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Update on European Hydrogen and Fuel Cell RTD&D Programmes

William Borthwick

Angel Perez-Sainz (head of unit)

B Coda, M Atanasiu,

J Martin-Bermejo, H Van Honacker, (DG RTD)

I Sabater, F Soeldner (DG TREN)

European Commission

Directorate General for Research

Unit J-2 "Energy Production and Distribution Systems"

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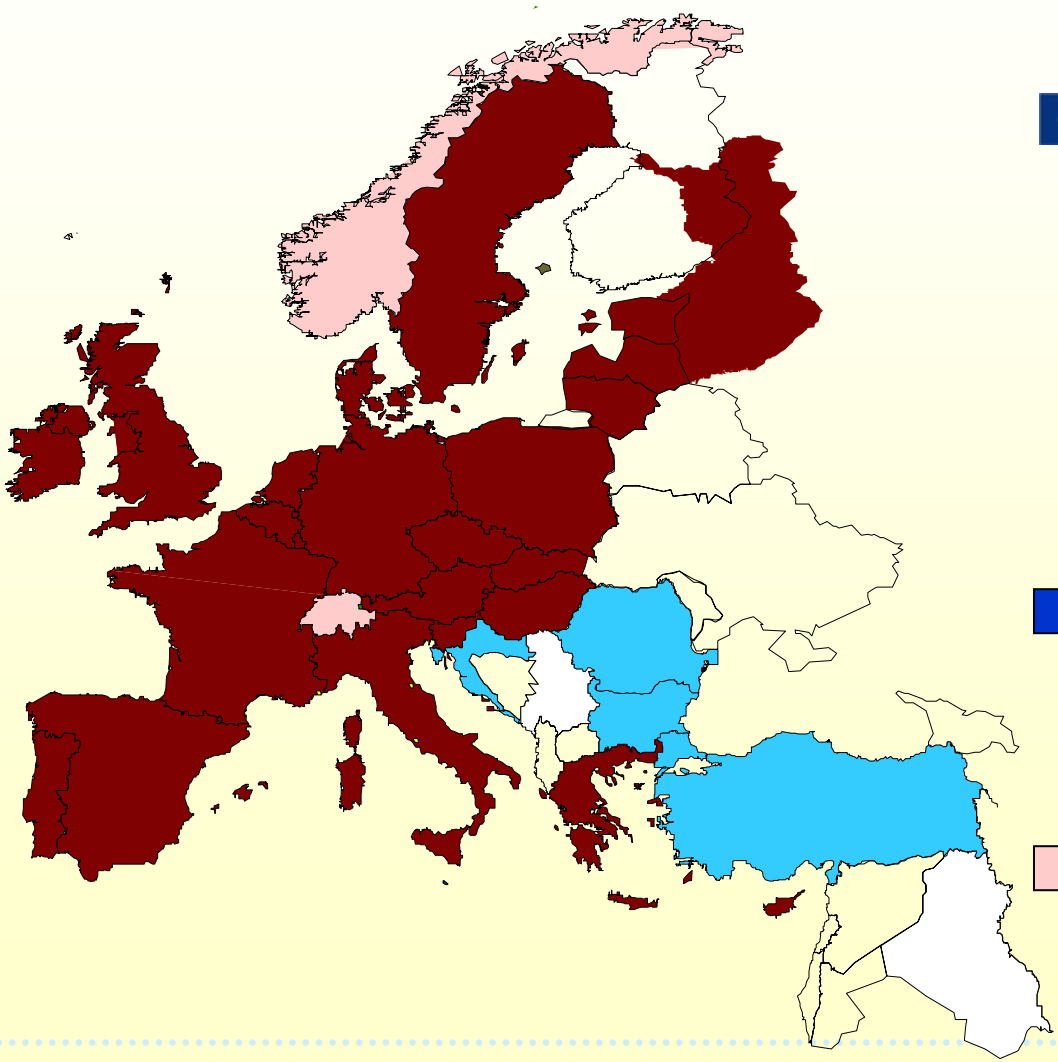
European Union



EU until 30 April 2004
- Austria
- Belgium
- Denmark
- Finland
- France
- Germany
- Greece
- Ireland
- Italy
- Luxembourg
- The Netherlands
- Portugal
- Spain
- Sweden
- United Kingdom

Since 1 May 2004:
- Cyprus
- Estonia
- Hungary
- Latvia
- Lithuania
- Malta
- Poland
- Czech Republic
- Slovenia
- Slovakia

Candidate countries:
- Bulgaria
- Croatia
- Romania
- Turkey

European Economic Area:
- Iceland
- Norway
- Switzerland

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Presentation outline

- EU Energy Policy context
- The 6th EU Framework Programme (FP6)
- A Strategy for Europe: The European Hydrogen and Fuel Cell Technology Platform
- Energy Research in the 7th EU Framework Programme (FP7): Joint Technology Initiative

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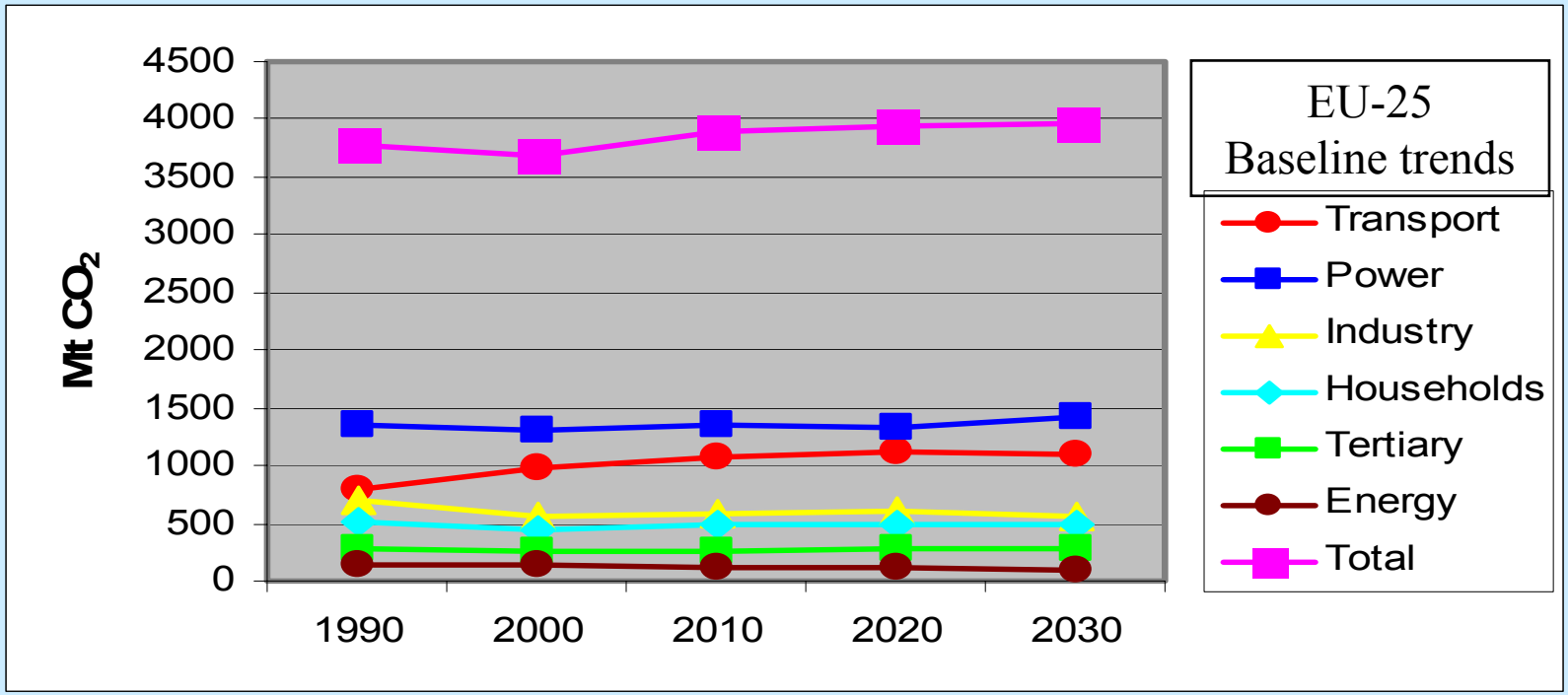
EU Energy Policy Context

- **Security of EU energy supply**
  - Import dependency forecast to grow from >45% today to nearly 70% by 2030 (90% for oil!)
- **Reduction of EU greenhouse gases and pollutant emissions (Kyoto and beyond)**
  - ✓ Increase share of renewable energy (from 6 to 12% in 2010)
  - ✓ Improve energy efficiency, reduce energy intensity (save 20% energy consumption by 2020)
- **Improve EU industrial competitiveness**

Trends in EU CO_2 Emissions



- CO_2 emissions projected to slightly increase
- Power production and transport remain main emitters

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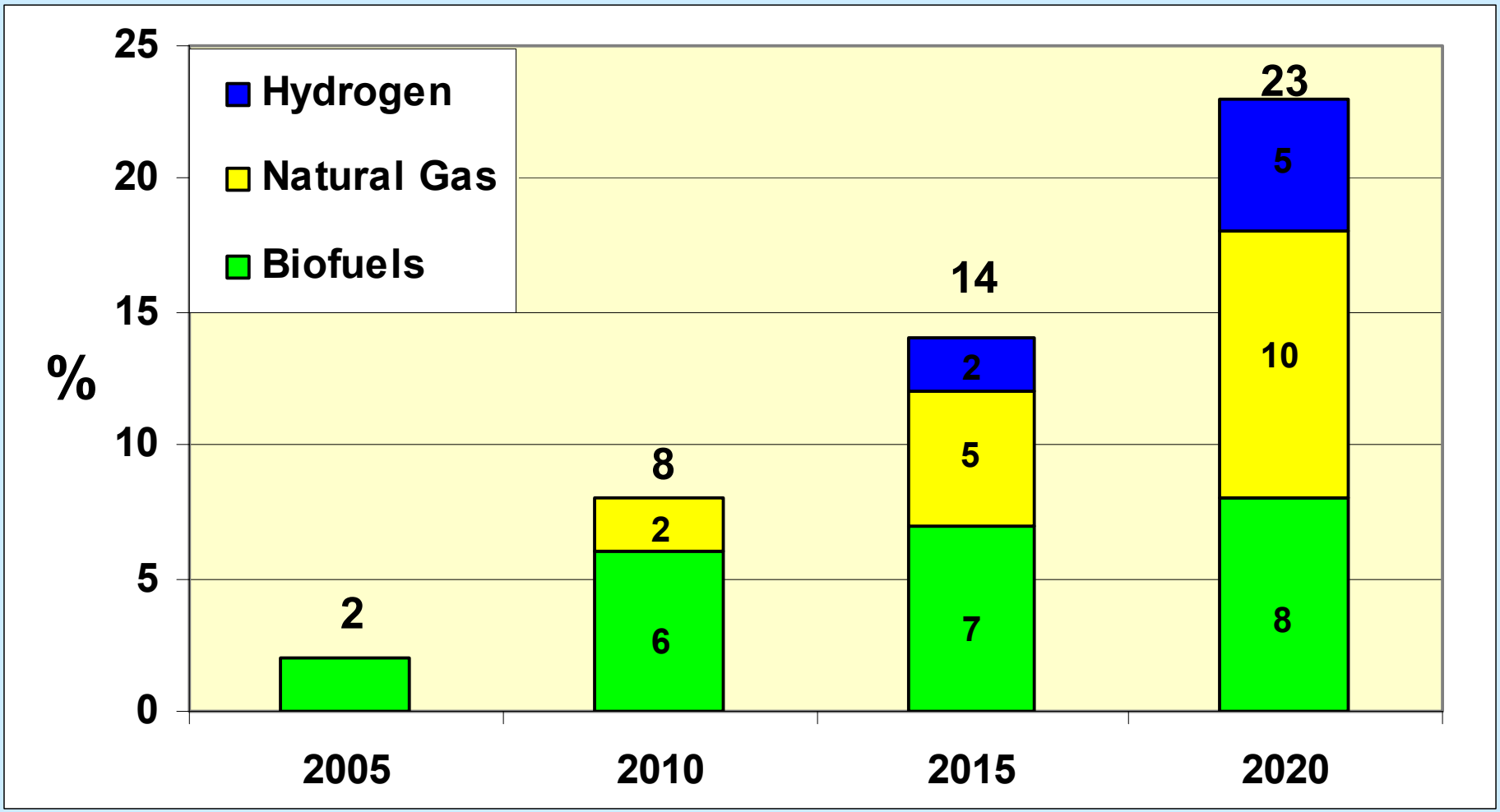
Alternative Motor Fuels Market Development Scenario



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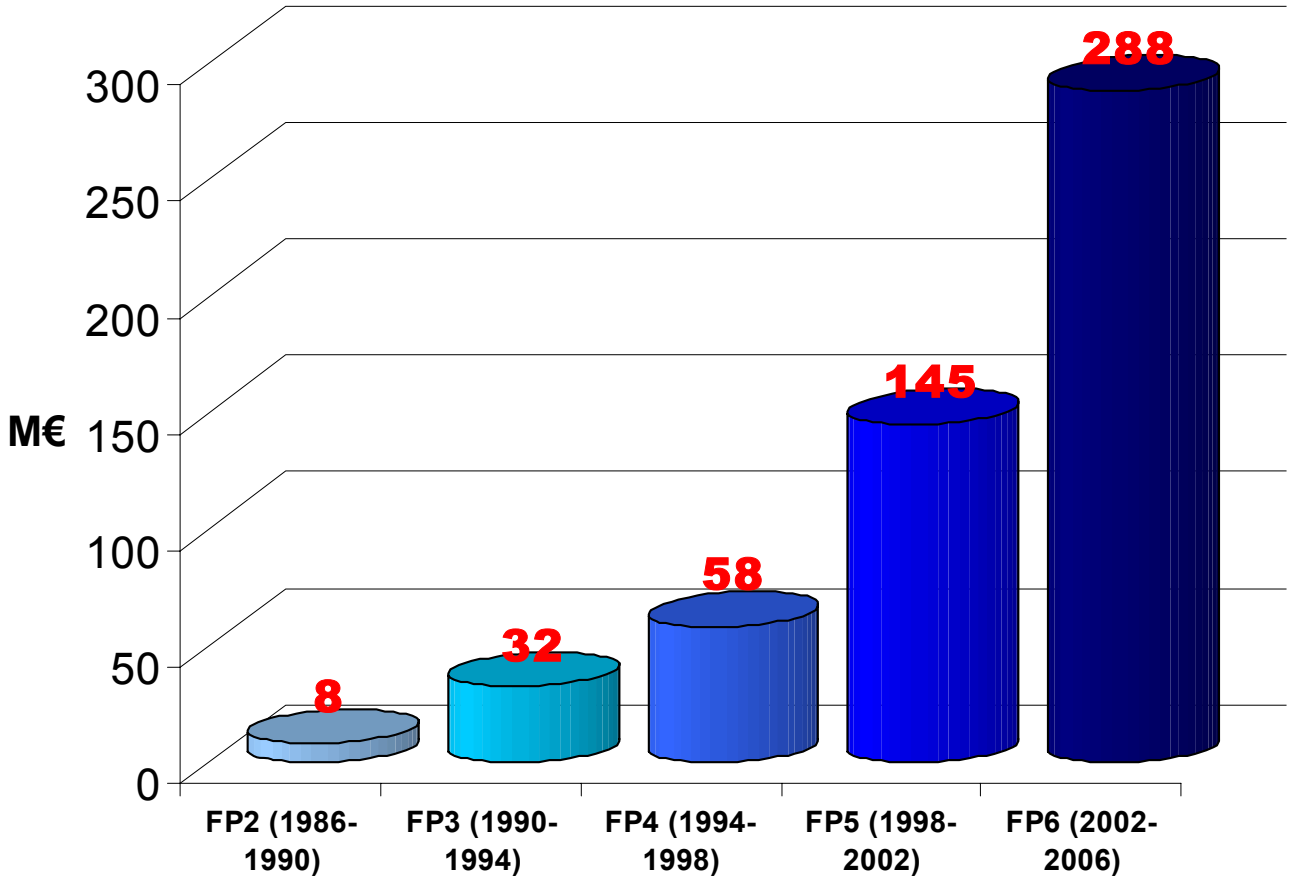
Sixth Framework Programme 2002-2006

- FP6 – Energy RTD and D supports main energy, environmental and industrial policy lines
- Short-medium / medium long term developments for conventional and hybrid ICE vehicles using oil derived fuels, NG, bio-fuels, hydrogen;
- RTD on clean and efficient fuel production, distribution
- FP6: Special emphasis to develop European Research Area
- Upstream RTD focusing on materials and process development, innovative drivetrain components and system integration,
- Downstream actions aimed at demonstrating clean and efficient new energy technology, combined with measures to promote deployment

EC Support to Fuel Cell and Hydrogen RTD in Framework Programmes



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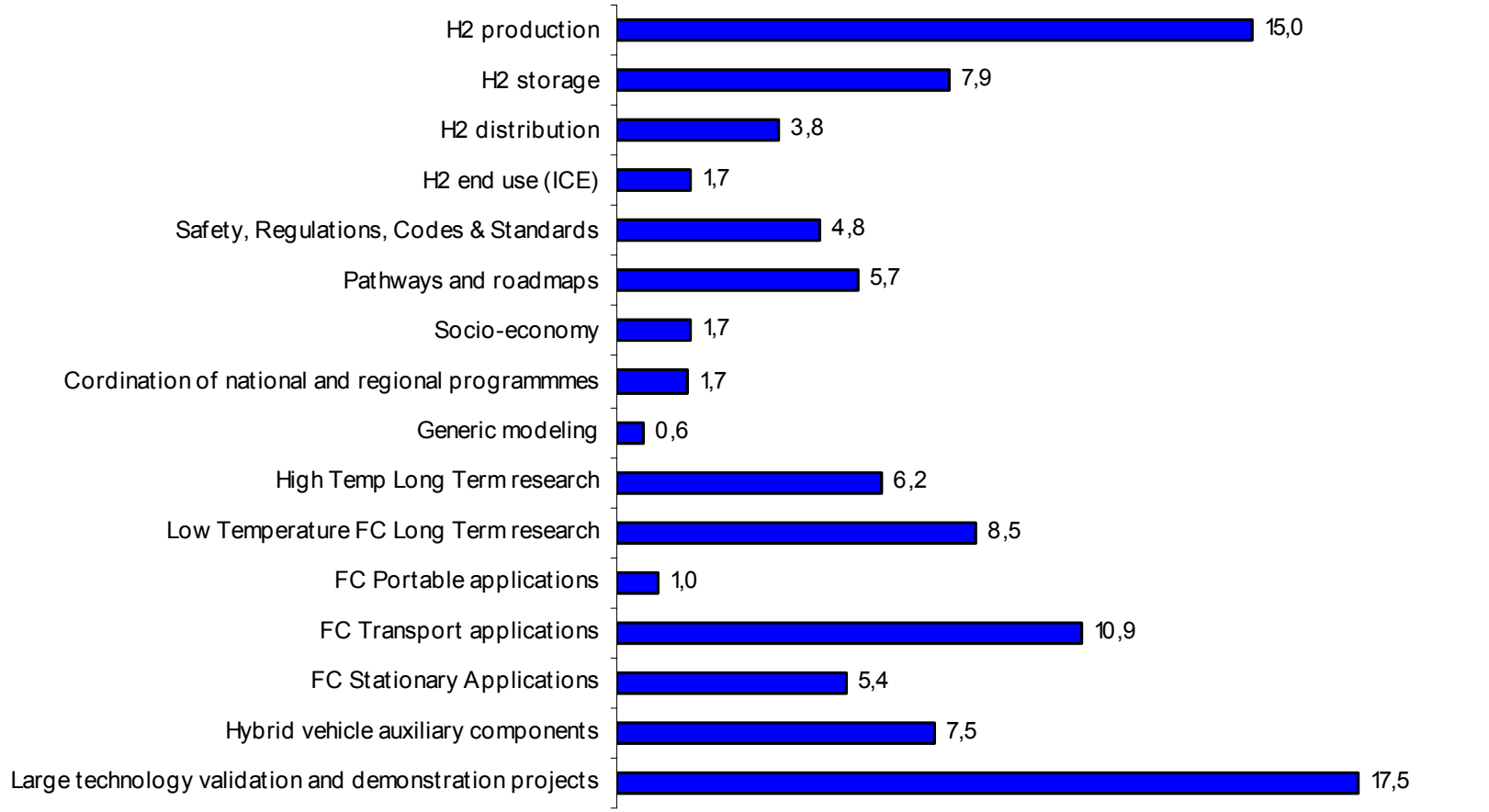
FP6 Budget Breakdown for H2/FCs
Total EC Contribution ~288 M€



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EU achievements in membranes and MEAs

MEA technology in the EU - status

- European Industry provides MEAs on commercial/pre-commercial basis for field tests, demonstration programmes and first commercial applications
- MEAs developed in-house, and through collaborative research between industry/research institute with national and EC-funding
- MEAs mainly based on currently commercially available perfluorinated sulfonic acid type membranes
- Approaches and activities towards high temperature membranes and MEAs and membranes based on new perfluorinated polymers, PBI/phosphoric acid, hybrid inorganic-organic membranes
- These polymers and membranes are currently used by MEA manufacturers and stack developers, as well as research institutes, mainly in small batches, as prototypes and in development products. Some developed through shared cost projects: FP5 "PEM-ED", "Optimerecell" …, FP6 FURIM

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EU achievements in membranes and MEAs

New approaches/new concepts

Objectives:

- operation between sub-zero and 130 °C for automotive application
- mechanical and chemical robustness
- independent of external humidification

✓ durable MEAs for high temperature (130 °C) based on inorganic-organic nanocomposite membranes, interpenetrating polymer networks, polymer blends

✓ membranes and MEAs based on a polymer and a solid non-extractable proton carrier

- ❖ broad temperature range
- ❖ resistant to contact with liquid water

developed in FP6 "autobrane"

Coordination of on-going activities on high temperature MEAs in Europe

"CARISMA" at negotiation stage

European SOFC programme

- Well integrated European SOFC R&D community by RealSOFC and SOFC600, involving most industrial stakeholders

- Harmonisation and standardisation of cell and stack testing procedures via FCTESTnet, FCTESqa in close cooperation with Real-SOFC and SOFC600

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Hydrogen via conventional routes- highlights

- **Kick-off of BP led demonstration project on 'decarbonised electricity' coupling H2 production from NG and CO2 storage for a 350 MW CCGT (Peterhead, Scotland)**

- **Develop technologies to reduce cost of CO2 capture to EU target of 20-30 €/tonn at 90% capture- Industrial application to NG fired 400 MWe CCGT (CACHET project)**

- **On site H2 production from gaseous and liquid feedstocks- development of a small-scale, fuel flexible H2 generator (target: PoP fuel processor prototype 10 Kg H2/day); emphasis on:**
  - ✓ reactor engineering, process and safety control
  - ✓ system integraion of reformers and further gas processing steps
  - ✓ separation membranes
  - ✓ novel, multi functional catalysts, sorption material and membranes

  (NEMESIS project)

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Alternative routes for H2 production

- **The « solar » European cluster:**
  - ✓ solar steam reforming- (**Solref)** development of 400 KW reformer
  - ✓ development of solar reactors (**Solhycarb)**- prototype (50 KW) for co-production of H2/C black from NG reforming
  - ✓ -water splitting via redox-pair based thermo-chemical cycles (target: building 100 KWth solar reactor plant based on previous succesful PoC- (regeneration cycles at 800-1000°C, up to 40 regeneration cycles)- a world record! (**Hydrosol** project)
  - ✓ -Exploring synergies between solar reactors and nuclear-based production with thermochemical cycles – basic research and concept definition **– (HYTECH** project)
- **Advanced electrolysers**
  - ✓ feasibility of SOEC electrolyser- **Hi2H2-** achievements- > 2 A/cm2 at HTE under thermoneutral voltage, and 3.6A/cm at 1.49V, a world record? 1000 hrs of operation on single cells without degradation
  - ✓ development of PEM electrolyser - **GENHYPEM –**, target 70% at 1 A/cm2, 1Nm3/h H2, >50 bars, 50 000 hrs lifetime, 25000 already achieved

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Alternative routes for H2 production

- **UPSTREAM research:**
  - ✓ linking molecular genetics and biomimetic chemistry to achieve RES H2 production- 1) photochemical water splitting; 2) photobiological hydrogen production: **SolarH**
  - ✓ blue-print for decentralised H2 production from biomass- development of a 2-stage bioprocess for the cost-effective production of pure hydrogen from biomass, (thermophilic fermentation and photofermentation) **Hyvolution**

Advanced 700 bar C-H_2 Storage

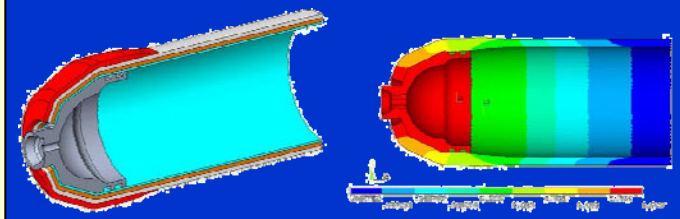
New 700 bar Type III&IV Vessels available

Nylon Liner : rotomolded, patented permeation barrier

Tank gravimetric energy density: 5,3 wt%

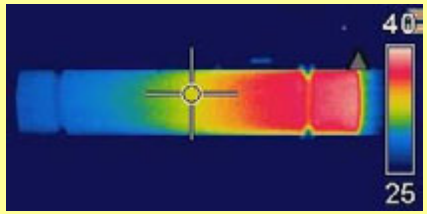
Seamless steel liner: mass production potentials

Thermoplastic vessel concept



700bar Filling Technology

High pressure filling components:
Coupling, breakaway system, linear valve

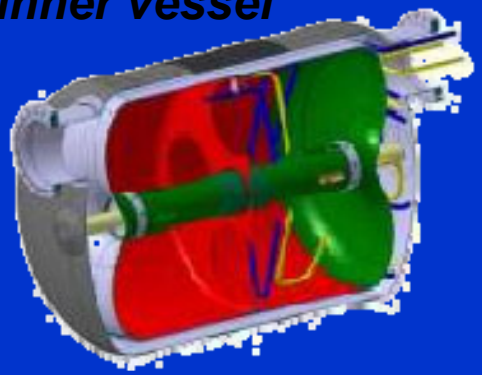


"Warm" and "cold" filling methods

Advanced L-H_2 Systems

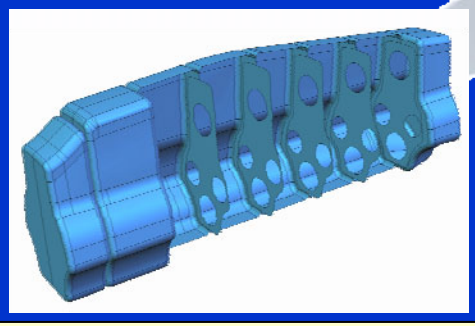
Lightweight Cryogenic Tank: Design and Manufacturing

Cylindrical L-H_2 tank: Composite outer jacket and inner vessel

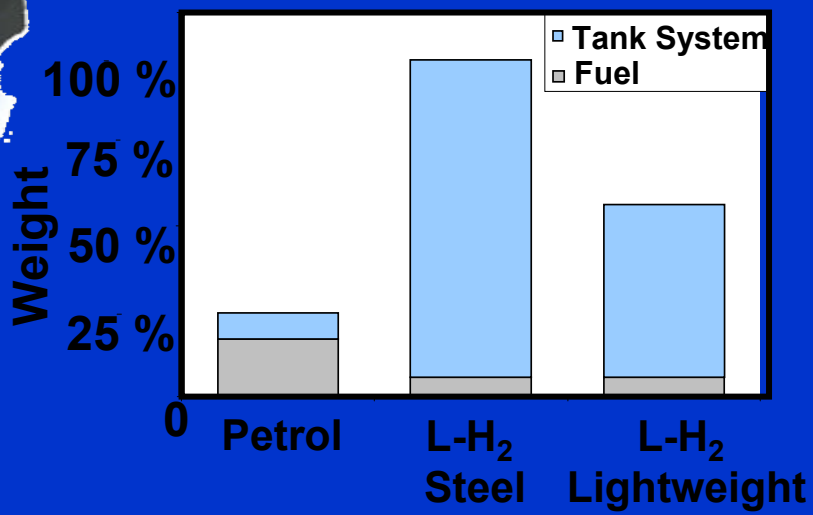


Manufacturing & pre-assembly process

Design options of a free-form L-H_2 tank



Weight reduction potentials



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H2 Safety and RCS - Highlights

- **Developing EU-harmonised set of codes for approval of H2 based systems:**
  - ✓ Fuel Infrastructure (including fuel vehicle interface) : Hyapproval ' handbook for approval of HRS in Europe – established
  - ✓ Stationary systems: HyPER (permitting guides for small stationary installations)- under negotiation
- **H2 safety (Hysafe NoE):**
  - ✓ HIAD database definition **Prototype accessible**
  - ✓ Successful initiation of the 1st Conference ICHS **(Pisa 2005)**
  - ✓ 4 CFD Benchmarks **Based on H2, large scale (industry relevant) experiments,**
  - ✓ H2 safety training: E-Academy – setting up of Europe-wide educational projects and development of first academy of H2 safety curriculum
  - ✓ 2 Internal sub-Projects : **InsHyde (internal releases in small confined spaces) HyTunnel (H2 safety in tunnels)**

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H2 Safety and RCS - Highlights

- **Safety of storage (Storhy project)**
  - ✓ assessment of modification of existing (EU) design test procedures (e.g. impact damage tests, fire engulfment tests)
  - ✓ investigation of a probabilistic safety approach for H2 storage requirements

- **Prenormative research :**
  - ✓ HarmonHy- EU roadmap towards harmonisation of technical standards and regulations (EU-wide and global)
  - ✓ Gap analysis on European standards in the EU internal market(CEN Mandate M/349)
  - ✓ A comprehensive set of fuel cell testing protocols (single cells, stacks and systems) for transport, portable and stationary applications established- (under FCTESTNET) protocols validation process started (FCTESQA)

"HYDROGEN FOR TRANSPORT"
(Demonstration Projects in FP6)

Buses

Cars

Mini:Transport

HYCHAIN hydrogenchallenge

PREMIA

Monitoring and Preparation of « Lighthouse projects»

Coordination action

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Building a Europe of Knowledge

Towards the Seventh Framework Programme (2007-2013)

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FP7: Technology Platforms (TPs)

- **Technology Platforms tasked with developing shared long-term vision**
  - ✓ Strategic Research Agenda
  - ✓ Deployment Strategy
- **Shared long term vision: investment climate more attractive**
- **Determine appropriate financial engineering to realise SRA and Deployment Strategy**
- **Building human capital : Analyse education and training requirements**
- **Encourage public debate on risks and benefits to facilitate technology acceptance**
- **European Hydrogen and Fuel Cell Technology Platform !**

  https://www.hfpeurope.org/

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Key Assumptions on Hydrogen and Fuel Cell Applications for a 2020 Scenario

	Portable FCs for handheld electronic devices	**Portable Generators & Early Markets**	**Stationary FCs** Combined Heat and Power (CHP)	**Road Transport**
EU H2/ FC units sold per year projection 2020	~ 250 million	~ 100,000 per year (~ 1 GW_e)	100,000 to 200,000 per year (2-4 GW_e)	0.4 million to 1,8 million per year
EU cumulative sales projections until 2020	n.a.	~ 600,000 (~ 6 GW_e)	400,000 to 800,000 (8-16 GW_e)	n.a.
EU Expected 2020 Market Status	**Established**	**Established**	**Growth**	**Mass market roll-out**
Average power FC system	15 W	10 kW	3 kW (Micro CHP) 350 kW (ind. CHP)	
FC system cost target	1-2 €/ W	500 €/kW	2.000 €/kW (Micro) 1.000-1.500 €/kW	< 100 €/kW (@ 150.000

Budget for FP7

- Commission proposal for Inter-Institutional Agreement on Financial Perspectives 2007-13
  - ✓ **47.8 billion euro (2004 prices)**

- Proposed agreement with Parliament and Council, 4 April:
  - ✓ **Additional 300 million euro (2004 prices)**

⇒ **Overall budget ~ 54 billion euro (current prices)**
  - ✓ **~ 60% increase compared to FP6**
  - ✓ **Only part of overall budget (~60%) will be allocated to specific programme on « collaborative » research**
  - ✓ **Allocations also to Specifc Programmes on people, ideas, capacities (infrastructure), Commission Joint Research Centre**

FP7 (2007-2013)

'*Cooperation*' budget breakdown per theme as proposed by the Commission - subject to revision

Specific Programme Co-operation = collaborative RTD

~60% total FP budget

9 Themes within Co-operation Specific Programme

Theme	Budget Breakdown (% of total)
1. Health	18.7
2. Food, agriculture and biotechnology,	5.5
3. Information and communications tech.	28.5
4. Nanotechnologies, materials and production	10.9
5. Energy	6.6
6. Environment, including climate change	5.7
7. Transport, including aeronautics	13.4
8. Socio-economic sciences and humanities	1.8
9. Security and space	8.9

Subject to revision!!!

FP7 – Proposed Topics in Energy

- Hydrogen and fuel cells
- Energy savings and energy efficiency
- Renewable electricity generation
- CO2 capture and storage technologies for zero emission power generation
- Renewable fuel production
- Clean coal technologies
- Renewables for heating and cooling
- Smart energy networks
- Knowledge for energy policy making

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FP7 Timetable

Next steps (indicative):

June 2006	Common Position of the Council
July 2006	Second reading / European Parliament
Oct./Nov. 2006	Adoption
Dec. 2006	First calls under FP7
Feb 2007	Launch conference (Brussels)

NEW for FP7 - Joint Technology Initiatives

The JTI is a new **management structure** that will allow a more efficient **organisation of the RTD&D** resources in Europe in fields of major European **public interest**. It will be **industry-led** and will have the **necessary critical** mass in terms of level of activity, excellence and potential for innovation.

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JTI concept and values

- Implements in an effective and efficient manner the Integrated Strategy for research and deployment developed in the Technology Platforms
- It is a Public-Private-Partnership with an appropriate governance and management structure (avoiding conflicts of interest)
- Envisages strong industrial participation
- Supporting a European Research Area (ERA)
- Developing outreach at international level
- Capitalising on FP5 and FP6

Translating the HLG *Vision Report* into a H2/FC JTI

- **High Level Group** H2 and FCs (2002-2003) - Vision report : "*Hydrogen energy and Fuel Cells – A vision of our future*"
- European Hydrogen and Fuel Cell Technology Platform (HFP) involving main stakeholders - January 2004
- Elaboration of two key foundation documents: "*Strategic Research Agenda*" and "*Deployment Strategy*" – *Endorsed in March 2005 at Platform General Assembly*
- *Strategic Overview* of the above 2 documents – June 2005
- FP7 **(2006 - 2013)** –Hydrogen and Fuel Cells *Joint Technology Initiative*

Hydrogen and Fuel Cell JTI

Four broad themes identified :

- **European fuel cell development programme** – focussed R&D programme with key milestones/ quality gates
- **Sustainable hydrogen supply programme** – accelerated development of the critical technologies of hydrogen production, storage and distribution
- **Lighthouse demonstration programme** – phased approach, with stepwise improvements in technologies and increasing number of sites and demonstrators
- **Market framework preparatory activities (cross-cutting)** – proactively fostering business opportunities and early market applications in Europe and removing non-technical barriers (transition pathway and infrastructure build-up analysis)
- **Hydrogen and Fuel Cell Technology Platform :**
  - ✓ developing concepts for implementable actions - Interim Implementation Plan due June 2006
  - ✓ exploring options for JTI governance

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Some Key Issues

- **Future perspective is mix of transport fuels, conventional fossil fuels, liquid bio-fuels and blends, NG, hydrogen**
- **Actual market shares for H2 FC applications proving difficult to predict – regional variations and competing demands from distributed stationary CHP, also in case of bio-mass, bio-refinery**
- **In reducing dependence on imported oil as transport fuel:**
  - ✓ Need transition pathways which do not increase energy / environmental burden, but demonstrably lead to substantial long term reductions (on lifecycle basis)
  - ✓ Transition strategies for these alternative fuels need more in-depth scenario analysis and infrastructure build up analysis to ensure compatibility and long term « bankability »

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Some Key Issues

- A key issue for transition is centralised v localised H2 production (small and large scale SMR)
- Replacement of vehicle fleet is the biggest cost hurdle, not infrastructure investment;
- Big issue for OEMs / energy companies is how to realise commercially viable transition strategies, avoiding stranded investments in production and fuelling infrastructure
- Major OEMs looking to functional and cost benefits of H2 and FCs
- On-board H2 storage currently biggest barrier, but some interesting new solid state H2 storage technologies,
- Need more in-depth transition strategy analysis!
- Interest in developing international co-operation to address these issues
- EU actively supporting IPHE !

Staying informed

Energy Research web site and Energy Helpdesk:
http://europa.eu.int/comm/research/energy/index_en.html
rtd-energy@cec.eu.int

Energy Policy
http://europa.eu.int/comm/energy/index_en.html

Calls for proposals
http://fp6.cordis.lu/fp6/calls.cfm

CORDIS

RESEARCH

Towards Seventh Framework Programme
http://europa.eu.int/comm/research/future/index_en.html

Newsletter, Information days and similar events, conferences
http://europa.eu.int/comm/research/energy/pdf/renews4.pdf
http://europa.eu.int/comm/research/energy/gp/gp_events/action/article_2790_en.htm

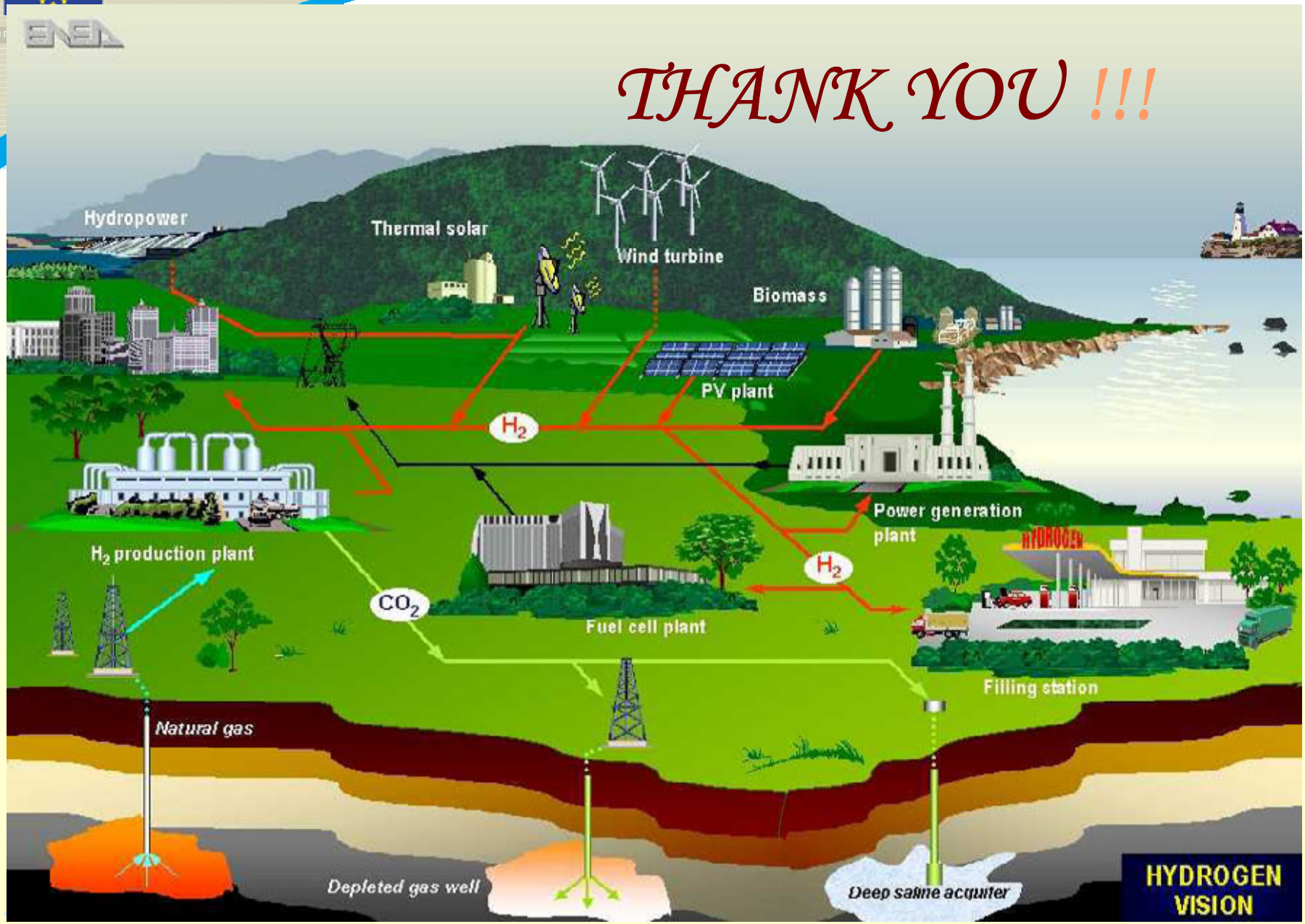
RENEWABLE ENERGIES FOR EUROPE
RESEARCH IN ACTION

European Hydrogen and Fuel Cell Technology Platform
www.HFPeurope.org

Joint Research Centre
http://www.jrc.cec.eu.int

JRC

THANK YOU !!!


Hydropower
Thermal solar
Wind turbine
Biomass
PV plant
H_2
Power generation plant
H_2 production plant
CO_2
Fuel cell plant
H_2
Filling station
Natural gas
Depleted gas well
Deep saline acquifer
HYDROGEN VISION

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Additional Information on EU Energy Policy Context

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Main EU Energy Policy Measures

DOCUMENT	Main messages
WHITE PAPER ON ***RENEWABLE ENERGY SOURCES*** (RES) (1997)	**12% final total energy** consumed in the EU from renewable origin in **2010**
GREEN PAPER ON ***SECURITY OF ENERGY SUPPLY*** (2000)	Outlines EU **long-term energy strategy** to rebalance its supply and demand policy. Priority to **fight against global warming**: new and renewable energies are the key to change.
DIRECTIVE ON ***PROMOTION OF ELECTRICITY FROM RES*** (2001)	**21% total electricity** in the EU from **RES** en **2010**
DIRECTIVE ON ***ENERGY PERFORMANCE OF BUILDINGS*** *(2002)*	No specific objectives for RES but big impulse to the **integration of RES in buildings**
DIRECTIVE ON ***COGENERATION*** *(2004)*	No specific objectives for RES but big impulse to the **use of RES in cogeneration**
DIRECTIVE ON ***BIOFUELS FOR TRANSPORT*** (2003)	**6% of automotive fuels** in the EU will be **biofuels** in 2010
PROPOSAL FOR DIRECTIVE *ON* ***ENERGY SERVICES***	Provide a framework to promote the market both for **energy services** and for **energy efficiency** measures in general in major energy end-use sectors
GREEN PAPER ON ***ENERGY EFFICIENCY: "Doing more for less"*** (2005)	Save **20% of energy consumption** by **2020** (i.e. **€60 billion** of EU energy bill) in a cost effective way. This will help EU to achieve the goals of the **Lisbon Strategy** and to meet its **Kyoto** commitments.

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Information on Selected EU Hydrogen and Fuel Cell Projects

FP6 Projects on H2 and fuel cells

HySafe

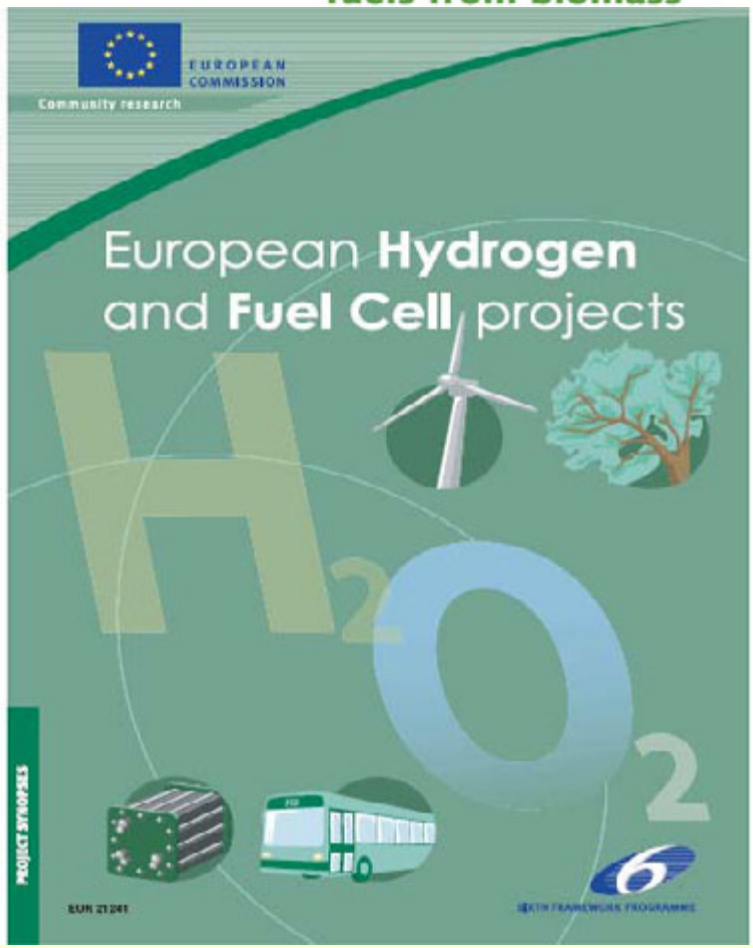
STORHY

FURIM

HyICE

HyTRAN

CHRISGAS
fuels from biomass



HyWays
Hydrogen Energy in Europe

FELICITAS

NATURALHY

Roads2

HyCom

NESSHY

REAL SOFC

FURIM: Further Improvement and System Integration of High Temperature Polymer Electrolyte Membrane Fuel Cells

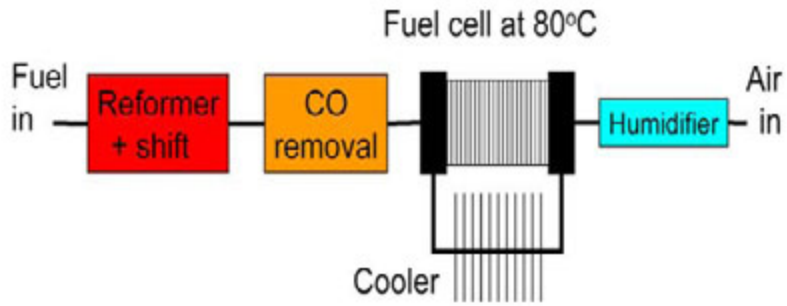
Overall Objective:

Developing a High Temperature Membrane Electrode Assembly for a FC Stack in order to overcome problems of water management, CO poisining and large cooling devices.

Total cost: ~ 6.2 M€
EC contribution: ~ 4 €
Duration: 48 months
Coordinator: Denmark technical University
Project web site*: http://www.furim.com*
Consortium: 13 partners comprising important actors of polymer development

Specific objectives

- A **2kWel HT-PEMFC** stack operating in a temperature range of **120-220°C**.
- **Single cell** performance: **0.7 A/cm² at 0.6 V**.
- Durability: > **5,000 hours**.
- A **hydrocarbon reformer** and a **catalytic burner** integrated with the stack.



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HyTRAN

Hydrogen and Fuel Cell Technologies for Road Transport

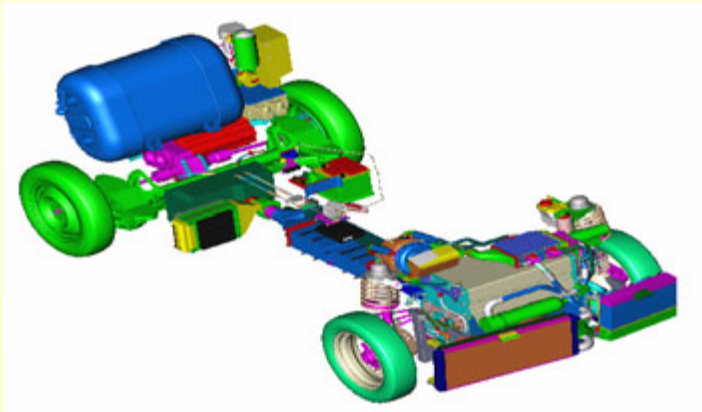
Main objective:

Development of two automotive fuel cell systems for powertrain and APU's

Core technologies:

- ☞Innovative **80 kW direct hydrogen** stack with strong weight and volume reduction, increased efficiency, durability and start-up time, and with innovative MEAs
- ☞Innovative **5 kW reformate stack**, introducing novel catalysts and electrode structures with very high CO concentrations allowed
- ☞Variable **displacement compressor**
- ☞ Innovative **humidification/dehumidification**
- ☞ **Heat exchanger** and radiator customised for the application
- ☞ **Micro-structured** diesel steam reformer and gas purification units

Instrument: Integrated Project
Project total cost: 16.8 M€
Maximum EC contribution: 8.8 M€
Coordinator: Volvo
Partners: CRF, Renault, VW, DC, DAF, Nuvera, JM; Opcon, Tenneco, WPT, Adrop, RWTH Aachen, ECN, Politecnico di Torino, PSI, IMM, ICSTM, Envipark
Project web site :www.hytran.org



Real*ising Reliable, Durable Energy Efficient and Cost Effective* ***SOFC*** *Systems*

Main goals:

Materials (ceramics, steels)
- durability, low ageing, tolerant to fuel & air impurities
- thermal and redox cycling
- cost reduction

Cells
- high power density vs. reduction of operating T
- improved mechanical properties
- industrial manufacturing processes

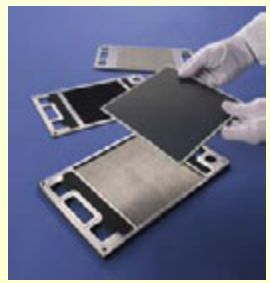
Stacks
- thermal cycling (sealing materials)
- weight and volume reduction

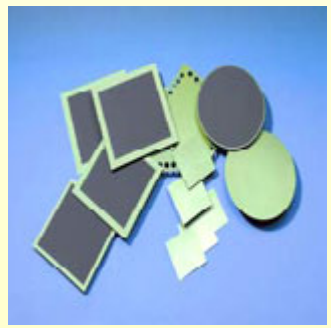
Manufacturing
- cost efficient manufacturing of all components

Systems
- cost reduction
- efficient Balance of Plant (BoP) components
- simplification / integration / packaging

Modelling
- understanding of E-M and thermodynamical processes
- prediction of cell, stack and system performance
- understanding of ageing processes

Total cost: 18,2 M€
EC contribution: 9M €
Duration: 48 months
Coordinator: FZJ Germany
Web site: http://www.real-sofc.com
Consortium: 26 partners comprising most of the important actors in European SOFC technology





BICEPS: *Biogas Integrated Concept a European Program for Sustainability*

Objective:

Bringing the **next generation** of cost-competitive renewable energy-technologies to the European market and optimizing the **production of electricity from biogas**

Main Targets:

- Development of a purification- / media-supply-unit suitable for all kind of biogases (digester, landfill…)
- **Development** of **1-MW Molten** Carbonate Fuel Cells (**MCFC**) for use of biogases
- **Demonstration of two 1 MW MCFC-systems** operating on biogases (landfill and sewage gas)

Core Technologies

Purification of biogas	from BASF
1 MW MCFC Solution	from AFCo and MTU-CFC
Engineering	from NAVANTIA

The two main European developers of MCFC are working together

Project (IP) under negotiation

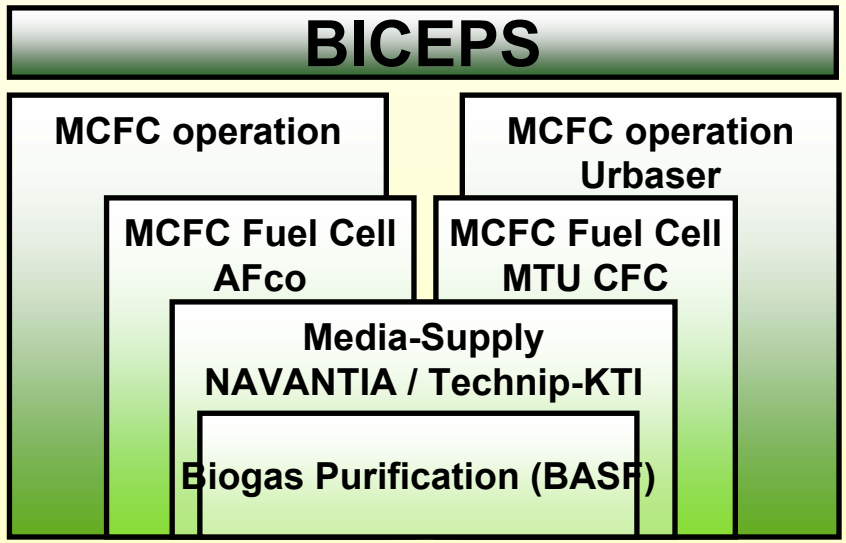
Coordinator: BASF Germany

Type: Integrated Demonstration

Total cost: ~17.5 Mio. € (6.9 from EC)

Duration: 3 Years (2006 – 2008)

Consortium: 10 partners



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Project

NATURALHY

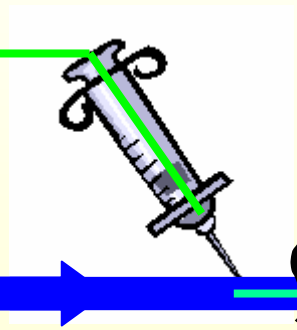
Socio-economic & LCA

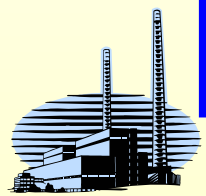
Dissemination (in cooperation with *HYSAFE*)

Collaboration with *HYWAYS* (roadmap development)

H2-production

Natural gas production





Full H2-area

Durability

Integrity

Safety

Standards and norms

Performance

H2-Membranes

Advanced 700 bar C-H_2 Storage

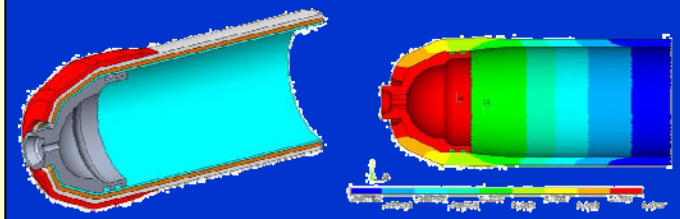
New 700 bar Type III&IV Vessels available

Nylon Liner : rotomolded, patented permeation barrier

Tank gravimetric energy density: 5,3 wt%

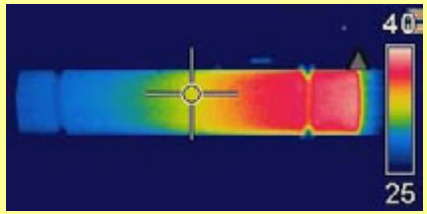
Seamless steel liner: mass production potentials

Thermoplastic vessel concept



700bar Filling Technology

High pressure filling components:
Coupling, breakaway system, linear valve

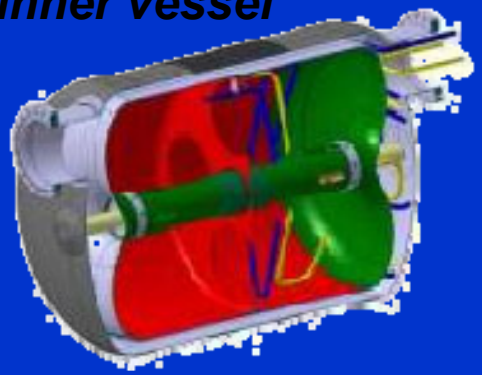


"Warm" and "cold" filling methods

Advanced L-H_2 Systems

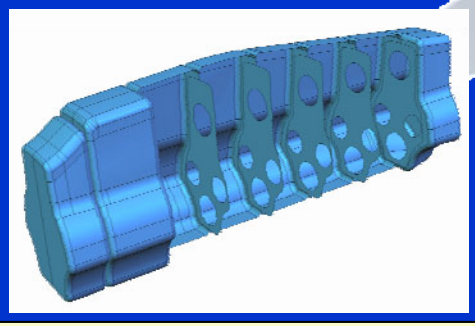
Lightweight Cryogenic Tank: Design and Manufacturing

Cylindrical L-H_2 tank: Composite outer jacket and inner vessel

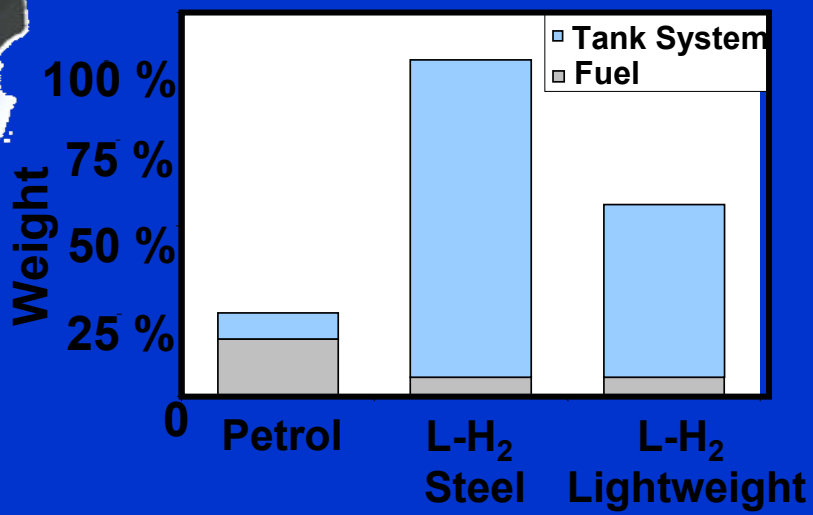


Manufacturing & pre-assembly process

Design options of a free-form L-H_2 tank



Weight reduction potentials



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FP7

FP 6: GREEN

State of the Art

- *Port Gas Injection*
- *Partial HCCI*
- *First steps variability*
- *BMEP < 25 bar*
- *Open loop control*

Improved HD Gas Engines
(including engine validator)

Advanced Flexibility
(including engine validator)

New Combustion System
Closed loop emission control

Very High BMEP
(including engine validator)

HD and Rail powertrain
- *Intelligent flexible*
- *new combustion*
- *model based closed loop controlled*

Related Issues:

Bio-fuels
Designed Diesel
NaturalGas Methane
...
Intelligent Vehicle Management
Friction
Transmission
Aftertreatment
...