zero-emission at point of use. As such fuel cell and hydrogen technology is key in the European energy policy (e.g. enabling the storage and uptake of renewable intermittent energies) and in the European sustainable transport policy (e.g. providing clean transport). Because of its relevance for decarbonising critical European economical sectors, hydrogen and fuel cell technology can play an important role in the necessary technological transition and subsequently contribute to Europe's energy security, sustainability and competitiveness objectives.

2 Decisive action is needed now to maintain Europe's global technology leadership for the future

Europe is aware of the need to be a technology leader in order to maintain its global competitive position. The before-mentioned technological shift towards a low carbon economy offers the opportunity to bring Europe (back) to the forefront of technological developments in sectors that are decisive for sustainable economic growth and inclusive employment.

Europe is still considered a technology leader in certain FCH application-areas but other regions are developing quickly as a result of public intervention and support. Impressive technological progress has been made by European companies, especially in the transport sector, also due to good support from projects developed jointly under the European R&D framework programme. However, current funding levels and financial mechanisms will require to be significantly increased if Europe's ambitions are to be met in 2020. Decisive action is needed now to prevent Europe falling behind other regions such as North America, Japan or China.

3 A purely market-driven approach alone will not enable the introduction of clean technologies

The introduction of new clean technologies to replace mature existing applications is a slow and costly process that will not be facilitated by the market on its own. This is especially true since the case for change is driven mainly by political and societal aspirations as opposed to market indicators. During the transition period, the initial investment cost and risks are too great for private initiatives alone. This means that society needs to share the initial risk with the private sector in order to bridge the gap to the market.
Several of the fuel cell and hydrogen technology applications have come close to market. To enable their actual deployment and to tap their benefits, important upfront investments – including dedicated (parallel) infrastructures – are necessary in the coming period.

(1) Compressed at 700 bar, H_2 is well over 100 times more energy dense than a Li ion battery (33 kWh/kg H_2 vs 0.2 kWh/kg battery)

Besides private sector investments, a strong political commitment and financial support of the European Union and its Member States will therefore be required. Clear, long-term strategic orientations to create a supportive, stable investment climate are needed to turn the current first mover disadvantage into a first mover advantage.

4 Public Private Partnership is the appropriate structure to support the technologicaly shift

Close coordination between public and private stakeholders is needed to maximise cost efficiency and accelerate the technologicaly shift. At European level, the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) was founded in 2008 to develop and implement a targeted R&D programme with a total budget of €940 million up to 2013, of which 50% is contributed by the EC and 50% by the private sector.

The members of the FCH JU are the European Commission and the industry and research community organised in respectively NEW-IG and N.ERGHY. The programme focuses on four main application areas (AA):

- AA 1 - Hydrogen vehicles and refuelling stations, for sustainable mobility
- AA 2 - Sustainable hydrogen production, to prepare for the transition to clean energy carriers
- AA 3 - Stationary fuel cells for heat and power generation, for efficient, distributed and diversified energy production
- AA 4 - Fuel cells for early markets, to foster commercial use of both fuel cells and hydrogen

In addition, cross-cutting issues like regulations, codes and standards (RCS) are adressed in the programme, wich are crucial for technology deployment and social acceptance.

Over the last four calls, the FCH JU has funded close to 100 projects, a full list of these projects can be found at www.fch-ju.eu. In its relatively short life, the partnership has managed to bring together a broad range of stakeholders to progress the technology towards market application. These projects include important breakthrough demonstration projects in transport and materials handling sector with significant involvement of the European regions and the private sector.

For the period 2014-2020, this fruitful collaboration within the FCH JU and with regional and local authorities should be continued in order to prolong a predictable and dedicated support-structure for FCH technology. Given the broad range of application-areas and market-introduction needs, the FCH JU's scope, budget, flexibility and ability to grow must be reinforced and further extended on the basis of efficient governance, shared between Industry, the European Commission and the research sector.

5 Joint public/private effort needed for FCH technology breakthrough across sectors reach €17,9 bn for 2014-2020

The fuel cells and hydrogen sector has developed a financial perspective on the joint investment in development and deployment of hydrogen and fuel cell technology up to 2020, in order to gain the necessary progress towards the longer term objectives by 2030 and 2050. This report, "Fuel Cell and Hydrogen technologies in Europe 2014-2020", spans the full innovation cycle, ranging from R&D, demonstration and pilots to market-introduction measures. It should serve as a basis for strategic orientation and allocation of resources and financial mechanisms within, for example, the next multi-annual financial framework and Horizon2020.

The total sectoral investment for the period 2014-2020 is estimated at €17.9 billion across the major application areas, for covering implementation of FCH Technology Roadmap (in appendix 1) plus market-introduction support for early market-applications. This investment should be shared between society and the private sector, whereby the closer an application gets to the market, the bigger industries financial share becomes. About €6.4 billion is dedicated for R&D and demonstration activities while an €11.5 billion investment is needed to support market introduction activities.

Sector Financial Effort				
	R&D	Demonstration Programmes	Market Introduction Support	**Total**
Transport & Refueling	500	2 171	9 429	**12 100**
Production	330	492	984	**1 806**
Stationary	1 465	135	659	**2 259**
Early Markets	830	178	409	**1417**
RCS	150	150	0	**300**
Total	3 275	3 126	11 481	**17 882**

These estimates are developed on the basis of existing forecasts and fresh sectoral input by the FCH JU members. For R&D and demonstration activities, the calculation is based on the multi-annual implementation plan of the FCH JU (MAIP) and the FCH Technology Roadmap (appendix 1). Regarding the market introduction figure, industry estimated the 'market-gap' in reference to today's market price and production cost and estimated the financial effort required for closing this gap over time.

6 Investment focus is twofold: Improving the competitiveness of FCH technology solutions and increasing the share of renewable sources in the hydrogen production mix

Within the transport sector, the investment will be used for demand-size incentives and to develop the capabilities necessary to produce cost-efficient fuel cell electric vehicles and to initiate a Europe-wide refuelling infrastructure. Investment in production and storage of hydrogen from renewable sources is needed to scale up the production and storage capacity from these intermittent energy sources and to demonstrate the feasibility of a carbon neutral energy supply chain. In this respect, production methods in combination with carbon capture and storage (CCS) should also be developed. For stationary applications, investment is needed to achieve commercial viability of small and large scale systems, for both residential and industrial use. Finally, with this investment, European industry will have capacity to provide competitive alternatives to existing fossil-based technologies, in particular for material handling vehicles and back-up and distributed power supply.

7 Combined public and private investment is needed for all stages of the innovation cycle, from R&D to first-of-a-kind commercial references (2)

The respective shares and form of public and private contributions depend strongly on the stage of the innovation cycle the project is in.

Contribution to Financial Effort				
	R&D	Demonstration Programmes	Market Introduction (*)	**Total**
Industry	50%	~50%	70-90%	**€10 - €14 bn**
European Commission	30-50%	30-40%	10-20%	**€2.5 - €4 bn**
National / Regional	National programmes	10-20%	10-20%	**€2 - €4 bn**
New Financing Tools Needed		✓	✓	

(*) this proposed split is indicative, as we have to deal with both cost and risk sharing solutions. Overall, the closer the market, the stronger the share taken by Industry.

- For R&D and demonstration projects, about 30-50% of EC funding would typically be sought in the form of grants and subsidies. Activities in this segment range from applied research to demonstration and light-house projects.

(2) First-of-a-kind commercial references: product sold to customers but not all conditions are met for a profitable activity (Incomplete industrialization, low utilization rates, incomplete RCS framework, etc.)

- Financial support for the market introduction of hydrogen technologies (first-of-a-kind commercial references), should be shared by the private sector and the public sector (both at national and EU level), whereby the public share is in particular needed for risk sharing purposes. The closer the application gets to a commercial stage, the more industry must take up investments. However, in particular for innovative SME's and for initial high risk investments in the transition period, access to affordable funding is a challenge. This can be facilitated by using innovative mechanisms, such as a mixture of adequate regulatory frameworks, direct co-investment and (non-)budgetary support mechanisms.These include incentives, risk sharing facilities, loans, reimbursable advances, guarantees and green procurement, covering the actions needed for actual market transition, including build up of initial infrastructure networks and scaling up of product volumes.

8 Bringing clean technologies to the point of market breakthrough might require a shift from technology to sector support

The main challenge to overcome for market introduction is to break through the first-mover disadvantage and to raise sufficient financial resources. Due to the high risk and amount of initial investments to enter a mature and established market, there is little economic incentive for any individual market-player to move first. It will be essential to maximise the potential of pooling of resources for two main reasons: firstly for fundraising and secondly to commit multiple stakeholders and strengthen a coordinated and joint approach. A shift from technology to sector specific support should be considered strongly, in particular those sectors that are close to the market.

9 New financial instruments are needed to finance first-of-a-kind commercial applications and support market introduction

New sector-based support mechanisms (both financial and non-budgetary) should be explored and those existing should be assessed and updated. Combining different programmes from the European Investment Bank (EIB) or Regional funds should be made easier, as should it be to pool other EU and national support programmes. Furthermore, adequate mechanisms should be developed to attract a wider pool of private investors/investment funds, such as an EU investment Fund, insurance-based solutions, reimbursable advances and state aid as well as other competition/state aid-rule exemptions for a certain period of time. These would in particular support infrastructure investments inherent to clean technology deployment

The total EC contribution between 2014 and 2020 could range from €2.5 - €4 bn, in addition to an estimated €2 - €4 bn funding from national/regional programmes. Public funding would thus leverage private investment amounting to €10 - €14 bn.

10 Fuel Cell and Hydrogen technologies should benefit from various European programmes

Technologies using hydrogen fuel cells are typically linked to energy-applications. However, applications cover a broad range of markets and sectors, including transport, telecoms, logistics, power generation and energy storage, to name a few. Progress in one application area could be beneficial for the development of low carbon solutions in other areas. Explicit connections need to be made between hydrogen fuel cell technology and its role in strategic concepts across the various EU programmes aimed a decarbonisation and energy efficiency. These include smart grids, smart cities, (renewable) energy storage, Carbon Capture and Storage, Clean Urban Transport, SET-plan, STTP, TEN-T, among others, to optimise potential synergies and maximise cost-efficiency.

Combined with the use of targeted market-based support mechanisms it should provide a strong support structure for a healthy and prosperous low carbon European economy by 2050.

1. Fuel cells and hydrogen: key enablers for a competitive, inclusive, low carbon society

"Fuel cell and hydrogen technology respond directly to the societal challenges identified in the EU 2020 Strategy"

The European Union is committed to transforming its transport and energy systems into low-carbon systems by 2050 and to decoupling economic growth from resource and energy use, reducing greenhouse gas emissions, increasing energy security while maintaining a strong competitive global position [3]. No cheap or single transition-pathway exists. Only a shift to a portfolio of clean innovative technologies with their own properties, application-areas and infrastructure requirements can reduce oil-dependency sufficiently.

The Suzuki Burgmann fuel cell scooter, the world's first fuel cell vehicle to earn European whole Vehicle Type Approval

"Only a shift to clean innovative technologies can reduce oil-dependency sufficiently"

With the EU 2020 Strategy [4] the European Commission has put forward a strategy for smart, sustainable and inclusive growth, and identified focal areas for action up to 2020. Subsequent policy actions should be a geared towards meeting the 2050 objective of cutting greenhouse gas emissions by 80%. In the run up to 2020 significant investments are needed to accelerate market-introduction of low carbon mobility and power-generation solutions (including increased and stable influx of renewable energy) across Europe and therefore enhancing social and regional cohesion.

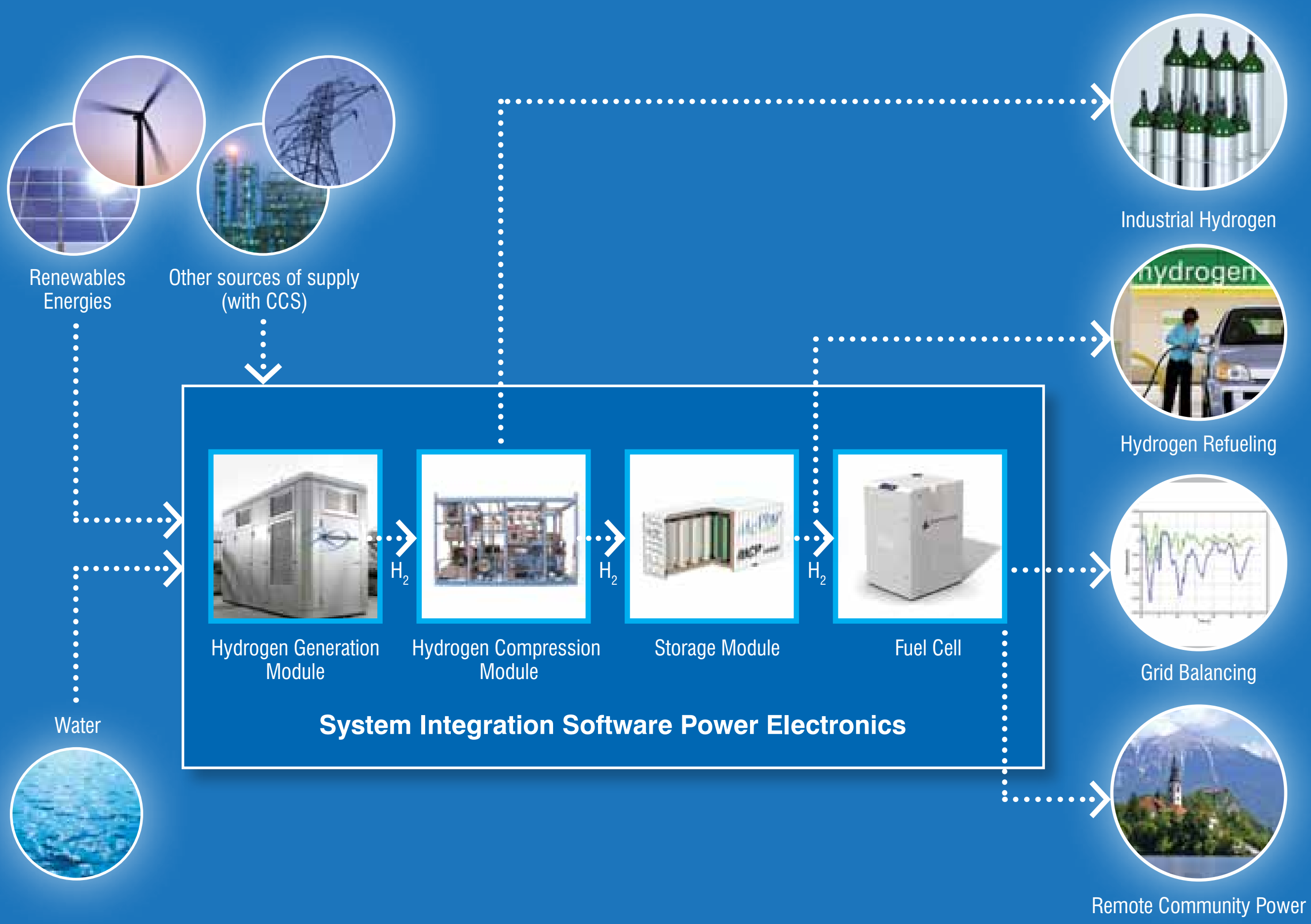
Hydrogen and fuel cell technologies are key enabling technologies for a competitive, inclusive, low carbon society and respond directly to the societal challenges identified in the EU 2020 Strategy, in particular to these addressed by the flagship initiatives "Innovation Union", "Resource Efficient Europe" and "An industrial policy for the globalised era".

(3) European Commission, COM(2011) 112, A Roadmap for moving to a competitive low carbon economy in 2050
(4) European Commission, COM(2010)2020, Europe 2020, A Strategy for smart, sustainable and inclusive growth

As an energy-carrier, **hydrogen** provides a unique opportunity to contribute to all major European policy objectives in the transport and energy sectors:

- Hydrogen is a non toxic gas with a high mass energy density, and is one of the most abundant elements in the biosphere
- It can be easily produced from **water, biomass, biogas, natural gas or from any other fossil fuel**, with mature production technologies, in centralized or distributed production facilities
- Used in conjunction with **fuel cells**, hydrogen provides an efficient decentralized solution for **combined heat and power generation**, both at an **industrial** and a **domestic** level;
- Hydrogen is an efficient way to store electricity, especially the renewable electricity generated by **intermittent sources** (solar, wind, hydroelectricity)
- Hydrogen can be used as an **alternative fuel** for clean mobility using fuel **cell electric vehicles**, including passenger cars, buses, light duty and material handling vehicles
- Hydrogen offers a **significant reduction of green house gases emissions** – hydrogen oxidation only produces water at point of use – and a **reduction in air pollution and noise**.

Fuel cells can generate electricity from various feed-stocks and can be used in connection with an electricity grid but also as a stand-alone power generator. Fuel cells have broader applications than any other power source currently available. The power produced can be used in many portable, stationary and transport applications and the heat, a by-product, can also be used for heating and cooling. As illustrated below, **fuel cells and hydrogen can provide a complete zero-emission (decentralised) power generation-pathway.**



"Without a technological shift, the EU will fail on its 2050 ambitions to decarbonise the energy and transport sectors"

1.1 Contributing to Europe's technological shift and competiveness

Europe is aware of its need to be a technology leader in order to maintain its competitive global position. There is broad recognition that "*...without a **technological shift**, the EU will fail on its 2050 ambitions to decarbonise the electricity and transport sectors. Given the time scale for the development and dissemination of energy technology, the urgency of bringing new high performance low-carbon technologies to the European markets is more acute than ever*"(5). This technological shift is even more crucial as new technologies play an increasingly important role in Europe's competitiveness.

Such transformation offers the opportunity to bring Europe to the forefront of technological development in decisive sectors for sustainable economic growth and inclusive employment which is a clear objective of the Innovation Union and the Industrial Policy Flagship Initiatives (6). So far this economic growth was strongly based on fossil fuel related industries, such as automotives, power-generation and manufacturing. It is imperative that Europe leads the development of new technologies in order to maintain its competitive position. In the transport sector for example, the European automotive industry employs 2.2 million people directly and indirect employment involves another 10 million jobs (7). The White Paper on Transport (8) has rightly pointed out that the race for sustainable mobility is a global race. Delayed action and timid introduction of new technologies could condemn the EU transport industry to irreversible decline.

"Transforming the energy and transport sectors and gaining global industrial leadership will require a tremendous effort and close cooperation between all public and private stakeholders"

Investment in innovative technologies is therefore critical to establish the necessary green jobs tapping the employment potential of a more sustainable economy based on skills and innovation, leading to sustainable growth. Growing the European fuel cells and hydrogen sector provides clear opportunities for such a high quality European workforce thus preventing a brain-drain to other more innovative regions.

Transforming the energy and transport sectors and gaining global industrial leadership will require a tremendous effort by all of the involved stakeholders. This does not only require substantial investment but also close cooperation between the public and the private sectors along the whole innovation chain.

1.2 Contributing to Europe's sustainability and energy security objectives

Sustainable and secure energy supply is at the forefront of the flagship initiative "Resource efficient Europe" (9). The subsequent Energy 2020 Communication (10), called for a step change in the way we plan, construct and operate our energy infrastructures and networks in order to meet the European Union's core energy policy objectives competitiveness, sustainability and security of supply (11). The European Parliament underlined in its response to the EU2020 Strategy: "*sustainable production processes, coupled with resource efficiency and an integrated energy policy, and the further development of renewable energy sources will enable the EU not only to meet its climate and energy targets but also to maintain a strong manufacturing base in Europe and to boost competitiveness, growth and employment*"(12). Industry also stresses the interconnection of these objectives. Hydrogen and fuel cell technology are at the heart of each of these objectives.

Fuel cells and hydrogen are ready to play a major role in decarbonising the European energy landscape in coming decades. Hydrogen provides a clean alternative energy carrier that can be easily produced from all primary energy sources, stored and distributed. It is relevant to all of the energy sectors - transportation, buildings, utilities, and industry. In combination with fuel cells power can be generated in large and small quantities at point of use without emitting greenhouse gases.

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(5) European Commission, COM(2010) 639, Energy 2020: A strategy for competitive, sustainable and secure energy
(6) European Commission, COM(2010) 546, Europe 2020: Flagship Initiative Innovation Union and COM(2010) 614, An Integrated Industrial Policy for the Globalisation Era Putting Competitiveness and Sustainability at Centre Stage
(7) Source: ACEA, European Automobile Manufacturers Association
(9) European Commission, Com (2011) 144, White Paper Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system
(9) European Commission, COM(2011) 21, A resource-efficient Europe – Flagship initiative under the Europe 2020 Strategy
(10) European Commission, COM(2010) 639, Energy 2020: A strategy for competitive, sustainable and secure energy
(11) Presidency conclusions, European Council, March 2007
(12) European Parliament Resolution of 16 June 2010 on EU 2020, P7_TA(2010)0223

Demand for energy is ever increasing whilst production from conventional sources is likely to decline, leading to scarcity, higher energy prices, more complex (and expensive) technologies for oil extraction (offshore drilling, shale gas, bituminous sands) and to a growing European dependence on oil exporting countries. Fuel cells and hydrogen technology can contribute to Europe's energy security and climate objectives for the following reasons:

- Hydrogen is produced in Europe and can be made from a wide variety of energy sources, allowing Europe to reduce its dependency on oil imports
- Hydrogen enables near zero-CO_2 emission power generation at both centralized and distributed levels; In case renewable energy is used for hydrogen production, the power-generation is completely carbon-free
- Hydrogen has the potential of storing virtually unlimited amounts of renewable energy to be converted back into the grid by stationary fuel cells with high efficiency and quick response times, enabling incorporation of large amounts of intermittent solar and wind power into the grid as base load [13]

FCH JU project Example STAYERS (2009)

Economical use of PEM fuel cell power for stationary applications demands a lifetime of the fuel cells of at least 5 years, or more than 40,000 hours of continuous operation. For the stationary use, especially in the chemical industry and in remote areas, robustness, reliability, and longevity are often more important than the cost of the initial investment. For stationary generators, the yearly cost of maintenance and overhaul are expected to be much larger than for intermittent applications such as automotive and back-up power. Project STAYERS is dedicated to the goal of obtaining 40,000 hours of PEM fuel cell lifetime employing the best technological and scientific means. Apart from materials research, it also requires a detailed investigation of degradation mechanisms and their mitigation during continuous operation. Factors relevant for the balance of plant (BOP) will also be addressed.

Project cost € 4.1 million
EC Project funding € 1.9 million
Private sector funding € 2.2 million

www.stayers.eu

(13) International Energy Agency, http://www.iea.org/techno/iaresults.asp?id_ia=23

1.3 The role of fuel cells and hydrogen in the European energy landscape

Fuel cells and hydrogen technology are vital for de-carbonising the European transport and energy system and bringing about the low carbon economy Europe is striving for. Hydrogen has the potential to reduce emissions to half of those projected in a "business as usual" scenario by 2050 [14].

Hydrogen production and energy storage

"An important European challenge is the integration of the share of renewables in the energy supply system.

Hydrogen storage options can help to balance the energy system"

There are various ways of producing hydrogen. Natural gas reforming, coal gasification and water electrolysis are proven technologies for hydrogen production today and are applied at an industrial scale all over the world. The current production methods can also be used for renewable energy sources, such as electrolysis for wind and solar-generated electricity, gasification of biomass or fossil fuel-based production in combination with carbon capture and storage (CCS). Decarbonising hydrogen production is a clear objective of the hydrogen production sector. By 2020, the goal is for 50% of hydrogen for energy applications to come from CO_2 emission-free production methods. Furthermore, hydrogen also appears as a by-product in industrial installations: reuse of this hydrogen either on site or in one of the numerous fuel cell applications is an efficient way of way of saving scarce resources. In the future, also direct production of hydrogen e.g. by photocatalytic splitting of water or by employing bio processes (e.g. bacteria and algae, fermentation) might become feasible routes for low temperature / low energy hydrogen production.

Another European challenge is the integration of the fast growing share of renewables in the energy supply system. To facilitate this change from demand oriented production towards supply oriented production from wind and solar, storage options will be required to balance the system. Hydrogen can be safely stored in gaseous,liquid form or in solid state materials, all in industrial and domestic environments. The storage capacity of hydrogen is virtually unlimited, offering stored energy up to the terawatt hour level which remains available for extended periods of time, as opposed to storage in batteries for example. Therefore, development of hydrogen technologies offers a huge opportunity for the European industry.

Off grid power applications

Off grid power generation is required where there is no electrical grid or when the cost of creating such a connection is prohibitively high. Off grid systems have the potential to include on-site power generation from wind or solar energy. Examples include the mining industry, telecoms in emerging markets, road-side and rail-side signage. Power requirements typically range from 1kw to 20kW, although larger units can be envisaged. Hydrogen fuel cells can play a major role in connecting remote areas and islands to an affordable (decentralised) power supply, linking it to renewable sources and help avoid power-poverty across Europe.

Fuel cells

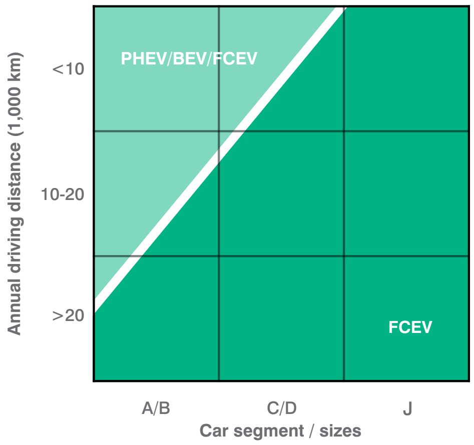
Converting the chemical energy of hydrogen into electricity is efficiently realized with fuel cells, across a wide range of industries, including automotive, large scale industrial Combined Heat and Power systems (CHP), domestic CHP, distributed back-up power and micro-applications in portable devices. Large stationary fuel cell installations will also be needed for reconverting stored renewable energy, either decentralised or connected to a (smart) grid system. Stationary fuel cells can be fuelled by various feedstock, including natural gas and hydrogen and already have a relevance of their own as they provide alternatives to products such as heat-boilers and diesel generators.

(14) IEA Energy Technology Essentials, http://www.iea.org/techno/essentials5.pdf

1.4 The role of fuel cells and hydrogen in transport and logistics

"FCEVs offer the opportunity for zero-emission transport and provide a clean alternative for all travel circumstances, urban, intercity and longer-distance"

FCEV present the lowest cost CO_2 abatement solution for >70% of the cars.

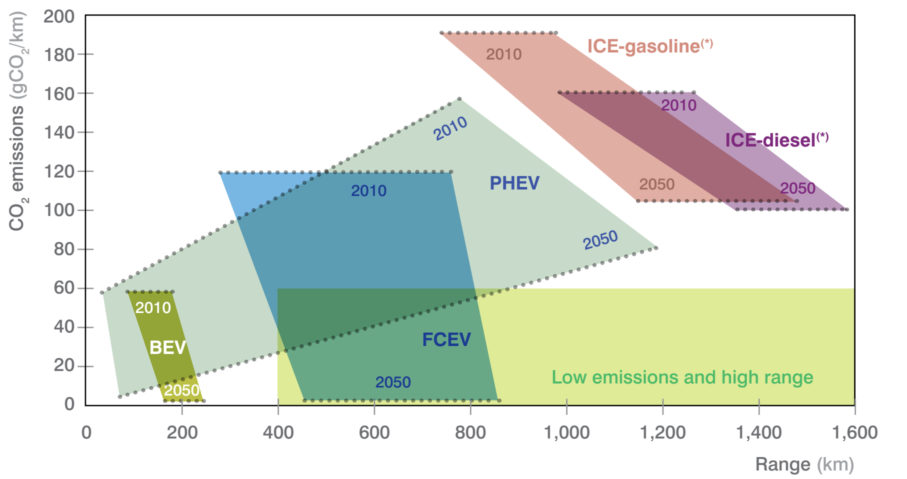


Fuel cell electric vehicles (FCEVs) provide a clean alternative and clear advantages for passenger and light duty mobility. There are no major performance compromises to be made by the user in terms of size, driving range or speed, refuelling time or other driving comforts in comparison to traditional cars. The FCEVs have no tail-pipe emissions, are silent and hydrogen can be produced from all (renewable) feedstocks. FCEVs offer the opportunity for zero-emission transport and provide a clean alternative for all travel circumstances, urban, intercity and longer-distance. FCEVs are also suited for larger passenger cars (e.g. family cars) which represent more than 70% of CO_2 emissions. FCEV has a TCO advantage over BEV/PHEV in heavy/long distance car segments [15].

"In case of public incentives, FCEVs can become cost-competitive as early as 2020"

For FCEVs to be a genuinely affordable option for European citizens, the car-fleet should be scaled up without delay and a dedicated hydrogen refuelling infrastructure should be built accordingly; these developments go hand in hand. If investments are well coordinated over the next 10 years (e.g. geographically and in relation with other applications like public buses, taxis, logistics and delivery vehicles), FCEVs could be fully commercial by and competitive with internal combustion engines (ICE) by 2025. In case of public incentives, FCEVs can become cost-competitive from 2020 [16].

BEVs and FCEVs can achieve significantly low CO_2-emissions



(*) ICE range for 2050 based on fuel economy improvement and assuming tank size stays constant. Assuming 6% CO_2 reduction due to biofuels by 2020; 24% by 2050.

(15) Report: 'A portfolio of powertrains for Europe: a fact-based analysis. The role of Battery Electric vehicles, Plug-in hybrids and Fuel Cell Electric Vehicles' (Nov 2010), p. 42
(16) Idem, p. 31

Europe is playing a major role in manufacturing and show casing fuel cell powered passenger cars, with several major development and demonstration initiatives [17]. In addition to passenger cars, identified as the market that can reduce overall cost as a result of its scale, **buses and the logistics sector** are also promising markets. In this context, it is worth highlighting Europe's leading role in fuel cell bus manufacturing and demonstration: the EU has been successfully conducting the largest fuel cell bus demonstration in the world - the so-called CHIC project [18] - a successful public-private collaboration between industry, Europe, regional and local authorities. Linking and expanding this visible contribution of hydrogen in urban transport could accelerate FCEVs market roll-out by creating greater customer awareness and acceptance.

FCH JU project example

" CHIC, a successful public-private collaboration between industry, Europe, regional and local authorities"

In the sector of **material handling** [19], a hydrogen powered forklift with fuel cells combines the advantages of diesel/LPG and battery powered forklift trucks. Hydrogen provides the same consistent power and fast refuelling operations – as LPG and diesel whilst also providing energy efficient and zero emission electric propulsion. Hydrogen powered forklifts have a clear benefit over competing technologies such as battery electric forklifts and diesel/LPG forklifts. Battery electric technology is commonly used in warehouses due to absence of noise and emissions, which is mandatory for indoor operations. However, the limited autonomy of batteries combined with the hazards of battery change and recharge processes give fuel cells a substantial productivity advantage, as demonstrated in the USA. LPG and diesel MHV are commonly used for outdoor operations. Hydrogen fuel cells provide higher energy efficiency and zero emissions potential for outdoor operations (LPG or diesel forklifts can emit a CO_2 amount on annual basis corresponding to that of 8 cars). As discussed hereafter, forklift market was identified as an early market for hydrogen fuel cell technologies.

(17) See for example the Clean Energy Partnership (CEP) and the H2 Mobility initiative in Germany and the Scandinavian Hydrogen Highway Partnership (SHHP).

(18) CHIC project, http://chic-project.eu/

(19) In this sector, Europe holds a strong global position, with half of the world's total production and an annual turnover of €45 billion, spread over a total of 1,000 companies and 160,000 employees.

2. Europe's technology leadership at stake

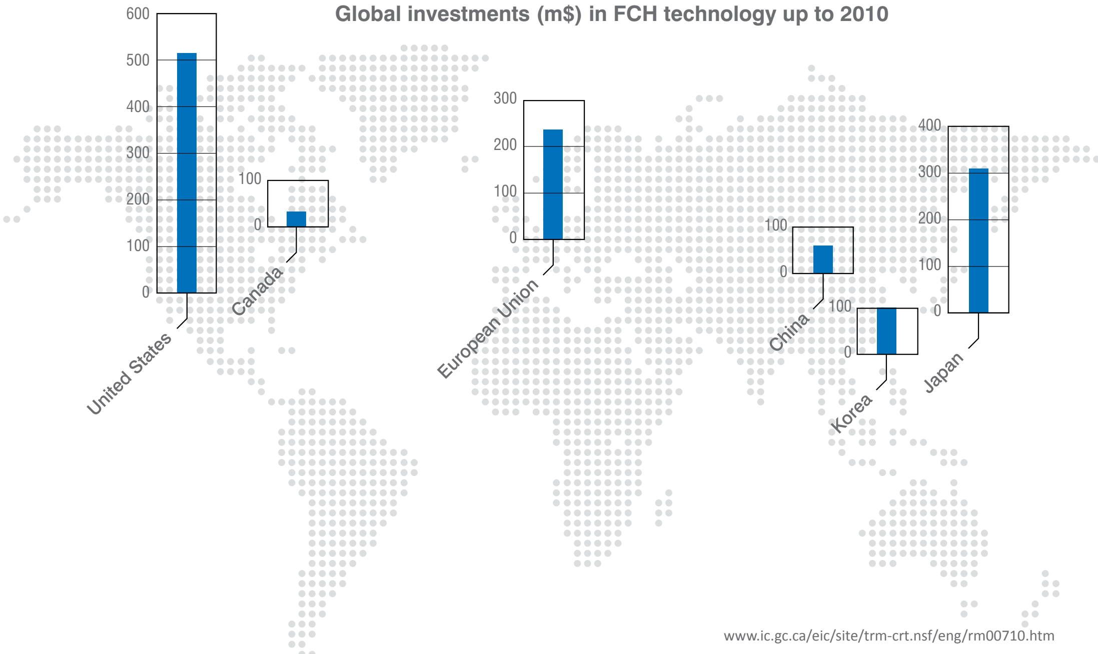
Japan and the USA are today's leading players in hydrogen fuel cell technology development, followed by Europe [20]. **Emerging countries such as China and Korea are catching up rapidly**. Targeted governmental support and intervention has lead to significant advances over the past couple of years. Without adequate action, Europe's global leadership position is at stake.

"Emerging countries such as China and Korea are catching up rapidly"

Japan is the global leader in fuel cell deployment. Residential fuel cells have been commercially available since 2009 and more than 5000 stations have been offered through a subsidization scheme which was estimated at $75 million in 2010. In early 2011, Japan launched the hydrogen town demonstration project including testing of feasibility of a hydrogen infrastructure. The government and energy companies are also funding hydrogen refuelling stations needed the cars' widespread use. Clear political commitment has been made for rolling out a hydrogen infrastructure by 2015. By 2012, demand from power suppliers, automobile companies, residential builders and electronics companies is expected to create fuel cell and hydrogen markets worth $3.9 billion [21].

The United States is currently leading the material handling vehicles sector. As a result of government incentives [22], fuel cell electric forklifts represent an estimated 2% penetration of annual sales of electric forklifts in the US. In 2009, the United States announced $42 million in Recovery Act funding to accelerate fuel cell commercialization and deployment. With approximately $54 million in cost-share funding from industry participants, the new funding supports the deployment of a significant number of fuel cell systems primarily intended for emergency backup power and material handling (plus infrastructure). The US Department of Energy (DoE) has devoted $170 million for Hydrogen Fuel Cell R&D, demonstration and commercialization activities in 2010 and 2011, and foresees to commit more than $100 million for 2012. In addition to the DoE federal programme, many States have financial incentives to support the installation of hydrogen and fuel cell stations [23]. Canada also is a significant player with a strong hydrogen and fuel cell industry focussed on near-to-market application deployments.

Global investments (m$) in FCH technology up to 2010



www.ic.gc.ca/eic/site/trm-crt.nsf/eng/rm00710.htm

(20) http://www.em.gov.bc.ca/RET/RenewableEnergyTechnologies/HFC/Documents/HFC%20Economic%20Impact%20Study%20-%20Final%20Report.pdf
(21) http://www.ic.gc.ca/eic/site/hfc-hpc.nsf/eng/mc00063.html
(22) These incentives have been established in 2008 and amount at $3 000 per kW for Fuel Cells (capped at 30% of the Fuel Cell investment) and at $200,000 for hydrogen refuelling station (capped at 30% of the investment). These incentives are provided in the form of tax credits and this mechanism has been established until 2016
(23) Major fuel cell programs have been established at state level, including New York (NYSERDA), Connecticut (Connecticut Clean Energy Fund), Ohio (Ohio Development Department), and California (California Energy Commission)

China urgently needs energy and natural resources to support its growth. The drivers for China's fuel cell and hydrogen R&D are concerns about energy supply, distribution and security, combined with air polution and the desire for manufacturing leadership. **China considers fuel cells and hydrogen as central to its long-term science and technology development strategy**. To date, China has invested approximately $2.8 billion in fuel cell and infrastructure RD&D. These activities have focused on portable, stationary and mobile applications and on the production of hydrogen from solar, biomass, natural gas and coal resources.

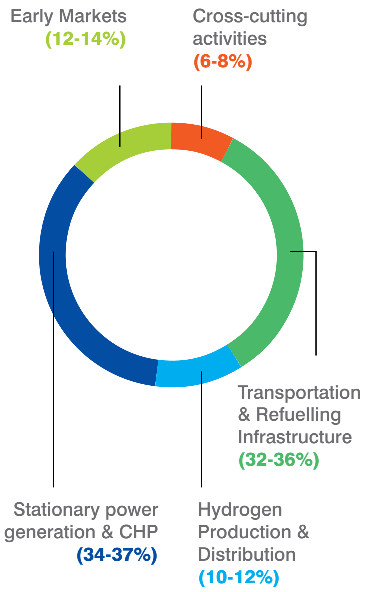
South Korea announced a programme to subsidize 80% of the costs of residential fuel cells for heat and power. The subsidy will fall to 50% between 2013 to 2016 and to 30% between 2017 to 2020. South Korea has also announced an ambitious goal to supply 20% of the worldwide shipments of fuel cells by 2025 and create 560,000 jobs in South Korea. A strategic plan for the city of Seoul includes 47% of renewable energy generation from fuel cells by 2030 - more than the power produced by solar, geothermal and all other clean energy technologies combined.

In general, **India** and **China** - with their large population and growing economies - and **Africa** - with large telecoms market and poor power-system - are identified as growth-markets for the next decades . In particular India and China present huge market potential, including the opportunity for new technologies to leapfrog conventional ones, as there are no established markets yet and state of the art solutions can be deployed from the start.

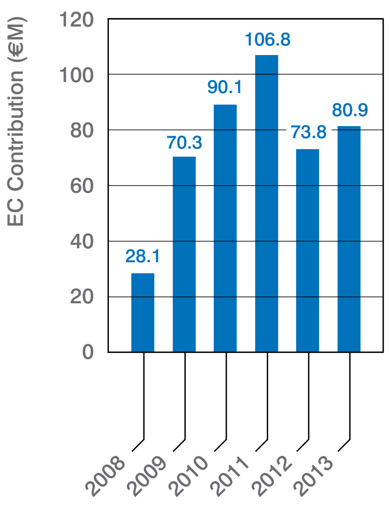
Drivers for public support and technology development vary in the different regions. Whilst the EU and Japan are mainly driven by environment, energy security and industrial competitiveness, the USA is driven particularly by energy security and reliability, air quality, industrial development and wealth generation.

3. Fuel Cells and Hydrogen Joint Undertaking: History and ambition of the European partnership for FCH technology

Funding per area



Preliminary operational budget of the JU (€M)



In 2003 the European Commission established the **European hydrogen and fuel cell technology platform** (HFP), bringing together key-stakeholders to "define the technological and market developments needed by 2020 to create a hydrogen-oriented energy system by 2050."[(24)] The HFP estimated the required investment for achieving these objectives to around €7.4 billion for the period 2007-2015.

Following the HFP, the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) was created in 2008 as the first Industrial Initiative under the EU SET Plan with a dedicated budget. The three members of the FCH JU are the European Commission, fuel cell and hydrogen industries represented by the NEW-IG and the research community represented by N.ERGHY. This public private partnership was set up as a vehicle to support the development of fuel cell and hydrogen technology, to position Europe at the forefront of development and to enable market breakthrough by supporting R&D in a coordinated manner. It also aims to accelerate the market introduction of these technologies, realizing their potential as instrumental in achieving a carbon-lean energy system.

From a financial point of view, a European integrated programme of R&D activities was developed with a **total budget of €940 million** between 2008 and 2013, funded half by FP7 and half by industry and research contributions. During the period 2008-2013, more than 100 projects will be granted by the FCH JU, across the four main application areas (transport & refuelling infrastructure, hydrogen production & distribution, stationary power generation & CHP and early markets) to achieve the technology objectives of the FCH consortium.

Whilst up to €470 million of EU research funds was set aside for executing the multi-annual implementation plan [(25)], a significant gap remained between the necessary €7.4 billion and the allocated figure of approximately €1 billion. The amounts made available to date are still insufficient for facilitating market breakthrough.

As the first Industrial Initiative under the EU SET Plan with a ring fenced budget, the FCH JU has managed to engage key stakeholders at EU, national and regional level to facilitate and co-finance large scale demonstration and technology development projects, supporting industry in making the last steps to commercialisation. A full list of projects supported by the FCH JU can be found at www.fch-ju.eu.

The predictability of the programme (long-term and dedicated funding) is a determinant factor for its success. Shared governance between Industry, the European Commission and the Research community allows for close coordination and prioritisation of the R&D programme.

However, the current economic climate and a relative lack of customized financing schemes at European level is hampering the launch of strategic deployment programs with the required ambition to accelerate cost reductions and customer awareness. In order to progress, this ambition should be backed up by a strengthened funding programme.

(24) www.HFPeurope.org, European Hydrogen & Fuel Cell Technology Platform, "Implementation Plan-Status 2006", Implementation Plan March 2007, p.2
(25) http://ec.europa.eu/research/fch/pdf/fch_ju_multi_annual_implement_plan.pdf

A selection of projects started under the FCH JU programme 2008-2009.

A full list of projects can be found at www.fch-ju.eu

ACTIVITY AREA: TRANSPORT

H2Moves Scandinavia

"H2moves Scandinavia" is the first FCH JU funded European Lighthouse Project for hydrogen fuel cell cars. Support is also given from both Danish and Norwegian (Transnova) national funds. A state-of-the-art hydrogen refuelling station was integrated in a conventional gasoline and diesel refuelling station in Oslo in early 2011, thus fulfilling all requirements specified in the call and offering the typical service profile of today's conventional fuelling stations. The objective is to provide hydrogen in a normal retail setting with a fully integrated purchase interface and in an urban environment with probably the densest hydrogen fuelling station network anywhere in Europe. A safety study will accompany the project to identify the certification gaps in Scandinavia to accelerate full commercialization of vehicles and fuelling stations.

Project cost: € 19.5 million
EC Project funding: € 7.8 million
Private sector and regional funding: € 11.7 million
http://www.h2moves.eu

CHIC

The Clean Hydrogen in European Cities (CHIC) Project is the essential next step to full commercialisation of hydrogen powered fuel cell (H2FC) buses. CHIC will reduce the 'time to market' for the technology and support 'market lift off' – 2 central objectives of the Joint Undertaking.

The project involves integrating 26 FCH buses in daily public transport operations and bus routes in five locations across Europe. The CHIC project is supported by the FCH JU with funding of €26 million, and has 25 partners from across Europe, which include industrial partners for vehicle supply and refuelling infrastructure. The project is based on a staged introduction and build-up of FCH bus fleets, the supporting hydrogen refuelling stations and infrastructure in order to facilitate the smooth integration of the FCH buses in Europe's public transport system. An important part of the project will be to assess the environmental, economic and social impacts of the use of hydrogen powered buses. The objective of CHIC is to move these demonstration vehicles towards full commercialization starting in 2015.

Project cost: € 81.9 million
EC Project funding: € 26 million
Private sector and regional funding: € 56.1 million
http://chic-project.eu/

ACTIVITY AREA: HYDROGEN PRODUCTION

Hydrosol 3D

HYDROSOL-3D aims at the preparation of a demonstration of a CO_2-free hydrogen production and provision process and related technology, using two-step thermochemical water splitting cycles by concentrated solar radiation. This process has been developed in the frame of EU co-financed projects within FP5 and FP6. From the initial idea over the proof of principle and over several steps of improvement - that have awarded to project HYDROSOL the EU "2006 Descartes Prize for Collaborative Scientific Research" - the technology has recently reached the status of a pilot plant demonstration in a 100 kW scale showing that hydrogen production via thermochemical water splitting is possible on a solar tower under realistic conditions. The present project focuses on the next step towards commercialisation carrying out all activities necessary to prepare the erection of a 1 MW solar demonstration plant. The HYDROSOL-3D consortium brings together the experience and knowledge elaborated in all the R&D work carried out up to the current status of HYDROSOL projects, with industrial leaders and innovative SME's capable to bring the technology to maturity and to the market.

Project cost: € 1.8 million
EC Project funding: € 1 million
Private sector and regional funding: € 0.8 million

ADEL

The ADEL project brings together European institutions with unique expertise, and as such, constitutes the most advanced European consortium in the field of Steam Electrolysis coupled to renewable energy sources for efficient hydrogen production. The ADEL project (ADvanced ELectrolyser for Hydrogen Production with Renewable Energy Sources) proposes to develop a new steam electrolyser concept - Intermediate Temperature Steam Electrolysis (ITSE) - aiming at optimizing the electrolyser life time by decreasing its operating temperature while maintaining satisfactory performance level and high energy efficiency at the level of the complete system including the heat and power source and the electrolyser unit. ITSE will first target the current H2 market and, in the mid-term, will be used for carbon free transportation applications. In addition, the technology will be applied in the field of long-term energy storage.

Project cost: € 4.1 million
EC Project funding: € 2.0 million
Private sector and regional funding: € 2.1 million
www.adel-energy.eu

ACTIVITY AREA: STATIONARY APPLICATIONS

NH34PWR

The Cell Phone industry is a recent major EU business success story; three of the 5 cell phone equipment manufacturers are European and many global cell phone companies are based in the EU. The developed markets are saturated, and growth is focussed in developing countries (Africa, Asia, Eastern Europe), where the operators' success has out-paced the electrical grid and power for cell phone towers is provided by inefficient, high maintenance, polluting and expensive diesel generators. This consortium has developed a low-cost, fuel cell based, self-contained power system (the PowerCubeTM), together with the relevant refuelling capability (using ammonia as the fuel) to cost-effectively replace diesel generators in this market, with a 2-year pay-back and an 80% reduction in greenhouse gases. The market is worth €7.5 bn per annum.

Project cost: € 8.2 million
EC Project funding: € 3.06 million
Private sector and regional funding: € 5.14 million

ACTIVITY AREA: EARLY MARKETS

MOBYPOST

Mobypost will develop the concept of electric vehicles powered by fuel cells using hydrogen produced locally by renewable energy (solar panels installed on the roofs of the buildings). Mobypost will implement low pressure storage solutions for hydrogen over two fleets of five vehicles on two different sites for postal mail delivery. Development of the vehicles and the associated refueling stations will be realized considering all the certification processes required and taking into account public acceptance toward solutions that will be implemented. Last but not least, Mobypost aims at transferring the project developed concepts to related business areas, fact that will ensure seizing the potential benefits offered by the hydrogen and fuel cells technology.

Project cost: € 8.2 million
EC Project funding: € 4.26 million
Private sector and regional funding: € 3.94 million

HyLift DEMO

The overall purpose and ambition of HyLIFT-DEMO is to conduct a large scale demonstration of hydrogen powered fuel cell forklifts, which enables market introduction starting no later than 2013. The HyLIFT-DEMO project objectives are: to conduct 2 year demonstration of 30 units of 2.5-3.5 tons forklifts with a fully integrated 3rd generation fuel cell system, to conduct 2 year demonstration of hydrogen refuelling infrastructure at 3 end-user sites throughout Europe where the fuel cell forklifts are to be demonstrated.

Furthermore the project will conduct accelerated laboratory durability tests on fuel cell systems to validate life time and sensitivity to shock, vibration & climate exposure, reaching 4,000 hours in laboratory, to validate value proposition & reaching of commercial and environmental targets and to plan and secure initiation of R&D of 4th generation commercial products. The project also aims at identifying Regulation, Codes & Standard needs in order to enable commercial high volume certification and use of hydrogen powered fuel cell forklifts.

Project cost: € 7.08 million
EC Project funding: € 2.88 million
Private sector and regional funding: € 4.2 million
www.hylift.eu

FITUP

A total of 19 market-ready fuel cell systems from 2 suppliers will be installed as UPS/backup power sources in selected sites across the EU. Real-world customers from the telecommunications and hotel industry will utilize these fuel cell-based systems, with power levels in the 1-10kW range, in their sites. These units will demonstrate a level of technical performance (start-up time, reliability, durability, number of cycles) that qualifies them for market entry, thereby accelerating the commercialisation of this technology in Europe and elsewhere. The demonstration project will involve the benchmarking of units from both fuel cell suppliers according to a test protocol to be developed within the project. It will conduct extensive tests in sites in Italy, Switzerland and Turkey. A lifecycle cost analysis using data from the project will be carried out to determine economic value proposition over incumbent technologies such as batteries or diesel generators.

Project cost: € 5.39 million
EC Project funding: € 2.48 million
Private sector and regional funding: € 2.91 million

4. A financial and technological perspective for FCH technology until 2020

It is fair to conclude that the efforts in the JU FCH, while fruitful, have not yet resulted fully in an acceleration of market breakthrough for early market applications. The necessary support schemes needed to overcome commercial hurdles need to be boosted. A concerted effort with all stakeholders, including the European regions, national governments, industry, research and the European Union, will be paramount for progression to the next stage. The time to act is now. Delayed action will only lead to higher overall costs and the risk of falling behind the (international) curve.

"For market introduction, the necessary support schemes to overcome commercial hurdles needs to be boosted"

Furthermore, if the necessary steps are not taken now to provide a long-term market perspective for the near-to-market applications, the sector may replace some activities to other geographies, wasting the significant investments made over the past decade to come to this pre-commercial stage.

As a context for strategic orientation of hydrogen fuel cell development in the period 2014-2020, the Industry Grouping of the Fuel Cells and Hydrogen Joint Undertaking (NEW-IG) has developed a financial and technological perspective for joint investment in the development and deployment of fuel cells and hydrogen technologies.

The estimates span the whole innovation chain, from applied R&D [26] to demonstration and deployment and should serve as a reference for allocation of resources to development and market-deployment over the next decade. This estimate is based on the technology objectives and project actions for each of the application areas, as detailed in the FCH Technology Roadmap (appendix 1).

Sector Financial Effort				
	R&D	Demonstration Programmes	Market Introduction Support	**Total**
Transport & Refueling	500	2 171	9 429	**12 100**
Production	330	492	984	**1 806**
Stationary	1 465	135	659	**2 259**
Early Markets	830	178	409	**1417**
RCS	150	150	0	**300**
Total	3 275	3 126	11 481	**17 882**

"The total joint financial effort – including both public and private contributions – is estimated at around €17.9 billion for the period 2014-2020"

The total joint financial effort – including both public and private contributions – is estimated at around €17.9 billion for the period 2014-2020. The share of R&D projects reaches €3.3 billion while demonstration projects will need a total of €3.1 billion. Around €11.5 billion should be devoted to market introduction efforts, of which more than €9.4 billion is dedicated to transport (fuel cell vehicles and refuelling infrastructure). This total effort should be shared by society and the private sector. The main technology objectives and the actions required per application area for the period 2014-2020 are summarised in the table on page 25 and will be elaborated in more detail hereafter.

(26) Fundamental research costs are not embedded in the present financial perspective for the FCH sector

SUMMARY OF TECHNOLOGY OBJECTIVES UP TO 2020	
Transport	Contribution of 500,000 Fuel Cell Electric vehicles (FCEVs) and 1,000+ hydrogen refuelling stations towards the transition of the transport sector towards electric drives
Energy production	Contributing to the transformation of the European energy mix by producing 50% of H2 used for these applications from renewables energies or from zero-CO_2 emission sources
Energy storage	Contributing to the integration of intermittent renewable energies (wind, solar) by applying hydrogen storage capacity up to 500 MV as part of a grid scalable storage
Early Markets	Contributing to the demonstration of cost-efficient solutions with clean and sustainable FCH technologies for material handling vehicles, back-up power and portable power applications
Heat & Power generation	Contributing to the transformation of the energy sector by providing heat and power to more than 50,000 households using stationary fuel cell systems

"London Cab" of Intelligent Energy parked in Brussels

4.1. Transport and refuelling infrastructure

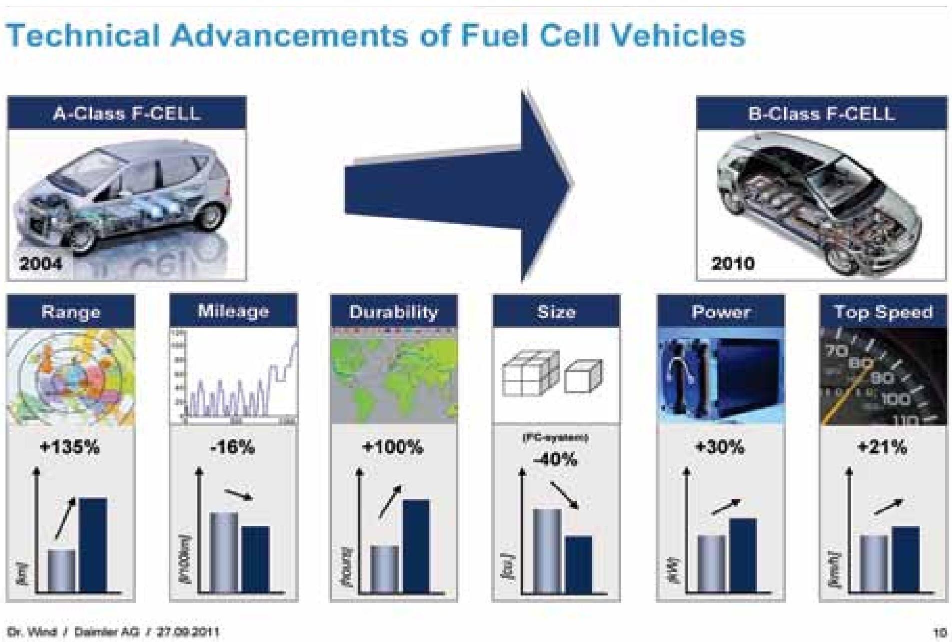
> *2020 Objectives: improve and validate hydrogen vehicle and refuelling technologies to the level required for commercialisation decisions by 2015 and a mass market roll-out as from 2020. Demonstrate competitive Fuel Cell Electric Vehicle (FCEV) and infrastructure solutions, by contributing around 500,000 FCEVs and around 1000+ publically accessible hydrogen refuelling stations to the transition of the transport sector into electric drives.*

For FCEV, a joint effort from public and private partners is needed over the coming years **to prepare for a full market roll out starting in 2020**. Immense technological progress has been made over the past years to overcome all technological hurdles The cars are ready now for market-introduction. Now is the time to start building up the refuelling infrastructure.

"It is clear that building up a hydrogen refuelling infrastructure is not an insurmountable financial hurdle. However, it is a necessary condition for providing EU citizens with a clean transport option"

To achieve the objectives set for 2020, the financial effort (public and private expected contributions) amounts to **€12.1 billion**. The budget needs for R&D are estimated at €500 million while the overall budget for demonstration programmes is estimated at €2.2 bn. The largest portion of financial responsibility for transport by 2020 will be absorbed by preparation of market-introduction of hydrogen passenger cars and busses. More than €9.4 bn is allocated to market-introduction activities, including scaling up the car-fleet, (65% of estimated cost) and building up of refuelling infrastructure (only 19% of estimated cost). **This clearly illustrates that building up a hydrogen refuelling infrastructure as such is not an insurmountable financial hurdle. However, it is a necessary condition for providing EU citizens with a clean vehicle/transport option.** As opposed to individual charging solutions for battery electric vehicles, the more FCEVs which are on the market, the cheaper the infrastructure in terms of TCO [27] will become.

In order to reach the target volume of cars and refuelling sites by 2020, a mass-production programme of FCEVs and improvement of the refuelling infrastructure is needed, leading to approximately 500,000 vehicles across Europe by 2020. The development and demonstration of Fuel Cell buses also needs to be accommodated in order to reach the target of 1000 buses by 2020.



(27) Total cost of ownership

© Air Liquide

The strategic build up of infrastructure can be achieved in several ways. Given the fact that initially the number of private investors will be limited, as a result of first mover disadvantage, a coordinated approach is needed while keeping in mind the overall European picture. This could start with an initial build up of about 100 refuelling sites in one Member State, followed by a second Member State build up of another 100 refuelling sites. The would build on the commitment of early adapting Member States and developing a replicable concept for broad EU roll-out after 2020. Currently, the ideal number of filling stations in the first member state should amount to a thousand.

Such hydrogen refuelling infrastructure could gradually be deployed in a cost effective manner by converting existing refuelling sites to hydrogen dispensing systems, reducing initial investment requirements. In addition large scale demonstration projects with several hydrogen refuelling sites per urban area combining the demonstration of public buses, captive fleets (taxi, LDVs etc) and passenger cars, potentially also fostering industrial material handling (airport, ports), should lay a network of strategic hubs that at a later stage can be interconnected. Furthermore connections need to be made with existing projects like the Scandinavian Hydrogen Highway Partnership and several hubs across Germany and the UK.

4.2. Hydrogen production & distribution (including energy storage)

2020 Objective: develop a portfolio of cost-competitive, energy efficient and sustainable hydrogen production, storage and distribution processes, with 50% of hydrogen used for H2 energy applications produced from renewable sources or from near zero-CO_2-emission sources.

© Linde

"High capacity and flexible electrolysis-systems are essential for hydrogen production for the EU wide increasing share of fluctuating renewable energies such as wind or solar – this technology development will be at the centre of future technology plans"

Hydrogen-production and distribution are already mature technologies. Europe has the largest hydrogen pipeline network in the world and everyday in Europe Industrial gas companies deliver hydrogen to a few thousands industrial sites, representing more than 100 000 bulk and cylinder deliveries per year all over Europe. The mature production technologies include:

- **Reforming technologies** (and gas purification) based on **bio-fuels** as well as **conventional fuels**
- Cost-efficient **low-temperature electrolysers** adapted for the large-scale use of carbon free electricity
- **Biomass-to-hydrogen** (BTH) thermal conversion.

Long-term and breakthrough orientated research aim at improving efficiencies of technologies for water splitting using high temperature electrolysers as well as thermo-chemical processes based on solar, nuclear or waste heat, and at developing low-temperature, low-cost biological hydrogen (e.g. enzymes for fermentation) and photo-electrochemical processes for direct hydrogen production. High capacity and flexible electrolysis-systems are essential for hydrogen production for the EU wide increasing share of fluctuating renewable energies such as wind or solar – this technology development will be at the centre of future technology plans.

Another focal area is the establishment of a safe, efficient and reliable hydrogen distribution and refuelling infrastructure. Progress has been made in providing options for high volume and safe hydrogen storage such as underground storage capacities and liquefaction. This should be a stepping-stone for long-term research on improved hydrogen storage based on solid and liquid materials for increased efficiency and storage capability.

Regarding hydrogen distribution, the sector will strive to achieve a delivery cost to weight ratio that can compete with existing fossil fuel solutions.

The total estimated financial need for reaching the hydrogen production, storage and distribution objectives, as laid out in detail in the Technology Roadmap (appendix 1), is €1806 million. Almost 50% of this amount is needed for R&D (€330 million) and demonstration projects (€492 million). The financial effort to support market introduction is estimated at €984 million, covering deployment of distributed production (€498 million), centralised production and underground storage (€390 million) and carbon capture technologies for hydrogen production (€96 million).

4.3. Stationary power generation & Combined Heat and Power (CHP)

2020 Objective: demonstrate the economic viability of the use of fuel cell technologies for providing electricity and heat for residential and industrial needs and contribute to the transformation of the energy sector by providing heat and power to more than 50,000 households using stationary fuel cell systems.

Stationary fuel cells have been labelled for a long time as a technology of the future. However, this is no longer correct. Fuel cells are already commercially available today in various applications. As demonstrated in Japan, with adequate incentives on residential combined heat and power (CHP) units, it is possible for stationary fuel cell systems to be commercially deployed today.

The overall objective of this application area for the mid-term is to improve the technology while reducing the total installed cost of fuel cell stacks and balance of plant components to the level required by the stationary power generation and CHP markets. This will be accomplished by bridging the gap between laboratory prototypes and pre-commercial systems. At the same time, scaling up the European manufacturing capacities will allow for industrial production of fuel cell products further lowering the total cost [28]. In addition, the stationary sector strives to provide the principal technical and economic specifications necessary for stationary fuel cell systems to compete with existing and future energy conversion technologies.

"For the next multi-annual framework up to 2020, the total investment needed for stationary fuel cells development is estimated at ~€2.3 bn. It is estimated that a budget of €1.5 bn will be needed for the necessary R&D (73%) and €135 million (7%) for demonstration programmes. The remaining 20% of the total effort is estimated for market support"

Two main fuel cell technologies are covered: Proton Exchange Membrane Fuel Cell (PEMFC) and Solid Oxide Fuel Cell (SOFC). The sector is currently carrying out a "scoping-study" to evaluate the potential of each of these technologies and the potential extent of their application. This will be followed by a larger bench-mark exercise to evaluate the market-readiness in economic terms of the main application areas.

Since the beginning of the program, significant improvements have been seen in fuel cell system development, specifically around performance, efficiency, power density, compactness and cost. Manufacturing has matured. Several larger scale stack production units have been started up in the EU. In addition, more attention is paid to the detail and finish of their products to ensure that the systems meet the reliability requirements of their intended applications. Significant progress has also been made in reducing the platinum loading in PEM fuel cells (to less than half), reducing cost and dependency on imported materials.

Examples of stationary application area progress from 2008-2011:

- Cell and stack degradation has been reduced from more than 2%/1000 hours to less than 1%/1000 hours, thus increasing the stack lifetime tremendously. Certain groups even report less than 0.5%/1000 hours degradation.
- SOFC stack power density has increased 2-3 fold, reducing the cost per kW installed.
- Technology validation is initiated, although still at insufficient scale. System electrical efficiencies approaching 50% (AC/LHV) is reached for the hydrogen production and distribution sector.

For the next multi-annual framework up to 2020, the total investment needed for stationary fuel cells development is estimated at €2.3 bn. It is estimated that a budget of €1.5 bn will be needed for the necessary R&D (73%) and €135 million (7%) for demonstration programmes as described in appendix 1.

(28) http://ec.europa.eu/research/fch/pdf/fch_ju_multi_annual_implement_plan.pdf, p14

The remaining 20% (€659 million) of the total effort is estimated for market support. Particular focus will be placed on the demonstration of combined heat and power generation both at domestic and industrial scale, allowing flexible and decentralised power-generation which is decoupled from oil.

4.4 Early Markets

Objective 2020: contributing to the demonstration of cost-efficient solutions with clean and sustainable FCH technologies for material handling vehicles, back-up power and portable power applications.

Early markets are considered strategically important to build up and sustain a manufacturing and supply base for fuel cell products and systems. Subsequently, this application area aims to develop and deploy a range of fuel cell based products capable of entering the market in the short term. Given the key importance of early markets in preparing for the widespread deployment of fuel cell and hydrogen technologies the largest share of the budget for this application area focuses on short-term demonstrations and deployment support for ready-to-market products.

Market-introduction support in the form of adequate incentives – similar to the US programme - will be needed to bring fuel cell forklifts to a commercial stage and to implement the necessary infrastructure. Several larger demonstration projects are foreseen under the current FCH JU Programme (like HyLift Demo), but targeted demand side stimulus would be needed for the transition to the market.

Regarding portable fuel cells the sector has identified market potential with portable fuel cells in education applications, auxiliary power systems (APUs), recreational applications and military applications. Further research is needed to achieve the necessary miniaturisation necessary for fuel cells to be integrated into consumer electronics which will unlock another significant market[29].

"Particular focus will be placed on the demonstration of combined heat and power generation both at domestic and industrial scale, allowing flexible and decentralised power-generation which is decoupled from oil"

(29) The Fuel Cell Today Industry Review 2011

© H2 Logic A/S

Deployment of back-up power systems for the telecom market is another area of attention. Fuel cell based systems allow efficient power generation in areas with limited grid-connections or for urban heating systems final users to get rid of lead-acid batteries and diesel gensets thus eliminating fuel logistics, heavy maintenance, frequent substitution, fuel price uncertainty. The immediate challenge for Europe will be to remain in a leading position for these near-to-market applications.

The total estimated amount needed for market-breakthrough of these early applications is in the region of €1.4 billion. An amount of €830 million is reserved for R&D, €178 million should be made available for pilots and for demonstration projects. For deployment support an amount of €409 million is needed during the period of 2014 to 2020.

In view of securing a commercial breakthrough in the early markets, towards mechanisms and funds for large scale demonstration and market deployment support are needed to help reaching competitive volumes and costs.

Such mechanisms are in place in the USA with, for example, tax incentives for end-user purchase of fuel cell products. These have helped initiate an early market introduction, pushing demonstration and deployment volumes above several thousand units. Similar initiatives will be needed in Europe from 2018 onwards in order to enable market introduction. Continued RTD efforts in parallel with the market introduction are to ensure that the technologies from 2020 onwards reach full commercial targets, therefore, enabling sales without public support.

4.5. Regulation, codes and standards (RCS) and Pre-Normative Research (PNR)

Objective 2020: ensure that the needed standards and appropriate regulatory framework are in place in time for commercialisation. Close the knowledge gaps in relation to performance based standards with PNR and develop a good understanding of the conditions of societal acceptance;

The appropriate standards and regulatory framework need to be in place for the deployment of hydrogen and fuel cell technologies in all the areas above. The right RCS framework does not only allow to remove barriers to commercialisation, but is also a strong enabler, providing a strategic advantage to Europe in the global marketplace. An industry-led RCS stategy coordinationfunction should be implemented to represent the sector at international level.

Further, pre normative research is an essential part of the effort to develop well founded performance based standards providing for safety, interoperability, and reliability without hampering continued technological progress. Research is already yielding valuable results on topics such as improved design requirements for tanks in composite material and hydrogen safety indoors and in confined locations. Further efforts are needed for instance with regards to fire safety of hydrogen storage systems, lifetime assessment of metallic components in hydrogen service, or metering of delivered quantities.

In addition, dissemination and educational activities regarding the new material are needed to support uptake by the relevant actors. In this context, increased efforts are needed to improve societal awarness and acceptance.

Standards development is well advanced with ISO and SAE standards already providing globally harmonized requirements with regards to key items such a:

- hydrogen refuelling interface, .
- hydrogen fuel quality,
- and hydrogen refuelling station safety and lay out requirements.

In the regulatory arena, some important steps have already been made such as the European regulation for EC type approval of hydrogen fuelled vehicles. The next objective for the transport sector is to have an efficient EC framework supporting large scale deployment of hydrogen fuelling stations and the associated hydrogen production and supply systems.

Thanks to agreements in place between ISO and CEN, these standards can readily be adopted as European standards where needed for interaction with EC regulation, while keeping the benefits of global harmonization.

Development of the RCS framework requires continued efforts in line with commercial deployment. European industry led coordination is required to ensure that the needs of European stakeholders are well addressed by international standards, and to support the establishment of an efficient regulatory framework calling out these standards.

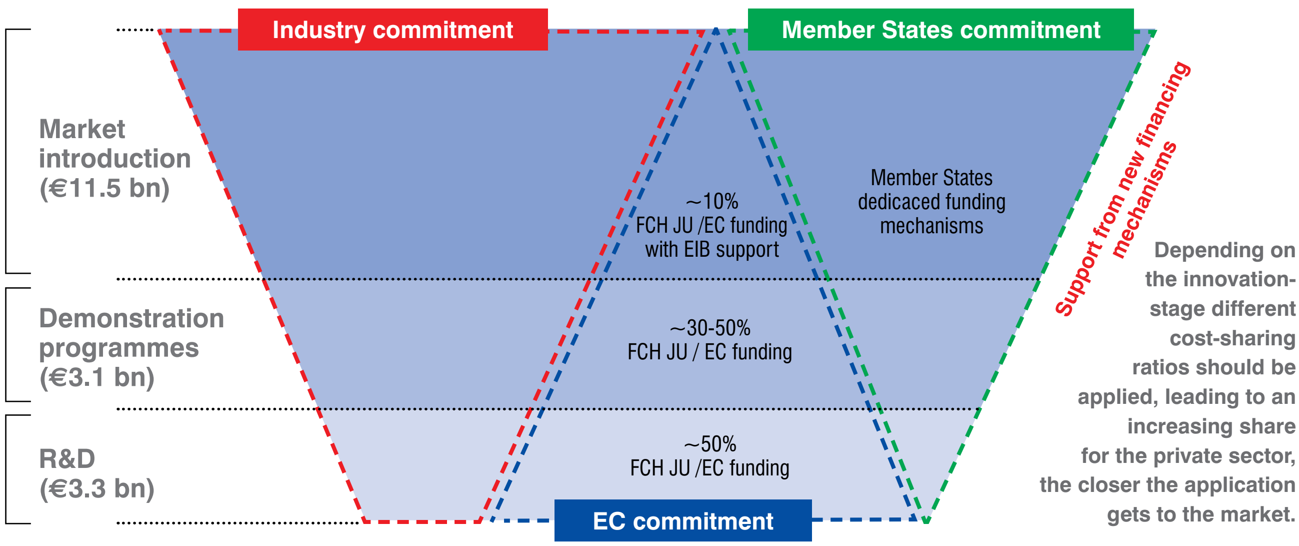
For the period up to 2020, the costs of these activities is estimated at €300 million as follows: €230 million for PNR, €60 million for dissemination and education and monitoring of societal acceptance, €10 million for RCS coordination activities.

5. 2014-2020: how should Europe continue to support FCH technology development?

Europe's political vision for a low carbon society must be supported by a clear financial engagement in favour of clean technologies including Fuel Cells and Hydrogen. Technologies deployed in the next 20 to 40 years will be the result of policy and funding decisions taken today. 'Action now' is required to provide a clear and strong signal that European policy makers are serious about their ambitions. Postponing hard choices to beyond 2020 or even 2030 will undermine credibility and predictability that users, manufacturers, technology providers or investors needs. This urgency is underlined by the fact that fuel cell and hydrogen technology exist already while suitable policy instruments to deploy them are pending.

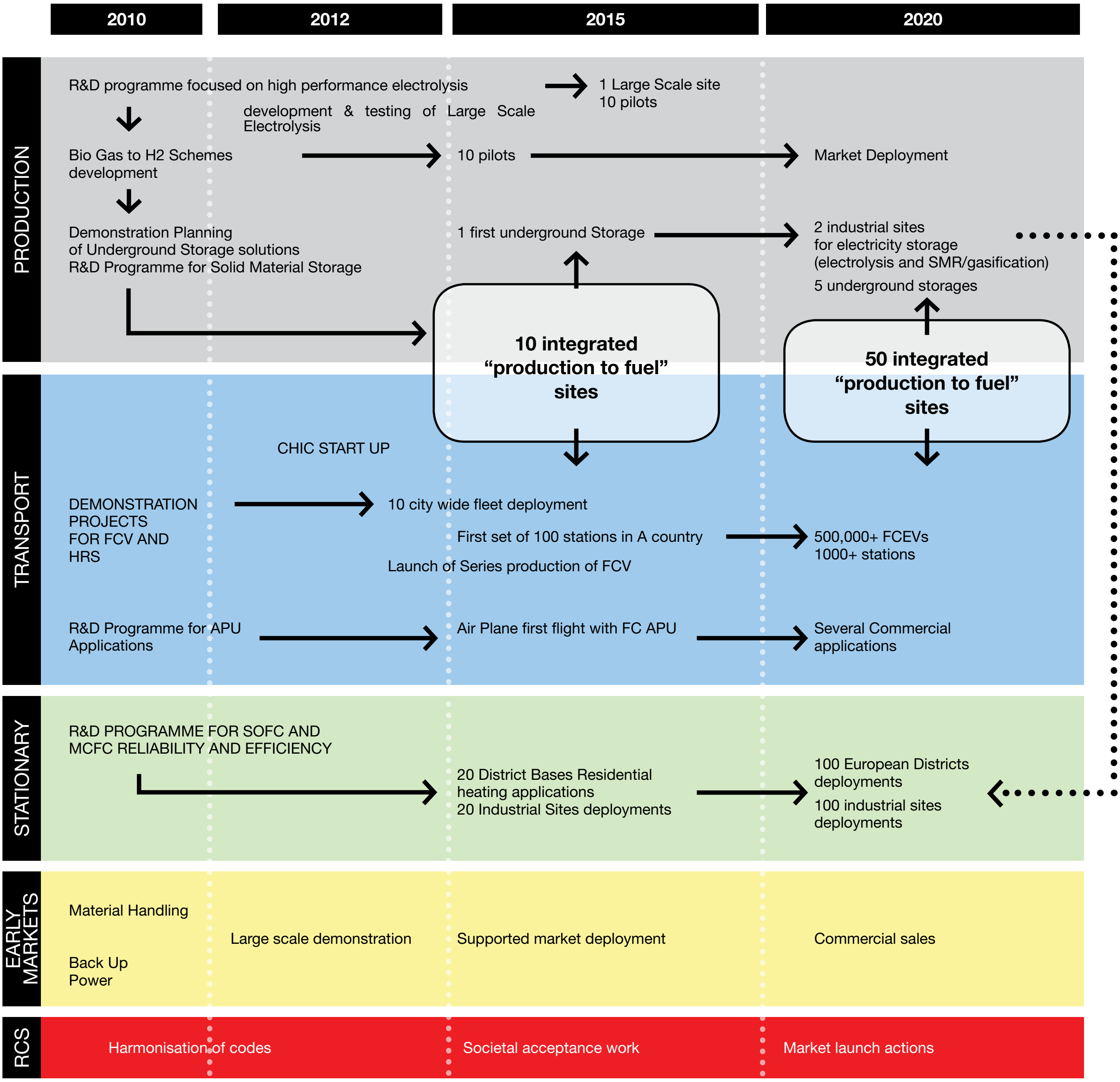
The transition towards a low carbon society will only happen if strategic decisions are taken now and if the Europe Union renews and intensifies its political and financial support for clean technologies.

Clean technologies are not likely to play a role in future energy and transport systems without decisive and favourable policy support and incentives designed to overcome the valley of death. Even though the role of the industry sector needs to grow with market introduction schemes, all steps continue to require a concerted approach and shared costs and risks mechanisms with European national and local authorities, and the introduction of support measures to create consumer acceptance and investor security. For R&D projects, the sector suggests that industry contribution continues to cover about 50% of the financial needs while the remaining 50% [30] is shared between the European Union and the national programmes deployed by the Member States. Demonstration programmes, which play a determinant role in bringing proven technologies to commercially available products, will have a stronger local component, meaning the split should involve increasingly member states and regions (10% to 20%), Europe matching 20- 30% and industry the remaining part [31]. Finally, the level and methods of public support for transitional market introduction support should be discussed and new financial instruments should be created in order to bridge the gap between the cost of clean technologies and the cost of mature incumbent solutions which should be replaced.



(30) Taking into account renewed matching rules for computing in kind contribution mechanisms from Industry and Research, so as to effectively lead to 50/50 funding results.

(31) This proposed split is indicative, as we have to deal with both cost and risk sharing solutions. In certain cases, the issue will be more for offsetting market and technology risks, than to get a higher level of subsidies. Overall, the closer the market, the stronger the share taken by Industry.

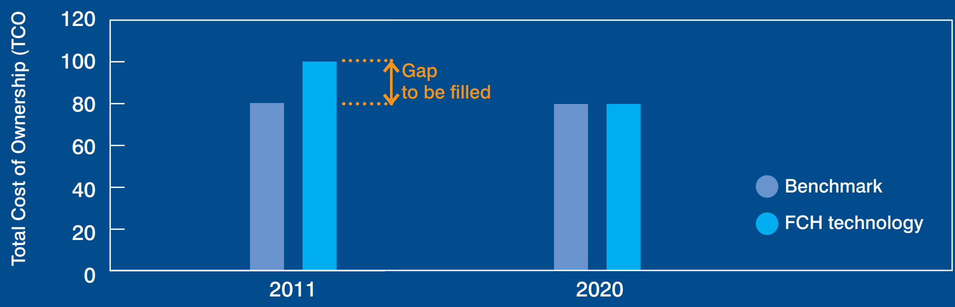


This ambition leads to the estimate that a total EC contribution of ~€2.5 to €4 bn is needed over the 2014 to 2020 time frame, together with a national/regional investment of ~ €2 to €4 bn to leverage an investment of ~ €10 to €14 bn from the private sector.

Based on the key-technology indicators a Technology Roadmap (appendix 1) has been developed in accordance with the other PPPs under the SET-plan. In addition, based on KPIs such as price and performance of existing products, a market-deployment perspective was added. This lead to an indication of the type of supporting tools needed to stimulate market-uptake and bridge the gap between demonstration and deployment.

Methodology

The report, "Fuel Cell and Hydrogen technologies in Europe 2014-2020", quantifies the total estimated financial need per application-area and span **all stages of the innovation-cycle from research to market**. The estimates cover the three main stages of the innovation cycle: 1) **Research & Development**, 2) **Demonstration** and 3) **Market introduction.** To estimate the budget required for R&D, a **'bottom-up' approach** was used, building on the revised FCH JU Multi Annual Implementation Plan (MAIP). This plan indicates the R&D priorities per application area and is constructed on the basis of inputs from the industry and research communities, the scientific committee and the States Representatives Group of the FCH JU. The calculation method is based on a detailed evaluation of the cost of research projects needed to achieve the technology performances targeted in the period 2014-2020.



For estimating the cost of market-introduction of early market applications, in order to bridge the initial gap between large scale demonstration and early commercialisation, a **'market gap approach'** was used. This market-gap approach is based on the calculation of the Total Cost of Ownership (TCO) for both current mature technologies and for FCH technologies. For a given technology, the Total Cost of Ownership includes both the acquisition cost and the operational costs. Each fuel cell technology ('clean technology') is compared with the incumbent competitive technology (designated as 'benchmark technology') that it aims to replace. The table hereafter shows several examples of technology benchmarks used for the market-gap calculation, whereby the gap to be filled corresponds to the difference between the TCO of the benchmark and the TCO of the FCH technology today. For each fuel cell technology, this gap is modeled during the period 2014-2020. The total cost of market introduction is finally calculated using the market projections for the period 2014-2020.

Benchmark technologies used for the estimation of market introduction costs	
Fuel Cell Hydrogen Technology	**'Benchmark' Technology**
FCH Vehicles	Internal Combustion Engine Vehicles
Hydrogen Refuelling Stations	Gasoline Refuelling Stations
FCH Auxiliary Power Units	Diesel Auxiliary Power Units
Fuel Cell Systems for combined heat and power generation	Traditional natural gas boilers
FCH forklifts	Diesel forklifts
FCH Back-up power and Uninterruptible Power Supply	Diesel power generators

6. At the edge of innovation and financing mechanisms

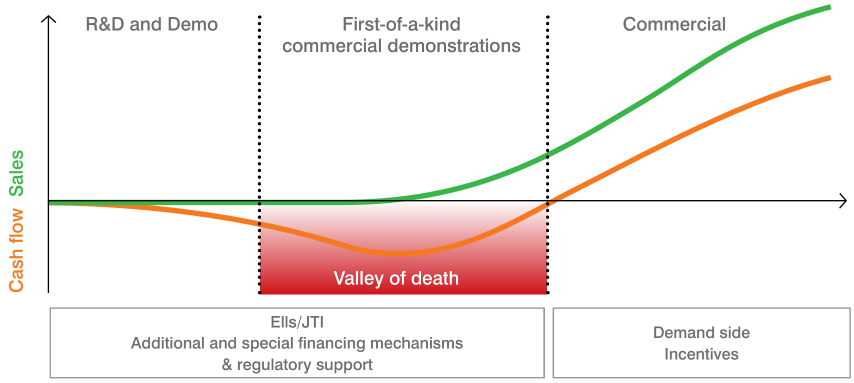
Why a purely market-driven approach will not be sufficient at the start to enable commercial deployment of clean energy technologies?

To realize the necessary technological shift, the key challenge is to achieve the substitution of current mature carbon-emitting technologies with alternative clean technologies. This substitution will not be achieved with a pure market-driven approach because clean technologies are, to date, more expensive that these current carbon-emitting technologies and do not benefit from volume effects. Without public incentives, appropriate regulation measures or public funding, clean technologies will not be chosen by the consumers.

For market-introduction, the main challenge to overcome is to break through the first-mover disadvantage and to raise sufficient financial resources. Due to the high risk and the amount of initial investments to *enter a mature and established market*, there is little economic incentive for any individual market-player to move first.

The evolution of the sales and of the cash-flow along the innovation value chain is shown in the figure hereafter. Bringing a new technology in the market implies to cross the “valley of death”, where ~80% of the cash is consumed. The so-called “valley of death” typically corresponds to the step where the technology is proven, with available commercial products but where the product has not yet reached the market break even.

Figure 1 – Evolution of sales and cash flow along the innovation



For applied research, it is important that sufficient levels of investment in R&D are stimulated. Attractive funding rates, the opportunity to pool funds from different sources (EU, national/regional) and public/private partnership in developing the calls are essential for success. In particular, in the first term of the JU-FCH, the funding rates have been structurally lower than the general FP7 levels as a result of matching-complexities and correction-rates. This situation has lead to unpredictable actual funding rates and made the programme less attractive for industry and should be avoided for the future.

SMEs are the driving force behind innovation and access to finance is vital for participating in funding schemes but it is often a challenge. Guarantee systems, simplified procedures and direct support systems, like the Competitiveness and Innovation Framework programme (CIP), are needed to support SME participation.

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Pooling of resources from different sources will be essential to raise the necessary funds for deployment. As the first fuel cell vehicle demo projects under the FCH JU have demonstrated, many regional governments are interested in considering significant contributions to facilitate local hydrogen infrastructure developments and engage local industrial stakeholders to enter the first markets. Therefore, from a fundraising perspective, but also to commit multiple stakeholders, a coordinated and joint approach should be stimulated at EU level to allow customized financing schemes and backing. A shift from technology to sector support should be considered, in particular in the sectors that are close to the market.

"A purely market-driven approach will not be sufficient to start commercial deployment"

An increased effort is needed to leverage the budgets of the key Industrial Initiatives of the SET Plan including FCH JU: as an energy carrier, the use of hydrogen linked to the challenges of intermittence and grid balancing of other clean energy technologies could enhance market development of both.

Aside from traditional funding schemes, more tailored mechanisms should be developed to support market-introduction of fuel cell and hydrogen technology in mature and incumbent technology driven markets. Market-drivers and incentives need to be put in place to stimulate market-uptake by converging end-user cost of the clean and existing options. Economies of scale will drive the cost down and alternatives will become more cost competitive. This initial phase of transition requires support from society, particularly through risk-sharing mechanisms. Funding mechanisms should encourage and reward early adapters and investors instead of penalising them with high interest rates and thresholds. In addition consideration should be given to the local impact on employment and economic impacts on avoided costs in conventional energy and transport infrastructure maintenance and reinforcement.

In this context, we would like to highlight the incentive of a 'reimbursable grant', which is already used in different Member States.

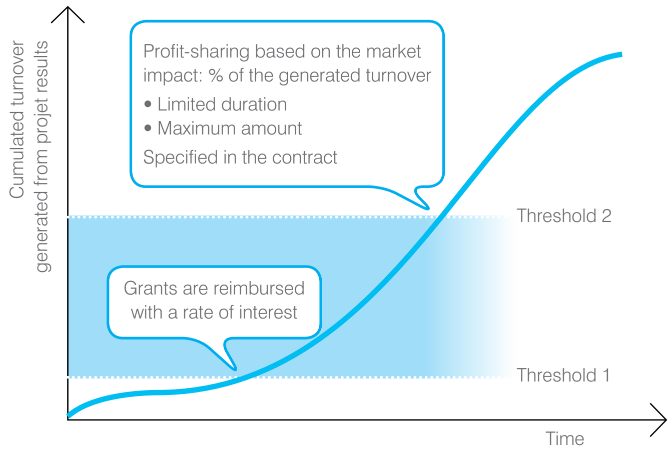
"The initial phase of transition requires support from society, particularly through risk-sharing mechanisms"

A reimbursable grant is a grant attributed to support first-of-a-kind commercial references and accelerate the market roll-out of substitution technologies. This grant is calculated by comparing the Total Cost of Ownership [32] (TCO) of the clean technology and the TCO of the current mature technology to be replaced ('the benchmark'). The grant is used to bridge the gap between the clean technology TCO and the benchmark TCO during a few years to allow both TCOs to converge.

When both TCOs are equal, the replacement of the 'benchmark' by the clean technology can be purely driven by the market.

In the case where the market introduction is a success, these grants are integrally reimbursed (with interest) by the company. This is done in accordance with a precise business case that is commonly established by the company and the public institution at the start of the project. This business case is set for the complete duration of market introduction phase and cannot be changed. A bonus might be paid by the company, corresponding to a percentage of the profit generated by the new product(s).

Reimbursable grants: a new financial instrument to support EU political ambition



Grants are reimbursed when the cumulative turnover generated by the project reaches a first threshold.

In a second time, if the cumulative turnover crosses a second threshold, the profit can be shared between the funding agency and the grantee.

(32) For a given technology, the Total Cost of Ownership (TCO) includes both the acquisition cost and the operational costs

7. European Policy Support

"Alongside direct and indirect financial mechanisms, innovation needs to be pushed by a favourable regulatory framework"

Alongside direct and indirect financial mechanisms, innovation needs to be pushed by a favourable regulatory framework. Experience in the renewable sector was demonstrated that long-term political and regulatory perspectives create the right stimulus for market-uptake, without spending public money [33]. Clear political direction and commitment, for example in the form of binding targets and broad integration in EU energy and climate policies, proved to be instrumental in retaining investors' trust. It opened the door to policy-related funding mechanisms (e.g. RSSF, Marguerite Fund, CIP) and stimulated market development. Similar approaches could be applied to the transitional phase from lab to market of certain fuel cell and hydrogen technology applications.

In parallel, a technology deployment strategy including research and development for advanced low-carbon technologies will be required, channelled through the FCH JU. While such a strategy should be based on the principle of technology neutrality to avoid governments picking supposed technology winners, some low-carbon transport technologies might be disadvantaged because of lack of scale, lack of energy infrastructure (e.g. lack of standardisation) or because existing technologies benefit from a depreciated infrastructure or lack of internalisation of external costs (e.g. environment, climate change, security of energy supply etc.). This will require tailor-made support in line with technological needs. Such a strategy would need to cover all (promising) technologies, specifically efficiency improvements, EVs, hydrogen and bio fuels, thereby addressing on a case-by-case basis the specific barriers related to each individual technology. Application oriented programmes, like Smart Cities, should accommodate the various technological solutions to build up experience and a basis for evaluation of 'best practices'.

The fuel cell and hydrogen sector welcomes the holistic approach towards the upcoming innovation funding framework Horizon2020. It is necessary to include the transitional cost towards full market deployment in the innovation chain, in order to make proven technologies commercially available.

"It is necessary to include the transitional cost towards full market deployment in the innovation chain, in order to make proven technologies commercially available"

The European Commission recently presented its EU 2020 Budget with proposals geared at implementing the EU2020 strategy successfully. The FCH sector welcomes the proposed increase for innovation to €80 billion for the 2014-2020 period for the Common Strategic Framework for Research and Innovation, the so called Horizon 2020. The Societal Change pillar, which encompasses the whole value chain of a given technology, from R&D to market introduction, clearly fits with the current status and needs of the FCH Sector and its natural financing vehicle, the FCH JU. This funding should be complemented by support from the Structural Funds, at least similar to the €60 billion spent on R&D from these funds in the period 2008-2013 [34].

Besides the EU infrastructure policy (energy and transport), the Regional and Cohesion Funds will need to make a significant contribution to the transition towards a low-carbon system. This will require a cost-benefit analysis including carbon impacts for future infrastructure investment and EU-level incentives for low-carbon infrastructures. With most of the money for infrastructure coming from public private partnerships, financial engineering rules will need to take into account low-carbon infrastructures.

(33) In this context it is worth mentioning that the Renewable Directive includes the use of electricity and hydrogen in vehicles towards the EU 10% renewable energy in transport target. Comprehensive monitoring in collaboration with local authorities supporting the uptake of electromobility is necessary to identify the impact of these measures as the mining of data on the use of these energy carrier in transport is not consistent throughout Europe.

(34) European Commission, COM (2011), 500 final, A Budget for Europe 2020, p. 11

8. Beyond market: reaching Europe's ambition

The call for shifting to a low carbon economy by 2050 is driven by a clear societal and political choice to significantly reduce transport's carbon footprint and meet a wide range of EU policy objectives. Today's established markets for energy and transport will not cater for the necessary change by themselves.

The role of fuel cells and hydrogen in a decarbonised energy and transport system can be significant, provided ongoing financial efforts are made by all public and private stakeholders, to further the technology and bring applications to the market.

Enhancing global leadership will have positive effects on Europe's competitiveness and economic growth. Furthermore, integration of fuel cells and hydrogen technology in Europe's energy system enhances energy security.

The FCH sector has made a concerted effort to calculate the total cost until 2020 for progressing FCH technology development and deployment of early markets and FCEVs to facilitate the development of appropriate mechanisms and a long term (regulatory) framework to accommodate the necessary investments needed to transfer the European economy into a low carbon economy by 2050.

The FCH sector is looking forward to collaborating with the European Commission, national governments and local authorities to accommodate the financial need as described in this financial perspective within the various strategic programmes like "Horizon2020" and "TEN-T", "Smart Cities" (among others) and to developing the appropriate support tools and regulatory framework including, where needed, targets and privileges for clean technologies to enter the mature energy and transport markets.

Up to 2020, all stakeholders should act together to reach European ambitions, by introducing clean technologies, including hydrogen and fuel cells to the market. Let's start together now!

APPENDIX

TECHNOLOGY ROAD MAP 2010 – 2020

EUROPEAN INITIATIVE FOR HYDROGEN AND FUEL CELL APPLICATIONS

1. INTRODUCTION

This document addresses the decision of the Governing Board of the Fuel Cell and Hydrogen Joint Undertaking (FCH JU) to strive towards a common programmatic and implementation frame for the Fuel Cell and Hydrogen Joint Technology Initiative (FCH-JTI) with that of the SET-Plan European Industrial Initiatives (EIIs). For each of the EIIs, a costed technology roadmap for the period 2010-2020 has been proposed by industry and consolidated with the Commission [1], which forms the basis for strategic planning and decision-making. These roadmaps put forward concrete action plans aimed at raising the maturity of the technologies considered to a level that will enable them to achieve large market shares during the period up to 2050.

The present document presents the Technology Roadmap to 2020 proposed by New-IG, the FCH JU Industry Grouping, for the hydrogen and fuel cell technologies, using the approach followed by for the other EIIs.

2. STRATEGIC OBJECTIVES

To put at the disposal of the on-going transformation of the European Energy and Transport Systems clean, efficient and market-ready solutions that exploit the properties of hydrogen as an energy carrier and fuel cells as energy converters to enable their contribution to the EU competitiveness and integrated energy and climate change goals.

Industrial sector objectives

Contrary to the technologies covered in the majority of the SET-Plan EIIs which primarily address power generation, fuel cell and hydrogen technologies are used in a number of sectors, each with specific market penetration objectives by 2020.

- To contribute to the integration of intermittent renewable energies (wind, solar) by providing 500 MWe cumulative hydrogen conversion capacity, for centralized or distributed energy storage, as well as for use in motive and stationary applications, including chemical feedstock or injection into the natural gas grid;
- To have an installed hydrogen production capacity from renewable sources (electricity grid/biogas/biomass) of 100 t/d for hydrogen energy applications;
- To have 50% of hydrogen used for H2 energy applications produced from renewable sources or from near zero-CO_2-emission sources (nuclear power and steam methane reforming with carbon capture and storage);
- To contribute with around 500,000 Fuel Cell Electric Vehicles (FCEVs) and around 1000+ publically accessible hydrogen refuelling stations to the transition of the transport sector into electric drives;
- To contribute to the transformation of the European energy sector by providing heat and power to more than 50 000 households and more than 500 MWe to industrial and commercial installations, using stationary fuel cell systems;
- To contribute to the demonstration of cost-efficient fuel cell based solutions for material handling vehicles (20,000 vehicles), back-up power/UPS (20,000 systems) and portable power systems (250,000 systems), as competitive early market applications, with recognisable market shares in each of these market segments.

(1) Commission Staff Working Document (SEC(2009)1295) accompanying the SET-Plan Investment Communication (COM(2009)519).

3. TECHNOLOGY OBJECTIVES

Being able to provide market-ready and efficient solutions in a number of applications requires driving down the total cost of ownership of hydrogen and fuel cell technologies to that of existing market benchmarks to allow for their market introduction. This objective will be achieved by strengthening fuel cell technology performances (in terms of energy efficiency, durability, reliability, emission reduction, safety…) by developing and by scaling-up the production volumes and developing a competitive clean route for H2 production and retail. In this section, all comparative targets refer to the status of hydrogen and fuel cell technologies in 2010.

3.1. Hydrogen Production & Storage: reach H2 delivery cost/kg at point of use at a competitive cost compared to fossil fuel solutions in 2020, excluding taxes.

a) Enable the development of 100 MW scale centralized production capacity schemes based on electrolysis;

b) Increase the efficiency (by 30%), double the capacity and reduce by a factor of 2 the capital cost for distributed production schemes using electrolysis and biogas-based reforming technologies;

c) Demonstrate the capability to use H2 as an energy carrier, available on demand at any moment to produce power, using large underground storage sites;

d) Increase the capacity of distributed gaseous storage by a factor of 10 and develop alternative storage solutions based on solid materials at competitive capital and operational costs;

e) Increase the unit capacity of gaseous distribution trucks by a factor of 3, while reducing the distribution cost per ton by a factor of 3;

f) Demonstrate the feasibility of feeding up to 5% hydrogen into the existing natural gas network.

3.2. Transport applications: demonstrate competitive Fuel Cell Electric Vehicle (FCEV) and infrastructure solutions.

a) Reduce by a factor of 10 the production cost of fuel cell systems to be used in transport applications, while increasing lifetime towards 5000 operation hours and maintaining or even increasing performances;

b) Reduce by a factor of 10 vehicle integration costs through the development of specific volume based technologies production.

c) Set up production capacities for FCEVs in order to meet the goal of 500,000 passenger cars in 2020 in Europe;

d) Develop a safe, competitive and efficient H2 refuelling infrastructure in terms of refuelling time, capacity, availability and cost.

3.3. Stationary Applications: demonstrate the economic viability of the use of fuel cell technologies for providing electricity and heat for residential and industrial needs for the following market segments.

a) Enable the commercial viability of <5kWe – micro-CHP (Combined Heat and Power) for residential markets and demonstrate a reliability comparable to current state-of-the-art solutions (gas-fired boiler/heater and electricity from the grid), targeting a system cost of 5,000 € per system (1kWe + household heat).

b) Enable the commercial viability of large scale units between 5 kWe and 1 MWe for Industrial Combined Heat and Power solutions / Distributed Generation (DG) using both H2 and natural gas/biogas as feedstocks:
→ for CHP systems in the range of 5 kWeto 40 kWe, reach benchmark cost and reliability of competitive incumbent solutions, targeting a cost of 1,500 €/kW for H2-fueled systems and 2,000 €/kW for natural gas-fueled systems;

→ In the range between 40 kWe and 1 MWe (distributed dwellings and commercial, district heating, larger commercial buildings and offices, generic DG), reach benchmark cost and reliability of competitive incumbent solutions targeting a cost of 1,500 €/kW for H2-fueled systems and 2,000 €/kW for natural gas-fueled systems [(2)]

3.4. Early Market Applications:
make fuel cells a visible and a competitive technology option in early market applications

a) Reach benchmark cost of competitive incumbent solutions (diesel generators) on a total cost of ownership basis for fuel cell systems as backup power solutions, reaching a system cost of less than €700/kW;

b) Reach benchmark cost of competitive incumbent solutions (diesel generators) on a total cost of ownership basis for fuel cell systems as remote power sources for isolated and off-grid power needs, reaching a system cost of less than €700/kW;

c) Reach benchmark cost of competitive incumbent solutions (electric forklifts) on a total cost of ownership basis for fuel cell systems powering forklifts and other material handling applications (indoor, outdoor, airports and ports, and other areas), reaching a system cost of less than €1,000/kW;

d) Reach benchmark cost of competitive incumbent solutions (batteries) on a total cost of ownership basis for fuel cell systems in portable & micro power applications, reaching a system cost of less than €5,000/kW.

e) Investigate the technical (versus incumbent solutions) and commercial (benchmark costs) feasibility for other FCH applications such as wheelchairs, vehicles for luggage transport or for moving airplanes on the ground of airports, boats for the European lakes and rivers, tractors (with hydrogen from biomethanisation), ULMs, handling devices in harbours.

3.5. Regulation, Codes & Standards (RCS), Pre-normative Research and Societal Acceptance:
ensure common standards are approved and applied throughout Europe within a positive societal acceptance of the technologies

a) Ensure a proper uniform set of standards and regulations is set in place for hydrogen energy technologies and applications;

b) Develop the pre-normative research needed to close knowledge gaps in relation to the development of performance-based standards;

c) Develop a good understanding of the conditions of societal acceptance in order to support the establishment of these conditions.

4. ACTIONS

4.1. Hydrogen Production and Storage

a) Conduct further R&D programs on the different technologies for increased performance of centralised 100 MW (50 t/d) large scale electrolysis;

b) Demonstration of four underground GWh scale storage sites, with 100+MWe scale conversion capacity by 2020, with a first running by 2015, where the hydrogen is used as an energy carrier (e.g. transport applications, injection into natural gas grid) or a chemical feedstock in addition to being used to restore electricity to the grid when needed;

c) Conduct further R&D programs for reducing the cost and increasing the energy efficiency of distributed hydrogen production from the grid (by electrolysis, at varying rates depending on instantaneous grid balancing demand) or from biomass/biogas;

d) Demonstration of 50 t/d distributed production capacity, from the grid and from biomass/biogas, installed by 2020, including:

→ Demonstration of ten 3 t/d sites for biomass/biogas-based production by 2020, with 3 sites running by 2015.

→ Demonstration of ten 2 t/d distributed sites for electrolysis production by 2020, with 2 sites running by 2015.

e) Demonstrate the 2 concepts of the whole chain **for energy storage**: electrolyser-storage and SMR/ gasification with CCS-storage. These demonstrations could be achieved in collaboration with other European Industrial Initiatives

f) Demonstration of integrated carbon neutral energy supply chains **for transport applications** covering all the functions from production to delivery at point of refuelling, including stationary storage "Production to Car" sites testing the whole technology chain, from electrolysis/biogas to hydrogen refuelling stations, including alternative storage solutions (solid materials, high pressure, hybrid solutions), with 10 sites by 2015 and 50 sites by 2020.

4.2. Transportation & Refuelling Infrastructure

a) Conduct further R&D on fuel cell drive trains to allow for cost reduction, increase of lifetime, availability and vehicle efficiency

b) R&D aimed at simplification and cost reduction of components and systems (vehicle technology & refuelling technology)

c) Foster transition from research to development and production of components (vehicle technology & refuelling technology) by developing dedicated mass production and low costs methods.

d) Develop low cost methods for integration of fuel cell electric drive train components with 3 demonstrations for automatic assembly lines by 2020.

e) Achieve a robust and competitive supplier chain structure for FCEV components in Europe.

f) Start of hydrogen refuelling infrastructure build up in cities as a contribution to the European Smart Cities Initiative

g) Demonstration of one nationwide (in one Member State) roll out experience with 1000+ hydrogen refuelling stations deployed in this Member State for several hundred thousands fuel cell passenger cars by 2020 (around 100 refuelling stations for 3000 cars by 2015).

h) Demonstration of a second nationwide roll out experience starting in 2015, with 100+ hydrogen refuelling stations in 2018. These two demonstrations will be embedded in a wider European refuelling infrastructure in 6-7 Member States to support the introduction of Fuel Cell Electric Vehicles in the EU by 2020.

i) 10 demonstrations of Fuel Cell uses for Auxiliary Power Unit (APU) applications in aircrafts by 2015 and about a hundred by 2020. Same number of demonstrations targeted for maritime applications.

4.3. Stationary applications

a) Continue research efforts on micro-Combined Heat and Power systems (m-CHP) to allow for cost reduction, increase of lifetime, availability and energy efficiency.

b) Demonstrations of residential applications (m-CHP) in 20 European cities by 2015, with more than 1,000 units by 2015 and more than 50,000 by 2020.

c) Continue research efforts on Industrial CHP to allow for cost reduction, increase of lifetime, availability and energy efficiency.

d) Demonstration of Industrial CHP / Distributed generation based on H2 and NG/biogas fuel cell technologies, with 20 demonstration sites running by 2015 and 200 first-of-a-kind commercial systems by 2020.

4.4. Early Markets

a) Conduct further R&D programmes on fuel cell technologies to reach benchmark cost of competitive incumbent solutions (diesel generators, diesel engines, batteries)

b) Set up large scale demonstration projects for each of the early market segments that can provide basis for a following market deployment:
- → Material Handling vehicles: demonstration activities providing basis for reaching 5,000 fuel cell vehicles in operation by 2015 and 20,000 fuel cell vehicles in 2020, on 250-500 sites across Europe;
- → Back-up-power: demonstration activities providing basis for reaching 9,000 fuel cell systems in operation by 2015 and 20,000 fuel cell systems in operation in 2020 in Europe;
- → Micro & Portable power: demonstration activities providing basis for reaching 10,000 fuel cell systems in operation by 2015 and 250,000 by 2020.

4.5. Regulations, Codes and Standards (RCS), Pre-Normative Research (PNR) and Social Acceptance

a) Implement an industry-led RCS strategy coordination function to ensure that the needs of European stakeholders are well addressed by international standards and to support the establishment of an efficient regulatory framework calling out these standards where appropriate;

b) IIdentify and address pre-normative research needs in conjunction with the research community and ensure that the results are properly fed back to standardisation;

c) IConduct activities for information, education, dissemination and societal acceptance of hydrogen and fuel cell technologies.

For all the above identified actions synergies will be sought with actions included in the SET-Plan EIIs [(2)] and in other relevant partnerships with (partial) EU funding [(3)]. Long-term and breakthrough-oriented research will be streamlined with activities performed under the European Energy Alliance (EERA), whereas materials research activities will be aligned with the priorities identified in the Fuel Cell and Hydrogen chapter of the SET-Plan Materials Initiative [(4)].

Other Actions required

- A technology assessment framework, coherent with that of other SET-Plan EIIs implemented through the SET-Plan Information System SETIS, is required to monitor progress towards the FCH JU objectives and vis-à-vis major external developments. This entails setting up a mechanism to collect, validate and compare data from the research and demonstration activitities and to disseminate the results to the relevant stakeholders, through an agreed knowledge sharing framework

- Based on best practice with other (EU) instruments and platforms investigate the benefit of specific market and dedicated finance outreach tools for SMEs.

(2) For example with the EII on Sustainable Nuclear Energy hydrogen production, with the EIIs on Wind, on Solar and on Smart Grids for energy storage and grid interaction
(3) e.g. European Green Car Initiative launched under the EU Recovery Plan
(4) Expected publication in September/October 2011

5. INDICATIVE COSTS (2014-2020)

The financial efforts required for supporting R&D activities and demonstration programmes for hydrogen and fuel cell technologies amount to about €6.4 bn, for the period 2014-2020. This financial effort corresponds to the total sum of required public (EU+national) and private investments covering the type of research and innovation activities in SEC(2009)1295.

The breakdown of the financial effort for each of the actions introduced previously is presented in the following table. Research and development activities require a funding of about €3.3 bn, while about €3.1 bn are needed to support demonstration programmes. These figures do not take into account market introduction support financing to be put in place in order to reach the 2020 volume levels indicated in this roadmap. A dedicated approach to those financial efforts (around €11.5 bn) will need to be initiated with EU and Member States, using Innovative Financing Schemes.

Sector Financial Effort				
	R&D	Demonstration Programmes	Market Introduction Support	**Total**
Transport & Refueling	500	2 171	9 429	**12 100**
Production	330	492	984	**1 806**
Stationary	1 465	135	659	**2 259**
Early Markets	830	178	409	**1417**
RCS	150	150	0	**300**
Total	3 275	3 126	11 481	**17 882**

6. INDICATIVE ROADMAP

See page 34 of the main report “Fuel Cell and Hydrogen technologies in Europe 2014-2020”.

Aknowledgement

This document has been prepared on behalf of the New Energy World Industry Grouping (NEW-IG). The information and views contained in this document are the collective view of the NEW-IG and not of individual members, or of the European Commission. Neither the NEW-IG, the European Commission, nor any person acting on their behalf, is responsible for any further use of the information contained in this publication.

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The selection of FCH JU projects highlighted in the report has been made for illustrative purposes only. The selection does not express any statement, preference or opinion. A full overview of FCH JU funded projects can be found at www.fch-ju.eu

NEW-IG is a non-profit association representing Industry in the Fuel Cells and Hydrogen Joint Undertaking (FCH JU), a unique European public-private partnership between the European Commission and the fuel cell and hydrogen Industry and Research Community, with the objective to define and implement a target-oriented R&D programme (~€1 bn) to support broad market introduction of FCH technologies.

For more information, please visit: www.new-ig.eu

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