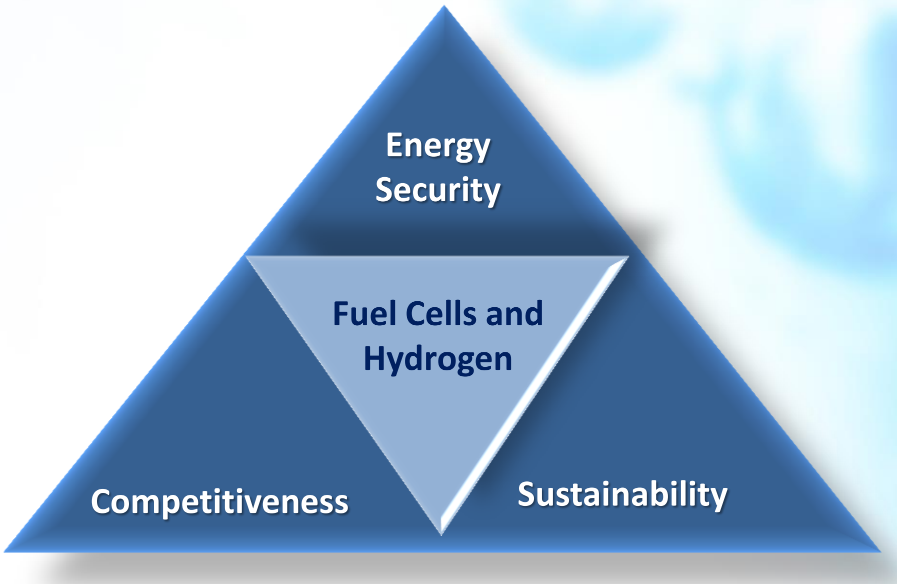
FCH 2 JU State of Play
Transport and Energy applications

7 April 2016

Mirela Atanasiu – Team Leader/Project Manager

Fuel Cells & Hydrogen technologies in the context of the European Energy policy



Sustainability

- H_2 is a clean energy carrier
- Transport and Energy applications, generate electricity and heat with very high efficiency
- Possibility for storage of renewable energy sources
- Reduction of CO_2 emissions

Energy Security

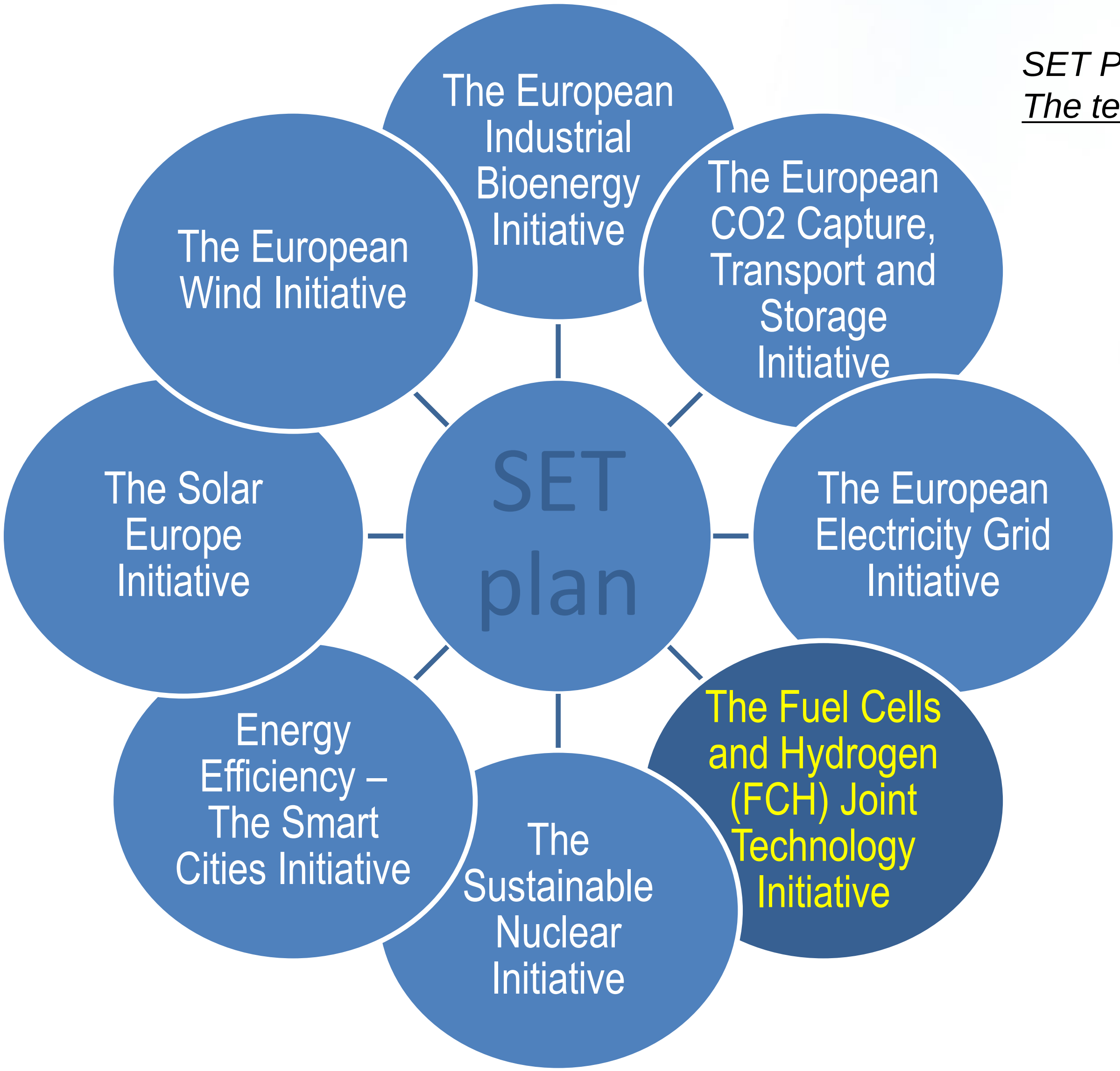
- Increase independence from unstable outside regions

Competitiveness

- research excellence leading to industry innovation and growth

From 80% dependency on fossil fuels to
80% reduction in GHG emissions in 40 years !
→ A reinvention of our energy system…

The FCH JU/JTI in the SET plan



SET Plan = Strategic Energy Technology Plan
The technology pillar of the Energy Union !

EU 2030 targets*:

27 % increase in renewables

27 % increase in efficiency

40 % decrease in emissions

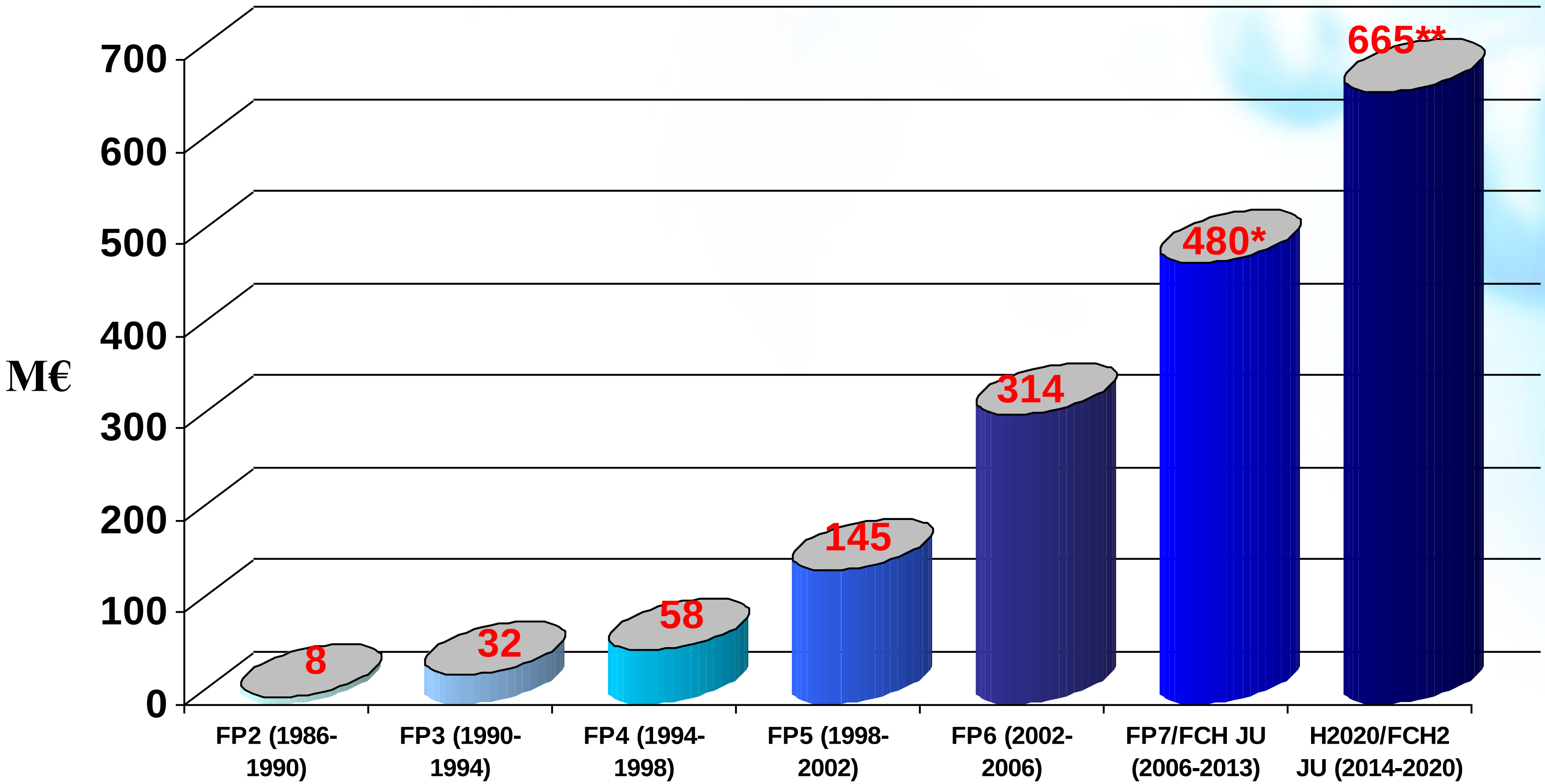
Fuel Cells and Hydrogen Joint Undertaking

- FCH JU - EU body
- Budget: 1.33 bill.€ (2014-2020)**
- FCH JU Programme Office

*European Council, October 2014

** continuation of previous exercise for 2008-2013 with a budget of approx. 1 bill.€

Continuous Support in the EU Framework Programmes



** 470 mill EUR implemented by FCH JU + about 10 mill EUR already spent from EU 2007 budget, before FCH JU in place*
*** 665 mill EUR only to be implemented by the FCH2 JU + additional budget from EU programmes for low TRL (basic research) and structural funds/smart specialisation*

Strong Public-Private Partnership with a focused objective

Fuel Cells & Hydrogen Joint Undertaking (FCH JU)

Hydrogen Europe

Industry Grouping
Close to 100 members
~ 50% SME

European Commission

N.ERGHY
RESEARCH ON FUEL CELLS & HYDROGEN

Research Grouping
Over 60 members

The Joint Undertaking is managed by a Governing Board composed of representatives of all three partners and lead by Industry.

To accelerate the development of technology base towards **market deployment of FCH technologies** from 2015 onwards

Legal basis:
Council Regulations:
521/2008 of 30 May 2008 ***(FP7)***
& amendment 1183/2011 of 14 Nov 2011
559/2014 of 6 May 2014 ***(H2020)***

Fuel Cell and Hydrogen community in Europe

+10%

average increase of annual **turnover** (on a 2012 total of €0.5 billion)

+8%

average increase of **R&D expenditures** (2012 total €1.8 billion)

+6%

average increase of **market deployment expenditures** (2012 total €0.6 billon)

+6%

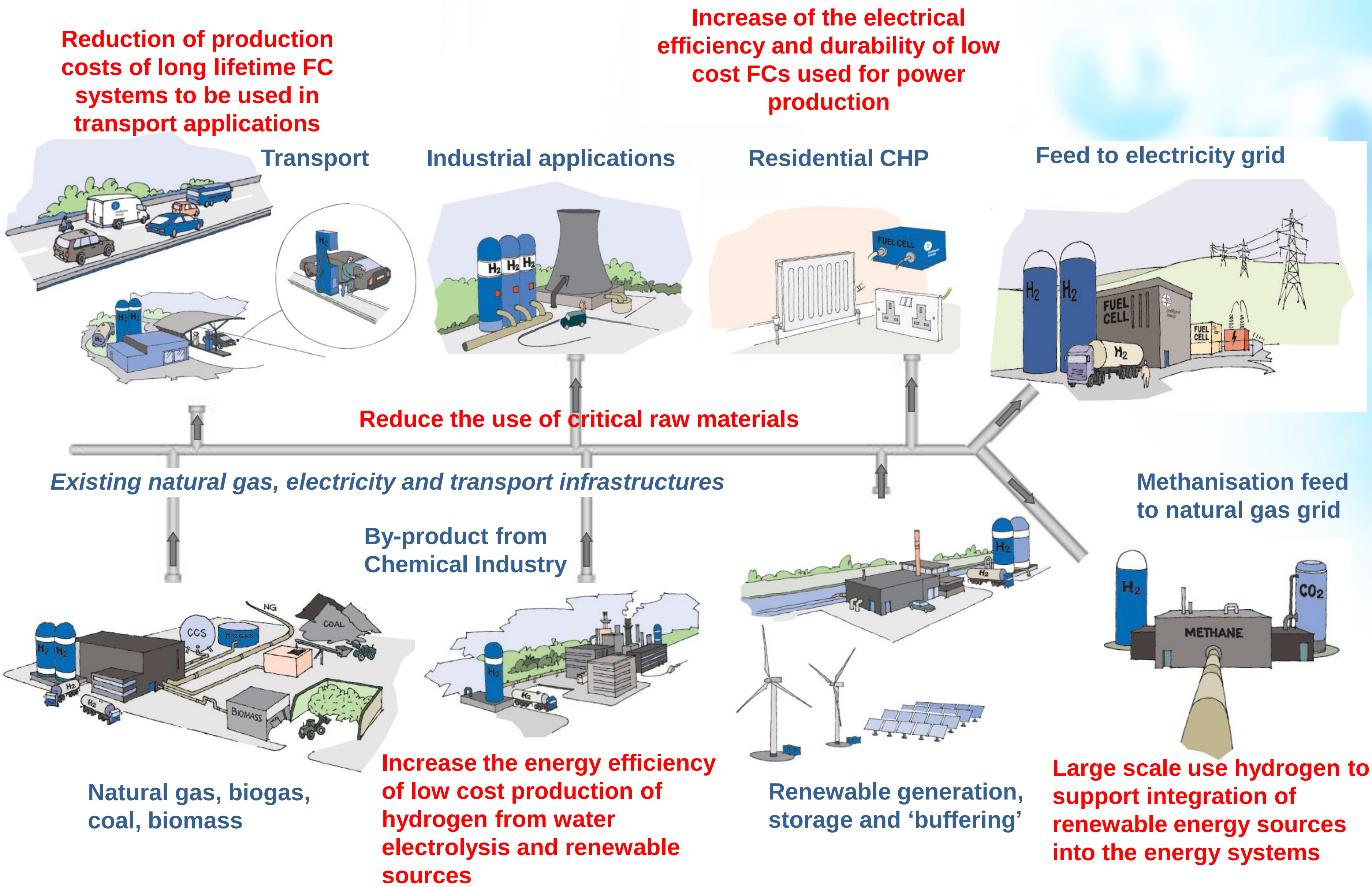
growth in **jobs** per year (~4,000 FTE in 2012) while average EU job market has contracted

+16%

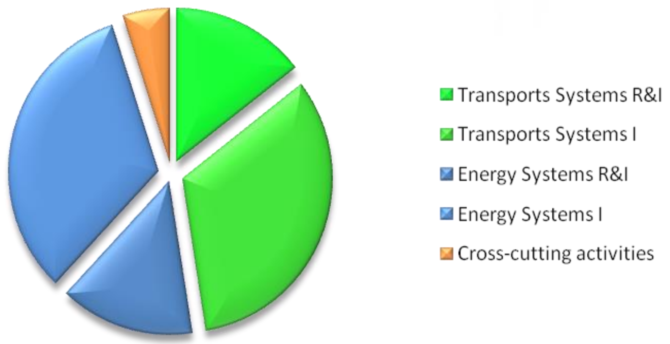
annual increase in **patents** granted in the EU to European companies (average 1.5% for all European industries)

Source: Trends in investments, jobs and turnover in the Fuel cells and Hydrogen sector, 2012

FCH 2 JU objectives



Multi-Annual Work Plan, MAWP (2014-2020)



Estimated budget of €1.33 billion
Strong industry commitment to contribute inside the programme + through additional investment outside, supporting joint objectives.

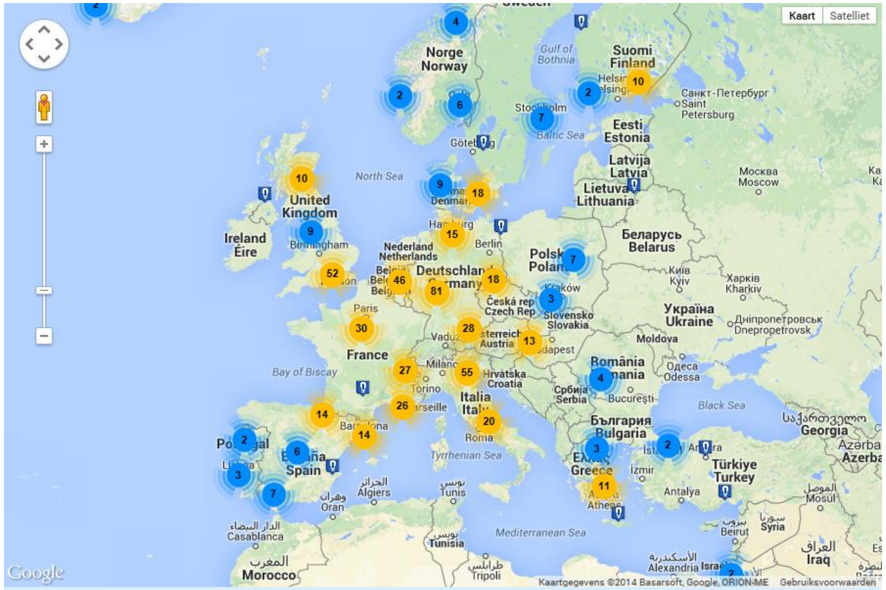
HORIZON 2020

- Road vehicles
- Non-road vehicles and machinery
- Refuelling infrastructure
- Maritime, rail and aviation applications

- Hydrogen production and distribution
- Hydrogen storage for renewable energy integration
- Fuel cells for power and combined heat & power generation

Cross-cutting Issues
(e.g. standards, consumer awareness, manufacturing methods, …)

Strong FCH community in Europe
Projects involving 22 EU Member States (under FP7)



1266 Participations

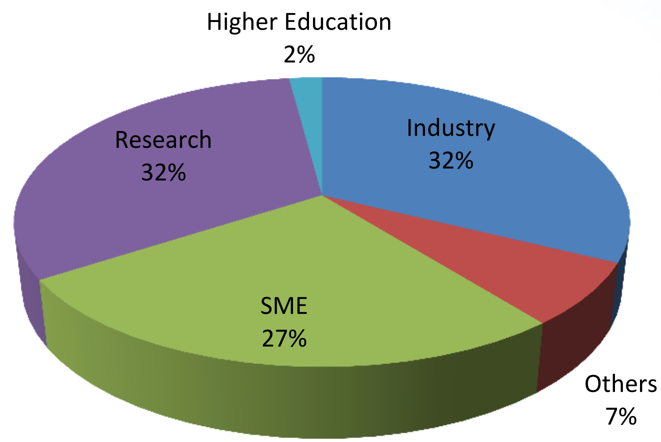
545 Beneficiaries:

- 192 Industries (35%)
- 154 SMEs (28%)
- 149 Research Organizations (27%)
- 20 High Education Institutions (4%)
- 30 Others (6%)

Incl international cooperation outside EU

(Additional non-EU countries: CH, NO, IL, TR, IS, RS, CN, RU & US)

Funding of beneficiaries categories



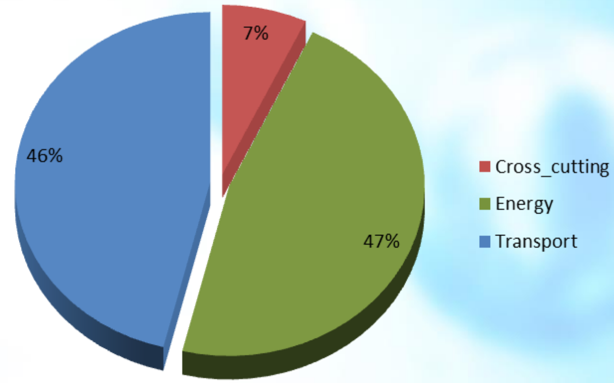
FCH JU portfolio of projects

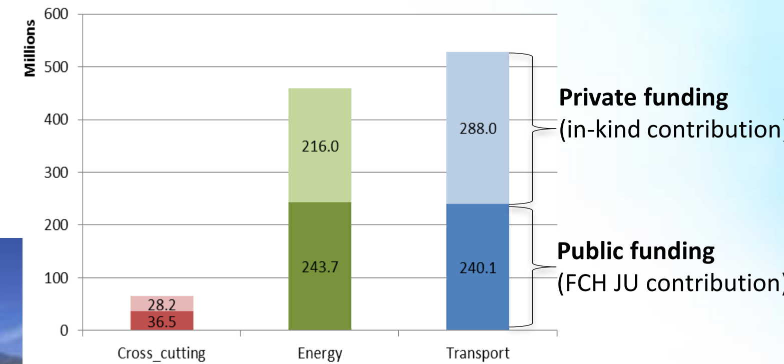
169 projects supported for about 520 mill €

(of which FP7: 155 projects for 446 mill €)

50/50 distribution betwen Energy and Transport pillars

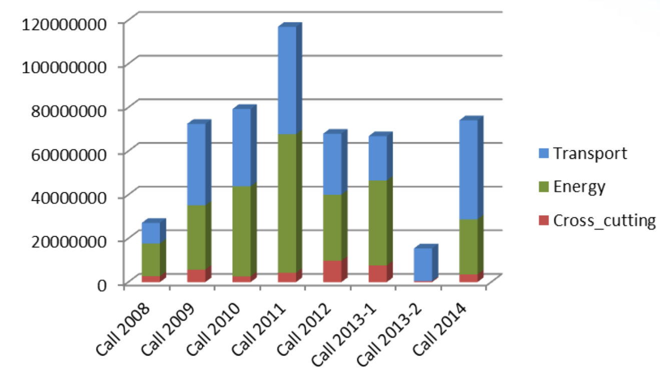
FCH JU contribution



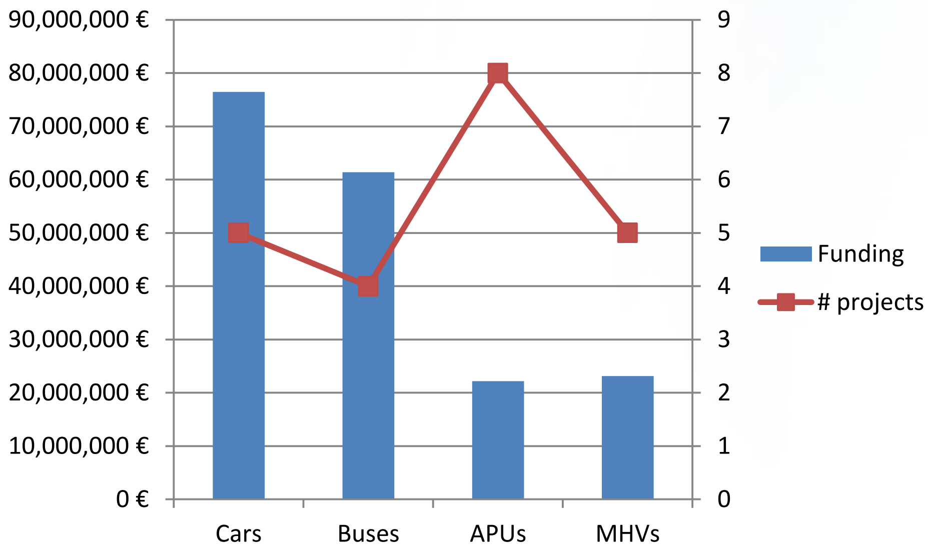


Similar leverage of private funding: 532 mill €

Continous/constant annual support (through annual calls for proposals)



TRANSPORT portfolio



Total FCH JU support:

- **242M€ for 42 projects**
- **183.1M€ for demos**

- Total of 544 passenger cars in 5 projects
  - Of which 125 with FCs as range extender
- Total of 40 refuelling stations

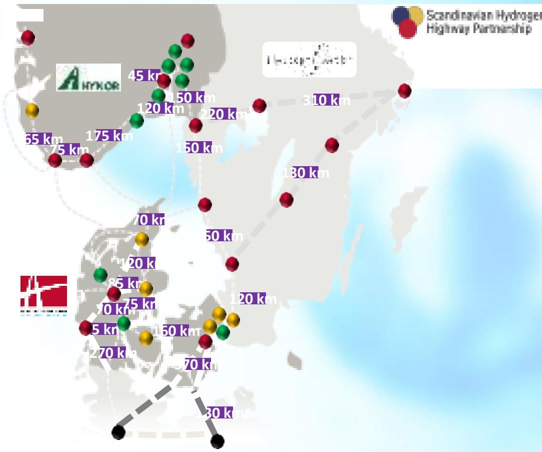
- Total of 67 buses from 4 projects in 12 locations

- Over 400 MHVs in 4 projects
- MHVs operated for 12,413hrs = 2200 shifts with overall availability of 95%
- 4,000 refuellings with 99.5% HRS availability

Cars – Member States plans

Advanced FCEV and HRS programs

- **France** – a large private consortium has agreed a strategy based on a transition from captive fleets to nationwide infrastructure for FCEVs.
- **Germany** –
  - 50 H2 stations by end of 2015 under the Clean Energy Partnership. Government and industry invest jointly over 40 M€.
  - the H2Mobility project has already signed a "term sheet" linking six industrial players to deploy 100 stations by 2017 and 400 by 2023 for 350 M€.
- **Scandinavia** – An initial network provides coverage for FCEVs, which can be purchased at equivalent ownership cost.
- **UK** – a consortium with significant Government presence has agreed a strategy based on seeding a national network of 65 stations by 2020. 7.5M£ have been committed by the Government for 15 HRS by 2015.

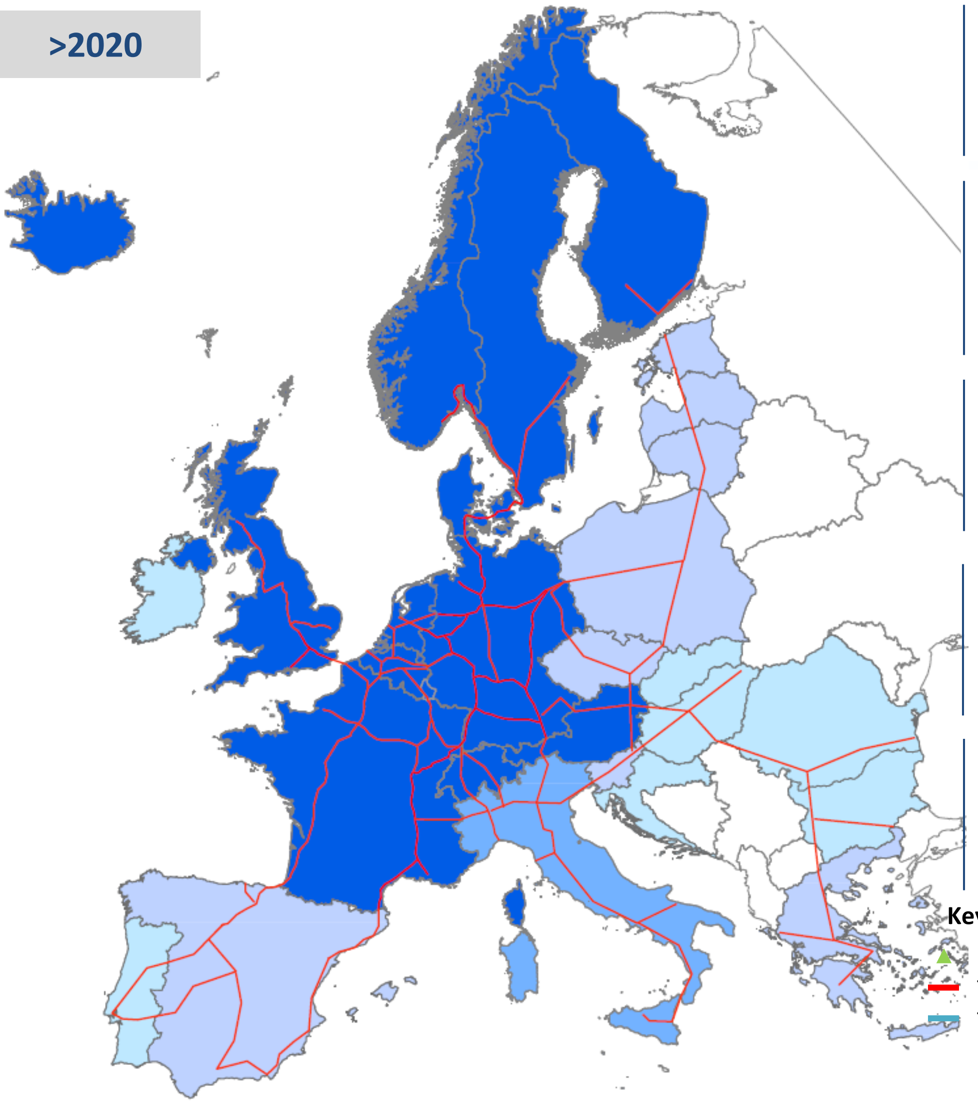


Similar initiatives are starting or running in other countries: **Austria , Belgium, Finland, Netherlands** (plan to be published before the end of 2014), **Switzerland**.

HRS – Member States plans

Likely implementation of the network by 2020 onward (>80 kg/day stations)

>2020



France

- The French network will keep on expanding with **30-40 HRS** by 2020 and **100 HRS** by 2023

Germany

- The German network will keep on expanding with **400 HRS** in 2023

Netherlands

- The Dutch network will keep on expanding with **20 HRS** by 2020 and **40-50 HRS** by 2023

Scandinavia

- The Scandinavian network will keep on expanding with **35-40 HRS** by 2020 and **50 HRS** by 2023

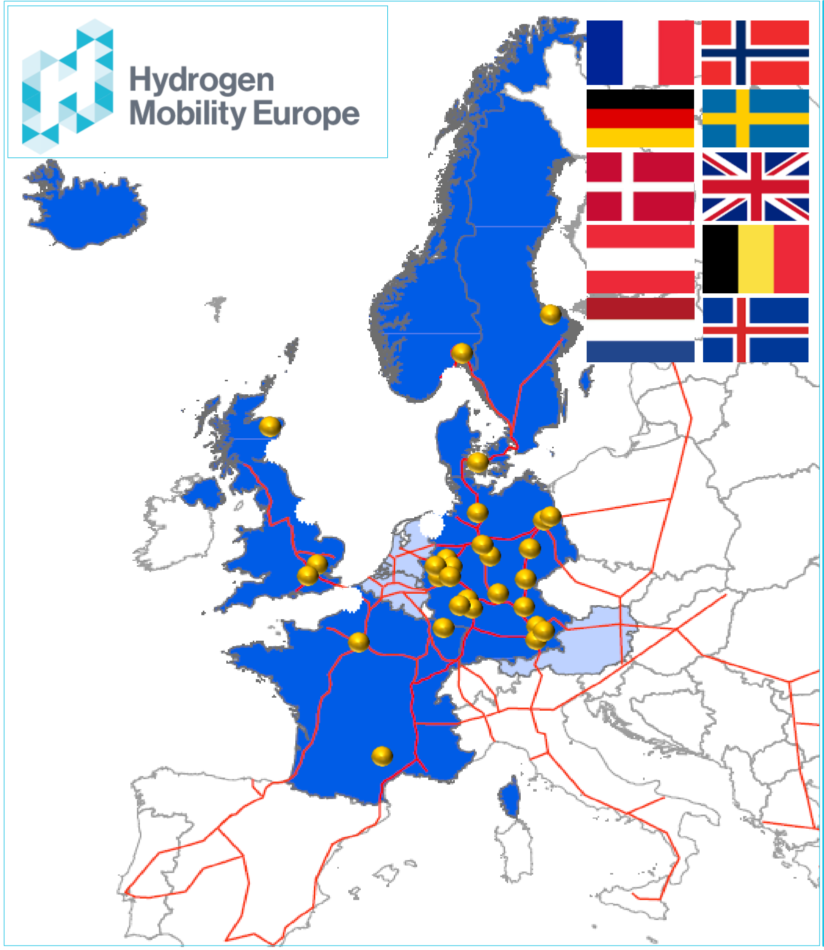
UK

- The UK network will keep on expanding with **60-70 HRS** by 2020 and **100 HRS** by 2023

Key:

- >80 kg/day HRS by 2015
- TEN-T Corridors
- TEN-T Corridors linked by early HRS
- Nations with H_2Mobility initiatives
- Nations with some activity and/or H2Mobility initiatives starting
- Follower countries starting to develop infrastructure

Project H2ME



Concept description:

- Joint initiative from the **most ambitious European hydrogen mobility initiatives**
- The project will see the deployment of **29 new HRS and 325 FCEVs** (200 FCEVs and 125 FC RE-EVs)
- **One 'working framework'** linking the hydrogen mobility initiatives of 10 countries, which will provide the opportunity to:
  1) identify **optimal commercialisation strategies** and **synergies between countries**
  2) develop a **pan-European strategy for commercialisation**
  3) **Refine sales and support strategies for the early FCEV customer across Europe**

Endorsers:

- Mobilité Hydrogène France
- H_2 MOBILITY WASSERSTOFF TANKEN
- UK H_2 Mobility
- Scandinavian Hydrogen Highway Partnership
- Mobility grouping in Benelux
- Hydrogen mobility grouping in Austria

Buses - Study

Current study

- → Local high-level cost analyses
- → Mobilisation of interested locations
- → Preparation joint procurement
- → Engineering of H_2 refueling infrastructure

2014-2015

- → Detailed cost analyses

JTI

- → Grant application for demo project
- → EU roadmap/ discussion on regulation

2016

- → Execution of demo projects
- → Local, national and EU funding schemes for demos

§

- → Regulations framework to support roll-out

2017-2020

Scale effects
Incentives
Regulation

VISION – FC electric buses commercially viable and rolled-out in Europe

2020 onwards

Buses – Study implementation

A broad stakeholder coalition of 82 organisations has been established

- Operators and local governments from 35/45 locations

Participating locations

Industry coalition members

Bus manufacturers

Infrastructure/ H_2 providers

Technology providers

Other organisations

Secure commitments for roll-out and large scale demos

84 buses in operation or about to start

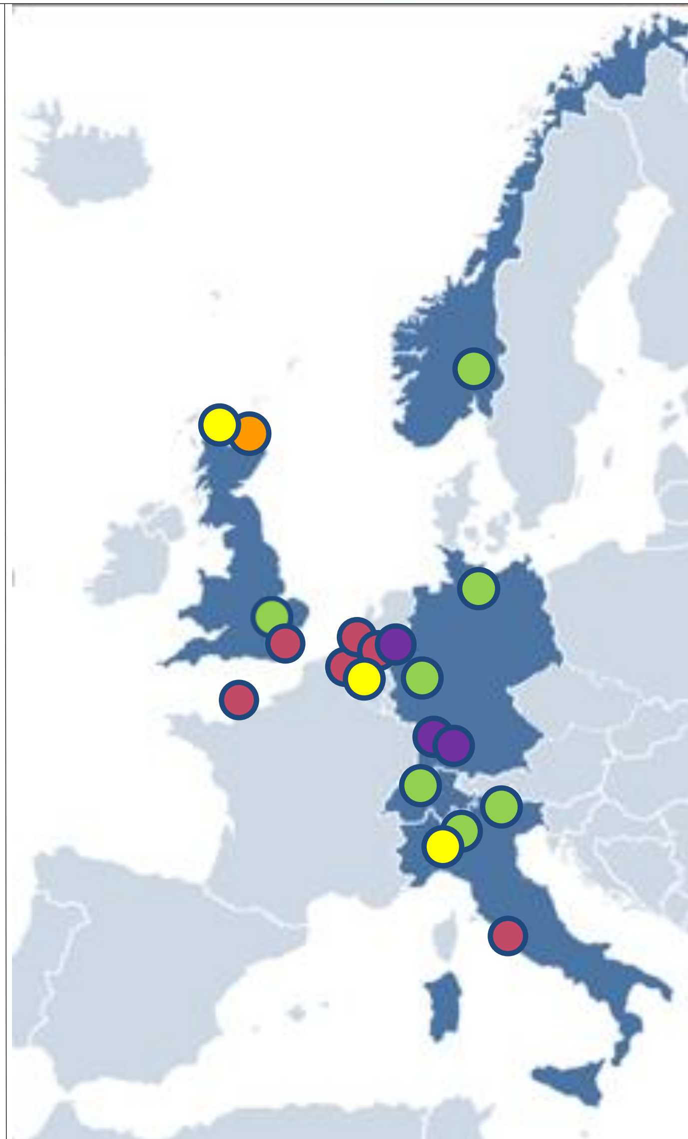
Current FCH JU-funded fuel cell bus projects

CHIC
- ✓ Bolzano – 5 FC buses
- ✓ Aargau – 5 FC buses
- ✓ London – 8 FC buses
- ✓ Milan – 3 FC buses
- ✓ Oslo – 5 FC buses

- ✓ Cologne* – 4 FC buses
- ✓ Hamburg* – 6 FC buses

High V.LO-City (operation start planned for 2015)
- ✓ Liguria – 5 FC buses
- ✓ Antwerp – 5 FC buses
- ✓ Aberdeen – 4 FC buses

HyTransit
- ✓ Aberdeen – 6 FC buses



Current FCH JU-funded fuel cell bus projects

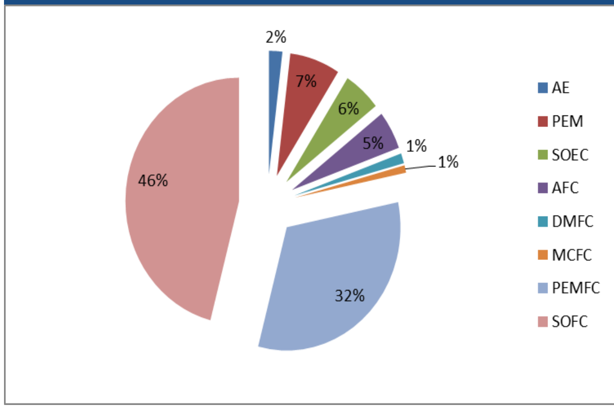
3Emotion (operation start planned for 2016/2017)
- ✓ Cherbourg – 5 FC buses
- ✓ Rotterdam – 4 FC buses
- ✓ South Holland – 2 FC buses
- ✓ London – 2 FC buses
- ✓ Flanders – 3 FC buses
- ✓ Rome – 5 FC buses

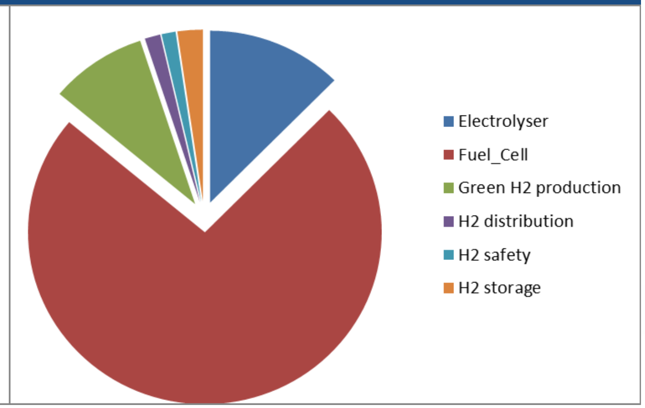
Current national/regional-funded fuel cell bus projects:
- ✓ Karlsruhe * – 2 FC buses
- ✓ Stuttgart * – 4 FC buses
- ✓ Arnhem* – 1 FC bus (operation start planned for Oct. 2015)

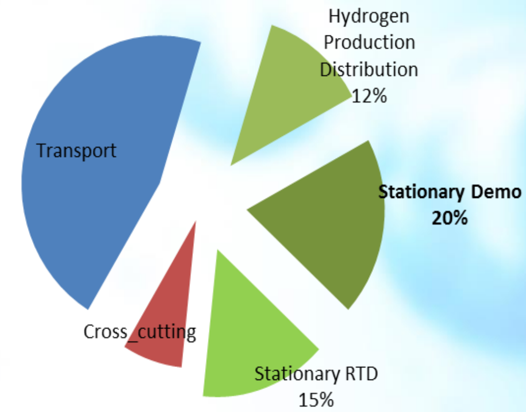
Legend:
- CHIC countries
- ✓ In operation
- ✓ Planned for operation
- * Co-financed by regional/national funding sources

ENERGY portfolio

96 projects under Energy pillar, for more than 240 mill €

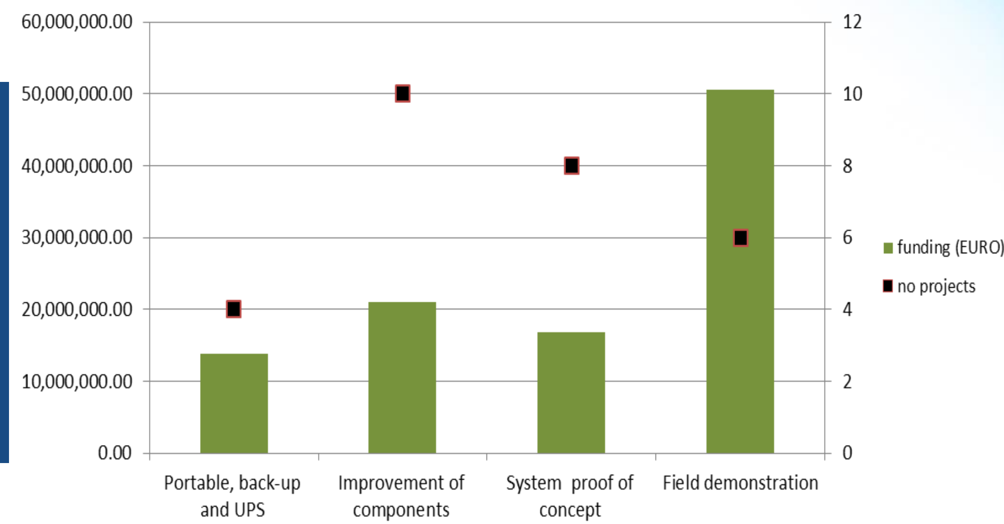






Technology neutral approach, however most support to Solide Oxide and PEM for both fuel cells and electrolyser applications

28 projects at TRL ≥ 3 for about 100 mill € (‘Stationary Demo’ type), mainly focusing on system integration and field demonstration (e.g. components development, including control systems; proof-of-concept; field demonstration of CHP and back-up power units)



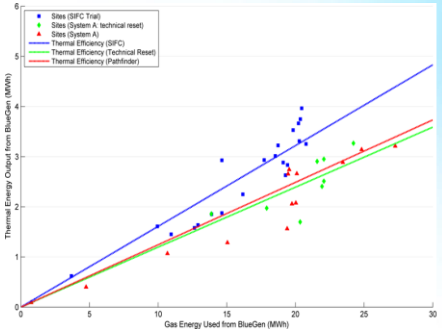
Solid Oxide Fuel Cell micro-CHP Field Trials

39 BlueGen Pathfinder Systems + 26 Integrated Fuel Cell Appliances (SIFC)

Total: **65 Fuel Cell Systems**

FC system Electrical efficiency (HHV) >40% (from 56% to 42% (HHV) and from 61.5% to 46.0% (LHV) over lifetime)

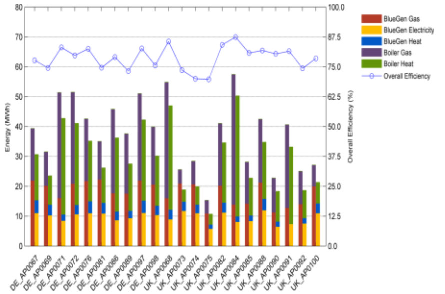
The mean overall system efficiency of the SIFC units was 79.0% for UK and 78.3% for German sites (an integrated Fuel Cell system is more efficient than modular!)



Achieved: 25% BlueGen Cost Reduction via Reengineering components & supply chain enhancements

FC system life time >10,000 h

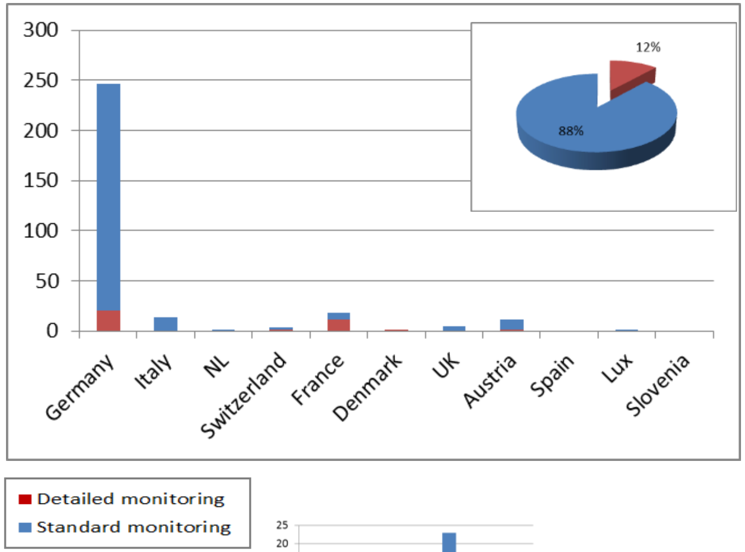
(at end of project: 12,792 hours & given its degrade rate expected to reach 27,118 hours)



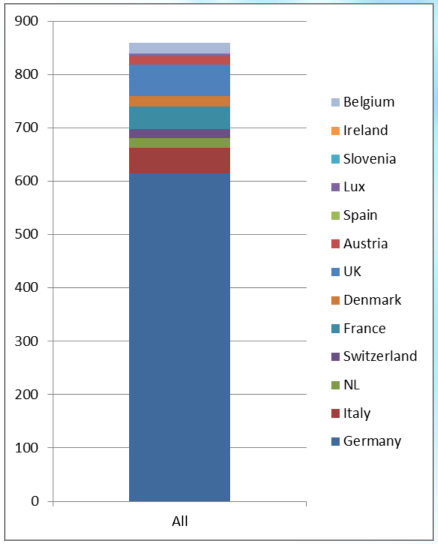
e·on ideal CERAMIC FUEL CELLS HOMA

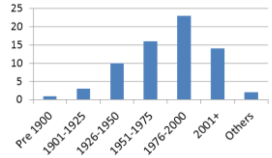
Field demonstration of small stationary fuel cell systems for residential and commercial applications

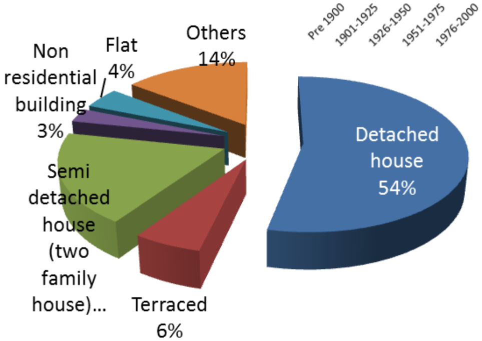
up to 1,000 residential fuel cell micro-CHP installations, across **11 key Member States**



- **400 units have been installed** across the 8 active field trials as of February 2016 in 8 countries: DE, UK, FR, DK, AU, CH, LUX and IT (the others 90% contracted)
- **30–150 identical units from each manufacturer!** (first stage demonstration)







Dachs InnoGen	Cerapower FC10 Logapower FC10	PEMmCHP G5	Elcore 2400	Galileo 1000 N	Inhouse 5000+	ENGEN 2500	BLUEGEN	Vaillant G5+	Vitovalor
LT PEM 700W	SOFC 700W	LT PEM 2kW	HT PEM 300W	SOFC 1kW	LT PEM 5kW	SOFC 2.5kW	SOFC 2kW	SOFC 1kW	PEM 700W
Natural Gas	Natural Gas, Gas	Natural Gas + Biogas	Natural Gas	Natural gas+ Biogas	Natural gas + Biogas + H2	Natural Gas	Natural Gas	Natural Gas	Natural Gas
Floor	Floor	Floor	Wall	Floor	Floor	Floor	Floor	Wall	Floor
SenerTec	Bosch Thermotechnik	Dantherm Power	Elcore	Hexis	RBZ	Solid power	Solid power	Vaillant	Viessmann

Power-UP

Field demonstration of large-scale stationary power and CHP fuel cell systems

240 kW system (built in UK, installed in Germany)

Commissioning of KORE System and production of power at Stade, Germany

Conversion efficiency (electr.): 61% per tier

Expected lifetime: 13,500hrs by the end of the project

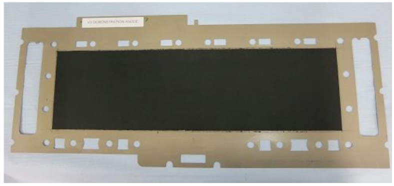
3 major components:

Electrodes: produce the power

Cartridges: house stacks

Balance of plant: fluid management, superstructure, safety systems, C&E, integration into customers site

Robot stacking cartridge

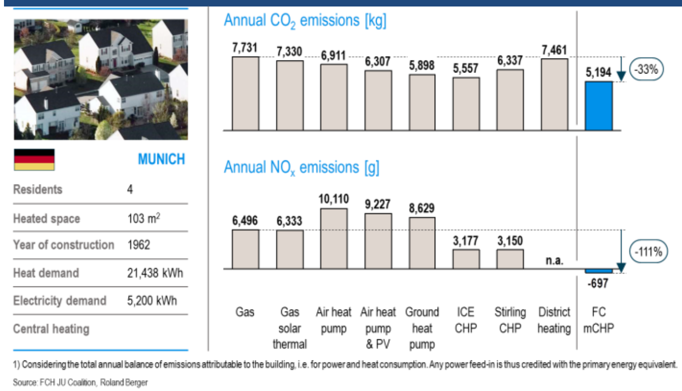


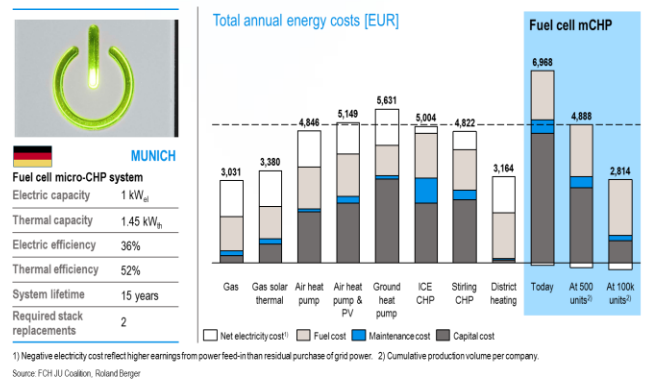
AFC energy plc · AIR PRODUCTS · innomech Automation Solutions · ZBT · PAUL SCHERRER INSTITUT PSI · FAST · EHA EUROPEAN HYDROGEN ASSOCIATION

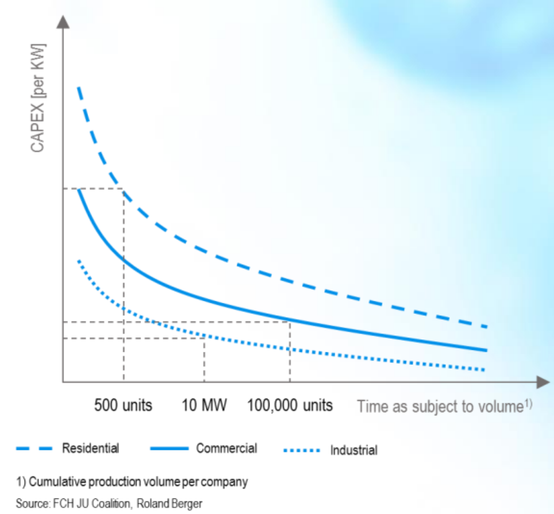
FC based CHP / Decentralised production of energy - Study

Roland Berger Study: ***Advancing Europe's energy systems: Stationary fuel cells in distributed generation***

- Industry coalition composed of more than 30 stakeholders – Results reflect common understanding
- The most comprehensive assessment of the commercialisation potential of stationary fuel cells in Europe (4 focus markets, 6 generic fuel cells, 35 years time horizon, 45 different use cases, >30 benchmark technologies, >3 energy scenarios, >34,000 resulting data points)

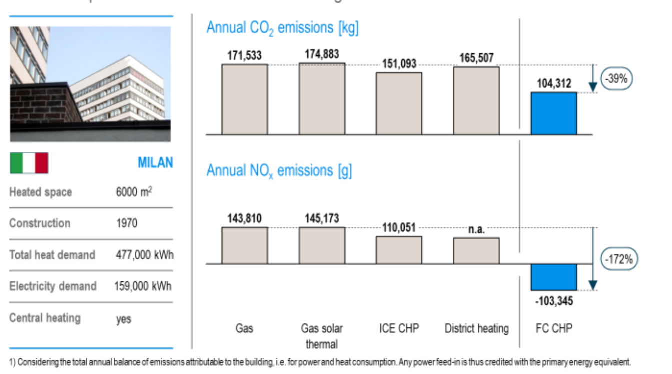




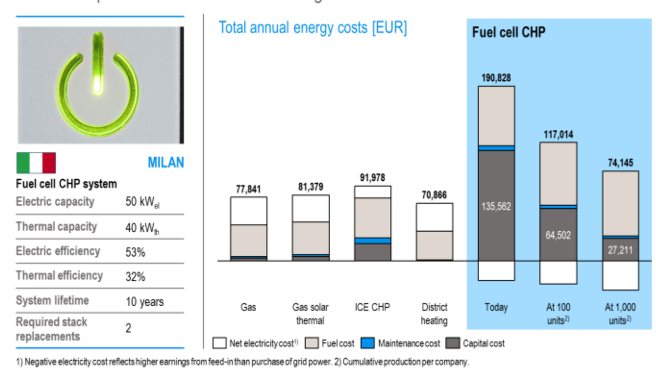


Today FC can reduce CO_2 emissions by more than 30%, while No_x emissions can be eliminated entirely; however, to become economically competitive, capital costs must be reduced substantially by increasing production volumes

Use-case specific environmental benchmarking[1]



Use-case specific economic benchmarking[1]

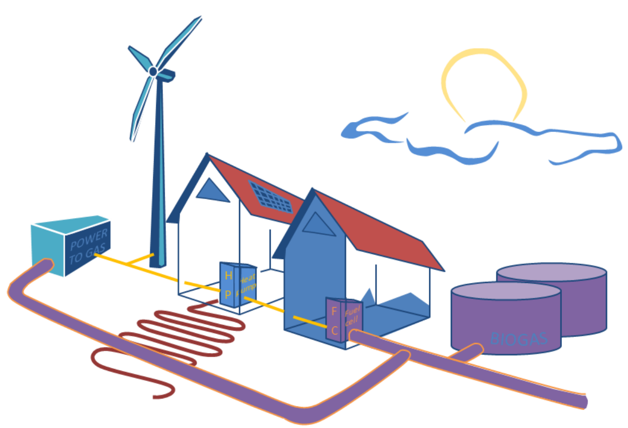


Industry sees ambitious potential (larger volumes allow for automation and bundled sourcing strategies, standardisation must increase within and across technology lines)

Industry is fully committed to decreasing cost with sufficient installation volumes !

Fuel cells are the highly efficient and complementary choice to future energy systems based on more and more renewables

European vision for stationary fuel cells



Fuel cell vision

- Highly efficient conversion of natural gas (and eventually green gas or pure hydrogen)
- In distributed generation, i.e. at the site of consumption
- Lowering the carbon footprint of energy supply
- Playing a omplementary role to renewables[1)]

20 members of the fuel cell industry

6 players in adjacent industries

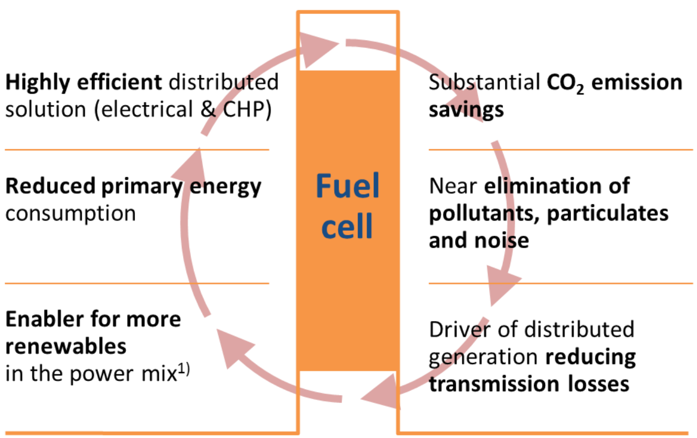
4 key associations

2 research institutes

3 public sector bodies

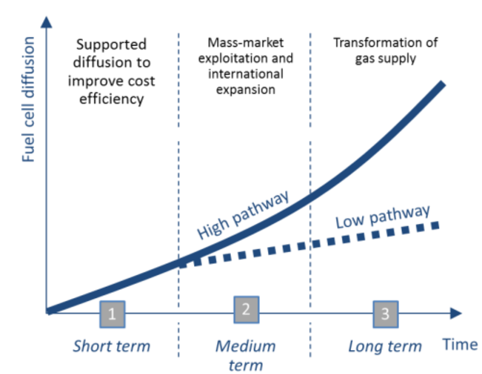
A coalition composed of more than 30 stakeholders – Results reflect common understanding of this group

Stylised overview of main benefits of stationary fuel cells



- **Fuel cell initially as bridge technology** with significant potential to reduce primary energy demand and emissions
- **Afterwards, transformation to a renewable technology** through decarbonisation of the gas grid

Potential development stages and pathways of the fuel cell technology



1. **Fuel cell systems reach competitive cost level to high-end heating solutions**
   - Policy support to trigger market pick-up and thus cost reduction
   - Starting point in the residential segment
2. **Fuel cell systems reach competitive cost level to mass-market solutions**
   - Continuous support if cost targets are reached
   - Commercial segment to be supported
3. **Fuel cell systems become a renewable technology through decarbonisation of gas supply**
   - Further growth and mass-market solution possible if gas supply becomes greener and more domestic

1) E.g. Stationary fuel cells as operating reserve with good performance at partial loads, complementary cycles of heat-driven CHP with electric heating demand

Source: FCH JU Coalition, Roland Berger

Hydrogen enables us to get the most out of our Wind and Solar energy

Achievements

On-site installation of **hydrogen equipment after receiving exploitation permit**, certification and CE conformity:

- Coupling to solar pannels (800 kWp) and wind turbines (1500kWp)
- 2 Electrolysers (one alkaline and one PEM): 130 kg H_2/day
- 2 Compressors: one mechanical and one electrochemical **(planned)**
- Hydrogen storage capacity 100 kg at 45 MPa
- Hydrogen dispenser for a fleet of 9 fuel cell forklifts and FC cars
- 100 kWe Fuel Cell connected to the grid

Continuous performance monitoring and control software installed for Life Cycle Assessment and Total Cost of Ownership analysis

Context

To demonstrate the technological readiness, performance, reliability and total costs of ownership of installations for production and short-term storage of hydrogen via water electrolysis from renewable electricity sources, with subsequent supply as a high value fuel and as controllable load for grid services.

In 2015, the European Parliamentary Research Service published an in-depth analysis presenting energy storage via hydrogen production as one of the ten technologies which could change our lives.

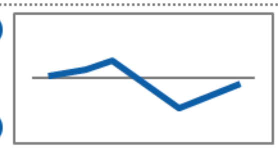
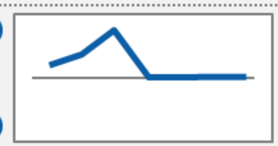
Challenges

- Installation and continuous operation of a standalone forecourt water electrolyser (between 100 and 500 kg H_2/day)
- Hydrogen production from renewable energy sources
- High level of availability (95%)
- Electricity consumption below 60 KWh/kg H_2
- Hydrogen purity
- Hydrogen production facility turn-key CAPEX: 3.5 M€/(ton/day)

Next set of Actions

- Increased capacity of **the electrochemical compressor** (from 2 to 60 kg H_2/day)
- **Field testing of the PEM unit** (60 kg H_2/day)
- Overview of pricing of renewable electricity green certificates
- **Running of test phase 2** (8000 hours in operation monitoring)

Energy Storage Study:
CONTEXT: There are 4 main options for integrating renewables, but all the options have significant limitations

RES integration solution		Deficit solved?	Surplus solved?	Residual load[1]	Limitations
0 Base case situation				Deficit +  Surplus −	
1 Dispatchable generation (hydro, bio-mass, fossil)		✓	✗	Deficit +  Surplus −	▪ Hydro and biomass quantity is limited ▪ Fossil fuels generate CO_2 emissions ▪ No utilization of excess energy
2 Transmission and distribution expansion		✓	✓	Deficit +  Surplus −	▪ Ineffective if RES production correlated over large area ▪ Hampered by permitting issues and long construction times
3 Demand side management		✓	✓	Deficit +  Surplus −	▪ Limited by amount of demand that can be shifted and time for which it can be delayed
4 Energy storage	Power-to-power	✓	✓	Deficit +  Surplus −	▪ *Focus of this study* ▪ *Technologies considered in the study included:* – *Batteries (Li-ion, NaS, Lead-acid, Flow-V)* – *Mechanical storage (pumped hydro, compressed air, liquid air)* – *Hydrogen power-to-power storage* – *Heat storage* – *Hydrogen for use outside of power sector*
4 Energy storage	Conversion to heat and heat storage	✓	✓	Deficit +  Surplus −	
4 Energy storage	Conversion to Hydrogen for use outside power sector	✗	✓	Deficit +  Surplus −	

All of these option come at a cost to society

1 Difference between demand and intermittent RES production

At realistic values of hydrogen, large installed electrolyzer capacity would be viable and able to utilize nearly all excess RES energy in the 2050 horizon

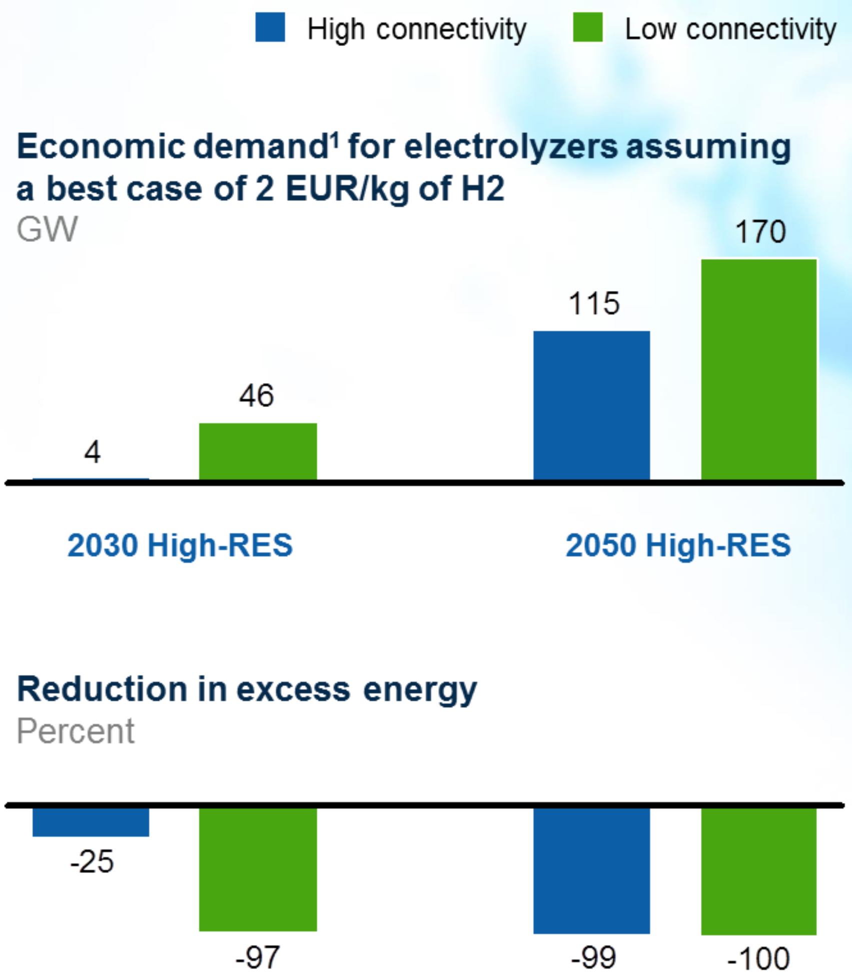
Germany archetype

Non-hydrogen P2P and heat storage will only be able to absorb a small part of the excess energy generated, resulting in the necessity of curtailment – from societal point of view, such electricity could be used at close to zero cost

The excess energy can be used to produce hydrogen via water electrolysis for re-electrification or use outside of the power sector

If the value of hydrogen at the point of production can reach a price in the range of 2-4 €/kg very large installed electrolyzer capacity would be economically viable and able to utilize nearly all of the excess electricity

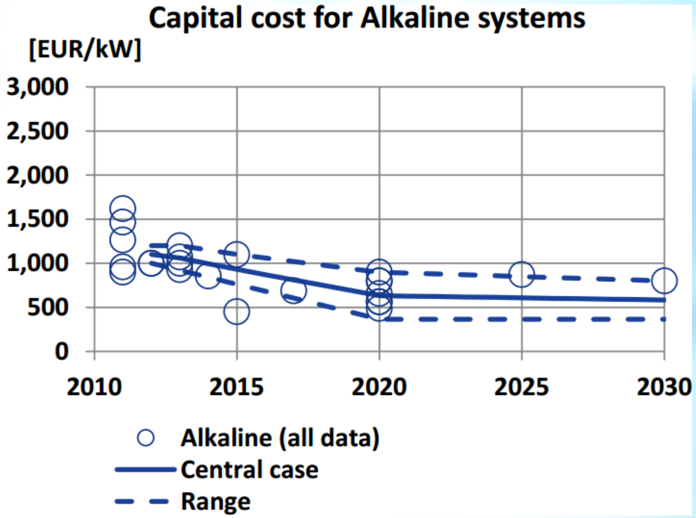
Such use of the excess electricity would create value for the society and the surplus could be divided between the electricity and hydrogen producer

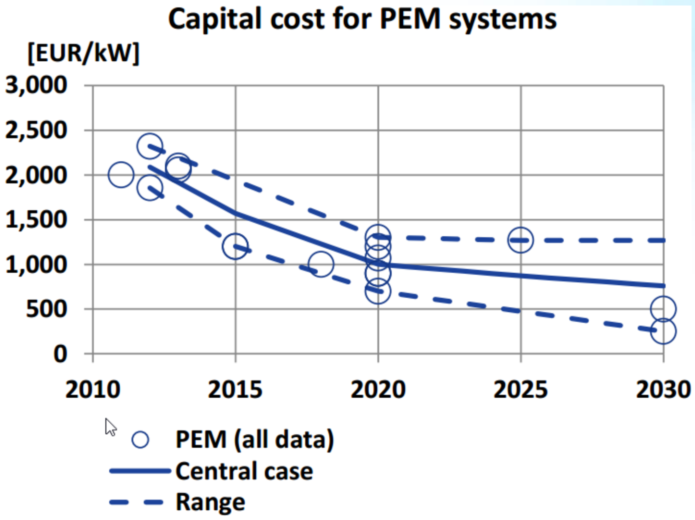


1 Installed electrolyzer capacity achieving 60 EUR/installed kW per year of benefits at given hydrogen plant gate cost – this corresponds to 370 EUR/kW capex, 8% WACC, annual opex at 1.2% of total capex and 10 years lifetime (FCH JU 2014)
Assumes electricity for free, no grid connections fees and no time-shift storage is in place.

FCH JU Electrolysers Study: Water electrolysis can be commercially viable in transport applications (and some others) by 2030

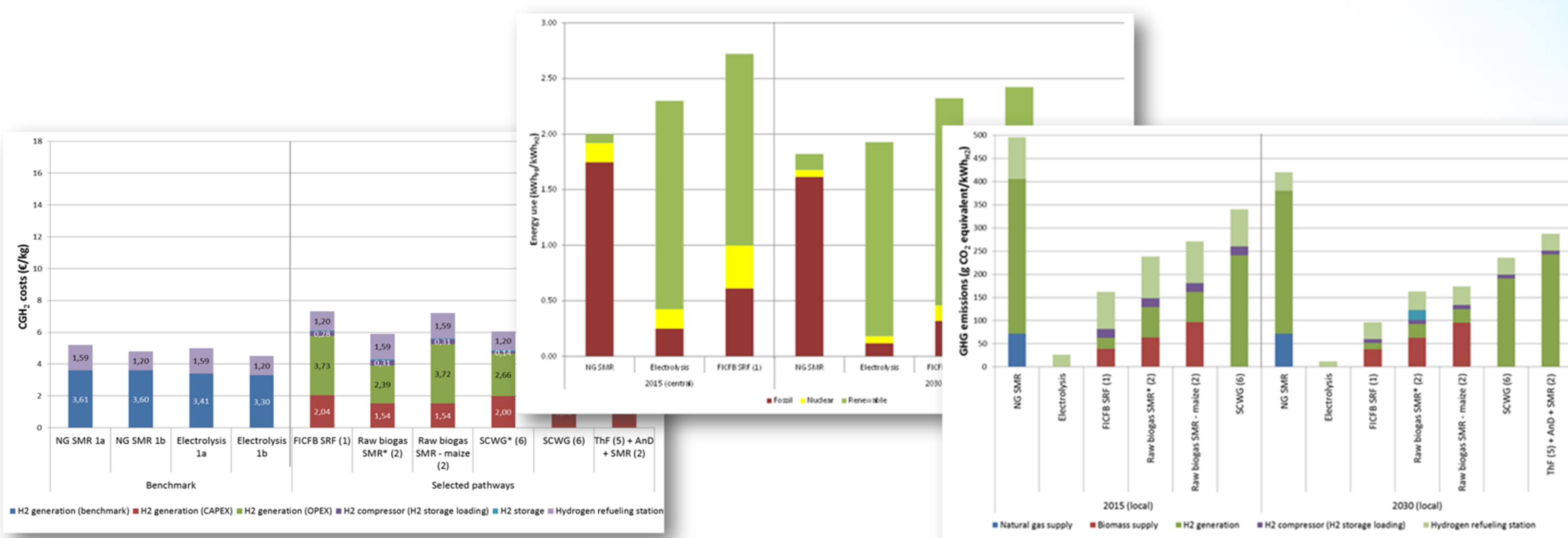
- Water electrolysis (WE) can be a commercially viable element of the future energy system
  - Hydrogen for transport
  - Industrial hydrogen uses
- Gigawatt scale cumulative deployment is plausible by 2030
  - In line with stakeholder expectations
  - Coherent with emerging hydrogen infrastructure plans
- But this is hard to achieve and requires:
  - Continued technology development and cost reduction
  - Supportive regulatory and policy framework conditions
  - Clear requirements for emerging WE energy applications





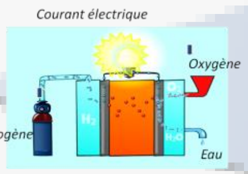
Green Hydrogen Pathways Study

- Aim: to identify most promising green H_2 production pathways based on a number of key parameters
- 11 pathways assessed, 6 selected
- Recently available at http://www.fch.europa.eu/studies



Fuel Cells and Hydrogen Joint Undertaking Achievements

Hydrogen Packard car (1927) - Woikoski



Marine & aerospace

Forklifts

Hybrid FC Buses

FCEV

FC in commercial planes

FCEV RE

1995 | 2000 | 2005 | 2010 | 2015 | 2020

Backup power

Large scale stationary applications

Energy storage

CHP Systems

Portable applications

The scope of applications is widening with time

FCH2 JU calls under H2020
Next plans

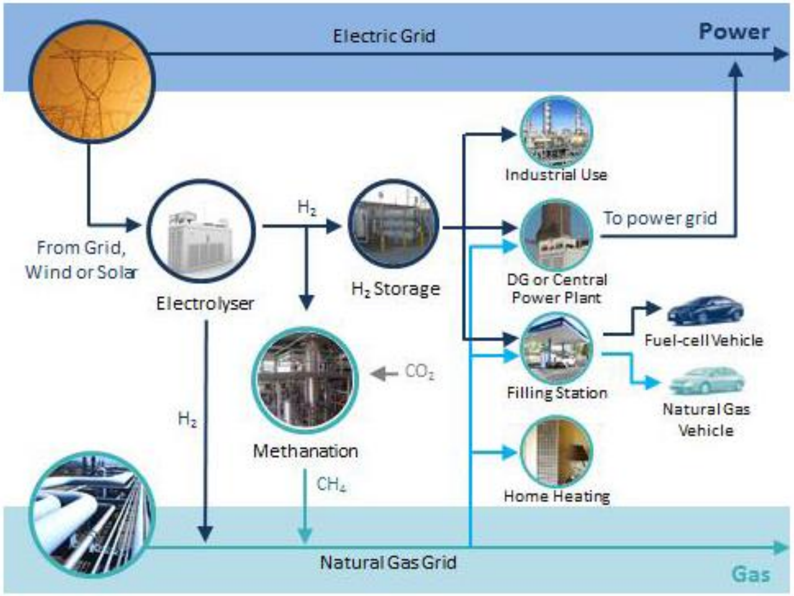
<u>Annual calls</u>
to be published in January each year

<u>Call 2016 plan</u>

Publication date: 19 January 2016

Deadline: 03 May 2016

Estimated budget: <u>EUR 117.5 million</u>



<u>Studies</u>
to support the multi-annual strategy and industry road-maps for the different technologies and applications:

- Business models for FC-CHP applications
- Hydrogen storage business cases/models (e.g. to integrate excess RES)

<u>Continous work with Members States Representatives (SRG) and National Programmes</u>
to coordinate/complement sources of funding for market penetration/early-commercialisation (H2 mobility initiatives, FC-CHP subsidies etc)

Thank you for your attention !

Further info :

- FCH2 JU : http://www.fch.europa.eu/
- HYDROGEN EUROPE : www.hydrogeneurope.eu
- N.ERGHY : http://www.nerghy.eu