The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA
International Atomic Energy Agency

2245-2

Joint ICTP-IAEA Advanced School on the Role of Nuclear Technology in Hydrogen-Based Energy Systems

13 - 18 June 2011

EU activities related to H2 economy

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EU activities related to H2 economy

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Hydrogen is needed for deep decarbonisation – EU enabling efforts

Elements of the hydrogen chain

- production
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- transmission and distribution infrastructure

Main end-use interest area: public transport

Research needs in hydrogen and fuel cell technologies

European Union Efforts

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- Research, Development and Demonstration (RDD)
    - Fuel Cell and Hydrogen Joint Undertaking (FCH-JU)
    - Joint Research Centre of the European Commission (JRC)

Additional slides

Recap from 1st presentation

H2 is needed for deep decarbonisation

The hydrogen economy is a compelling vision:

- It provides an abundant, clean, secure and flexible energy source
- Its elements have been demonstrated in the laboratory or in prototypes

However . . .

- It does not operate as an integrated network
- It is not yet competitive with the fossil fuel economy in cost, performance, or reliability
- It will take decades to realize the full potential of a hydrogen economy

H2 versus incumbent technologies

Fossil fuels	Hydrogen
cheap	no
well working	not proven
vested interests	no
regulations existing	starting
markets	small till now
consumers familiarity	no
educational programs	limited

- far from optimized technologies need to compete with efficient, well functioning energy (and transport) systems
- technological as well as non-technological barriers

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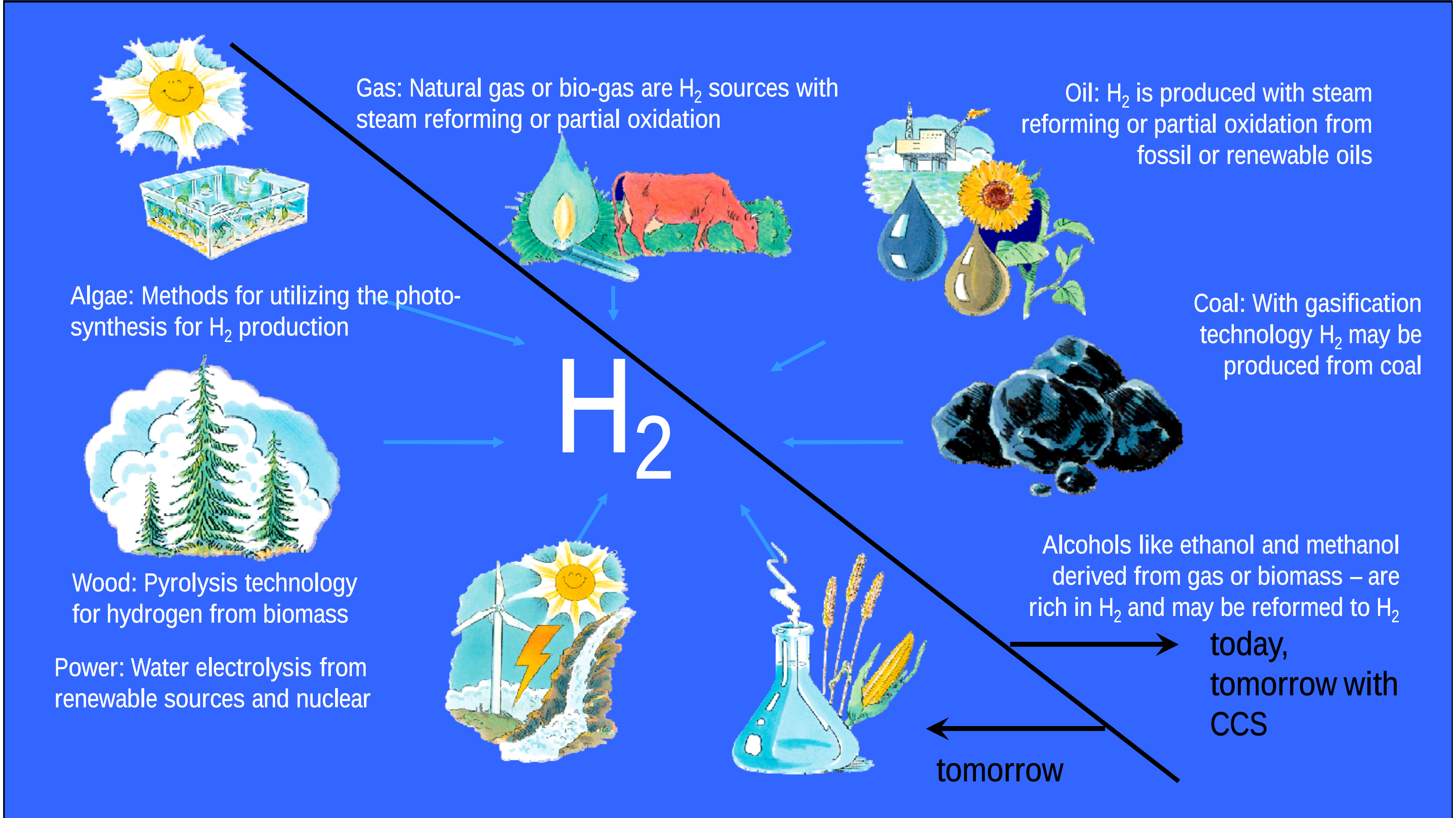
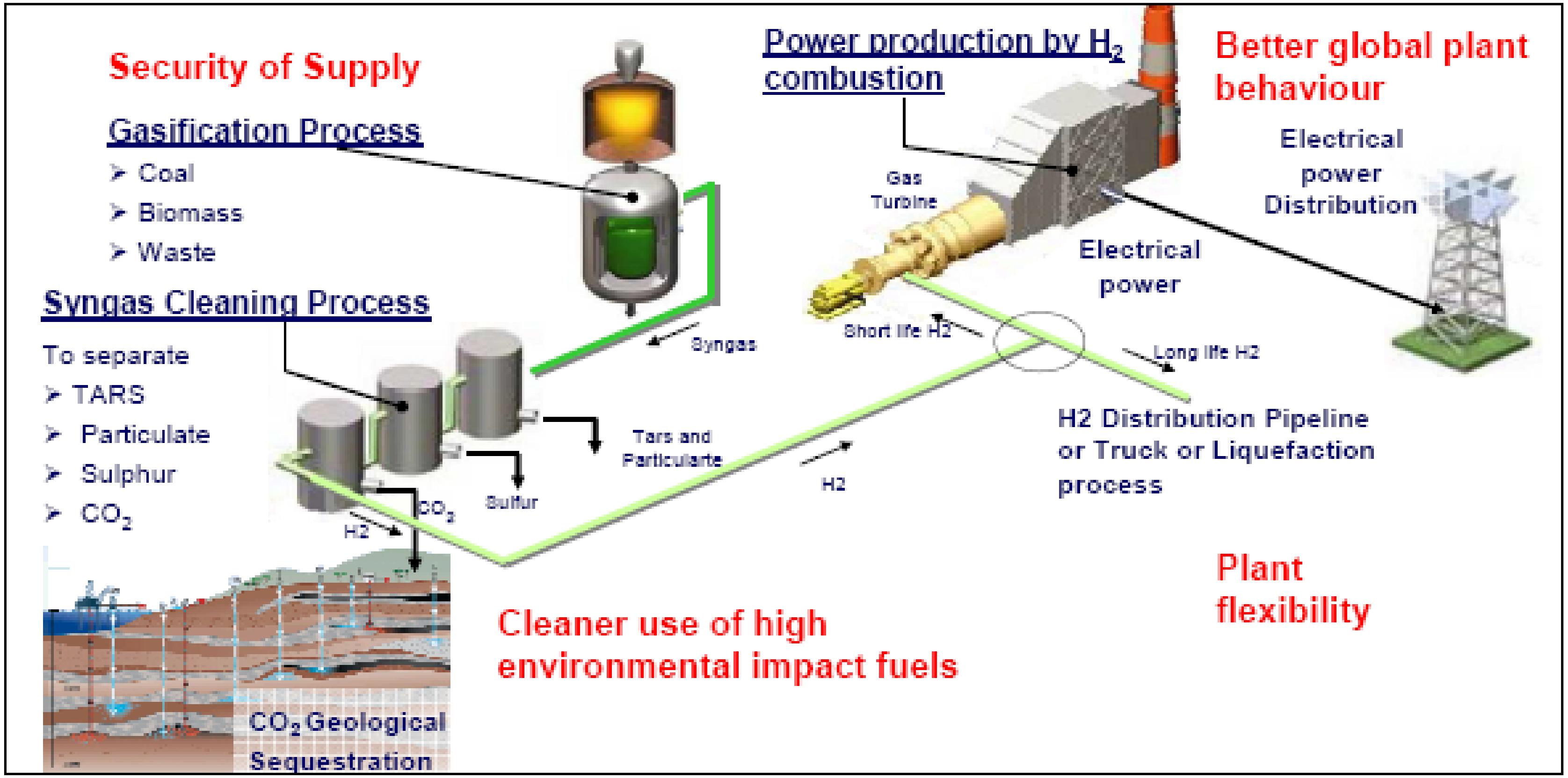
Hydrogen Production



Source: Hydro

H2 from fossil fuels: *with CCS*

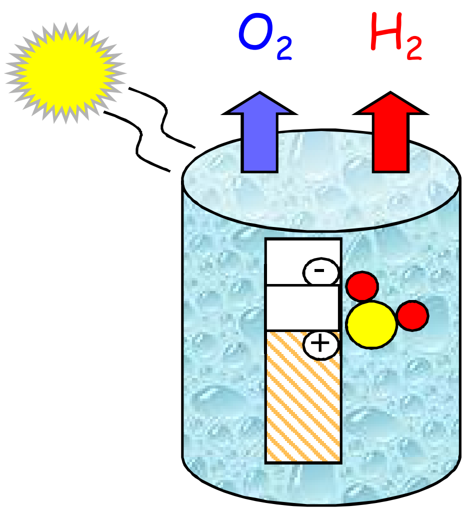


electricity and hydrogen are complementary energy carriers:

electron-based and proton-based

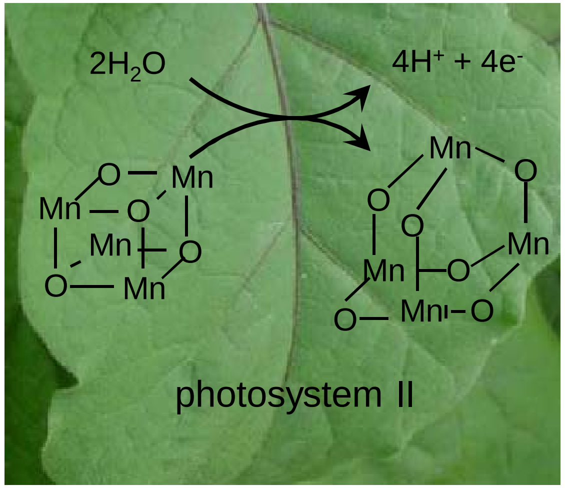
“ hydricity”

Hydrogen production tomorrow: splitting H_2O



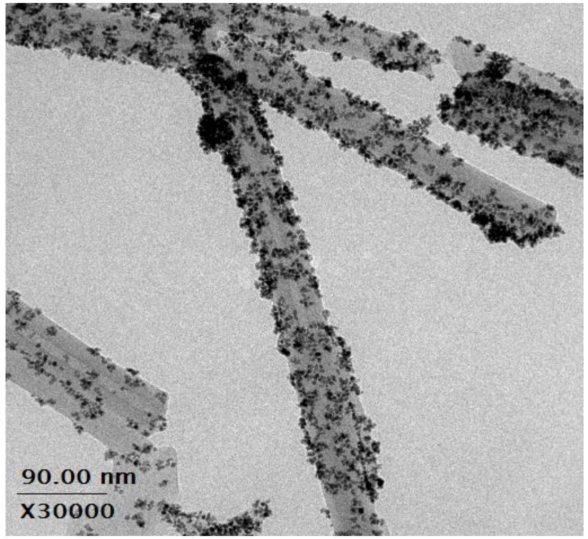
solar electrolysis

- functional integration at the nanoscale
- molecular transfer of energy and charge
- 6-18% efficiency in laboratory



bio-inspired nanoscale assemblies

- inexpensive Mn catalyst
- room temperature
- “one molecule at a time”



porphyrin nanotube hybrids

- porphyrin: harvests light
- Pt, Au: catalyst & electrodes assembly splits water in sunlight

nanoscale hydrogen production

source: Crabtree, DoE - BES

Hydrogen storage

Advantages

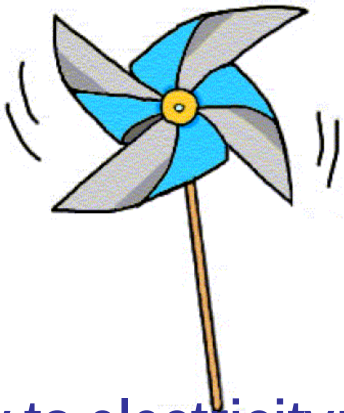
- high gravimetric energy density
- implementable from kW to multi-MW
- charge rate, discharge rate and storage capacity are independent variables
- potential to supply road transportation
- environmentally benign operation characteristics

Disadvantages

- low volumetric energy density
- costs
- low round-trip efficiency

Hydrogen storage for stationary applications

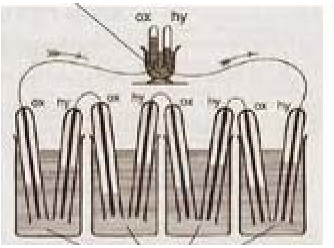
energy storage for intermittent renewable energy sources



Electrolyser

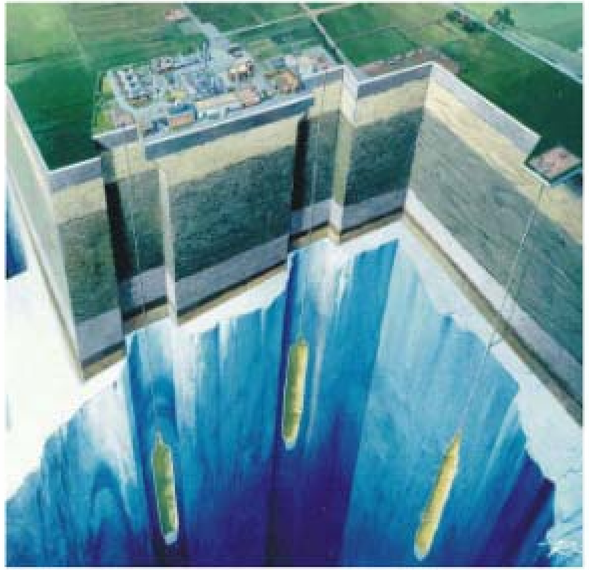
Storage

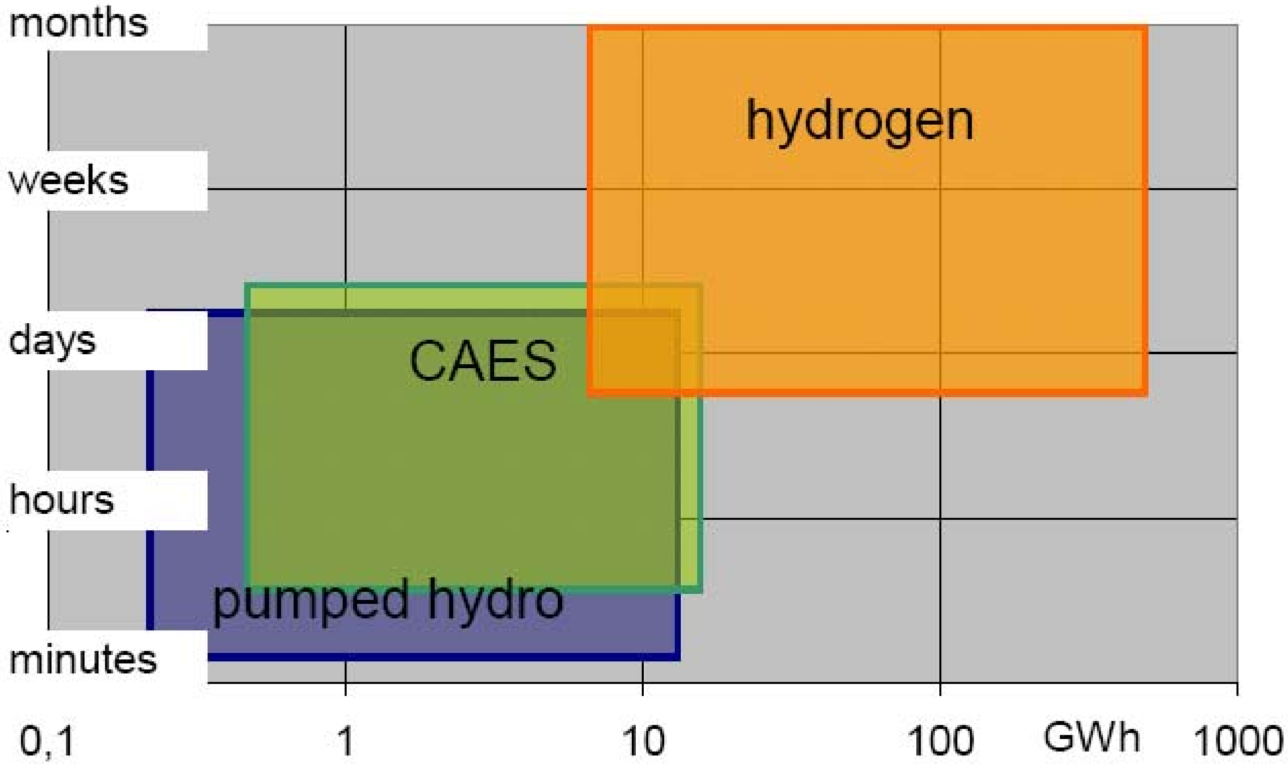
Fuel Cells



from electricity to electricity:
low round-trip efficiency –
incremental technology improvements

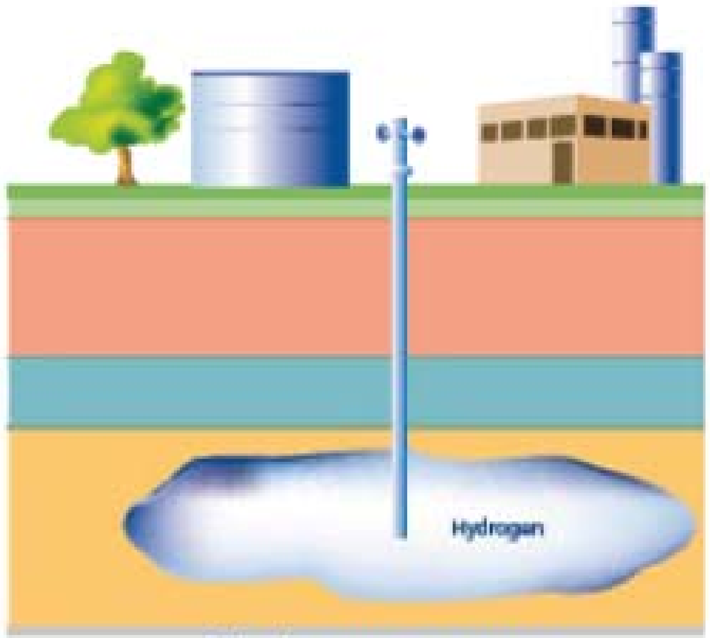
long term energy storage





Source: Crotogino et al. WHEC 2010

Bulk hydrogen storage



H_2 storage cavern

Salt cavern hydrogen storage

- proven technology
- about 60 times the electricity equivalent in the same volume as adiabatic compressed air storages
- bulk storage for long-term balancing

stored hydrogen can be

- re-electrified with fuel cells and combined cycle gas turbines
- used as feedstock in the chemical industry
- distributed via pipeline or as liquefied hydrogen to automotive end users

Automotive hydrogen storage options

Physical Storage

Compressed

„CGH_2*“

source: Dynetek

1kg - 6kg

single or multi-bottle pressure vessel

Demonstration level

Cryo-compressed

„CcH_2*“

source: BMW

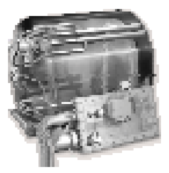
4.5kg - 12kg

insulated cryogenic pressure vessel

In prototype demonstration

Liquid

„LH_2*“



source: BMW

7.5kg - 12kg

insulated conformable or cylindrical cryotank

Demonstration level

Solid storage

Hydrides

- „metallic“
- „chemical“
- „organic“

Adsorption

- „activated carbon“
- „MOFs“
- „Zeolith“

Research level!

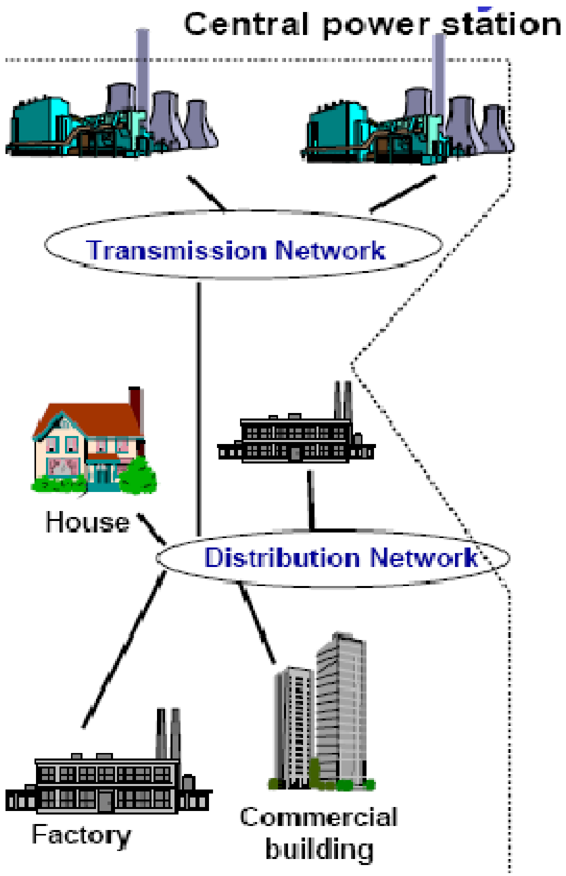
No existing solid storage system fulfills all automotive requirements yet

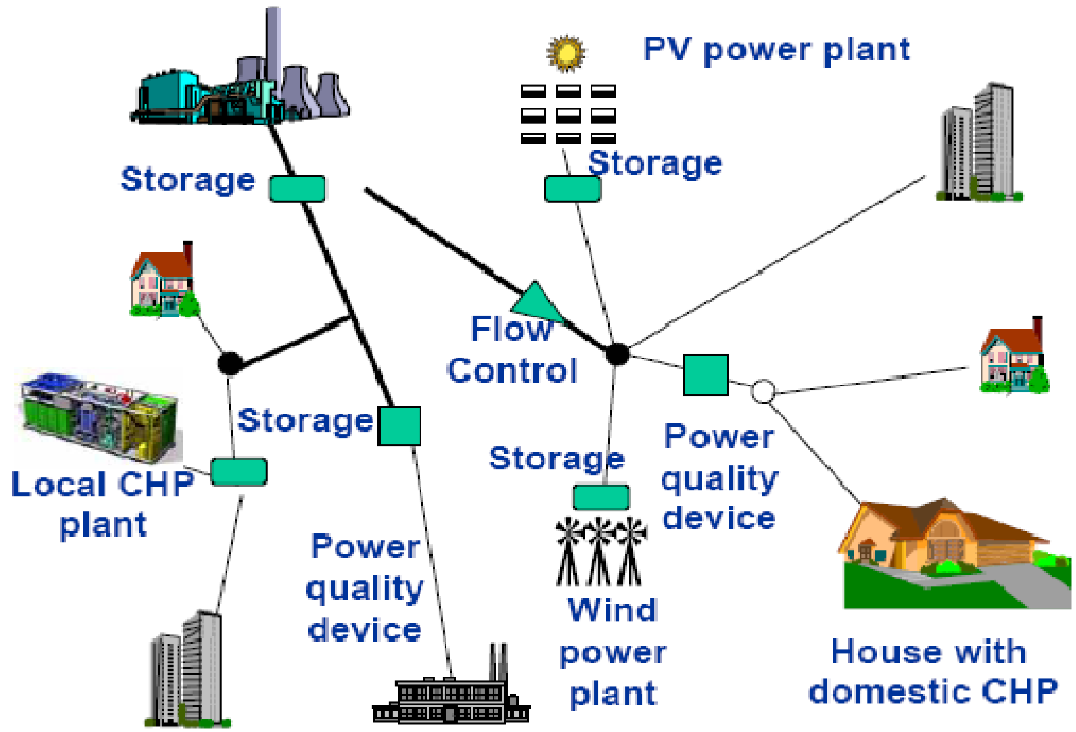
*) CGH_2 := Compressed Gaseous Hydrogen (700bar)
CcH_2 := Cryo-compressed Hydrogen (13bar - 350bar)
LH_2 := Liquid/Liquefied Hydrogen (1bara bis ca. 10bara)

T. Brunner, StorHy Final Event, 2008

Changing energy landscape

now → future





- *distributed generation with fully integrated network management*
- *from consumers to "prosumers"*

Hydrogen transmission and distribution

Energy transportation infrastructure (typcial sizes installed)	Energy transmission capacity
Oil pipeline (1 million barrel per day)	73 GWh/h (thermal)
Natural gas pipeline (30 billion Nm³/yr)	38 GWh/h (thermal)
High voltage direct current transmission lines (HVDC) (53 TWh/y)	6 GWh/h (electric)
Hydrogen pipeline (with the diameter of a natural gas pipeline) (79 billion Nm³/yr)	27 GWh/h (thermal)
Hard coal transport per ship from South Africa to Germany (4 TWh/yr)	0.5 GWh/h (thermal)

Table: Options for energy transport (LBST)

Source: EHA

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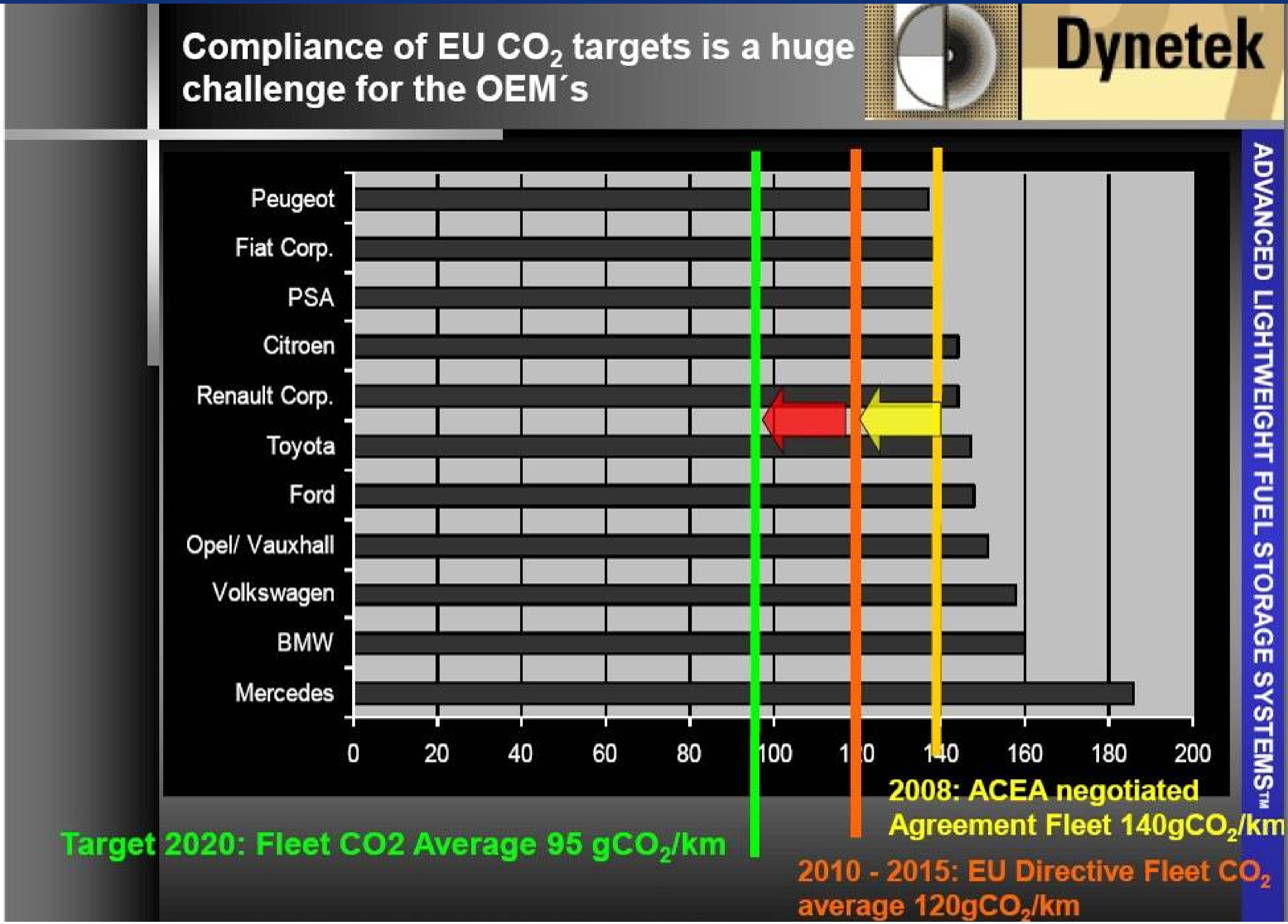
Additional slides

Transport (and distribution) of hydrogen

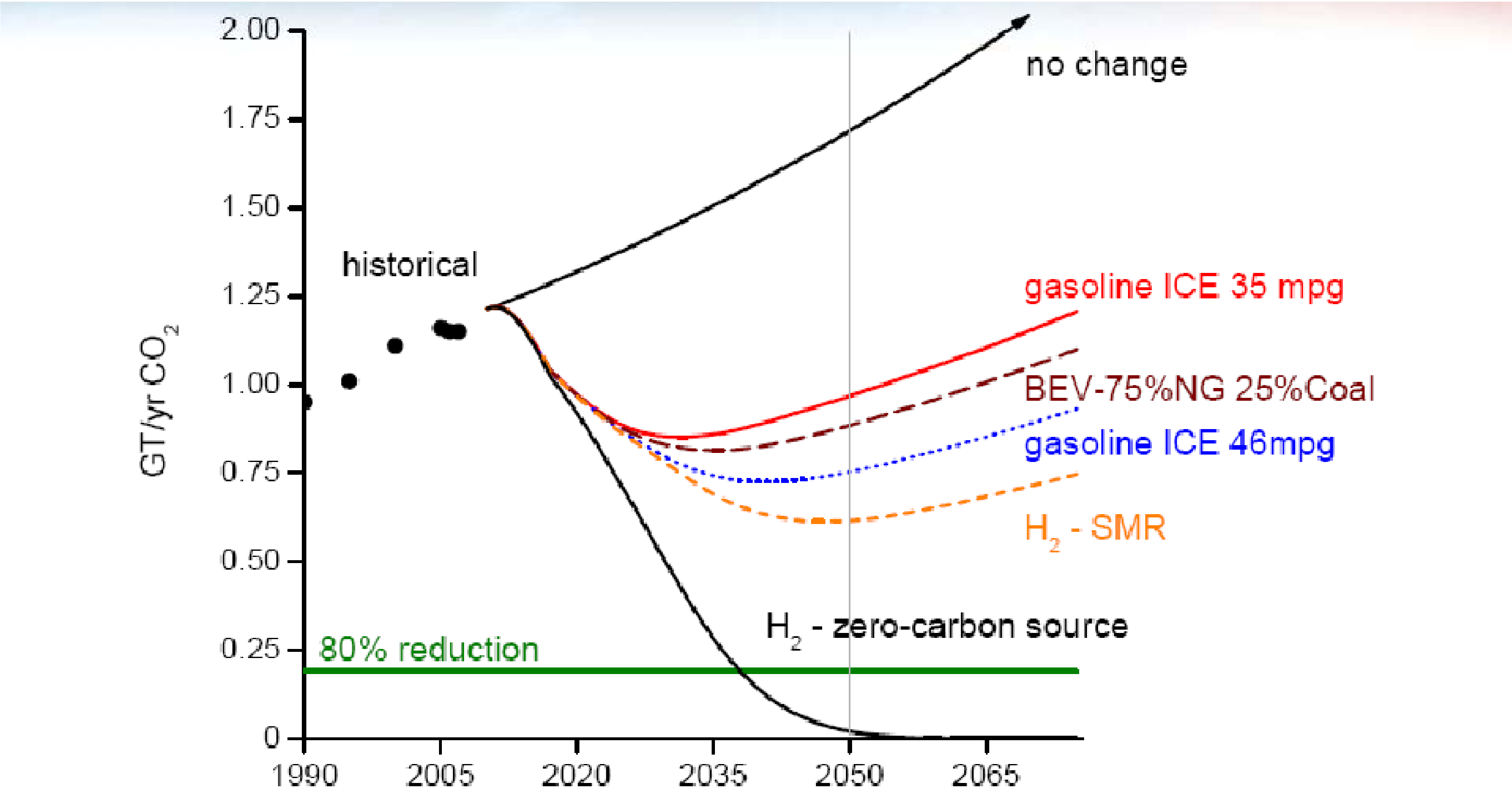
terminology: two "transport" concepts

source: *National Geographic*

Hydrogen for transport = vehicles

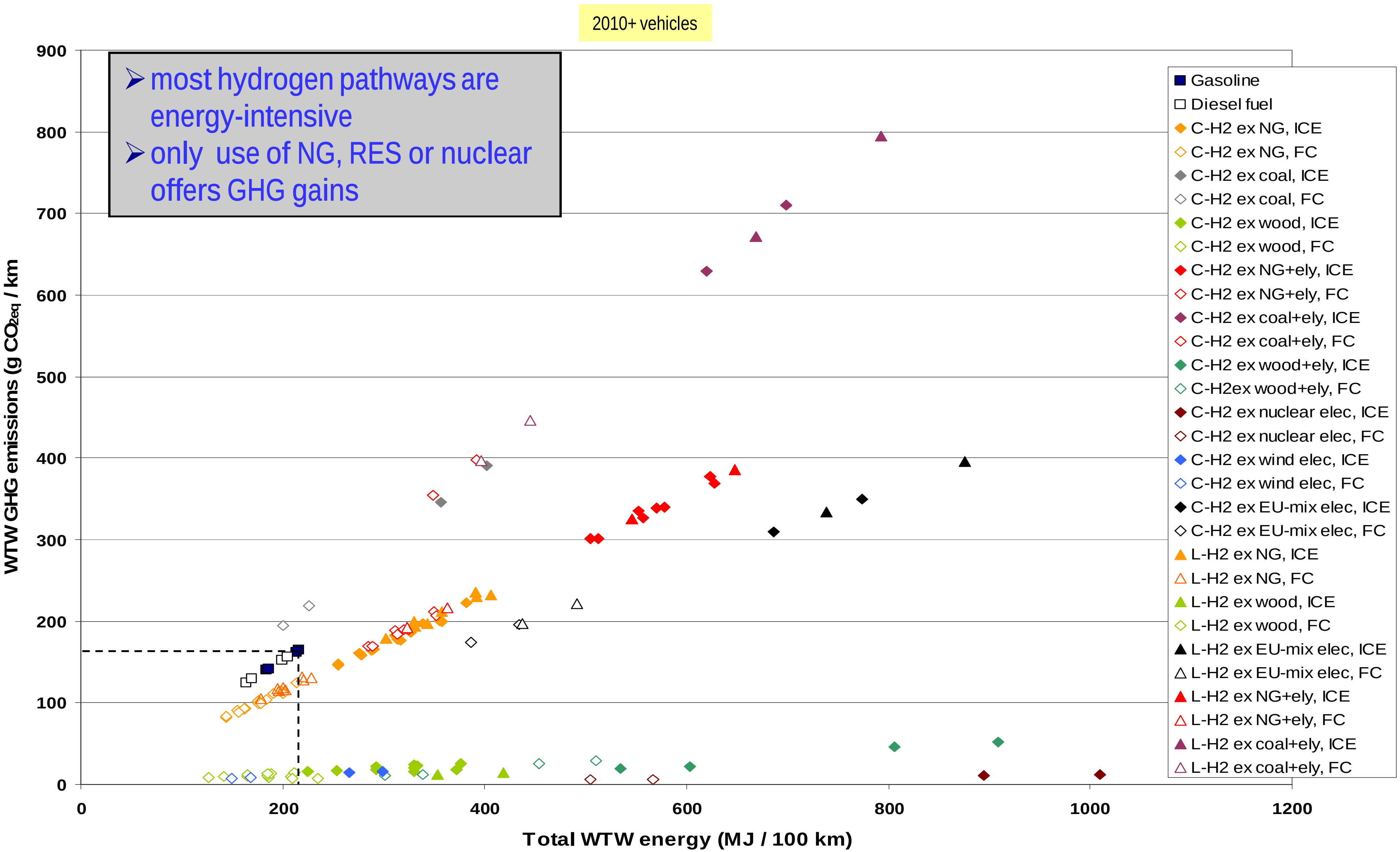

Compliance of EU CO2 targets is a huge challenge for the OEM´s
Dynetek
ADVANCED LIGHTWEIGHT FUEL STORAGE SYSTEMS™
Peugeot
Fiat Corp.
PSA
Citroen
Renault Corp.
Toyota
Ford
Opel/ Vauxhall
Volkswagen
BMW
Mercedes
0
20
40
60
80
100
160
180
200
2008: ACEA negotiated Agreement Fleet 140gCO2/km
Target 2020: Fleet CO2 Average 95 gCO2/km
2010 - 2015: EU Directive Fleet CO2 average 120gCO2/km

CO2 emission reduction in transport requires carbon-free fuel



Source: DoE-SNL

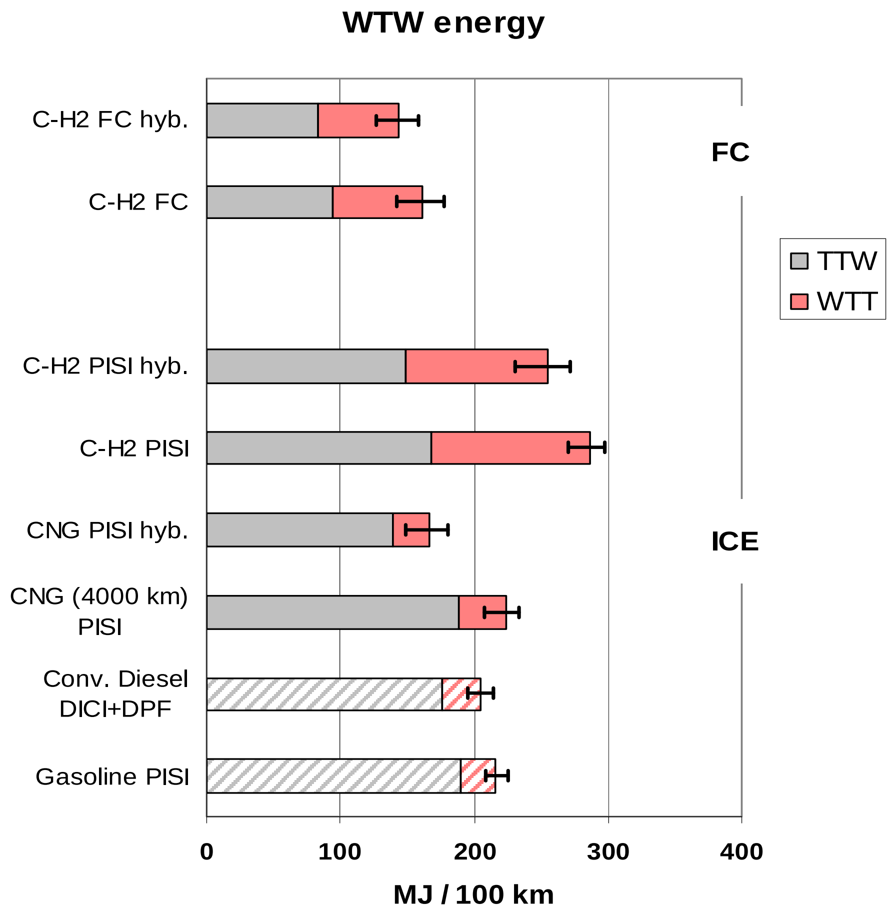
Overall picture: GHG versus total energy (Hydrogen)

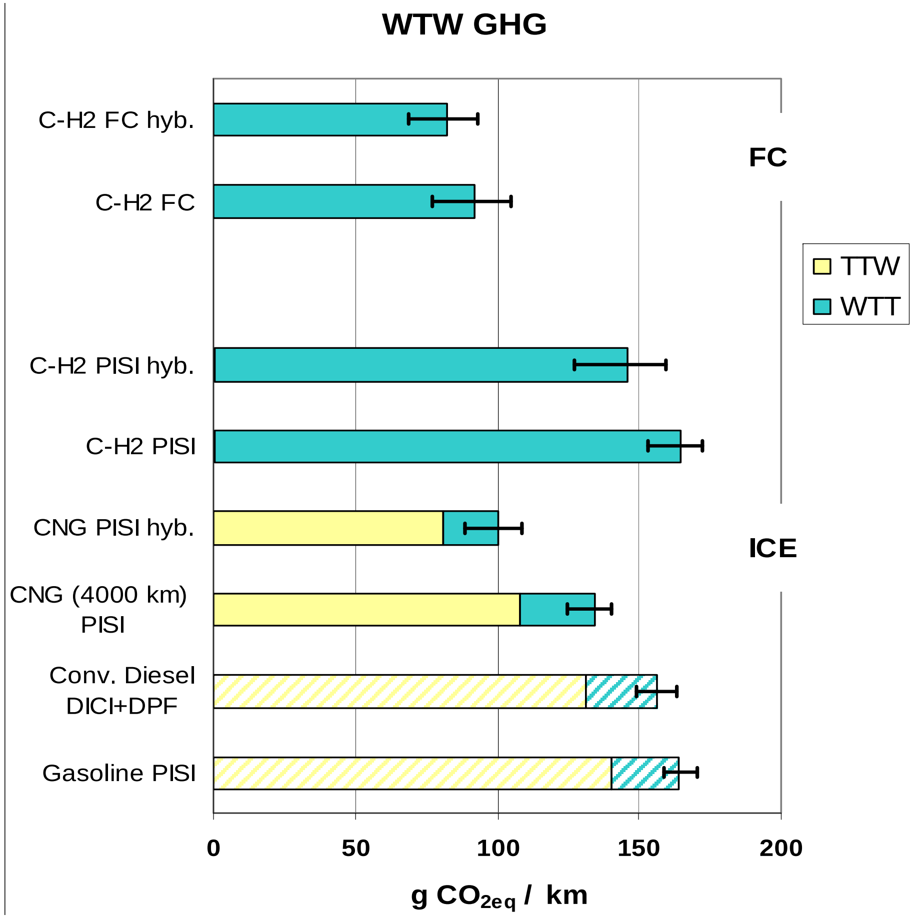


Ref: JEC study

Hydrogen from NG : ICE and Fuel Cell

2010+ vehicles



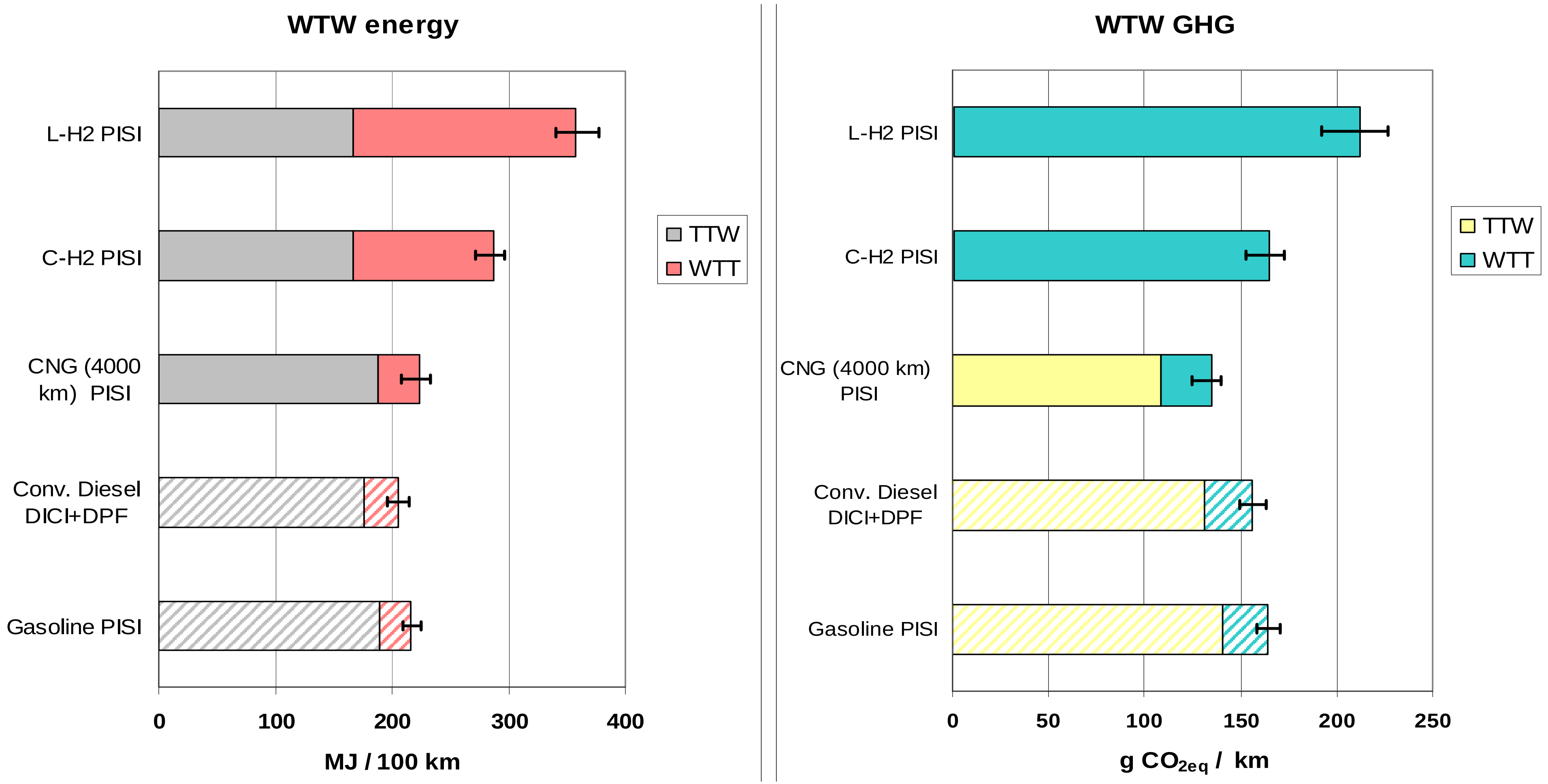


For hydrogen produced from NG
GHG emissions savings are only achieved with fuel cell vehicles

Ref: JEC study

Hydrogen from NG : Compressed versus Liquid

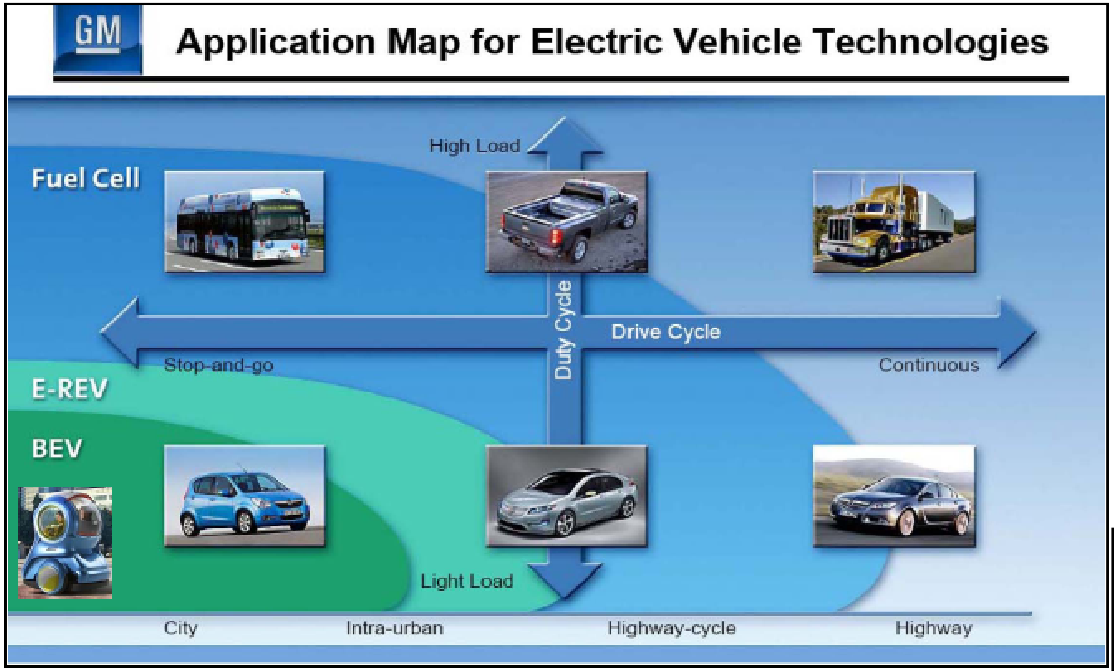
2010+ vehicles

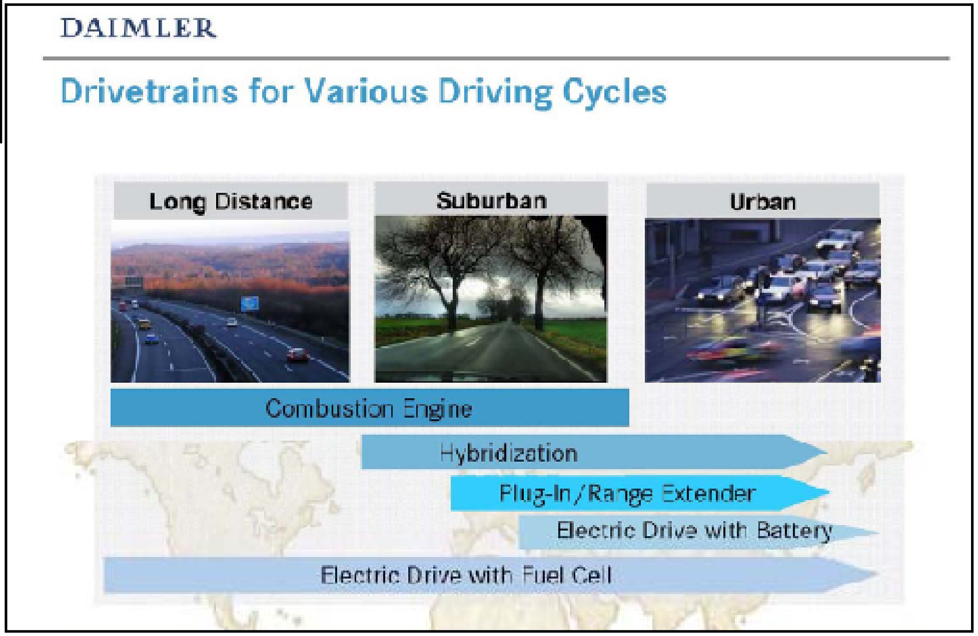


Liquid hydrogen is less energy efficient than compressed hydrogen

Ref: JEC study

Positions of Vehicle Manufacturers





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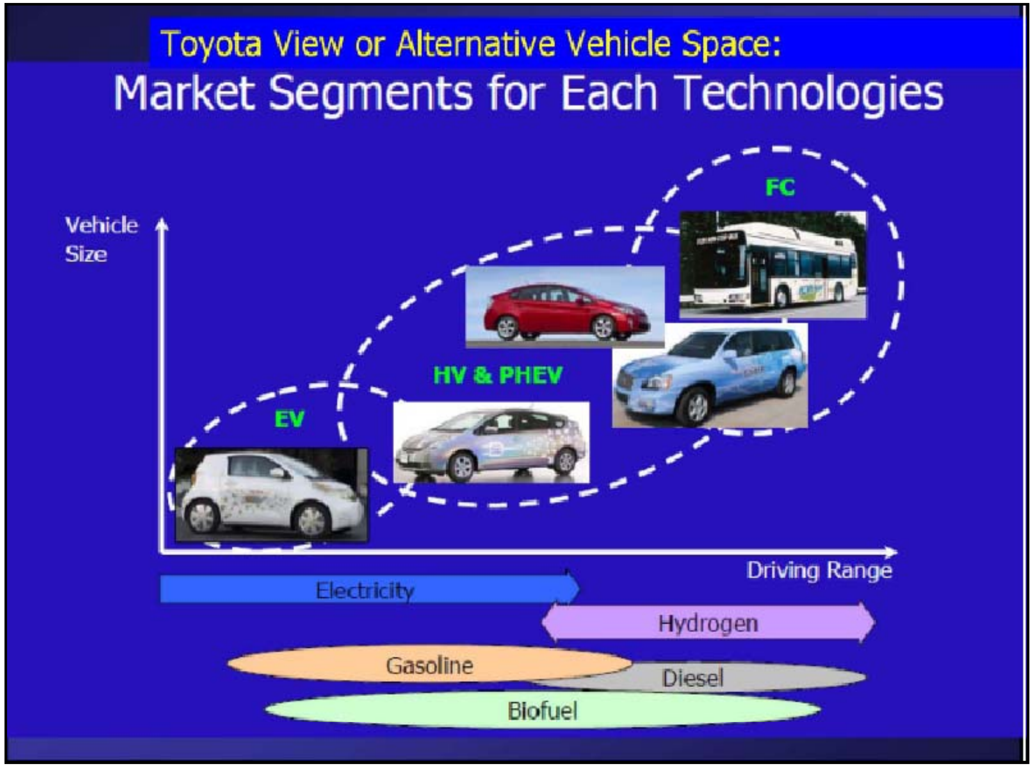

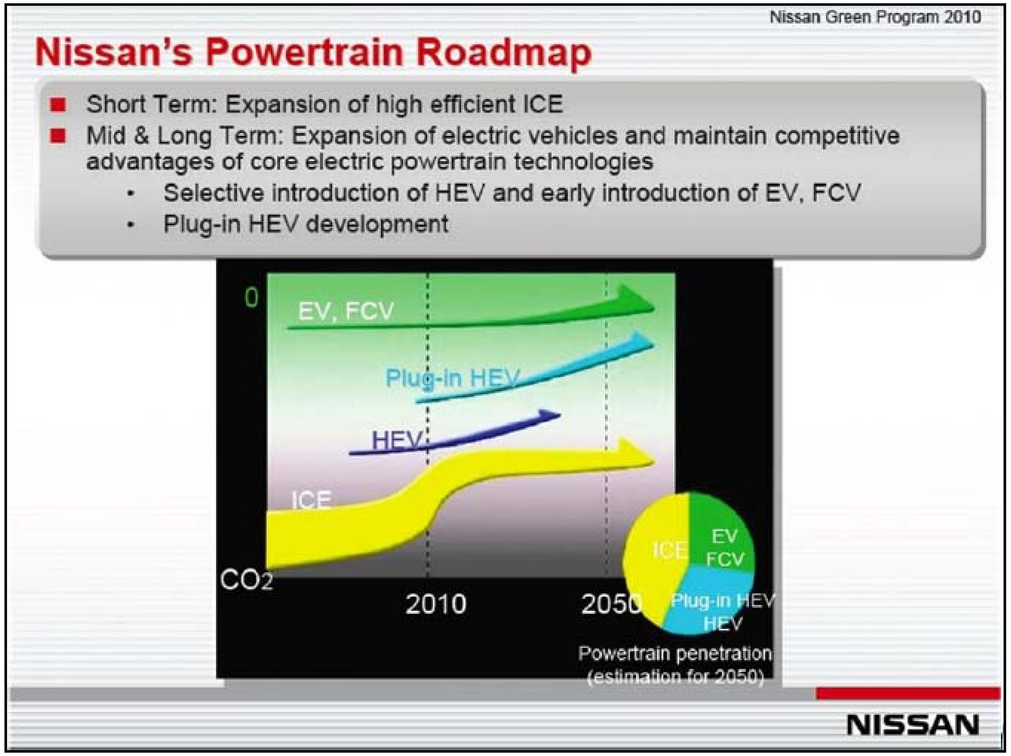

Letter of Understanding on the Development and Market Introduction of Fuel Cell Vehicles - September 2009

DAIMLER Ford GM OPEL HONDA HYUNDAI KIA MOTORS RENAULT NISSAN TOYOTA

- „*Based on current knowledge and subject to a varity of prerequisites and conditions, the signing OEMs strongly anticipate that from 2015 onwards a quite significant number of fuel cell vehicles could be commercialised. This number is aimed at a few hundred thousand units over life cycle on a worldwide basis.*“

- „[…] *The signing OEMs strongly support the idea of building-up a hydrogen infrastructure in Europe, with Germany as starting point and at the same time developing similar concepts for market penetration of hydrogen infrastructure in other regions of the world, with one US market, Japan and Korea as further starting points.*“

Memorandum of Understanding Sept. 2009 H_2 Mobility

DAIMLER EnBW THE LINDE GROUP NOW Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie OMV TOTAL VATTENFALL

Leading companies agree on build-up plan for hydrogen-infrastructure, flanking expected serial-production of FC-Vehicles starting 2015

– Phase I (until 2011):
  - standardization of hydrogen fuelling stations,
  - joint business plan for area-wide roll-out in Germany
– Phase II: Implementation of respective action plan

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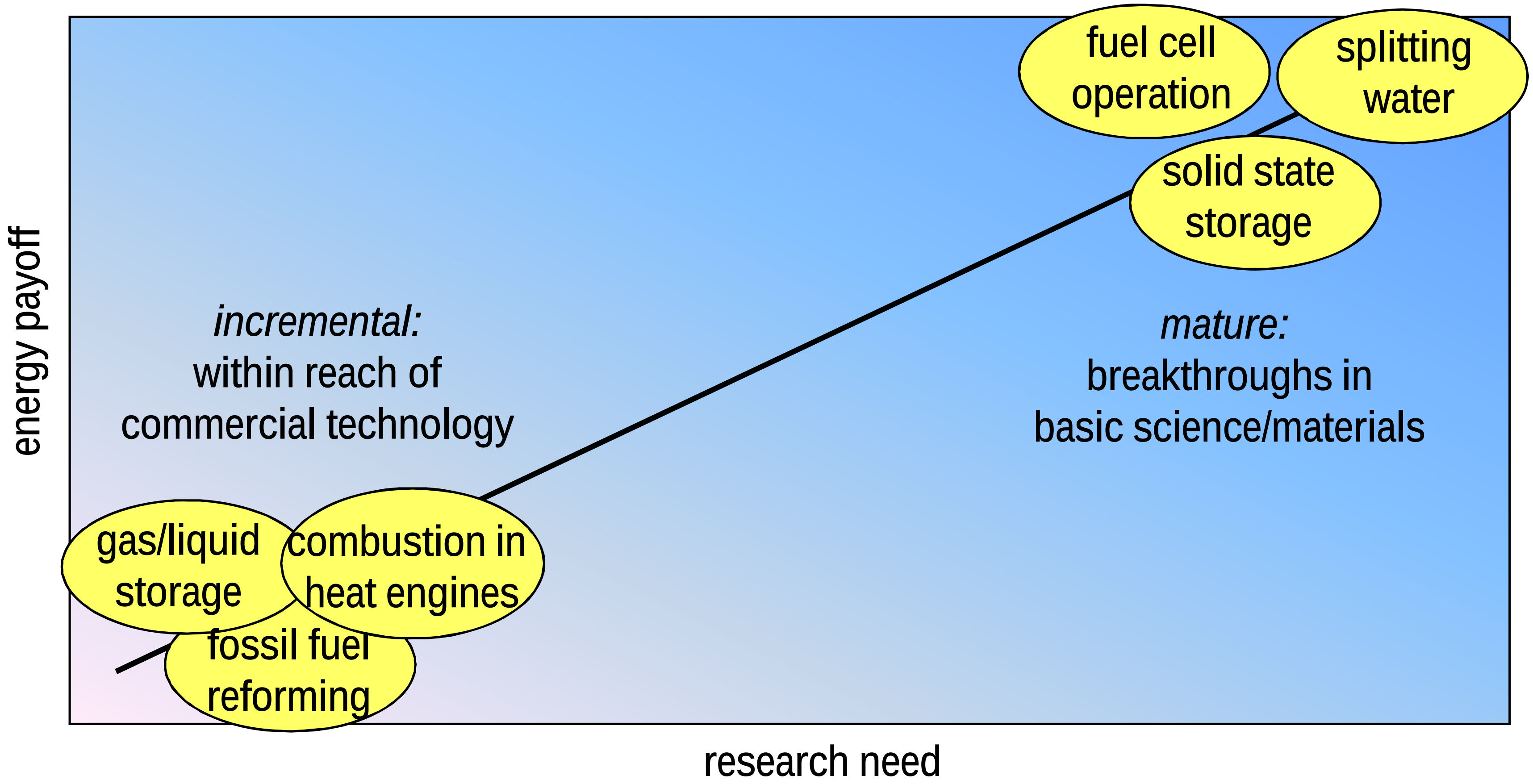
Additional slides

The Two Hydrogen Economies



nanoscience bridges the gap

source: Crabtree, DoE-BES

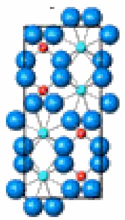
High Priority Research Directions for Hydrogen Economy

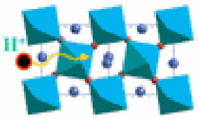
- Low-cost and efficient solar energy production of hydrogen
- Nanoscale catalyst design
- Biological, biomimetic, and bio-inspired materials and processes
- Complex hydride materials for hydrogen storage
- Nanostructured / novel hydrogen storage materials
- Low-cost, highly active, durable cathodes for low-temperature fuel cells
- Membranes and separations processes for hydrogen production and fuel cells

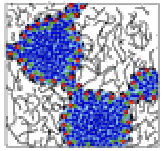
Source: DoE BES

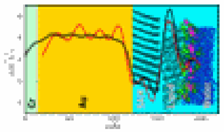
Neutron techniques in support of R&D

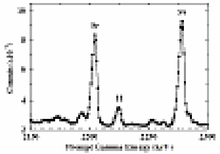
Information we need		Neutron Techniques
location of H, OH, H_2O	→	diffraction
hydrogen vibrations	→	vibrational spectroscopy
diffusion of H, H_2O	→	quasielastic scattering
nanostructure	→	small-angle scattering
H in thin films	→	reflectometry
quantitative H analysis	→	prompt-γ activation analysis
H/H_2O imaging	→	neutron imaging

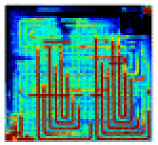












CRP F1.20.22

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WORKING MATERIAL

Application of Nuclear Methods in Microstructural Characterisation and Performance Testing Of Materials for Hydrogen Fuel Cell and Storage Technologies

Report of 1st Research Coordination Meeting (RCM)

organized by

International Atomic Energy Agency, Vienna, Austria

and hosted by

ENEA Headquarters, Roma, Italy

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WORKING MATERIAL

Role of Nuclear-Based Techniques in Development and Characterisation of Materials for Hydrogen Storage and Fuel Cells Report of the Technical Meeting

organized by

International Atomic Energy Agency, Vienna, Austria

hosted by

Université du Québec à Trois-Rivières

Quebec, Canada

(23 - 26 August 2010)

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Additional slides

Strategic EU Policy Objectives

By 2020 – the three 20s:

- 20% reduction in greenhouse gas emissions compared to 1990 levels (30% if global agreement)
- 20% reduction in global primary energy use (through energy efficiency)
- 20% of renewable energy in the EU's overall mix (minimum target for replacement of 10% of vehicle fuel)

By 2050: > 85% reduction in GHG

comparison basis = 1990

EC regulations on type approval of H2 vehicles

According to the Split Level Approach, it comprises two parts:

REGULATION (EC) No 79/2009 on Type-approval of hydrogen-powered motor vehicles

The "political" part (outlining the necessity of the proposal, general description, etc) adoption by the European Parliament and the Council.

REGULATION (EU) No 406/2010 implementing Regulation (EC) No 79/2009

The "technical" part (containing the application of the pertinent standards to containers and other specific components) discussed at Commission level.

What remains to be done?

- Review of separate type-approval regulations on vehicle safety (**crash conditions!**)
- extension of the regulation to **methane-hydrogen** mixture
- extension of the regulation to **L category** vehicles (Suzuki scooter 1st in Europe!)

Harmonization with the UN-ECE Global Technical Regulation (GTR)

Request by European Parliament for type approval for refuelling stations – still outstanding

Regulations for transporting H2

EU:

- transport of gasses under pressure
- Transport of dangerous goods by road
- Transport of dangerous goods by rail
- Transport of dangerous goods by in-land waterways

International:

- Transport of dangerous goods : UN-ECE
- Transport of dangerous goods by air: *IATA/ICAO*

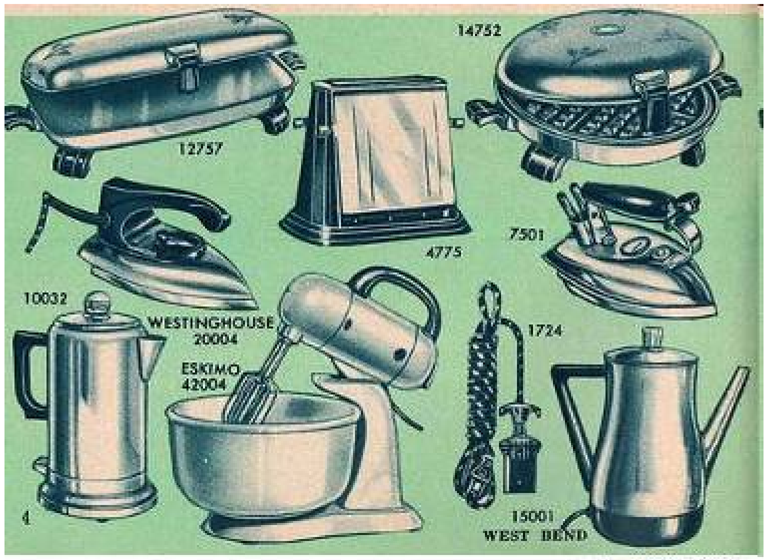
Regulation for storing H2

- Pressure Equipment Directive
- SEVESO II (large amounts of hazardous materials)

Regulation for H2 appliances

CE mark based on compliance with:

- Machinery safety directive
- Equipment and protective systems intended for use in potentially explosive atmosphere (ATEX directives)
- Pressure equipment directive
- Low voltage directive
- Electromagnetic compatibility directive
- Simple pressure vessels directive



wackystuff/ flickr

Public R&D on H2&FC in Europe

EU Research Policy: 2 legs

- co-funded R&D ("indirect actions")
- own R&D: Joint Research Centre (" JRC direct actions")

note: current evolution from R&D to research and innovation

indirect actions

- R&D activities in Europe are funded at different levels: EU, national and regional.
- EU level funding: consecutive framework programmes, currently FP7
  - EU dimension and added value
  - competitive calls for proposals (sollicitations)

http://ec.europa.eu/research/fp7/index_en.cfm?pg=cooperation

for H2 and fuel cells: EU funding as of 2008 through public-private partnership:

Fuel Cells and Hydrogen Joint Undertaking (FCH-JU), operating the Joint Technology Initiative:

- 1 B€ for R&D and demonstration (2008-2013)
- 50/50% cost share basis between EC and industry

Fuel Cell and Hydrogen Joint Undertaking

An <u>industry-led</u> Public-Private Partnership between

- The European Union represented by the Commission

http://ec.europa.eu/research/fch

- European Industry Grouping for the Fuel Cells and Hydrogen Joint Technology Initiative (NEW-IG)

http://www.fchindustry-jti.eu

- New European Research Grouping on Fuel Cells and Hydrogen (N.ERGHY)

http://www.nerghy.eu

to accelerate technology development to achieve market introduction from 2015

FCH JU and Stategic Energy Technology Plan

- The FCH JU has the minimum critical mass needed to develop and validate efficient and cost competitive technologies
- However, meeting the market entry targets set by industry will require substantial additional effort
- *The additional public and private funding needed is currently estimated as €5 bn for the period 2013-2020*

COM(2009)519: Investing in the Development of Low Carbon Technologies (SET-Plan)

The Mission of the JRC

… to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies …

The JRC functions as a centre of science and technology (S/T) reference for the European Union, independent of special interests, private or national ...

Pre-normative research as input to international standards and regulations

Execution of reference function in European Fuel Cell and Hydrogen Joint Technology Initiative

Scope:

- Fuel cell performance
- H2 storage and distribution
- H2 sensors
- H2 safety

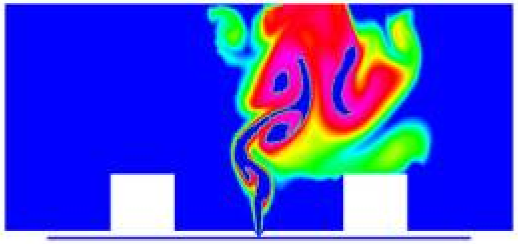
Representation of European Commission in international technical forums and collaboration activities:

IEA, IPHE, EU-US Energy Council Technology Working Group, …

Supported by underpinning research in networking mode

H_2 Storage, Distribution, Sensing and Safety

High Pressure H_2 Storage	On-board safety sensors	Modeling H_2 release	Solid-state H_2 Storage
GasTeF Safety bunker for stationary & cyclic testing facility up to 800 bar	SenTeF Laboratory for sensor testing	2D and 3D CFD codes dispersion/explosion modelling	SolTeF Laboratory for storage capacity characterisation



refuelling stations permitting

ISO TC 197
EC type approval
UN-ECE WP 29

IEA-HIA, IPHE (ICHS)
NREL, JARI, ...

Environmental and vibration testing of FC systems and their performance

efficiency, engine and evaporative emission testing

tests at level of

- MEA
- cell
- stack

ISO TC 197, IEC TC 105
UN-ECE WP 29

IEA-AFC, IPHE,
DoE, NEDO, KIST,
Dahlian Univ., RAS, …

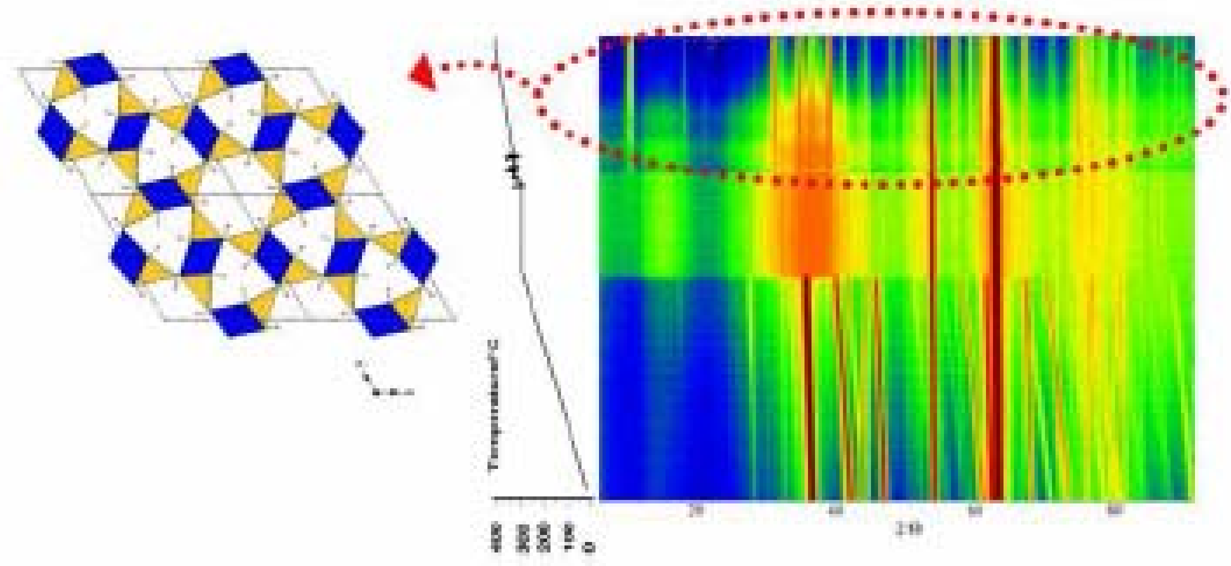
Underpinning research *(example)*

Topic: in-situ neutron diffraction of magnesium amide/lithium hydride stoichiometric mixtures with lithium hydride excess

Issue: improved solid date H2 storage capability

JRC work: clarification of reaction mechanisms and identification of new intermediate phase

Outcome: significant insight into hydrogen storage capabilities leading to input on tailoring of promising hydrogen storage materials



Dissemination, Education, Training

- International Conferences on Hydrogen Safety (2005, 2007, 2009, 2011)
- IPHE Conferences on H2 storage - (with US-DoE, Russia) (2005, 2009)
- International Workshops
  - Fuel Cell Degradation, 2007 *(IPHE)*
  - Accelerated Testing in Fuel Cells, 2008 *(IPHE)*
  - Diagnostic Tools for Fuel Cells Technologies, 2009 *(IPHE)*
  - Effects of Fuel and Air Quality to the Performance of Fuel Cells, 2009 *(IPHE, IEA-AFC, ISO)*
  - Early markets, 2010 *(IPHE, IEA-AFC)*
  - Fuel Cell Degradation, 2011 *(IPHE, IEA-AFC)*
- IAEA-IEA technical meetings on nuclear methods in H2 storage and FC research, 2009-2010-2011
- Hosting of researchers

The 4th International Conference on Hydrogen Safety

ICHS 2011
International Conference on Hydrogen Safety

September 12-14, 2011
San Francisco, California-USA

With the endorsement of:

U.S. DEPARTMENT OF ENERGY

IPHE International Partnership

HYDROGEN IMPLEMENTING AGREEMENT

Thank you for your attention!

http://www.jrc.ec.europa.eu/

http://ie.jrc.ec.europa.eu/

marc.steen@ec.europa.eu

Contents

Hydrogen is needed for deep decarbonisation – EU enabling efforts

Elements of the hydrogen chain

- production
- storage
- transmission and distribution infrastructure

Main end-use interest area: public transport

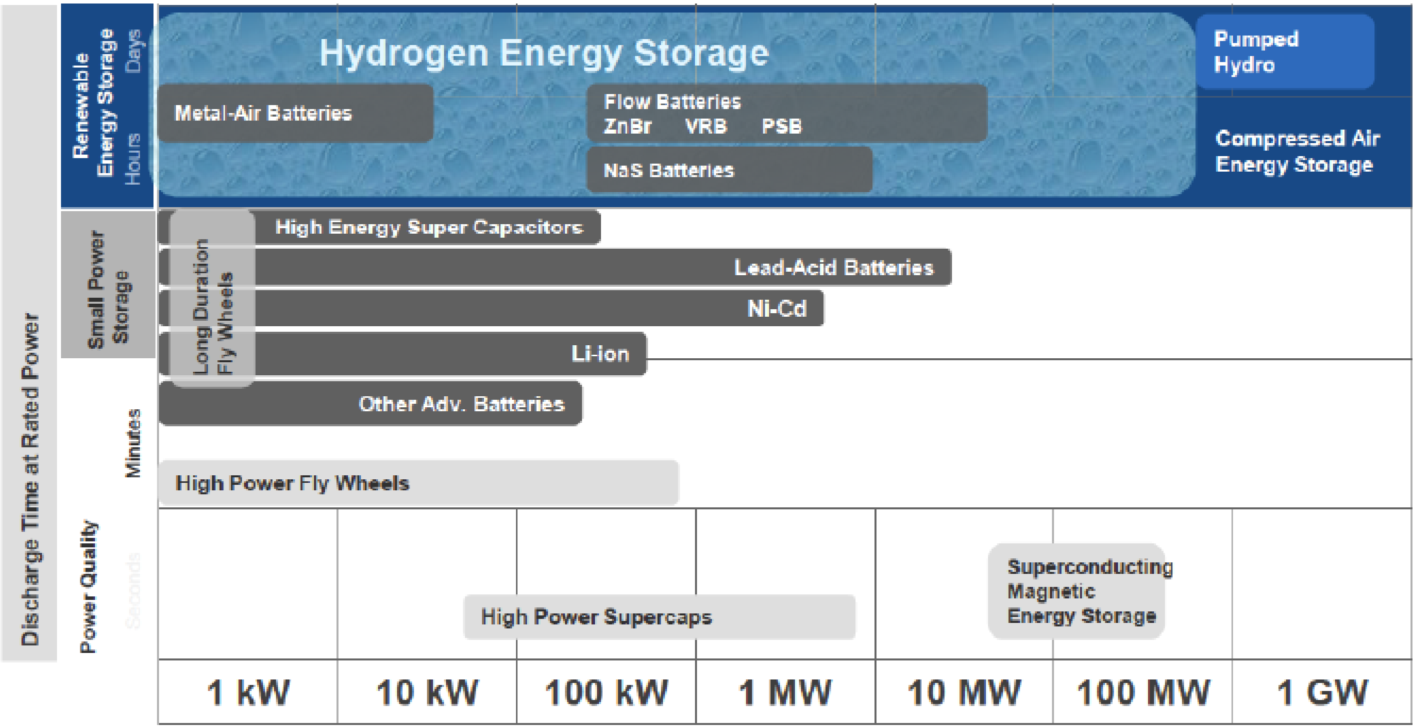
Research needs in hydrogen and fuel cell technologies

European Union Efforts

- Policies
- Research, Development and Demonstration (RDD)
    - Fuel Cell and Hydrogen Joint Undertaking (FCH-JU)
    - Joint Research Centre of the European Commission (JRC)

Additional slides – in order of main presentation

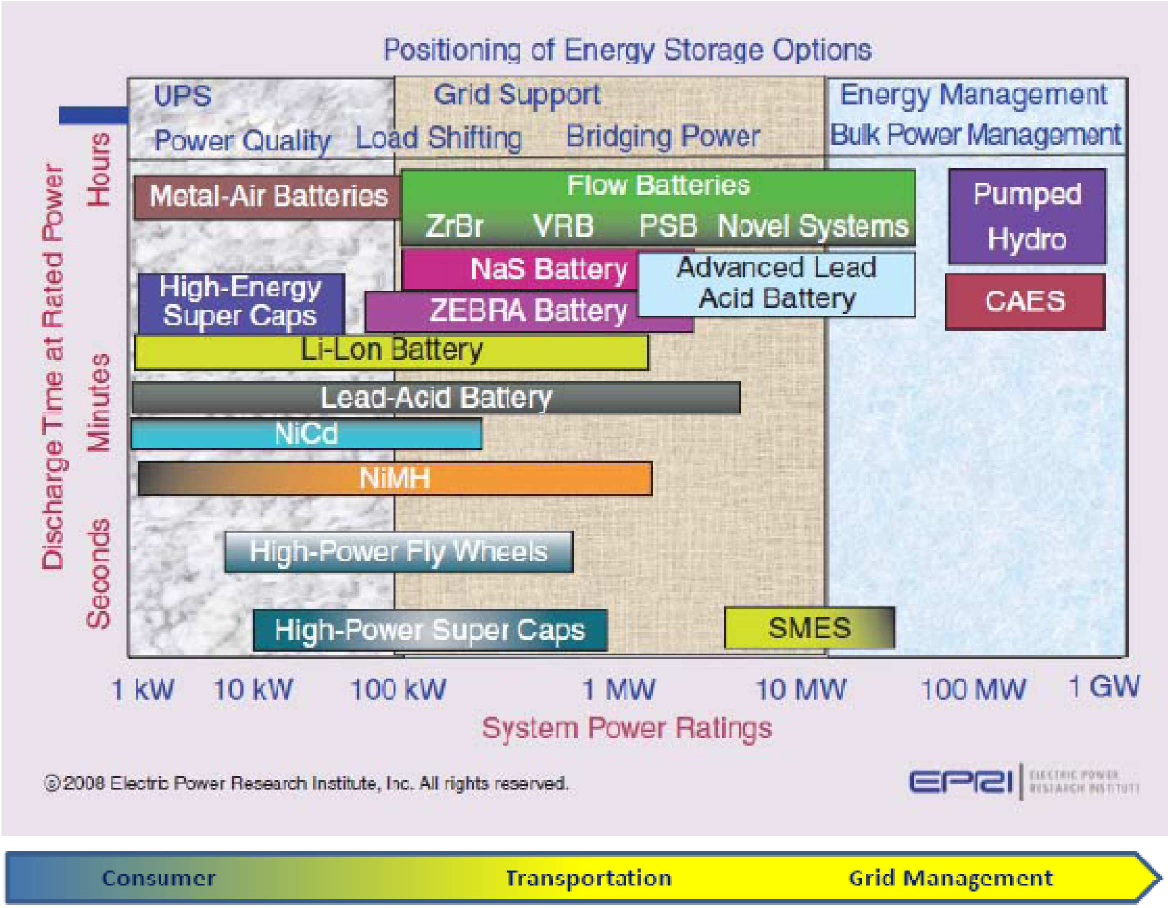
Power and Energy Specifications



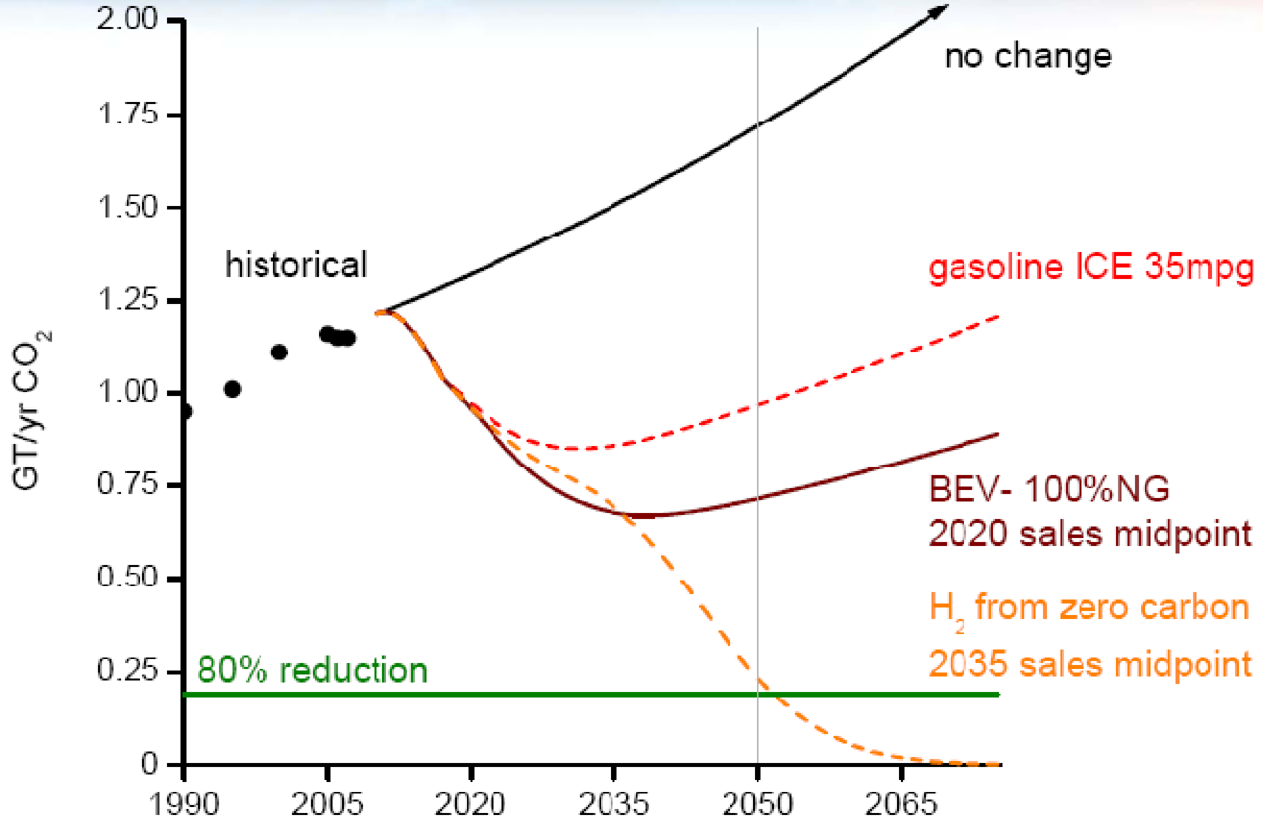
Source: Kevin Harris, Hydrogenics

Options for high pressure on-board storage

Current Battery and Energy Storage Technologies

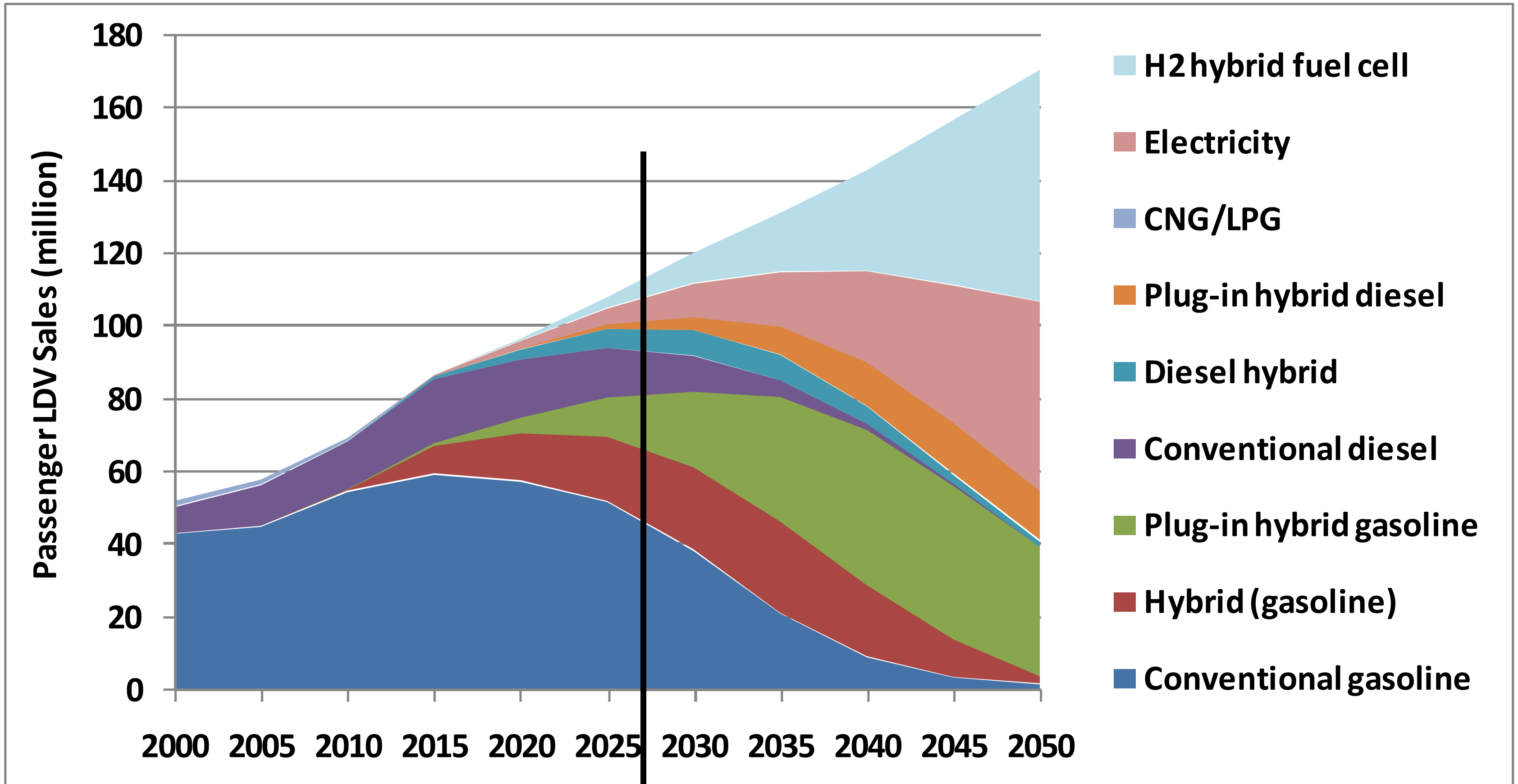


The type of fuel-vehicle system is more important than the speed of deployment



Decarbonisation of EU transport

Light-duty vehicle sales (millions), 2010-50

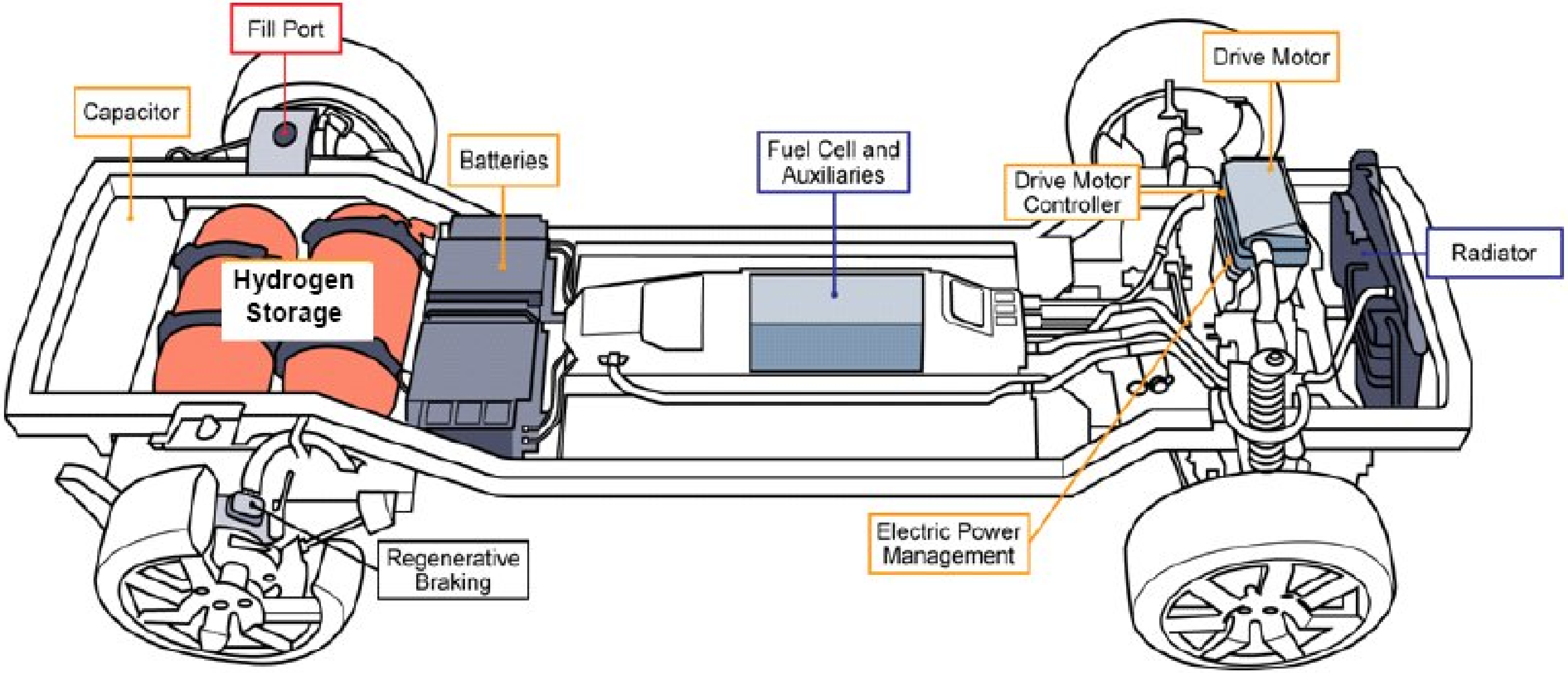


source: IEA Roadmap 2009

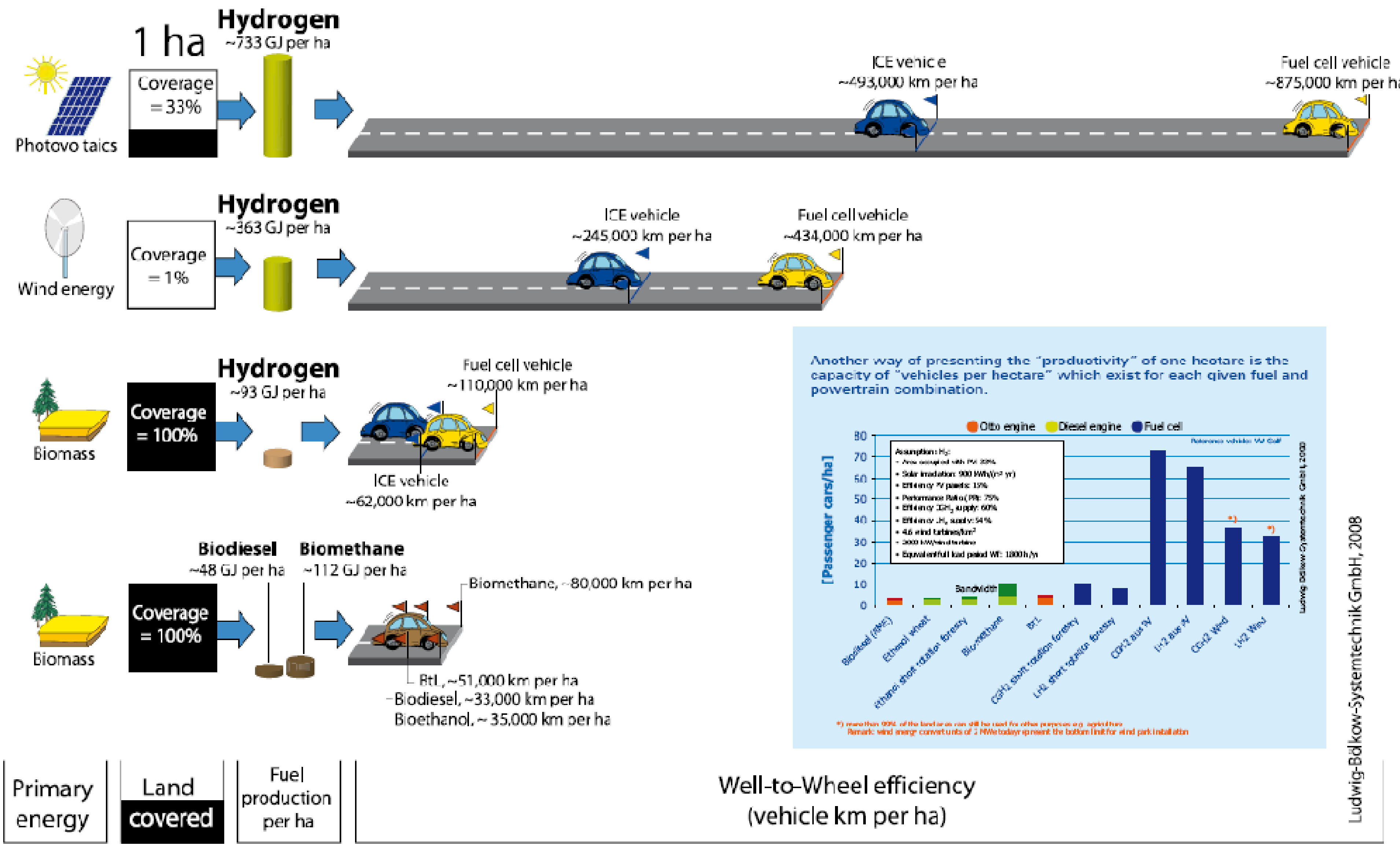
→ electric drive train: BEV and FCEV

+ behavioural change, intermodality

main hydrogen vehicle components



N. Nha, Doe Workshop July 2010, Beijing



ha = hectare
ICE = internal combustion engine

Reference vehicle: VW Golf [Concawe/EUCAR/JRC 2006], average driving performance = 12,500 km per year

Priority Research Areas in Hydrogen Production

Fossil Fuel Reforming

In the intermediate term, the reforming of coal will be the main source of hydrogen. A molecular level understanding of catalytic mechanisms, nanoscale catalyst design, and high temperature gas separation is needed.

Solar Photoelectrochemistry/Photocatalysis

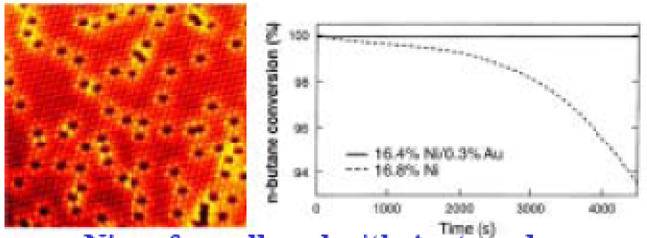
Long term, hydrogen will be produced using the sun as a renewable energy source. Research on light harvesting, charge transport, chemical assemblies, bandgap engineering, interfacial chemistry, catalysis and photocatalysis, organic semiconductors, theory and modeling, and materials degradation are needed.

Bio- and Bio-inspired H_2 Production

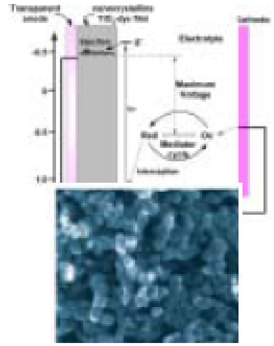
Living systems produce hydrogen at room temperature with high efficiency. Research on microbes & component redox enzymes, nanostructured 2D & 3D hydrogen and oxygen catalysts, and energy transduction are needed to engineer robust biological and biomimetic H_2 production.

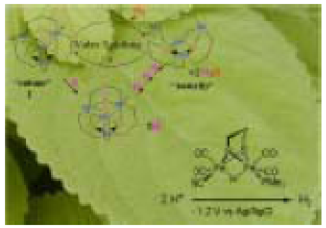
Nuclear and Solar Thermal Hydrogen

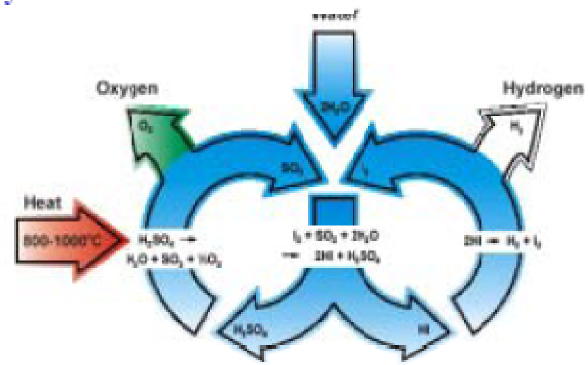
Research on thermodynamic data, modeling for thermochemical cycles (TC), high temperature materials and membranes, TC heat exchanger materials, and improved catalysts should benefit from this approach.



Ni surface-alloyed with Au to reduce carbon poisoning


Dye-Sensitized Solar Cells


Synthetic Catalysts for H_2 Production



Thermochemical Water Splitting

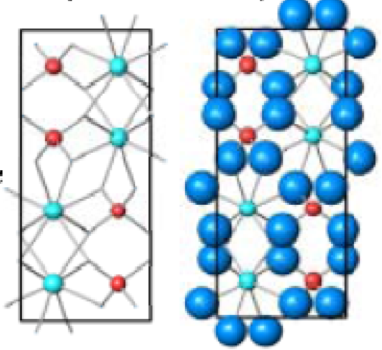
Source: DoE BES

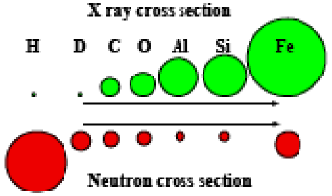
Priority Research Areas in Hydrogen Storage

Metal Hydrides and Complex Hydrides

Research is needed on high gravimetric and volumetric capacity materials, nanocatalysts for improving H_2 uptake and release kinetics, degradation and embrittlement mechanisms, effect of surfaces and dopants for hydrogen storage and release.

NaAlH$_4$ X-ray view NaAlD$_4$ neutron view

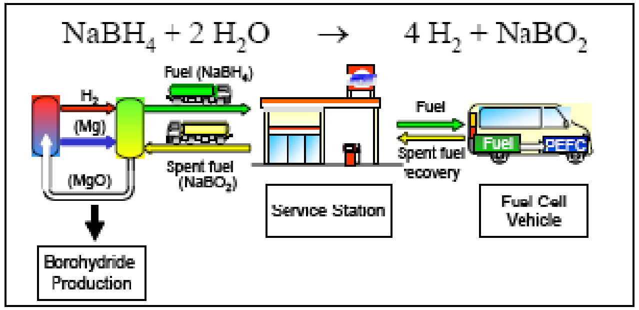




Neutron Imaging of Hydrogen

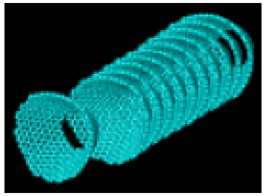
Nanoscale/Novel Materials

Research is needed on finite size, shape, and curvature effects on electronic states, catalytic activity, thermodynamics, bonding, and degradation mechanisms.

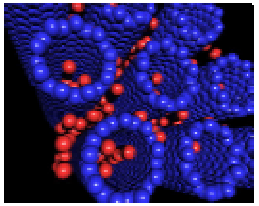


Theory and Modeling

Theory, simulation and first principles methods are needed for studying hydrogen bonding over a wide range of length and time scales. Hydrogen storage and release may be the most challenging problems of the hydrogen economy.



Cup-Stacked Carbon Nanofiber



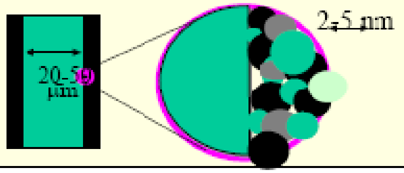
H Adsorption in Nanotube Array

Source: DoE BES

Priority Research Areas in Fuel Cells

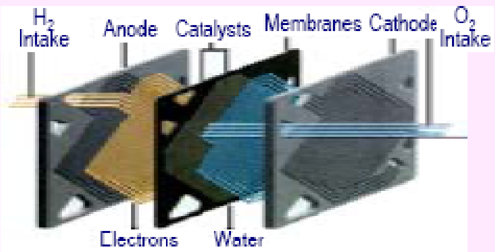
Electrocatalysts and Membranes

Develop catalysts to reduce overpotential, minimize rare metal usage and improve design of triple percolation electrodes.



Controlled design of triple percolation nanoscale networks: ions, electrons, and porosity for gases

Internal view of a PEM fuel cell (proton exchange membrane)

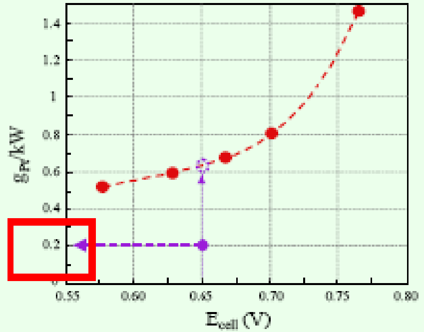


Source: T. Zawodzinski (CWRU)

Low Temperature Fuel Cells

Develop 'Higher' temperature proton conducting membranes, study degradation mechanisms, and develop functionalized materials with tailored nano-structures for enhanced efficiency.

Mass of Pt Used in the Fuel Cell — a Critical Cost Issue



Source: H. Gasteiger (General Motors)

YSZ Electrolyte for SOFCs

Porosity can be tailored

Source: R. Gorte (U. Penn)

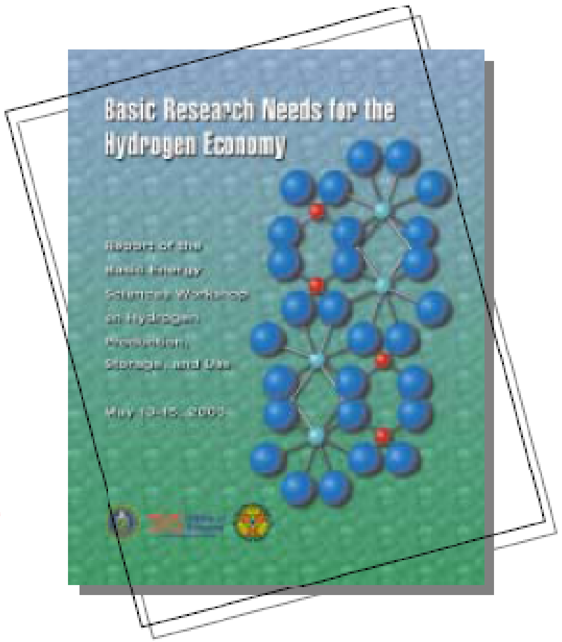
Solid Oxide Fuel Cells

Use theory, modeling and simulation, validated by experiment, to develop electrochemical materials and processes, advanced in-situ analytical tools, new materials and novel synthesis routes for optimizing device architectures.

Source: DoE BES

Messages

- Significant gap between present state-of-the-art capabilities and requirements that will allow hydrogen to be competitive with today's energy technologies
  - production: 9M tons/yr $\Rightarrow$ 40M tons/yr (150 million vehicles; ~75% of US fleet)
  - storage: 4.4 MJ/L (10K psi gas) $\Rightarrow$ 9.7 MJ/L
  - fuel cells: \$300/kW $\Rightarrow$ \$30/kW (gasoline engine high volume cost)
- Enormous R&D efforts will be required
  - Simple improvements of today's technologies will not meet requirements
  - High risk/high payoff basic research should be a critical component of the Hydrogen Fuel Initiative to overcome the technical barriers
- Research is highly interdisciplinary, requiring chemistry, materials science, physics, biology, engineering, nanoscience, computational science
- Basic and applied research should couple seamlessly



http://www.sc.doe.gov/bes/hydrogen.pdf

Source: DoE BES

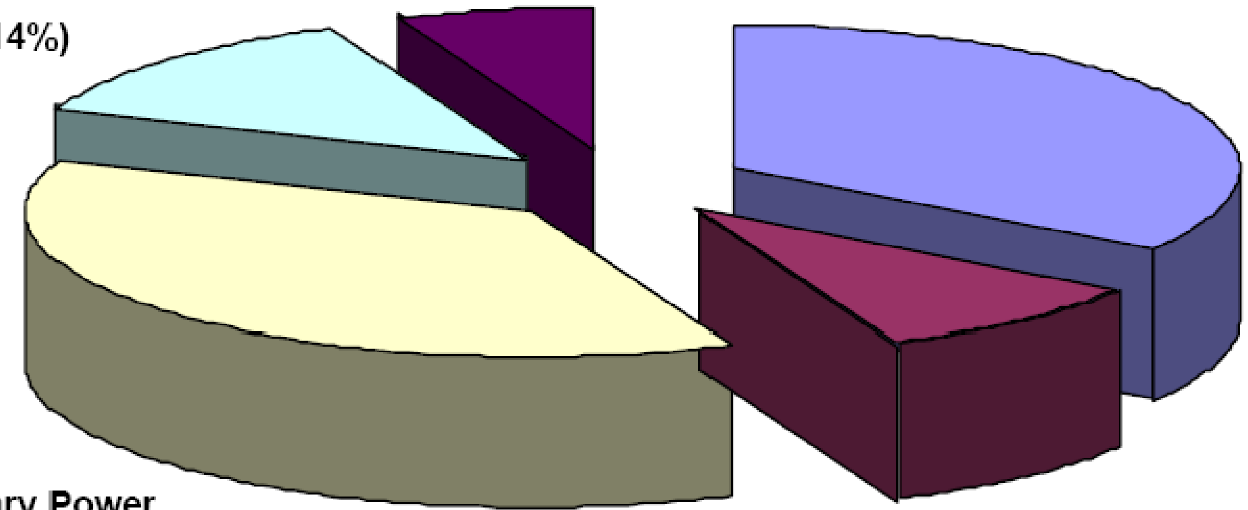
FCH JTI Targets

Application Area	Targets 2010	Targets 2015	
		Volume	Cost and Technology
Transport & Refuelling Infrastructure	~10 additional road vehicles (single site) plus mobile deployment to sites with existing refuelling infrastructure capable of refuelling up to 50 vehicles ~20 buses on 3 sites with appropriate refuelling capacity	~ 500 Light Duty Vehicles (mainly cars) at 3 additional sites with 3 new stations ~500 buses at 10 EU sites (of which at least 7 new ones) with refuelling stations (daily refuelling capacity >400kg)	System cost of approx. € 100/kW Durability in car propulsion systems 5000 hours Roadmap for the establishment of a commercial European hydrogen refuelling infrastructure
Hydrogen Production & Distribution	Appropriate H2 supply chain (including fuel purity) to match Transport, Stationary and Early Markets requirements. For 2015 10 - 20% of general H2 demand should be produced via carbon free/carbon lean processes		Cost of H2 delivered at refuelling station < €5/kg (€ 0.15/kWh) Improved system density for H_2 storage (9 %wt of H_2)

FCH JTI Targets - *continued*

Application Area	Targets 2010	Targets 2015	
		Volume	Cost and Technology
Stationary Power Generation & CHP	3 - 7 MW installed electrical capacity in the EU for pre-commercial demonstration	~ 100MW installed electric capacity	Cost of € 4,000 - 5,000/kW for micro CHP Cost of € 1,500 - 2,500/kW for industrial/commercial units
Early Markets	500 new units in the EU-Market: ♦ 50 UPS/back-up power ♦ 20 industrial and off highway vehicles ♦~ 400 portable & micro FCs	14,000 new units in the EU market: ♦ 1000 UPS/back-up power ♦ 500 industrial and off-highway vehicles ♦ 12,000 - 13,000 portable and micro FC's	

FCH JU Budget



budget breakdown by Application Area - total 940M€

http://ec.europa.eu/research/fch/pdf/fch_ju_multi_annual_implement_plan.pdf

Standardisation: Who does what?

- Refuelling stations, H2 components, detectors, fuel quality, … :

  ISO/TC 197 *Hydrogen technologies*
- Fuel cell test methods and performance assessment

  IEC/TC 105 *Fuel cell technologies*
- Material compatibility for hydrogen storage:

  ISO/TC 58 *Gas cylinders*
- …

Useful information sources:

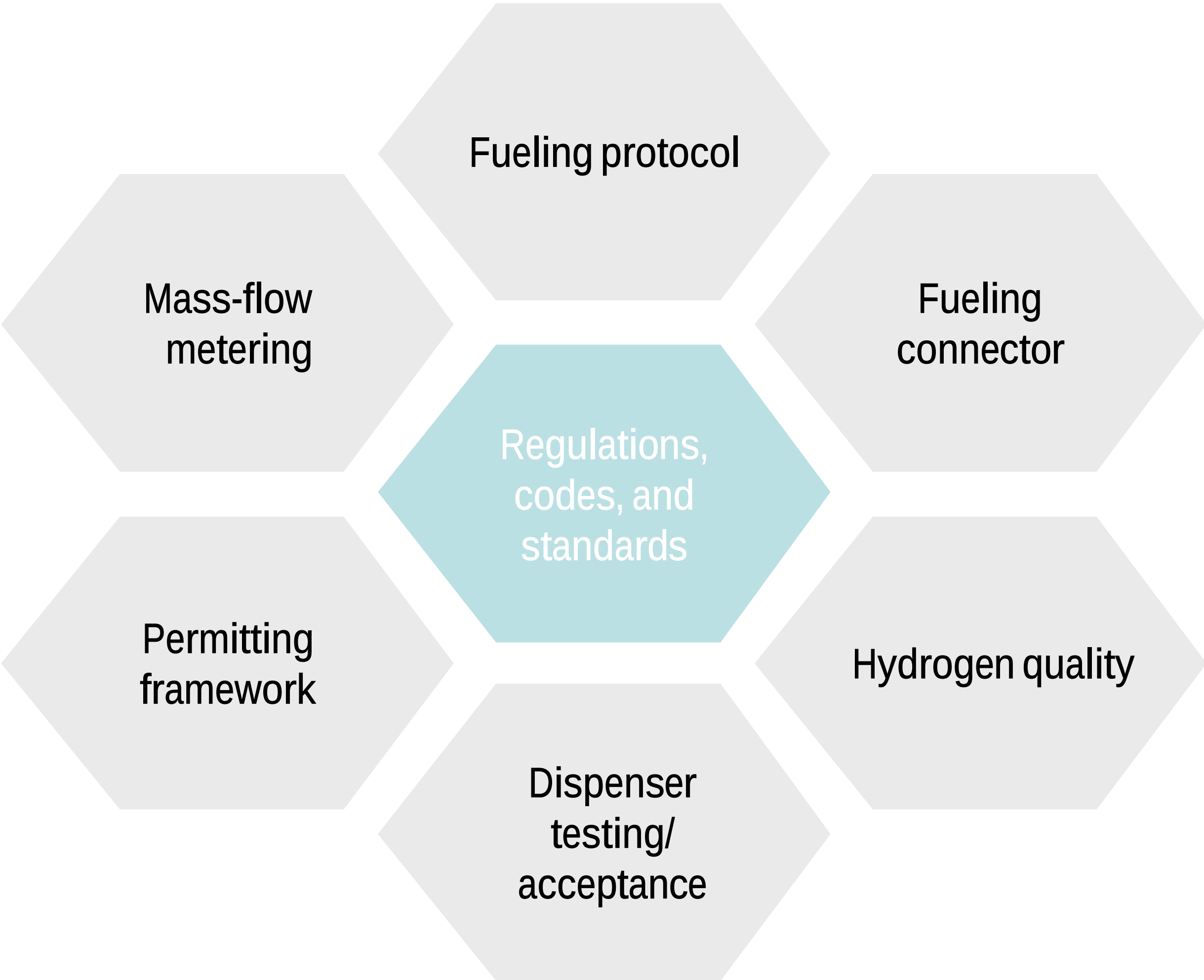
http://hcsp.ansi.org/

http://www.fuelcellstandards.com/Hydrogen%20Matrix.pdf, updated 1 May 2011

Current standardisation priorities

Alignment of regulations, codes, and standards to ensure compatibility of any hydrogen refuelling station and fuel cell electric vehicles

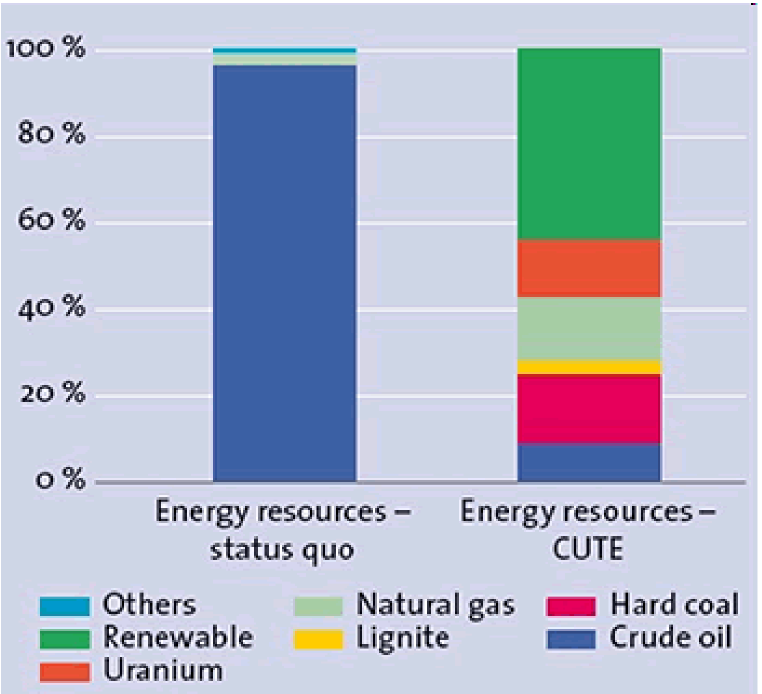
PNR on all is needed!



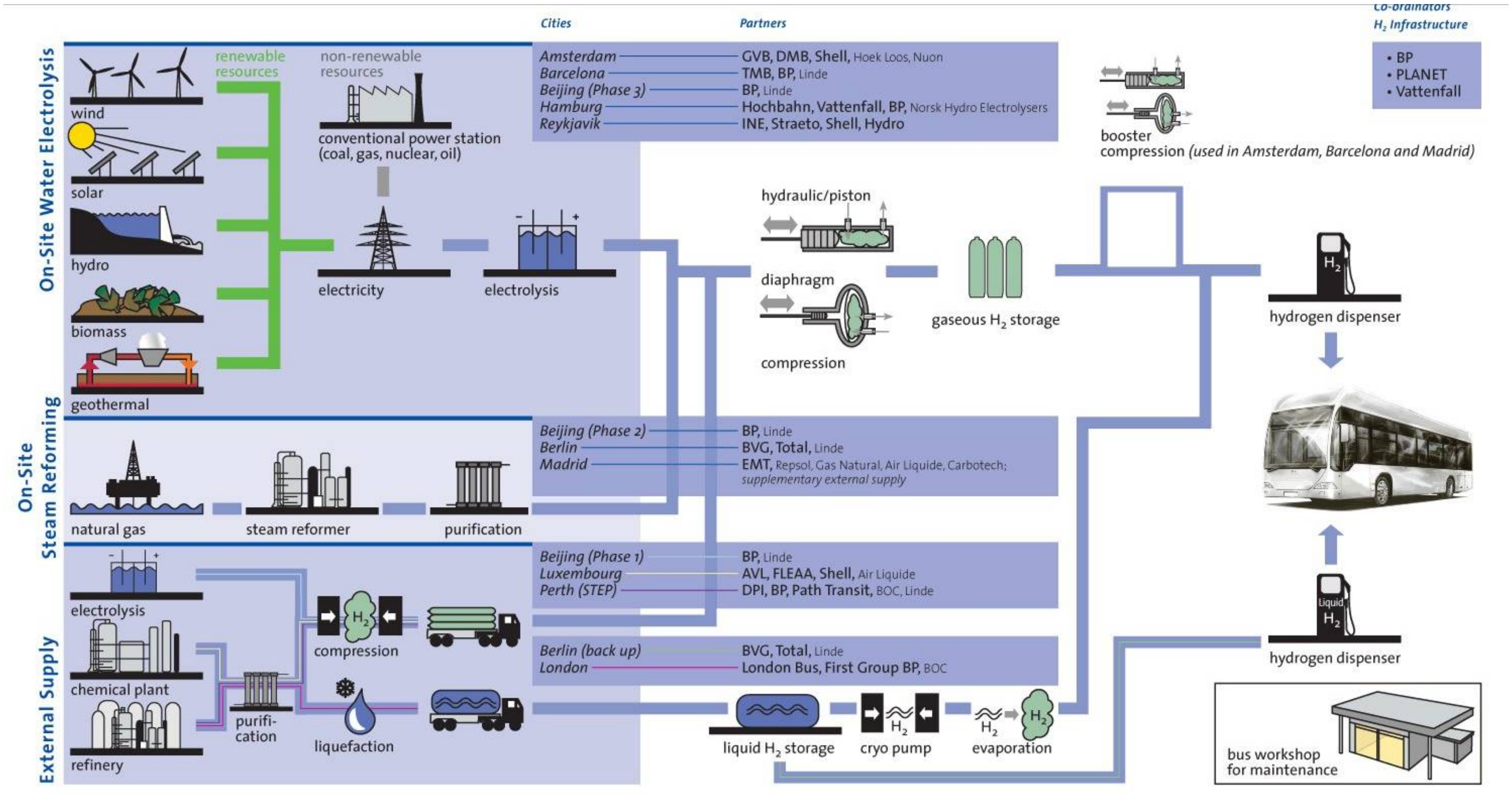
Source: K. Bonhoff, EO seminar, Mar. 2011

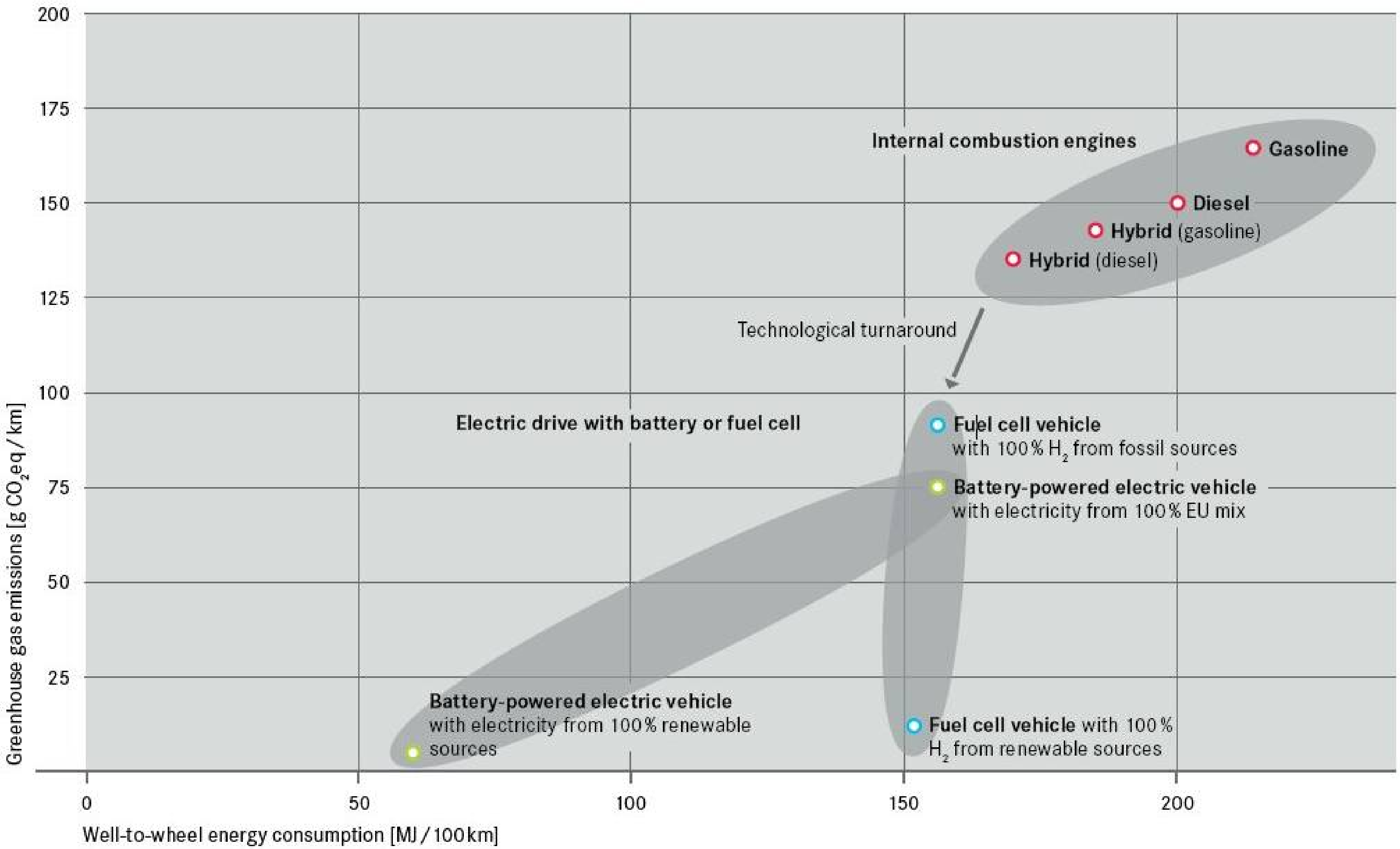
Demonstration projects are very important to gain real life experiences

HyFLEET:CUTE will see the operation of 47 Hydrogen powered buses in regular public transport service in 10 cities on three continents.



Hydrogen supply pathways for HyFleet:Cute





Fuel cell: large operating range (> 400 km), short refueling time (3 min.), car / vans / trucks / buses

Battery: ideal for city traffic (100-150 km), overnight recharging

Internal combustion engine
Electric vehicle with battery
Electric vehicle with fuel cell

Source: Eucar / Concawe "Well-to-Wheels Report 2004," Optiresource, 2006 Reference vehicle class: VW Golf


A portfolio of power-trains for Europe: a fact-based analysis
The role of Battery Electric Vehicles, Plug-in Hybrids and Fuel Cell Electric Vehicles

www.fch-ju.eu

JRC Mission:

to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies

The JRC functions as a centre of science and technology (S&T) reference for the EU, independent of commercial and national interests...

R&D by JRC is limited in scope by full compliance with the Subsidiarity Principle:

- "enabling R&D" activities
- targeting EU and public interests
    - pre-normative and co-normative research, performance assessment (incl. LCA), ...
    - scenario-building, road-mapping, SET-Plan Information System, ...
- networking within and outside EU absolutely necessary

on hydrogen and fuel cells:

Framework Agreement FCH JU - JRC: provision of reference facilities and programme support

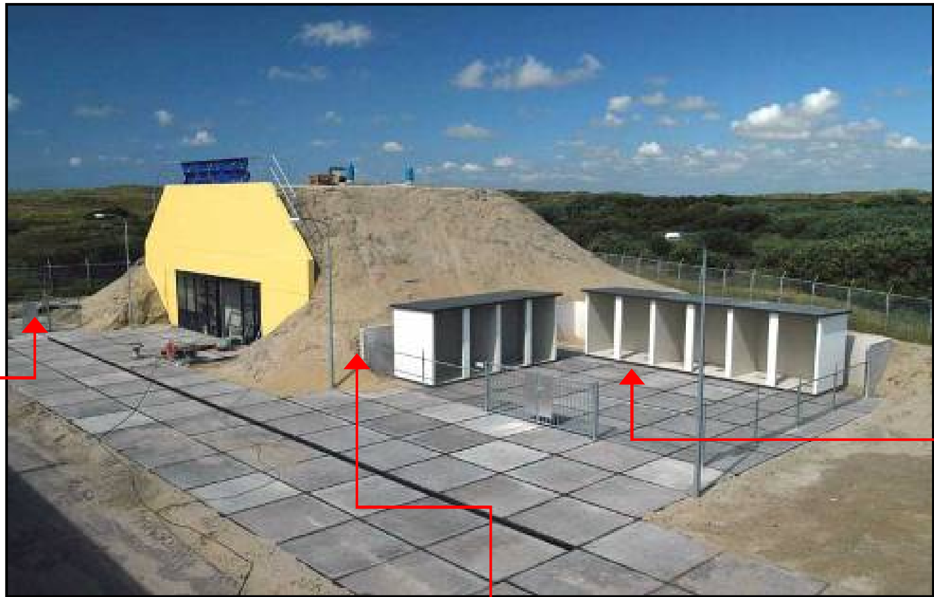
H2 production

autothermal reformer

- up to 100 Nm^3/hr H_2 peak capacity
- hydrogen quality 5.0 (99.999%)
- continuous monitoring of impurities
  e.g. CO, H_2S

Task 23 IEA HIA small scale reformers – harmonisation of efficiency measurements

High Pressure Gas Testing Facility



N_2 liquid storage

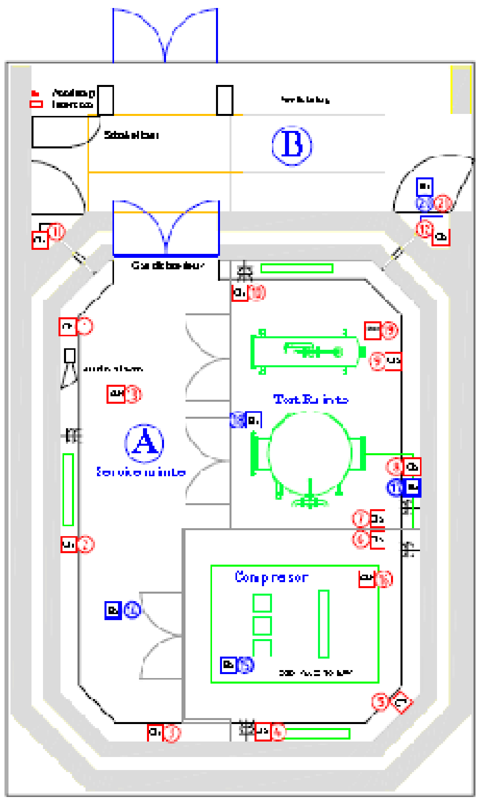
H_2 and CH_4 storage

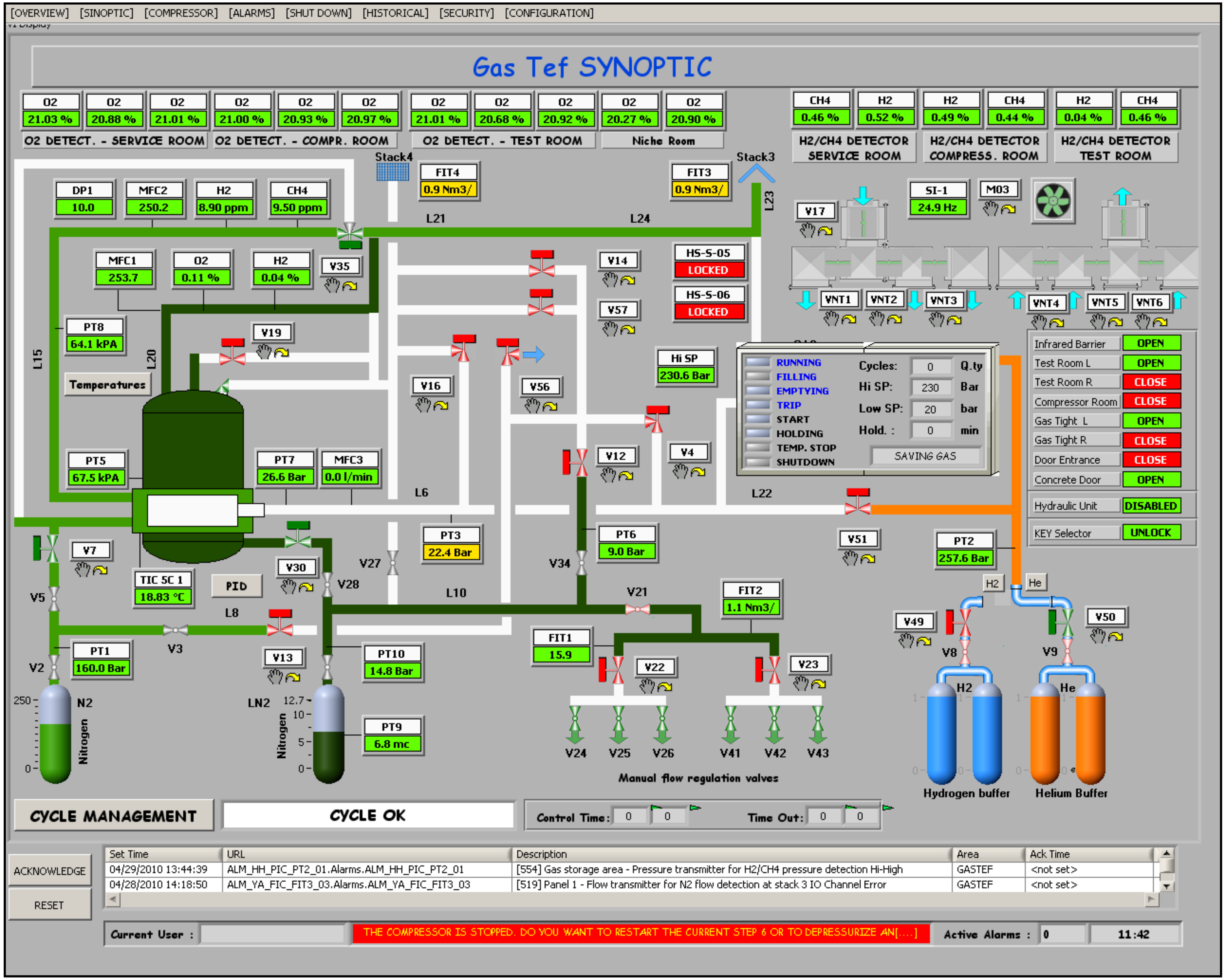
Compressor and tank testing “bunker”:
- 1 m thick composite walls
- 3 meters sand
- 40 tons sliding door
- 225 m^3 interior filled with N_2 during tests

EUROPEAN COMMISSION

… tightly controlled for reasons of safety…

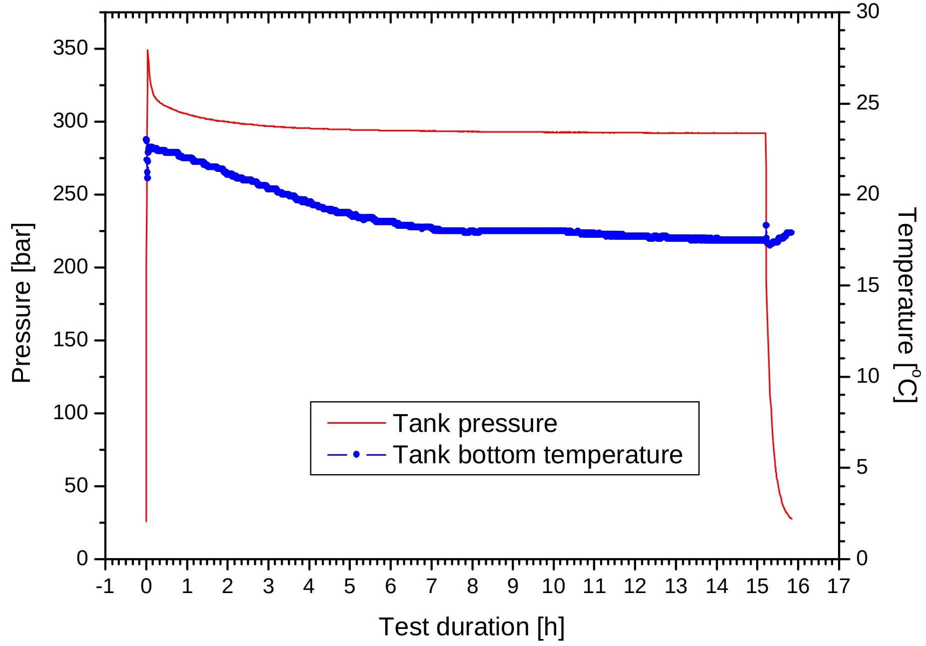
Institute for Energy

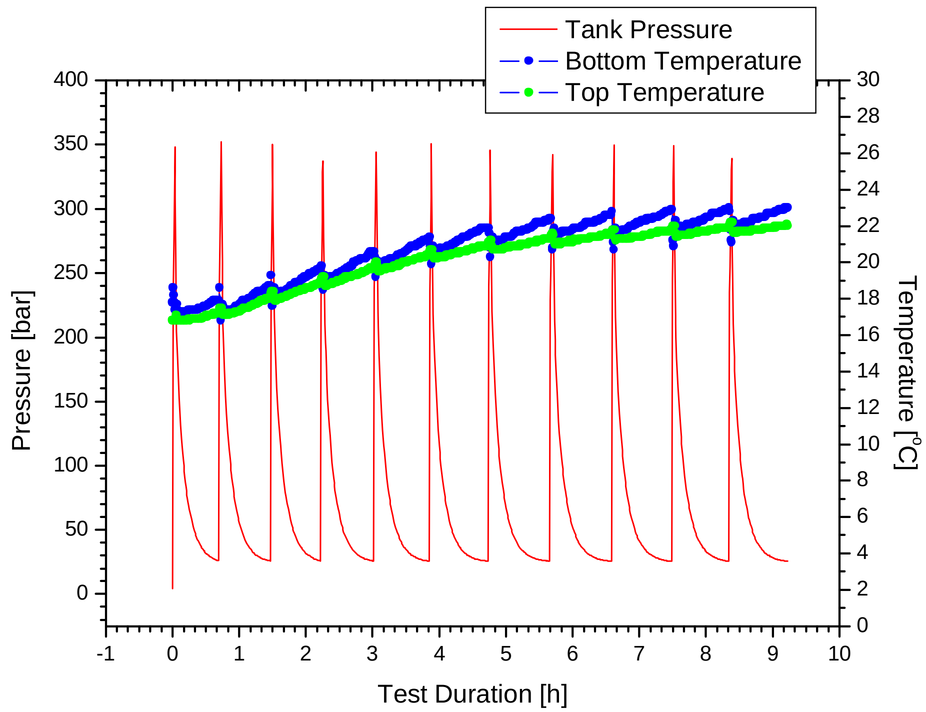




… to enable high-fidelity simulations and tests

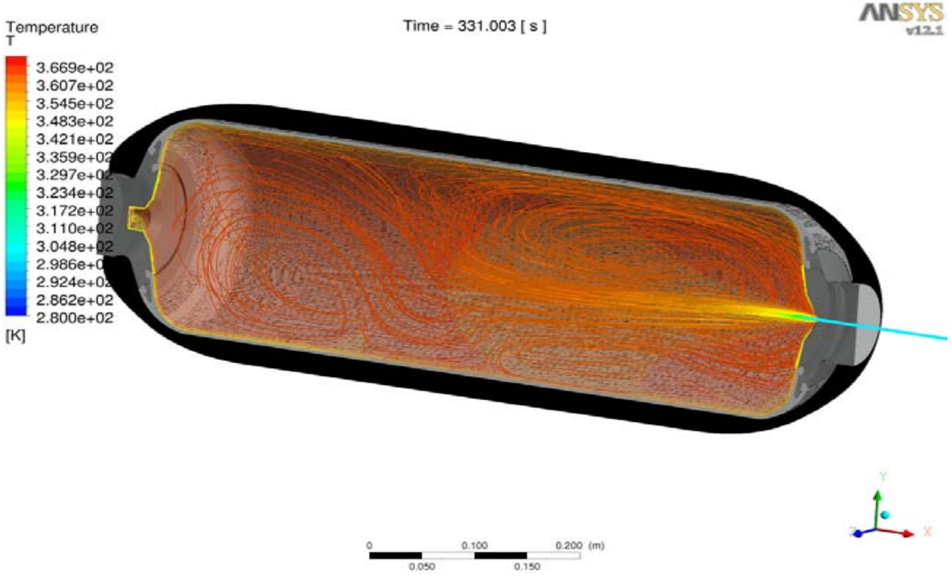
- Expose tanks and their accessories to temperatures between ambient and 100° C
- Provide a maximum filling pressure of 880 bar
- Perform the filling of the tank under test within 3 minutes
- Conduct permeation and cycling tests

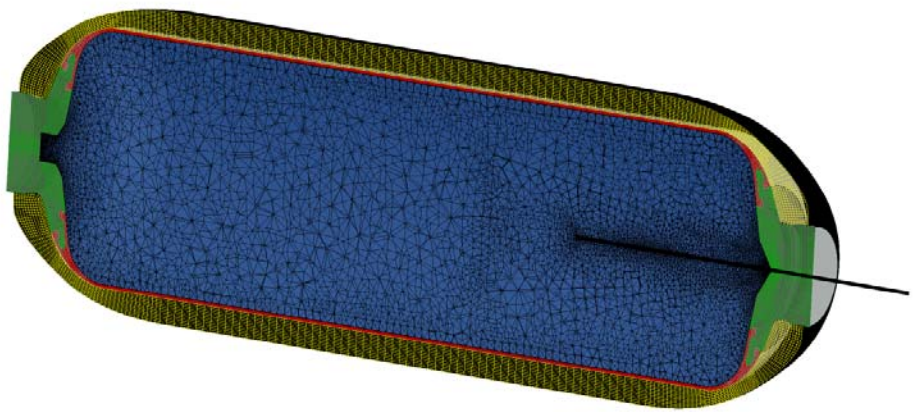




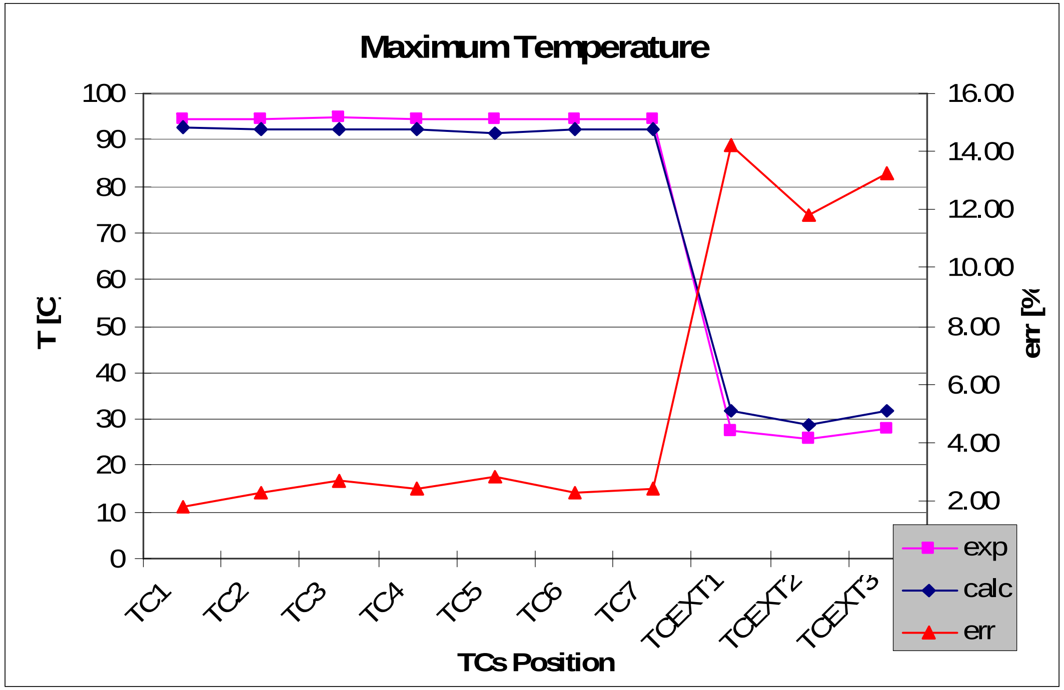
Fast Filling Validation

- Tank: Type IV (29.8L)
- Working Fluid: Hydrogen
- Test Conditions:
  - Initial Pressure: 1.2 bar
  - Final Pressure: 722 bar
  - Filling time: 331s
  - Initial tank temperature: 18° C

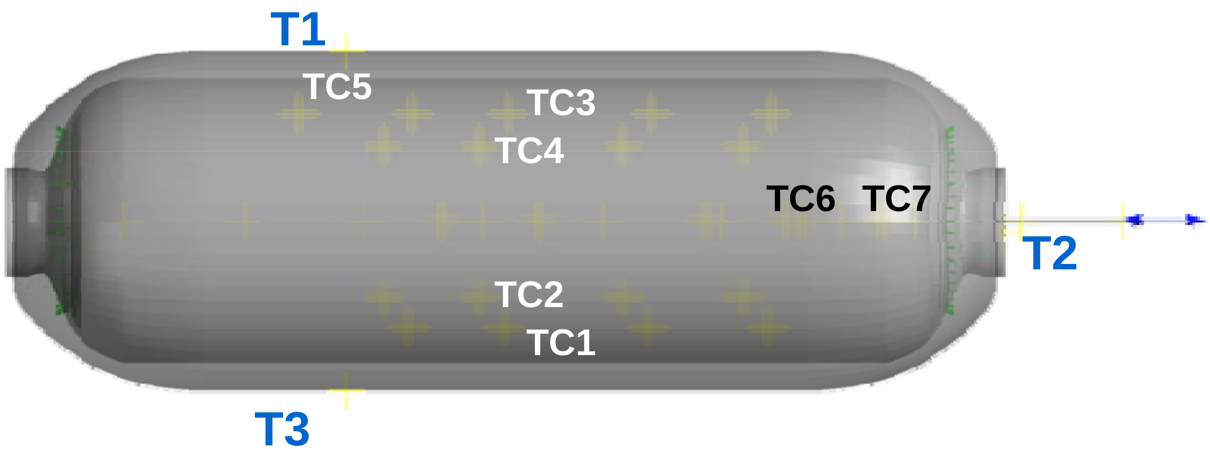




Fast Filling Validation

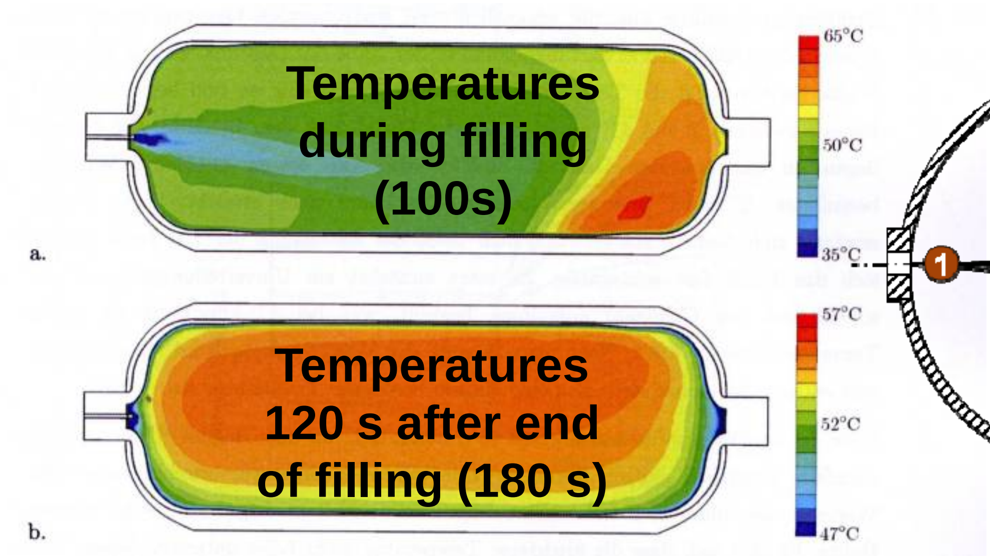


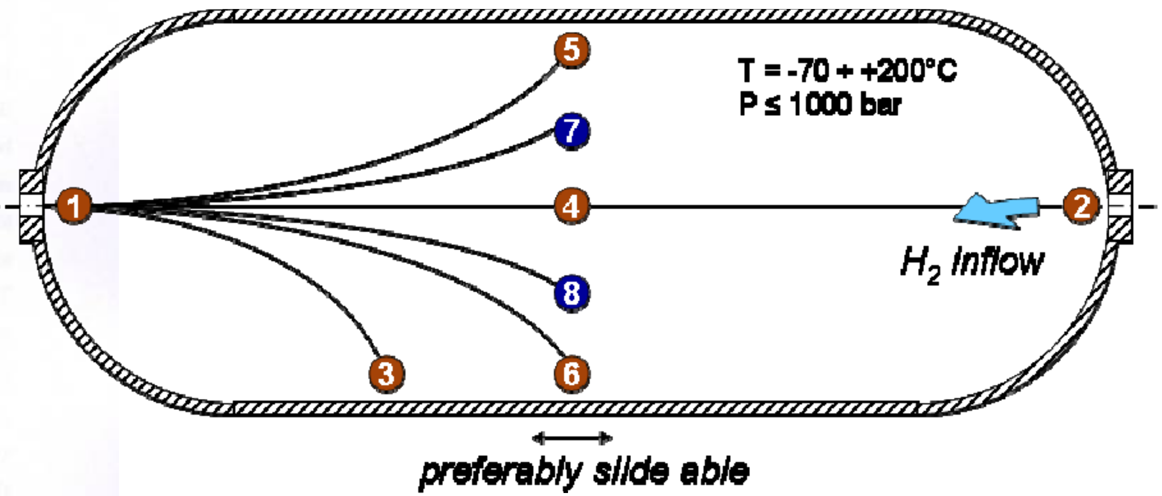
Temperature (error) versus sensor position



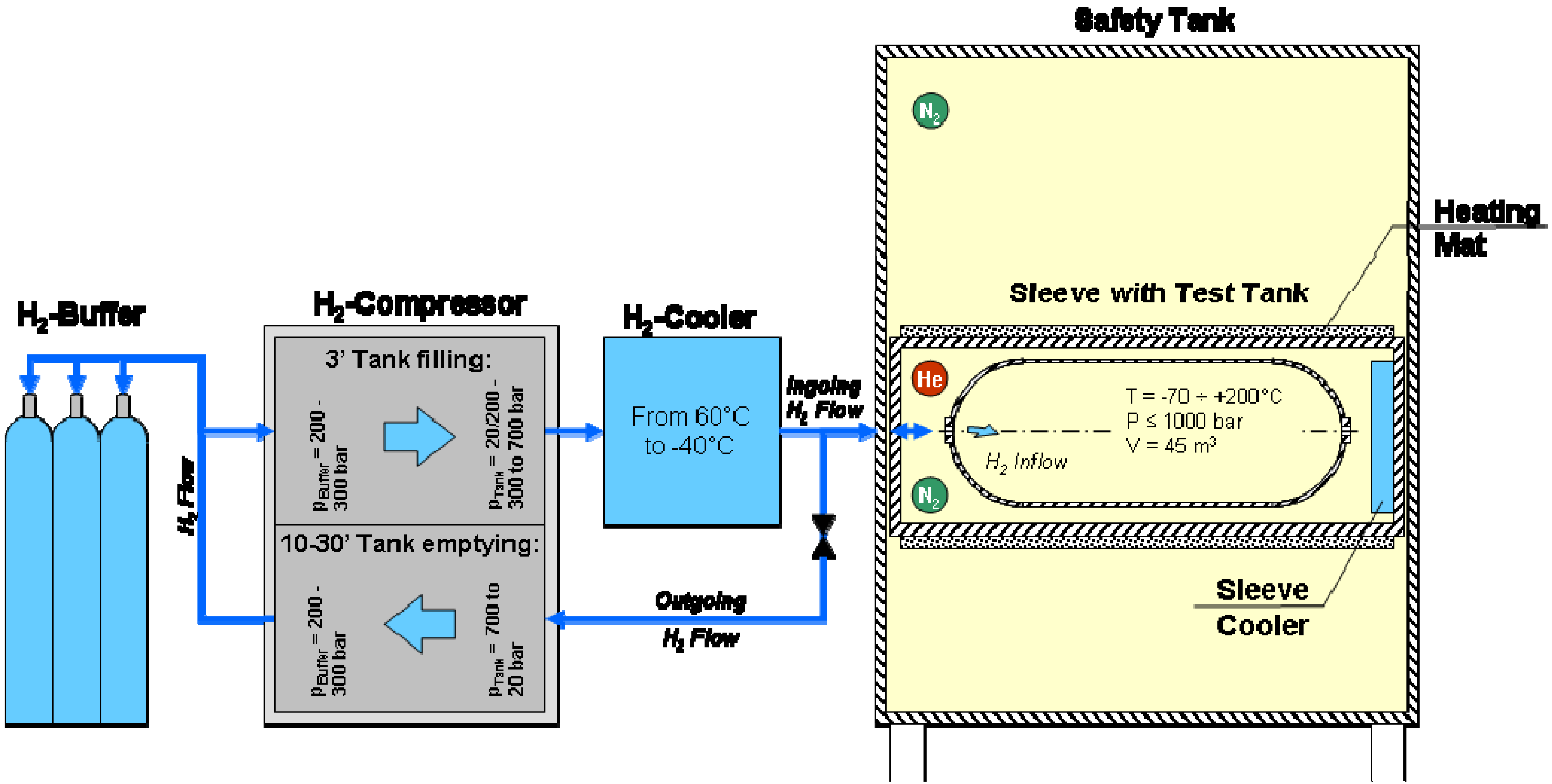
Position of the sensors in the tank. T1, T2 and T3 are placed externally

- Measure the temperature profile inside a H_2/CH_4 tank during filling to validate the software models, which are used to predict maximum temperatures inside the tanks





- Introduce a system into the bunker to cool down H2 when it is supplied to the tank
- Upgrade the environmental control system to provide very low ambient temperatures to simulate harsh environmental conditions of -40° C (or lower)



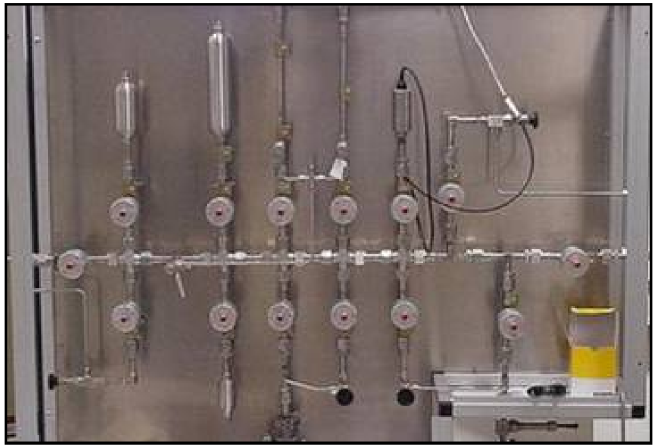
solid state H2 storage

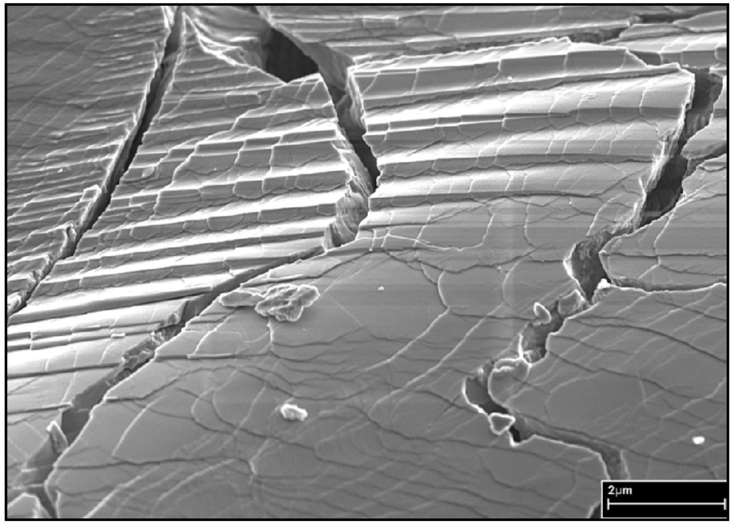
Facilities for sorption characterisation:

1. volumetric equipments
2. gravimetric equipment(s)
3. spectroscopy (Temperature Programmed Desorption)

Micro-structural characterisation:

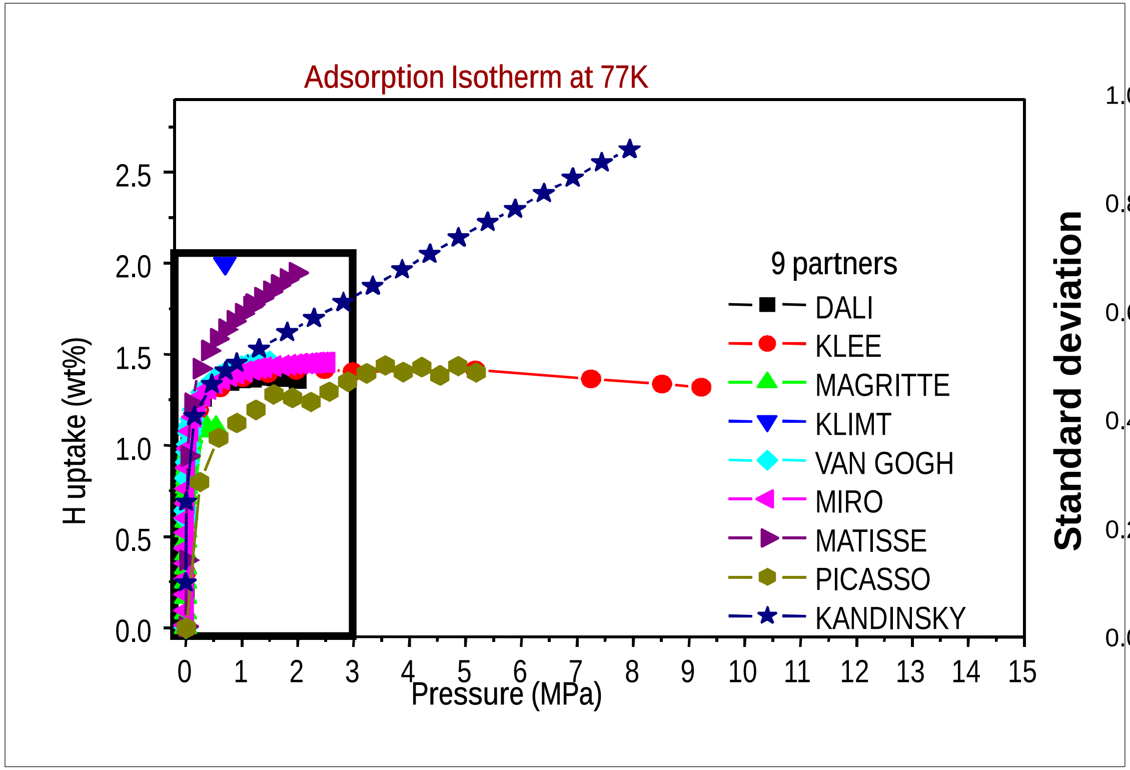
- FEG-SEM, EPMA, TEM, XRD
- Positron Annihilation Spectroscopy
- SANS

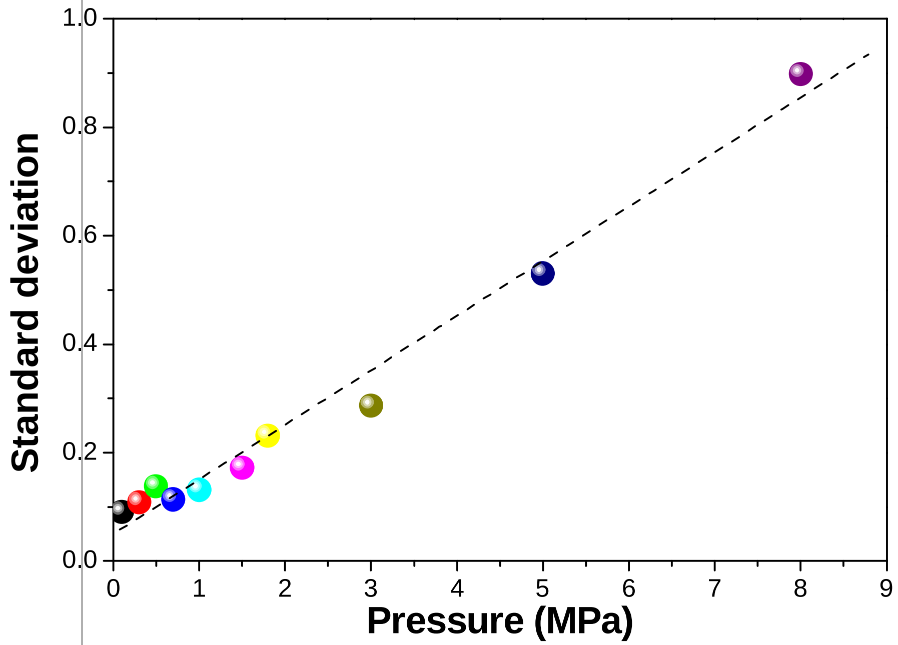




solid state H2 storage

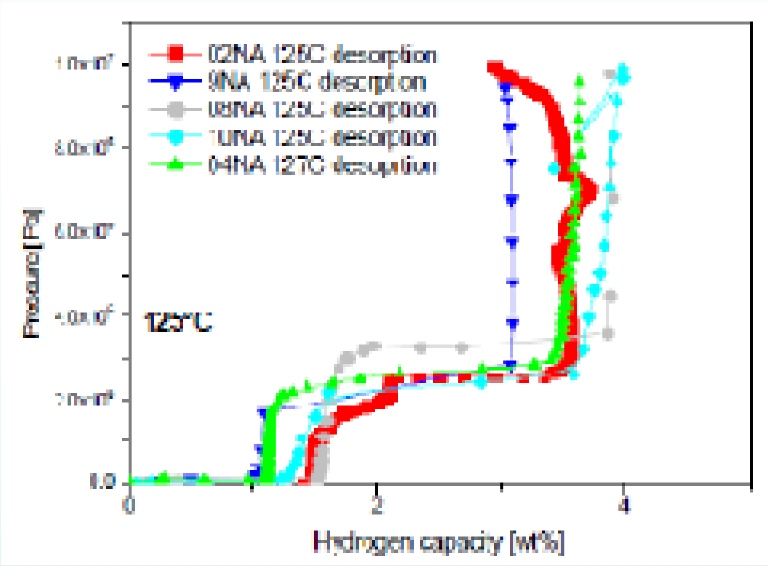
- organisation, participation, evaluation of first-ever global interlaboratory exercise on H2 solid state storage – meanwhile 3 held

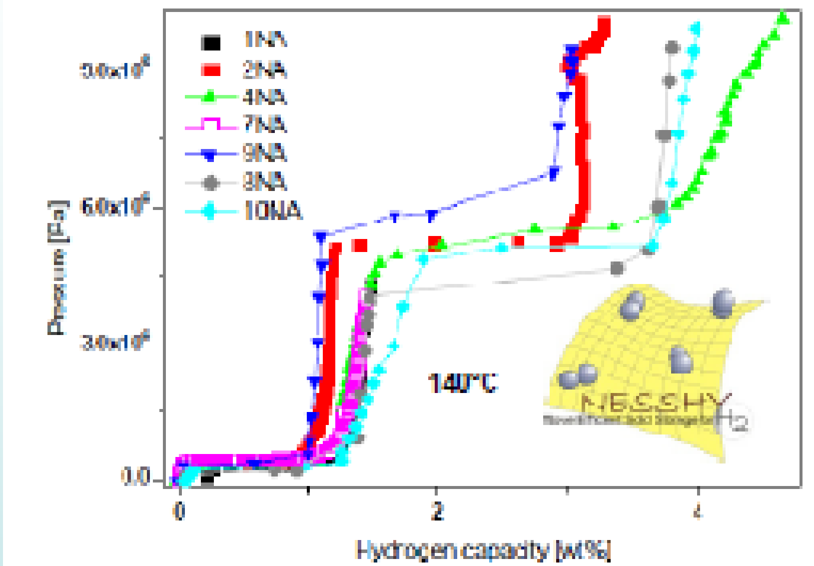




- continuous improvement of gravimetric measuring equipment

NESSHY Round-Robin Testing Results for $NaAlH_4$ ($CeCl_3$ Catalyzed)





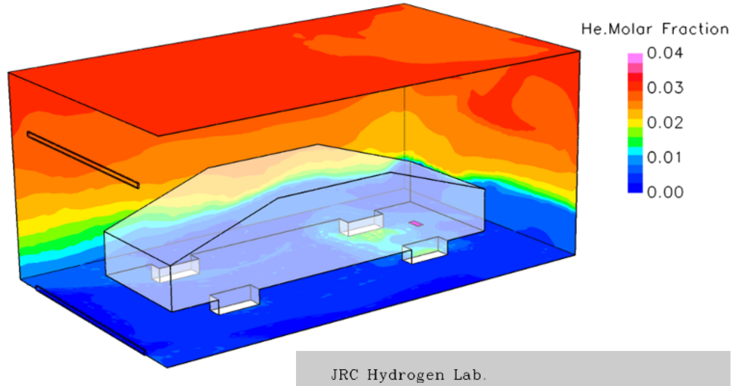
- A total of seven NESSHY partners participated in RRT, each one measured PCT isotherms (desorption and absorption) at two temperatures (125°C and 140°C) following the same preconditioning protocol
- Comparative results again show scatter in the measurements, though less scatter than the RRT study for physisorption in a carbon material at 77 K
- Overall, the results of this RRT study demonstrate the need to further develop standard guidelines for experimental procedures so that comparable and accurate quantitative results can be achieved among independent laboratories

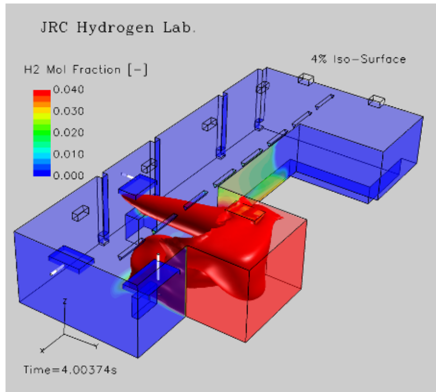
DOE Annual Merit Review Meeting, Washington DC, June 7- 11, 2010

H2 safety studies

- numerical simulations

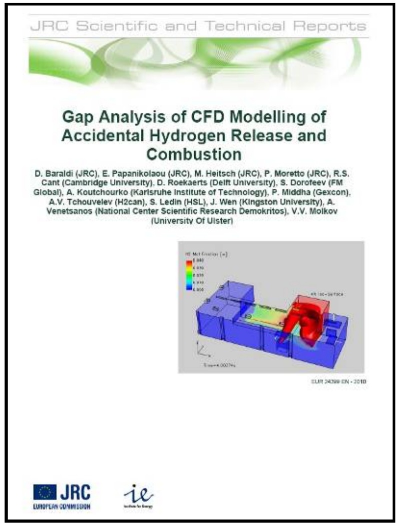
Environment	Release Dispersion	Explosions
Refuelling station		X
Garage	X	
Tunnels	X	X
Pipeline	X	
Urban street		X
Laboratory	X	





- simulations of fast filling procedure in hydrogen tanks

- gap analysis report on CFD simulations provided to FCH-JU


JRC Scientific and Technical Reports

Gap Analysis of CFD Modelling of Accidental Hydrogen Release and Combustion

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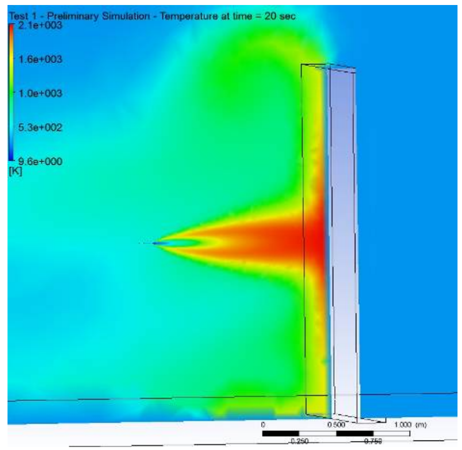
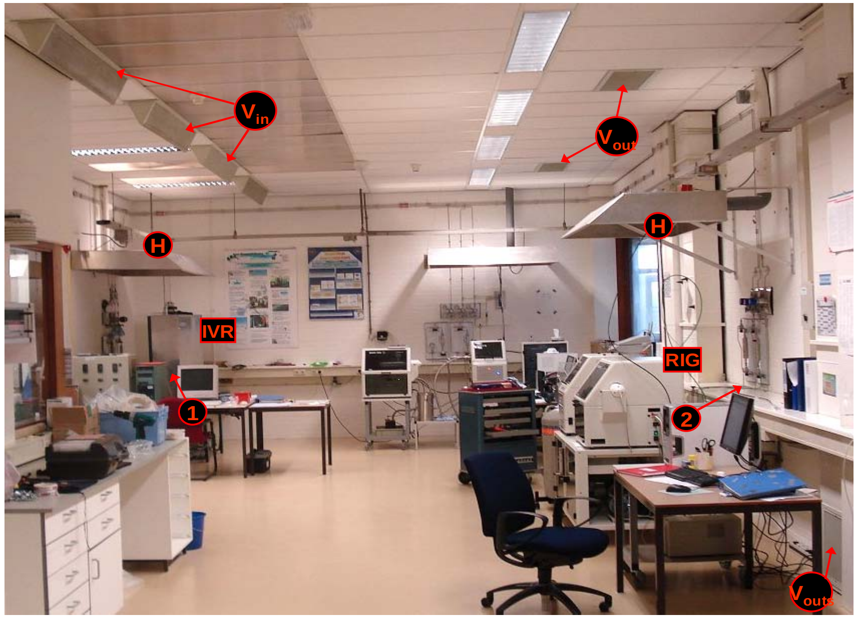
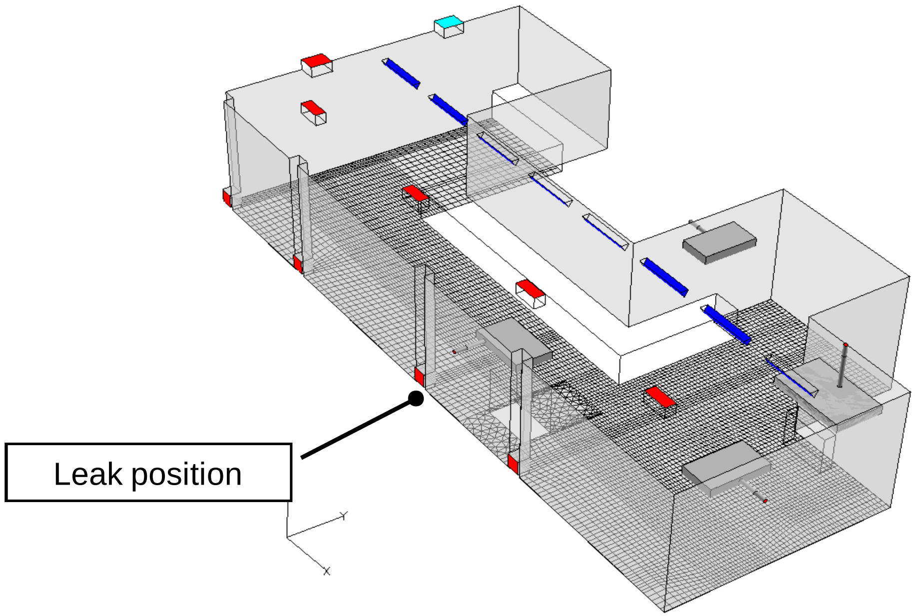


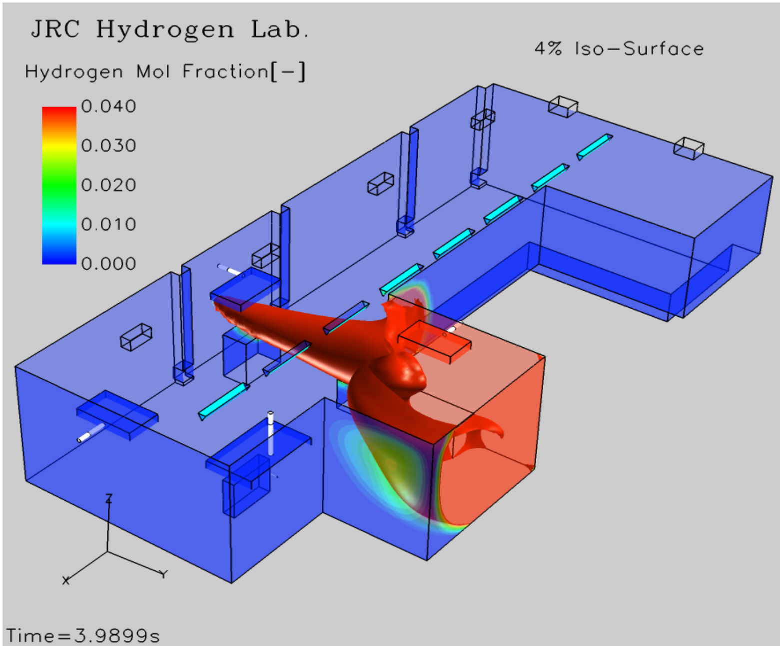
Numerical analysis (3D CFD) of accidental hydrogen release in SolTeF laboratory

- assumption of release scenarios based on Failure Mode and Effect Analysis (FMEA)
- modeling of real laboratory taking into account geometry, main obstacles, ventilation and air extraction characteristics
- calculation of hydrogen concentrations during and after release
- feedback to safety design, such as on optimal positioning of safety sensors

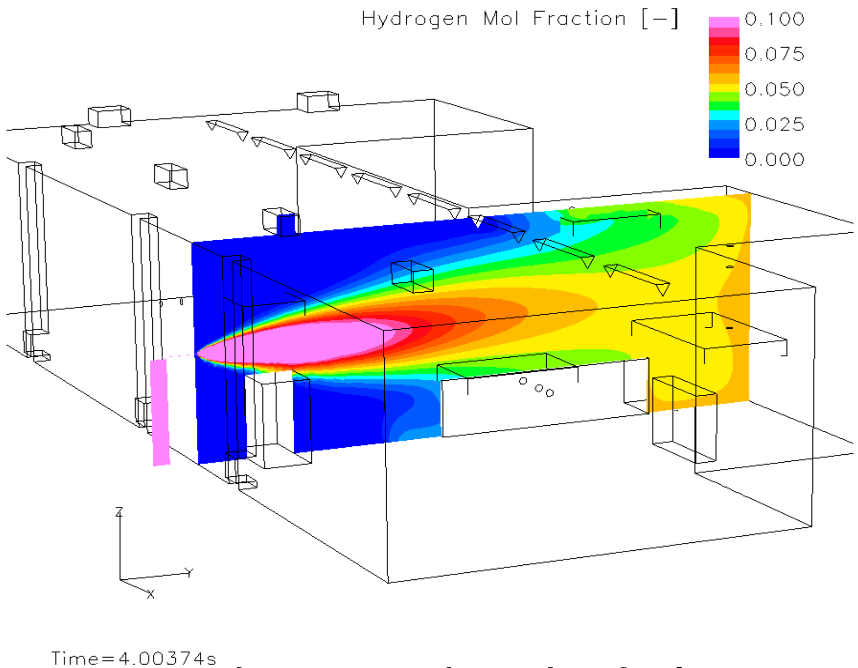




Results for the case of a guillotine break of a high pressure line in absence of mitigation measures (case beyond Max Credible Accident)



Iso-surface of hydrogen concentration at the lower flammability limit (4% of H2 in air)



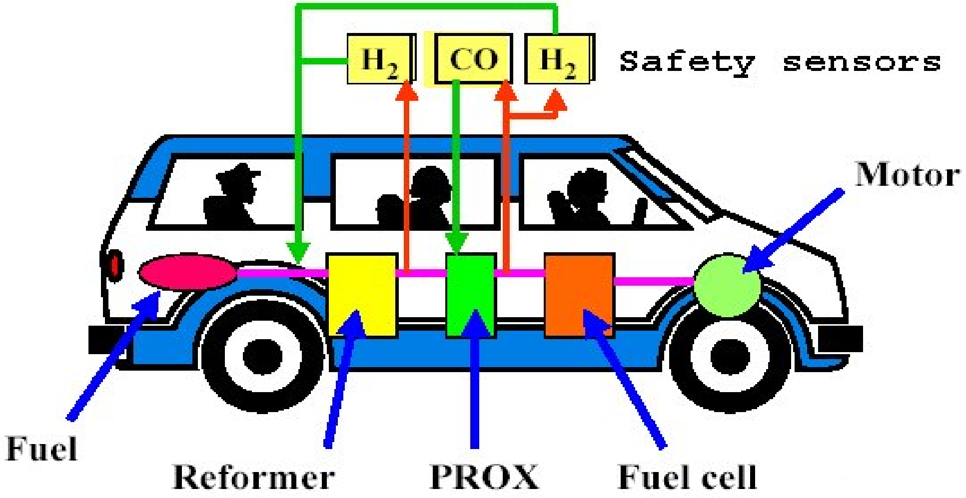
H2 concentrations at on the axis of release at 4 seconds from break

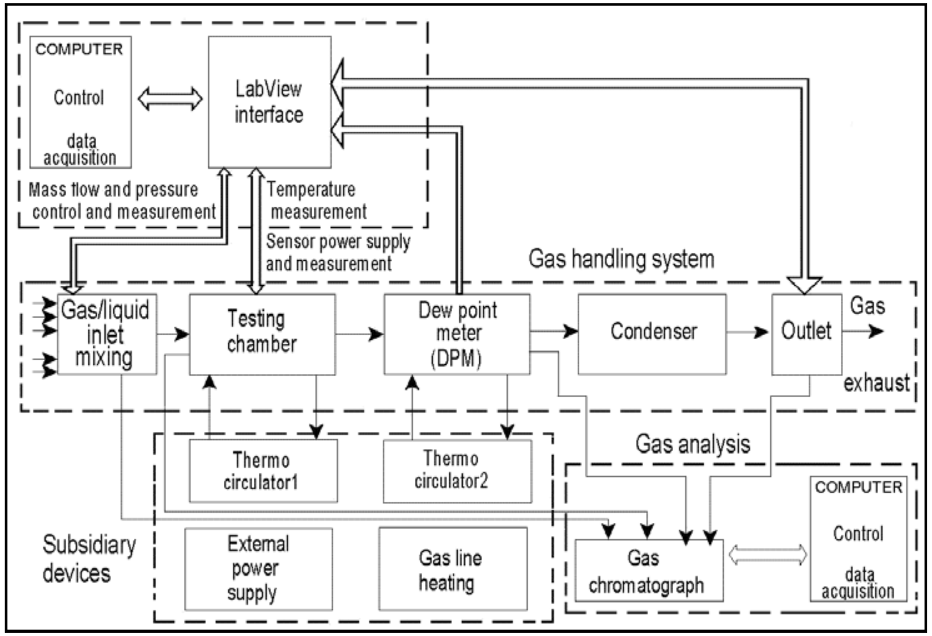
Main conclusions:

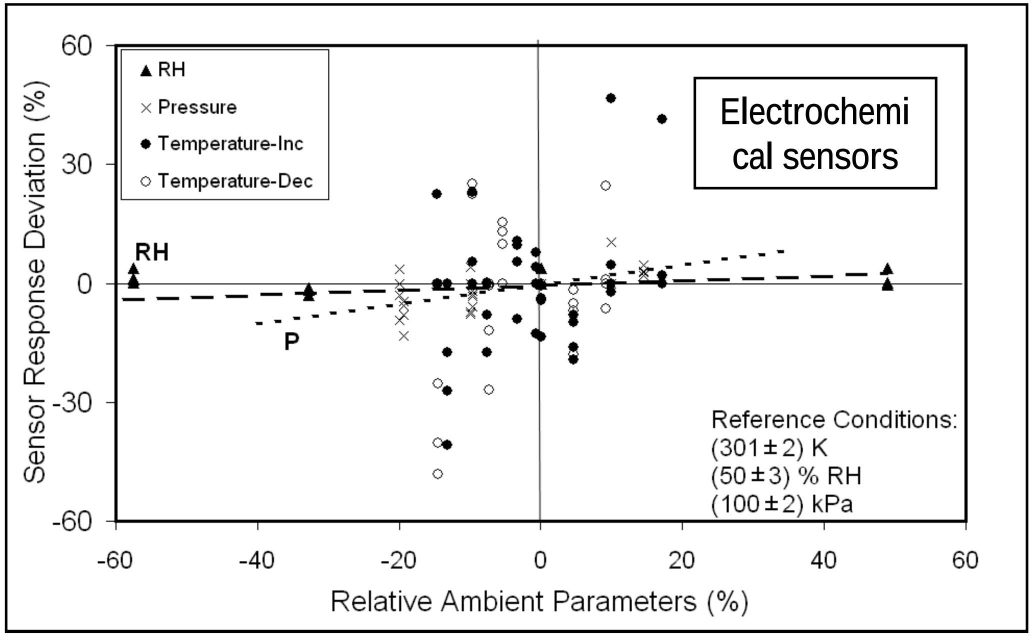
- despite the fact the hydrogen sensor detectors are placed on top of every equipment, the first detector which would give alarm is placed on the opposite wall.
- hydrogen concentrations for a short time above LFL, but mass involved not enough to sustain a flame

hydrogen safety sensors (on-board vehicle)

__objective__: to establish testing procedures for H2 safety sensor performance (lifetime, sensitivity, accuracy, reaction time, X-sensitivity,..) under real service life conditions

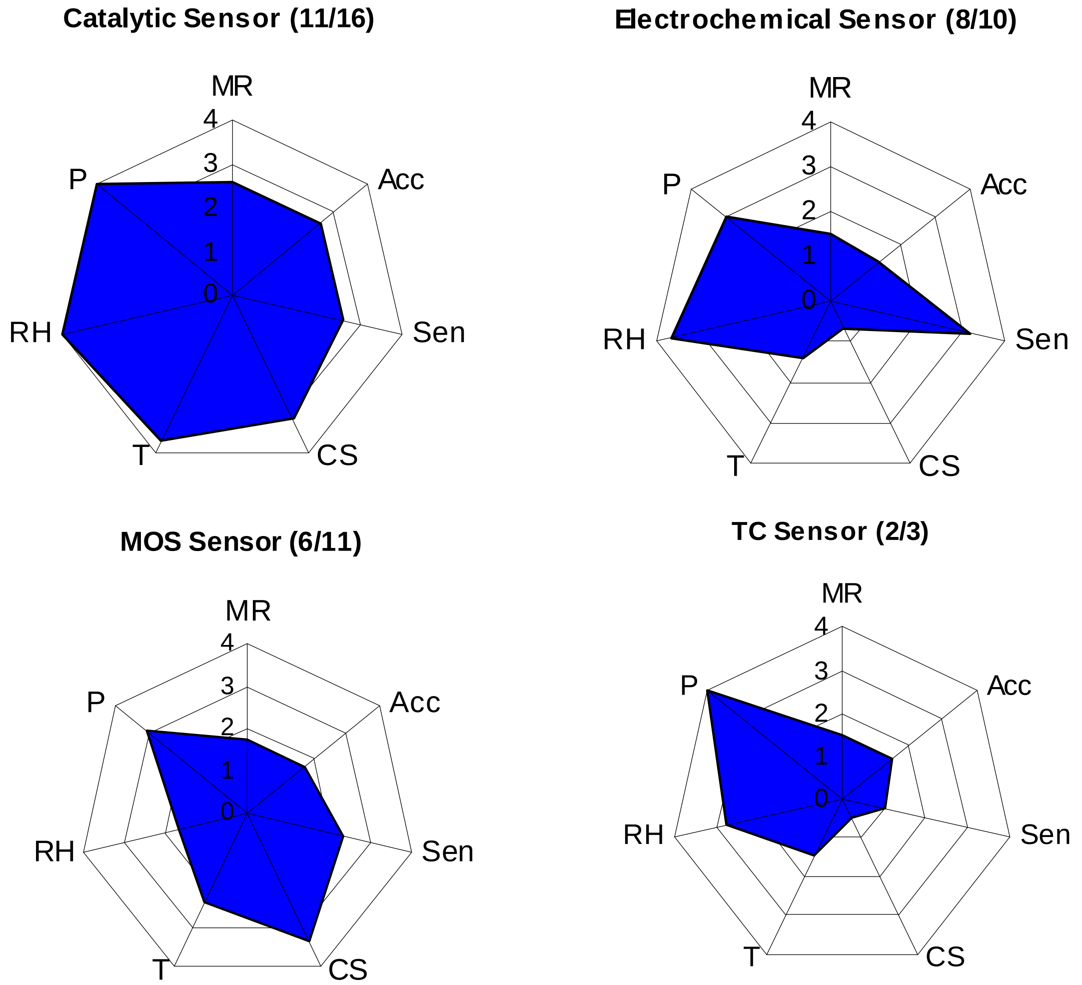






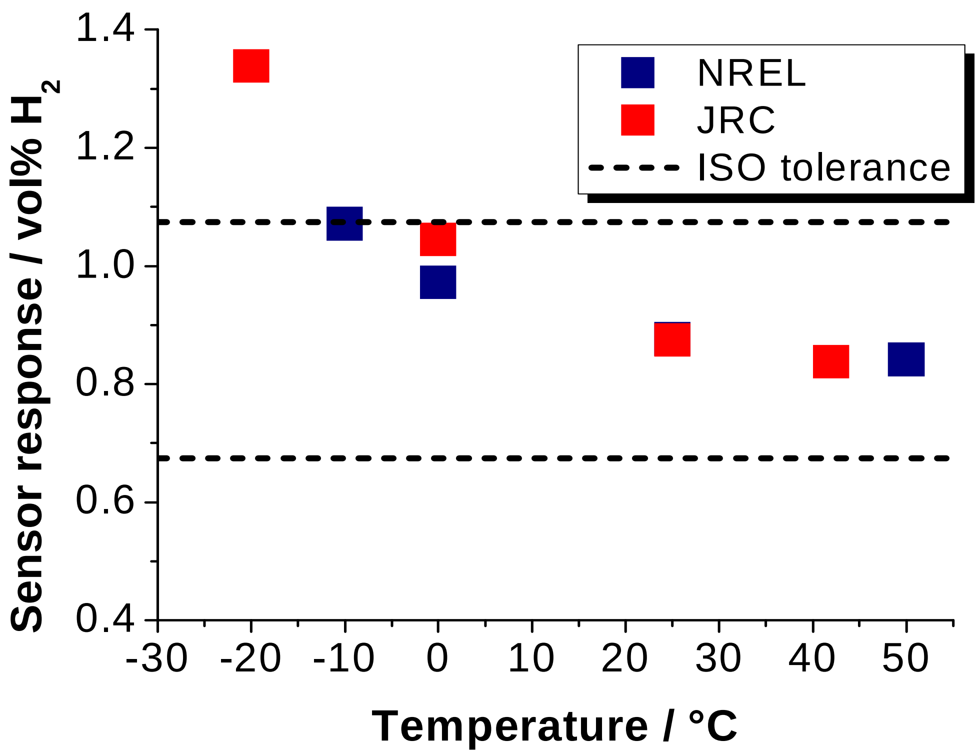
Performance of hydrogen safety sensors

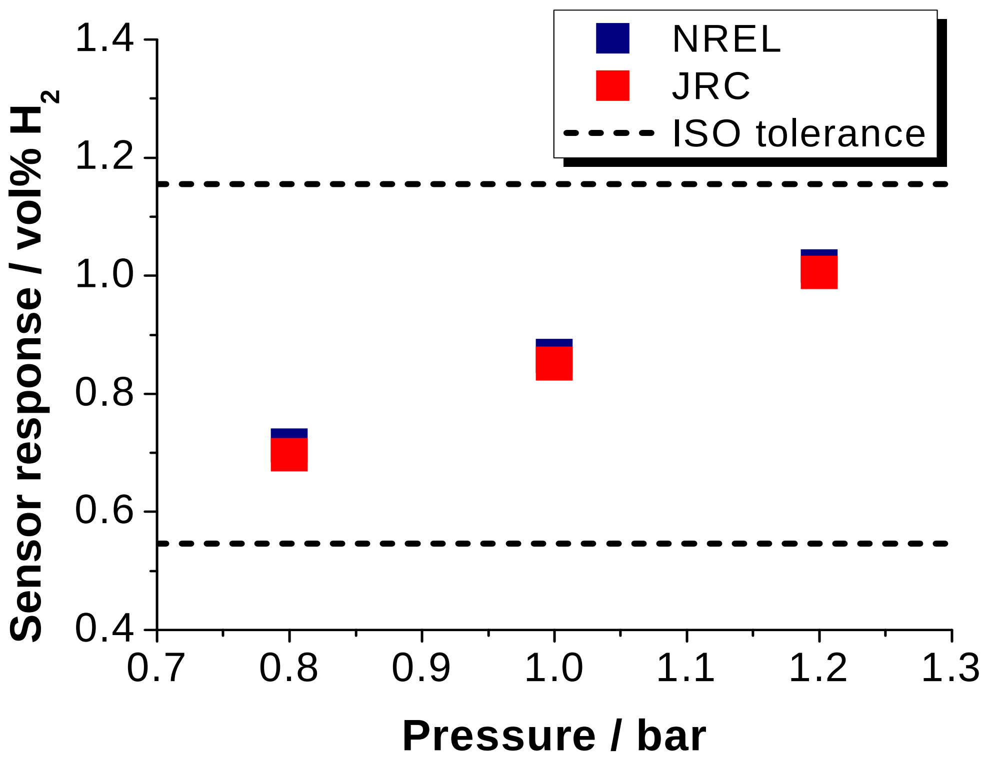
from individual parameter effect to performance evaluation: quantitative radar diagrams



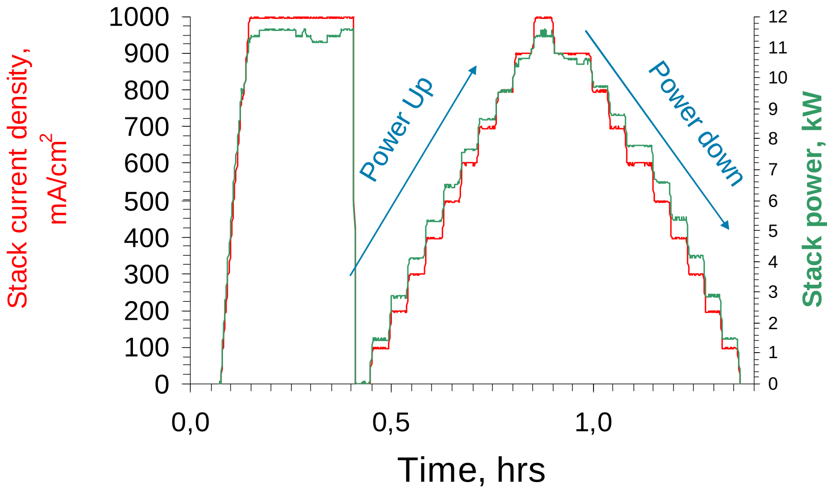
MR – measuring range
Acc – accuracy
Sen – sensitivity
CS – cross sensitivity
T - temperature
RH - relative humidity
P - pressure

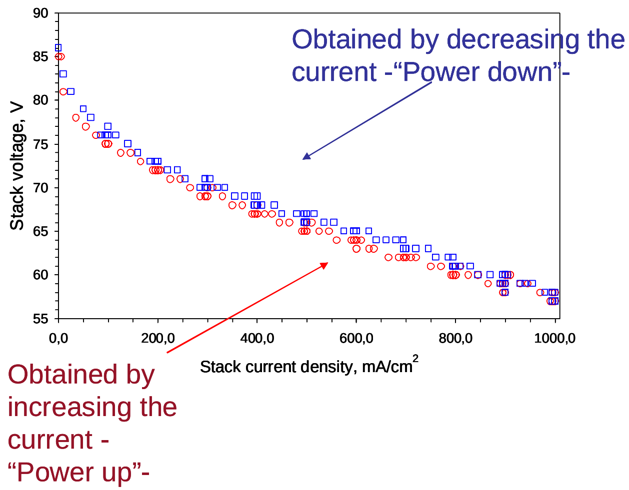
interlaboratory test programme to evaluate influence of environmental conditions (temperature, pressure, ...) on sensor response

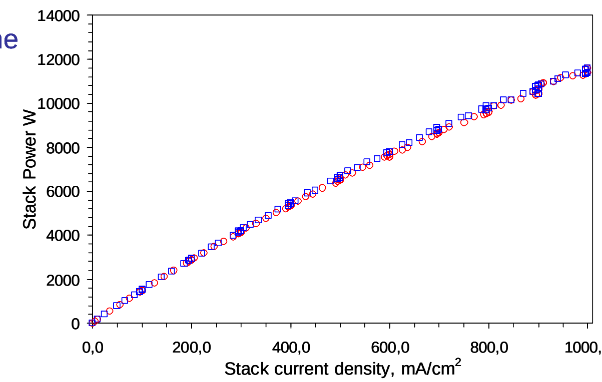


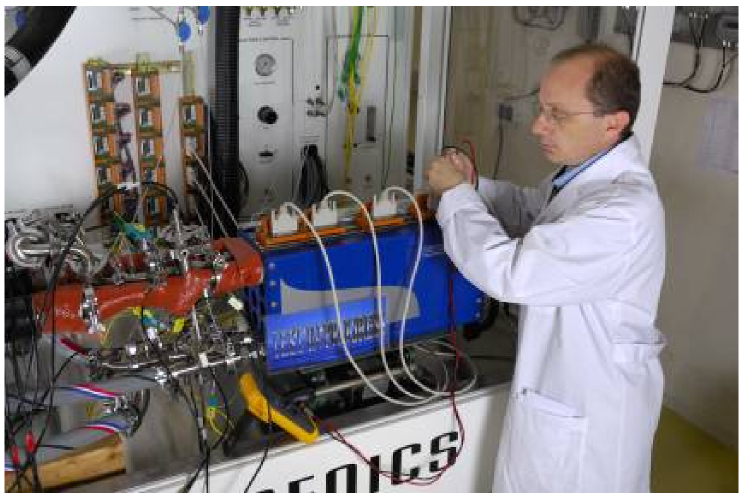


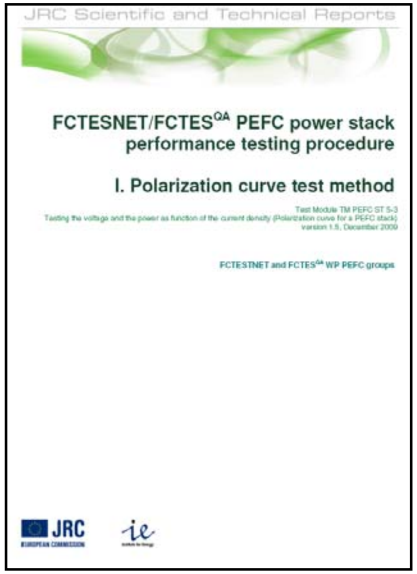
PNR for FC polarisation curves







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FCTESNET/FCTES^{QA} PEFC power stack performance testing procedure

I. Polarization curve test method

FCTESTNET and FCTES^{QA} WP PEFC groups

Underpinning research

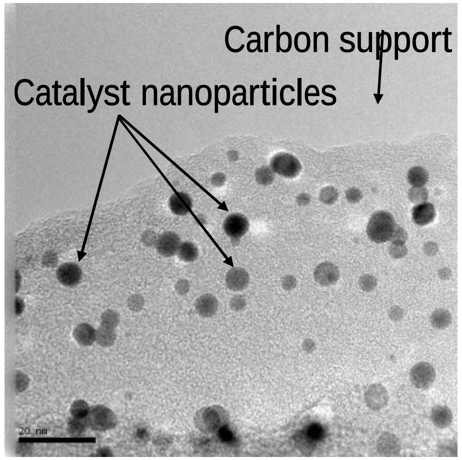
Topic: mechanistic understanding of the processes occurring at the atomic level within PEM fuel cells

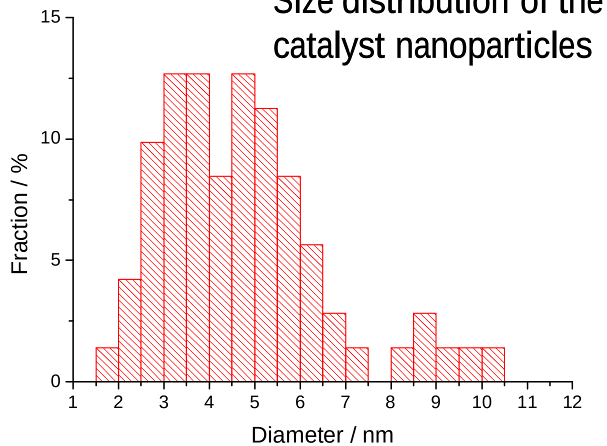
Issue: development of novel low cost and more CO tolerant nanocatalysts based on fundamental understanding of the processes involved

JRC work: kinetic studies of CO de-sorption on PtRu/C PEMFC anodes: temperature dependence and microstructural transformations

Outcome: significant insight into CO tolerance, which will likely change strategies applied for development of novel low cost and CO tolerant nanocatalysts

catalyst characterisation laboratory

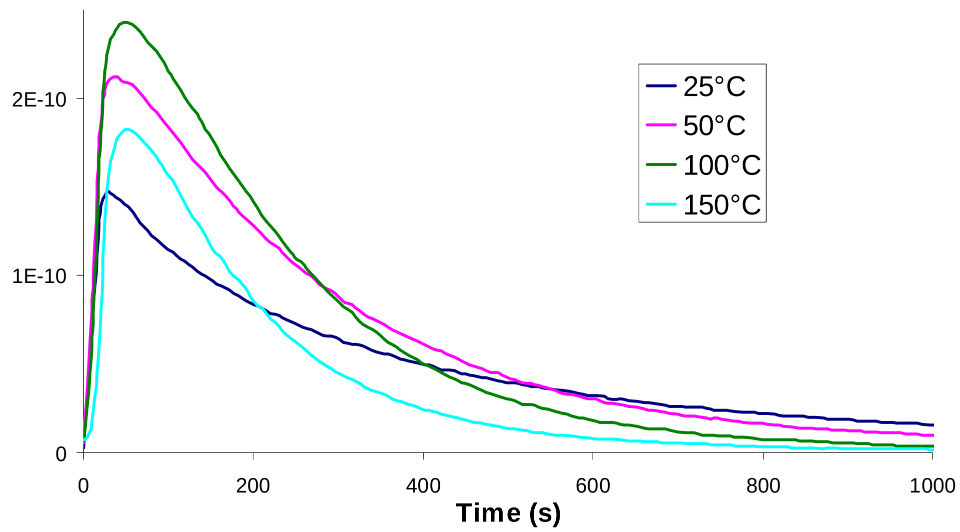


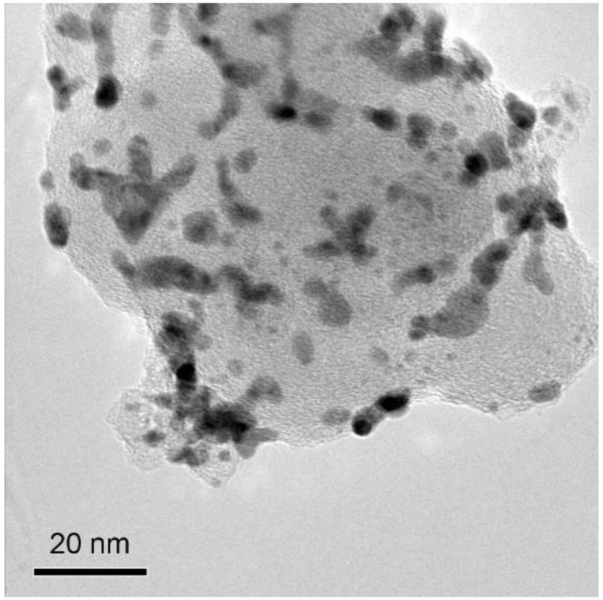


carbon-supported catalyst nanoparticles

Underpinning research

First measurement of temperature dependent CO de-sorption kinetic data on PtRu/C PEMFC anodes and assessment of the effect of thermal treatment





Improved insight into CO tolerance mechanisms expected to lead to better definition of fuel quality standards