

IEW 2009

Parallel Session 8 : Technology Learning & Diffusion
Venice - 19 June 2009

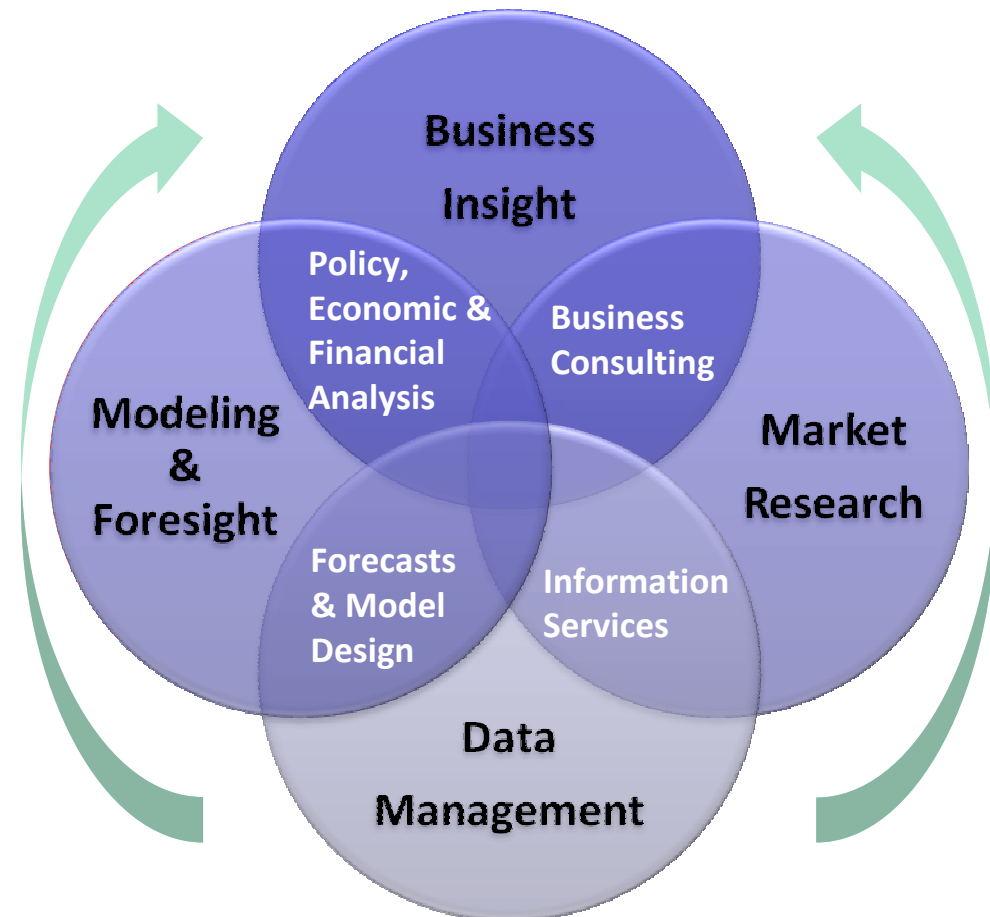
The role of Hydrogen in Long-Term Energy System: An Updated Quantitative Analysis with the POLES Model

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ENERDATA expertise in the Global Energy & Carbon Economy

- > ENERDATA is a **private independent company**, incorporated in 1991
- > Consulting and information services company **specialized in the energy and environment sectors**.
- > Experienced engineers, economists, statisticians and analysts
- > **In-house databases, models and methodologies**



OUTLINE

- 1. Updated hydrogen scenarios using POLES model**
- 2. Diffusion process of hydrogen in the transport system**
- 3. Oil supply constraint scenarios :**
The potential role of hydrogen on international oil markets
- 4. Climate policy scenarios :**
The potential role of hydrogen on mitigation strategies

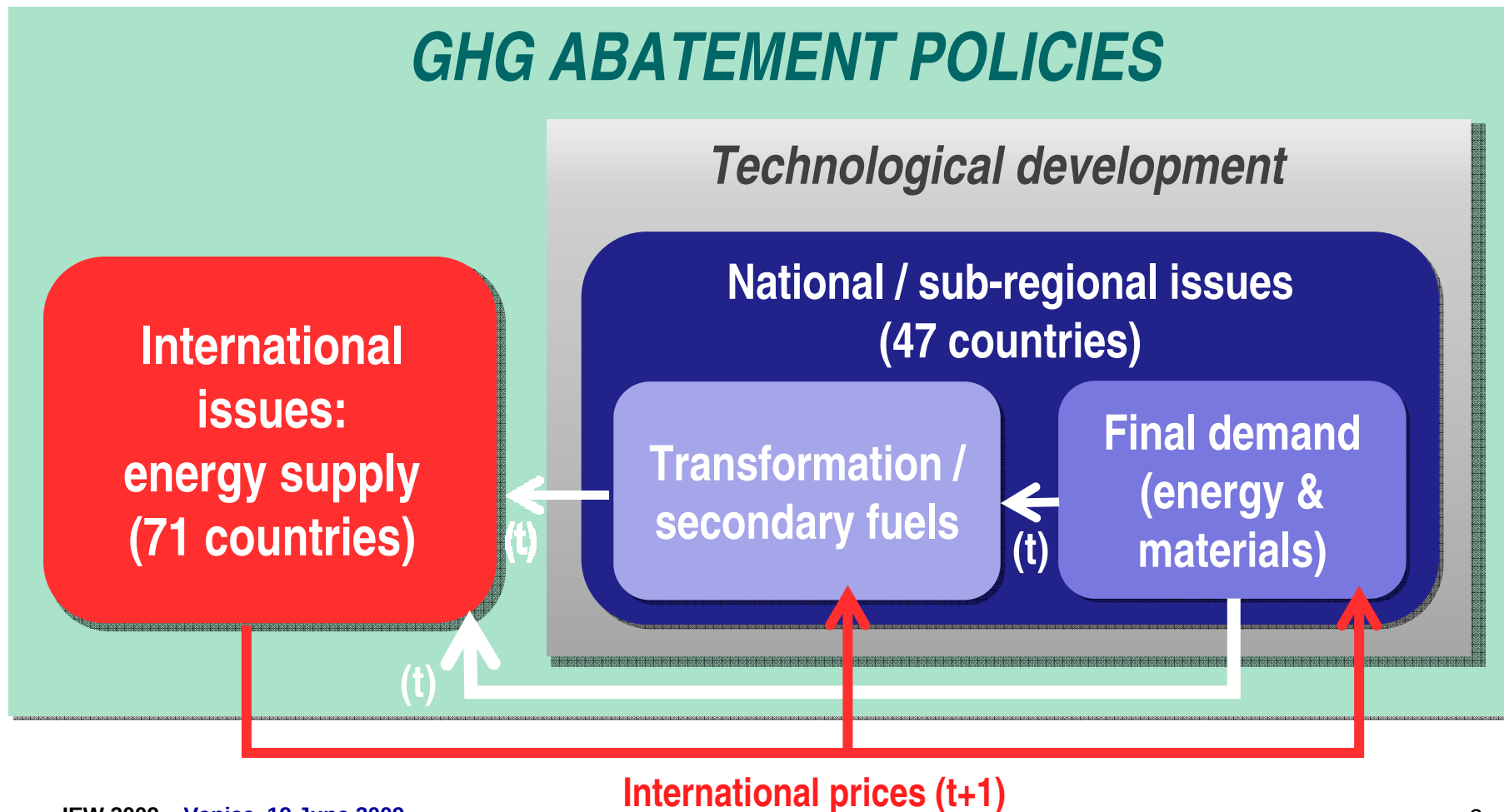
1. Updated hydrogen scenarios using POLES model

Main features of POLES model

- > Partial-equilibrium world model of the energy sector
 - Recursive (year-by-year) **simulation of energy demand and supply with endogenous international energy prices** (*Kitous et al, 2009*)
 - Hierarchical structure of **interconnected sub-models** at the international, regional and national level (47 regions and 15 demand sectors)
 - Allows for **energy and climate policies evaluation**
- > Substantial **technological description for power and H2** production, including **endogenous technological learning** (TFLC)
- > Increasing **technological detail** in the **demand side** : road transport , buildings, industry
- > Mostly mid/long-term & policy-oriented studies :
 - **National and international institutions**
 - **R&D and Strategy Department** of key corporate actors (energy, industry)

A « multi-issues » analytical model

> **POLES** : Prospective Outlook on Long-term Energy Systems



A technological outlook of hydrogen in transport : the PROTEC-H2 project

- > PROTEC-H2 is a project **funded by the French National Research Agency (ANR)** in the framework of the 2005 Edition of its **Hydrogen Program (PAN-H)** ; **coordinated by Enerdata**
- > Many French industrial and institutional partners are involved: CNRS (LEPII and CIRED), EDF, CEA, ADEME, IFP and BRGM, to **share their expert views** on key hydrogen technologies
- > Twofold objective:
 - **Organize the techno-economic information** on hydrogen chains for transport (hydrogen technologies from production to final use in vehicle) into an homogenous, rigorous and shareable database
 - Insert an original **economic and technological outlook of hydrogen in transport** (and its competitors) through H2 deployment scenarios quantified with the POLES model

New energy and climate scenarios in the PROTEC-H2 study

> **Baseline** scenario :

- Scenario **used as a reference** and aiming at evaluating diffusion and competitiveness boundaries of various technologies in different contexts (*Knopf et al, 2009*)
- Question : what future for hydrogen in a world without constraints, only submitted to markets forces, and without any specific support to hydrogen?

> « **Challenge** » scenario :

- Scenario with **constraint on fossil fuel resources** (*WEC, 2007*)
- Question : what possible role for hydrogen in a world structurally confronted to oil and gas supply rarefaction ?

> « **Solution** » scenario :

- Scenario with **stringent climate policy and fossil fuel resources constraints** (*IPCC, 2007*)
- Question : what place for hydrogen in world which is organized to stabilize GHGs concentration at 450e ppm ?

Hydrogen and electricity variants in transport

- > 3 variants for the « Challenge » and « Solution » scenarios
 - « **H2** » and « **Ele** » : technology breakthrough on hydrogen or electricity demand technologies in transport, supposing fast and substantial progress in some technology clusters due to network effects (*Criqui and Mima, 2008*)
 - « **H2+** » : same as “H2” + fiscal incentives and specific R&D policies devoted to the emergence of hydrogen as a new energy carrier in transport
- > Summary of the scenarios and variants :

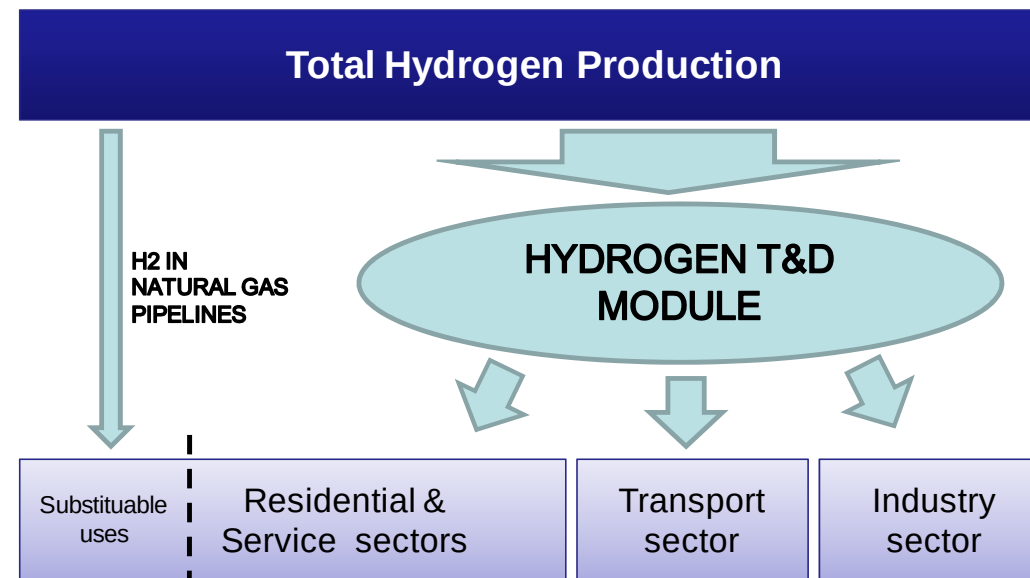
	Baseline scenario	"Challenge" scenario *	"Solution" scenario **
Base	X	X	X
"H2" variant		X	X
"H2 +" variant		X	X
"Ele" variant		X	X

* Oil supply
constraint

** Oil supply
constraint
+ Climate policy

Specific POLES developments in the framework of PROTEC-H2

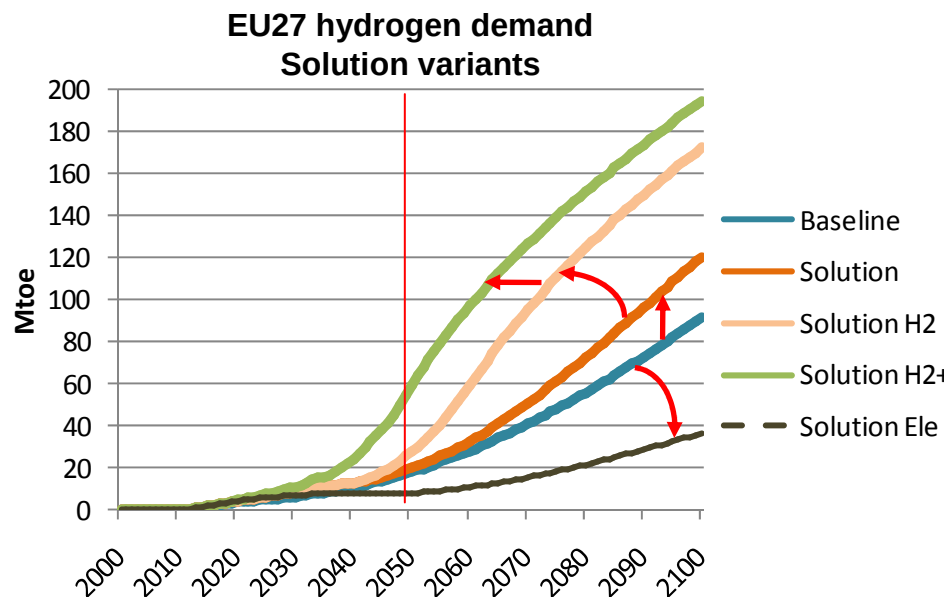
- > Development of the **Hydrogen Transport and Distribution (T&D) modeling**, including Transport of H2 in natural gas pipeline networks and a dedicated H2 T&D module with 5 explicit chains represented (*Amos, 1998 and Yang and Ogden, 2006*)
- > Integration of the **PROTEC-H2 database content as input of POLES model** for the calibration of the transport & distribution module and the calibration of the baseline assumptions for hydrogen production technologies (TECHPOL database)



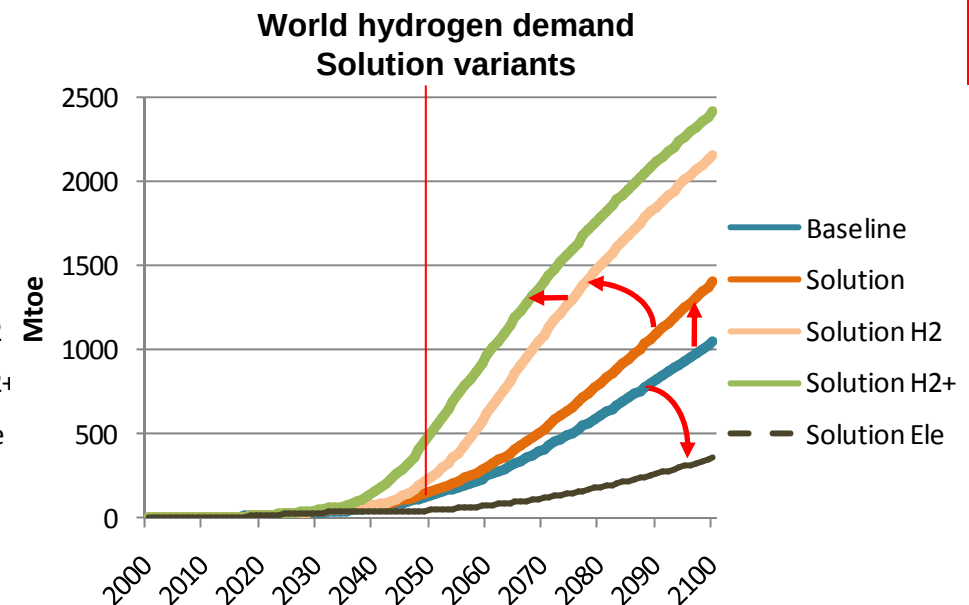
2. Diffusion process of hydrogen in the transport system

Total World and European hydrogen demand

- > Total demand for hydrogen demand is pushed by the transport sector
- > Hydrogen diffuses over two times more in « H2+ » variants than in the Baseline scenario (500 Mtoe in 2050 and over 2000 Mtoe in 2100 in the World)
- > Earlier possible development in Europe in comparison with the world average



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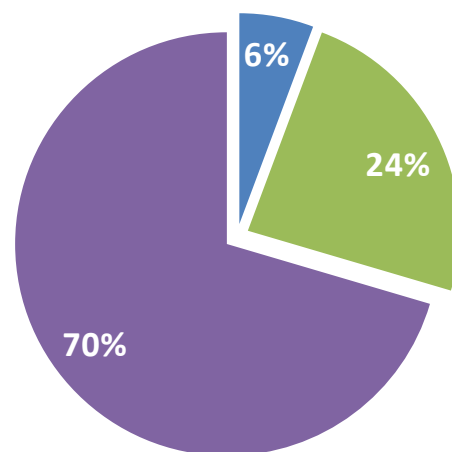


Main drivers for increasing hydrogen use in transport

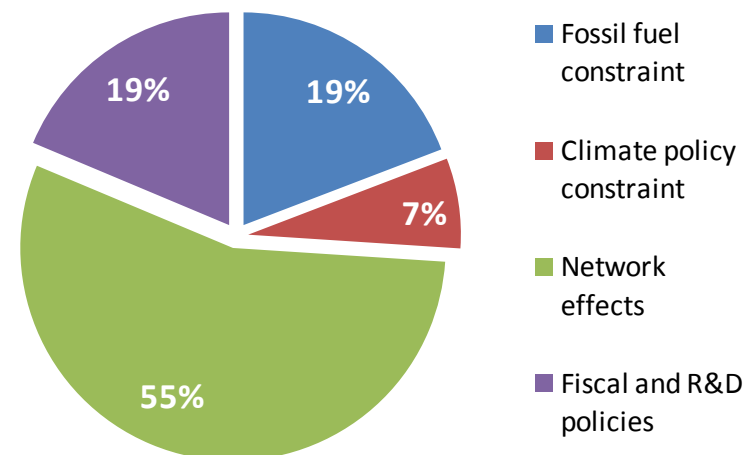
- > Main factors driving the emergence of hydrogen-energy in road transport :
 - In the **medium term** : **R&D and Fiscal policies**
 - In the **very long-term** : **Network effects** (incl. other optimistic assumptions)
- > **Climate policies do not favor hydrogen** in the medium term
- > Constraints on fossil fuel resources have a larger impact on hydrogen development over time

Drivers for hydrogen-energy development in the Solution “H2+” scenarios (in comparison with Baseline)

2050

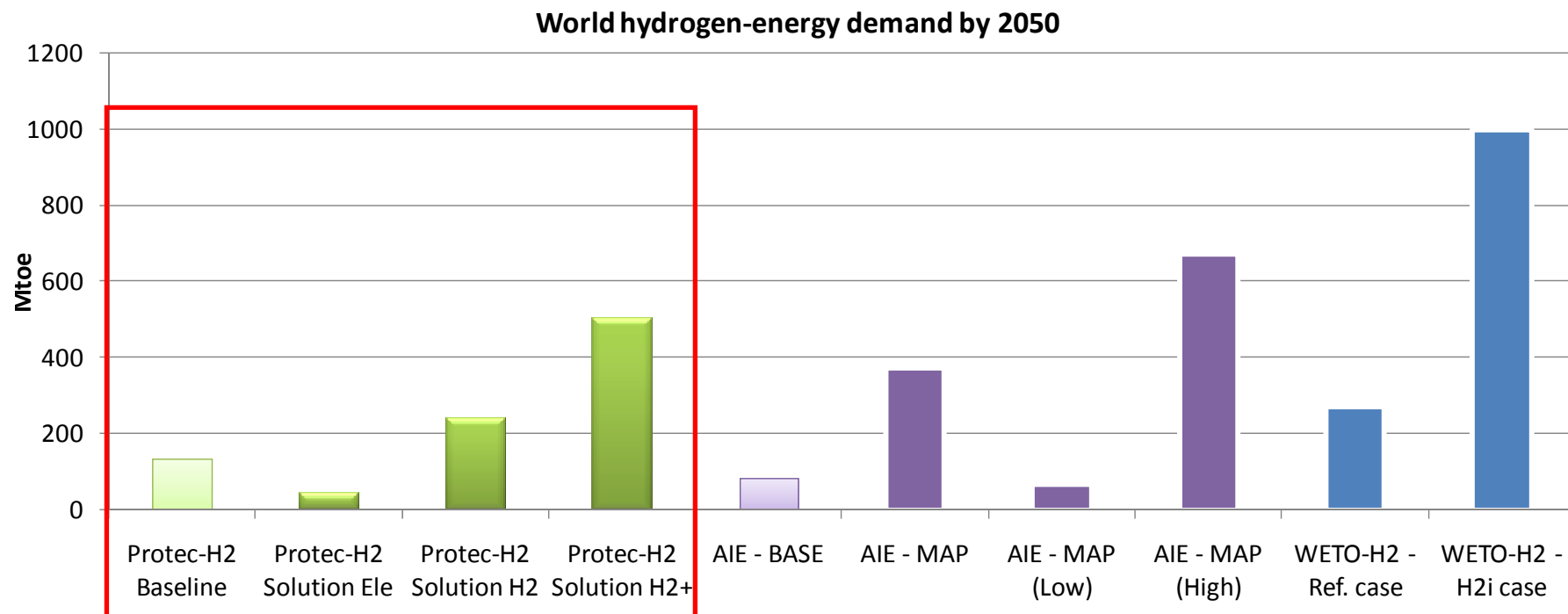


2100



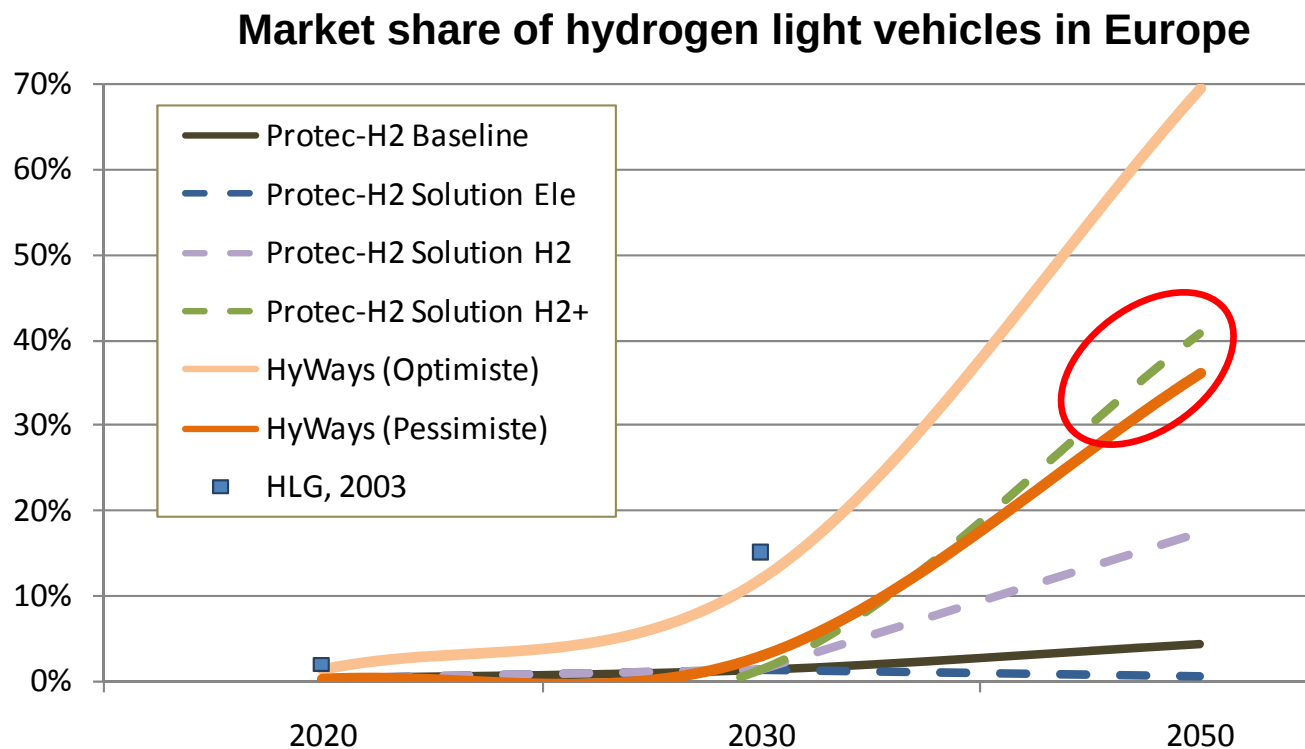
World demand for hydrogen in 2050 – comparison with other studies

- > In 2050, world hydrogen demand in **PROTEC-H2 scenarios are in line with the AIE-MAP scenarios** even if less contrasted (around 400 Mtep)
- > In 2100, PROTEC-H2 scenarios stand in the lower range of the literature (1000 Mtoe to 7000 Mtoe)



Diffusion of hydrogen vehicles – Comparison with HyWays

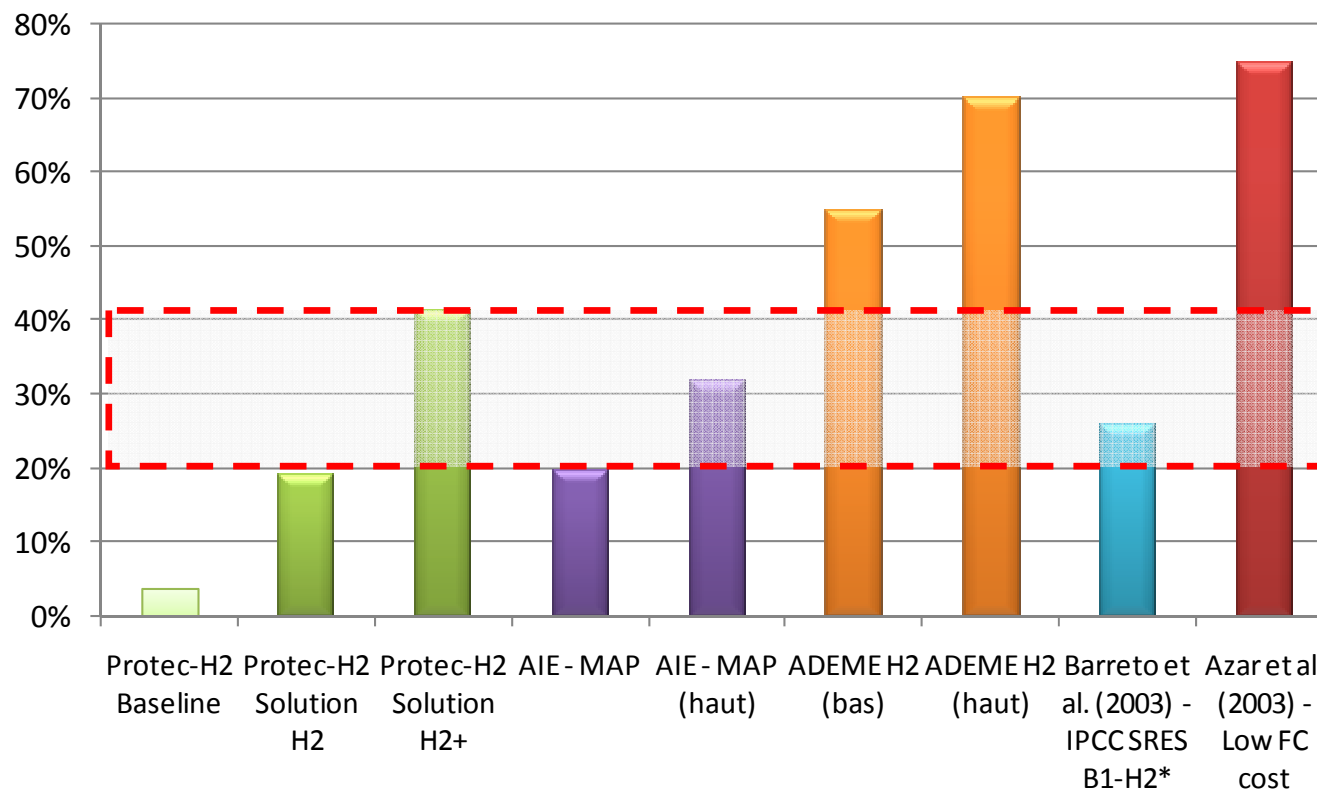
- > Solution «H2+», the **most optimistic PROTEC-H2 scenario** for hydrogen, is **close to the most pessimistic HyWays scenario** for light hydrogen vehicles in Europe (ie. around 40% of vehicle stocks by 2050)



Diffusion of hydrogen vehicles in 2050 – Comparison with other studies

- > PROTEC-H2 is in the **lower range given by the literature**, but this is not an official road-map or a partisan study

Market share of hydrogen light vehicles (World, 2050)



Diffusion of alternative vehicles in the PROTEC-H2 scenarios

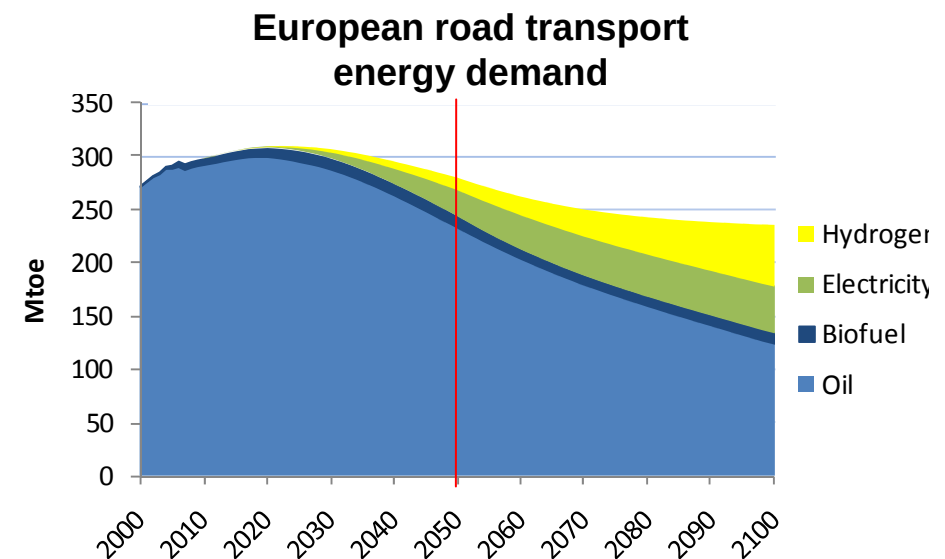
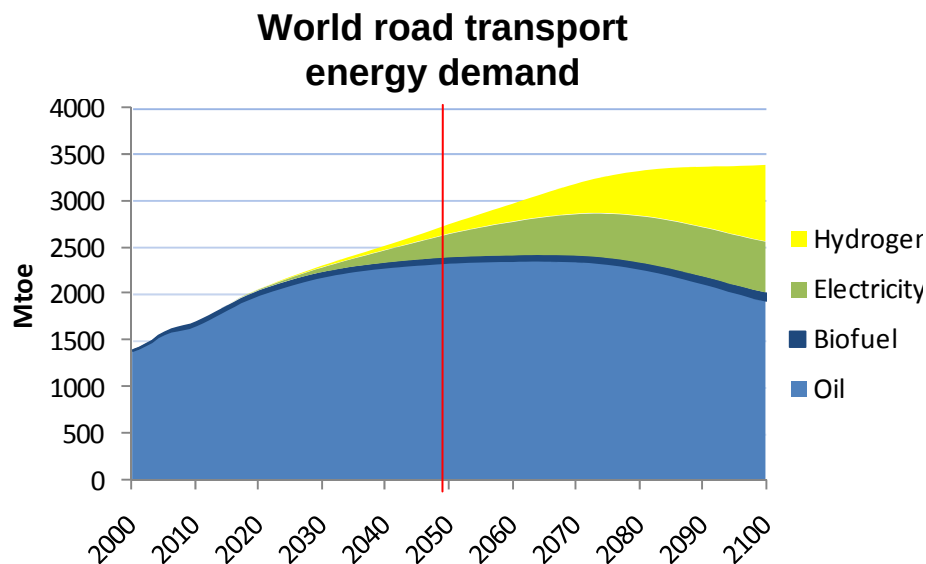
- > **Alternative vehicles already diffuse** in the Baseline scenario => reflects current tendency with the emergence of hybrid/electric cars ?
- > Diffusion of hydrogen vehicles is **delayed by 10 to 20 years** in the « H2+ » variant in comparison with electric vehicles in the « Ele » variants

Market share of alternative light vehicles (World)

	2000	2020	2030	2040	2050	2060	2070	2080	2090	2100
Total alternative vehicles (Baseline)	0%	2%	11%	25%	38%	47%	53%	58%	62%	67%
<i>of which Hybrid vehicles</i>	0%	1%	7%	15%	22%	27%	29%	30%	30%	30%
<i>of which Electric vehicles</i>	0%	1%	3%	8%	12%	14%	15%	15%	16%	16%
<i>of which Thermal H2 vehicles</i>	0%	0%	1%	2%	4%	5%	6%	8%	9%	11%
<i>of which Fuel Cell H2 vehicles</i>	0%	0%	0%	0%	0%	1%	3%	5%	7%	10%
Total electric vehicles (Solution Ele)	0%	3%	40%	75%	89%	94%	96%	97%	98%	98%
<i>of which Electric vehicles</i>	0%	1%	16%	34%	47%	55%	61%	66%	71%	74%
<i>of which Hybrid vehicles</i>	0%	2%	25%	41%	42%	39%	35%	31%	27%	24%
Total hydrogen vehicles (Solution H2+)	0%	0%	2%	12%	41%	60%	71%	77%	82%	86%
<i>of which Thermal H2 vehicles</i>	0%	0%	2%	3%	3%	3%	3%	3%	3%	3%
<i>of which Fuel Cell H2 vehicles</i>	0%	0%	0%	9%	38%	56%	68%	74%	79%	83%

Energy consumption in road transport : Baseline scenario

- > New energy carriers do appear from 2030
- > Electricity and hydrogen consumption remain under which of conventional fuels in the very long-term
- > Total consumption peaks at the very end of the period at 3400 Mtoe (in Europe it is peaking by 2020, slightly above 300 Mtoe)



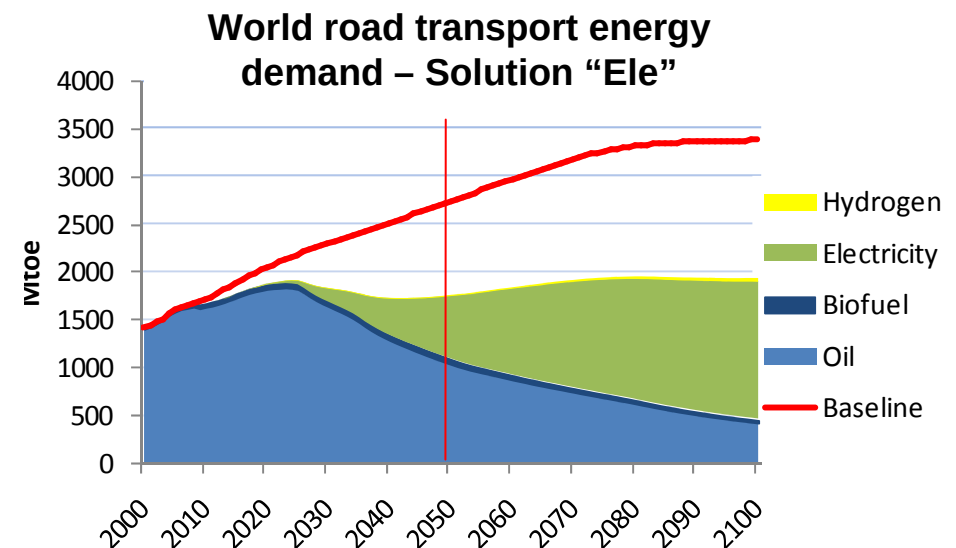
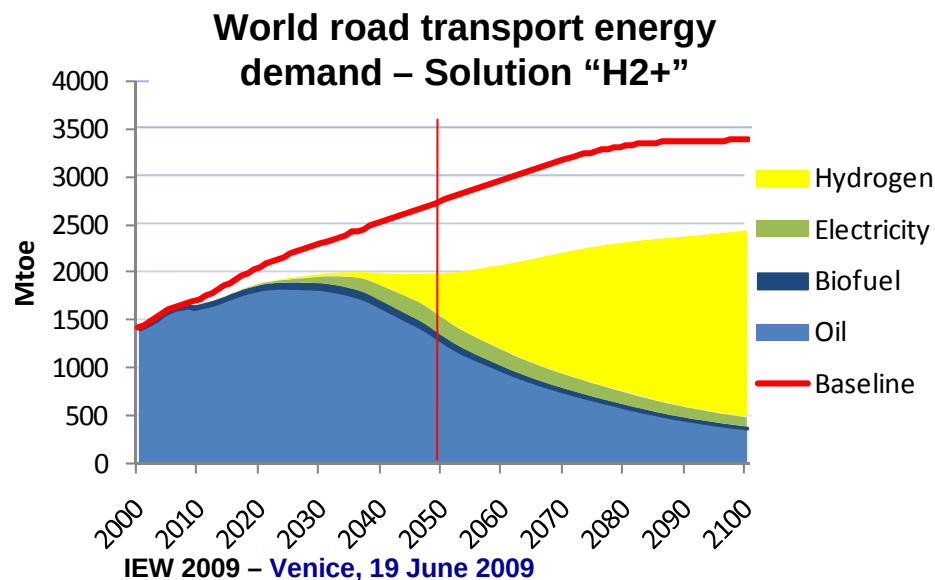
Energy consumption in road transport : Solution « H2+ » and Solution « Ele » variants

> Solution « H2 »

- Lock-in of hydrogen energy carrier in road transport from 2040 (with residual electricity in the fuel mix)
- Improved tank-to-wheel efficiency with hydrogen and fuel price effect (1000 Mtoe less than the Baseline by 2100)

> Solution « Ele »

- Same kind of development than hydrogen but earlier for electricity (from 2025)
- Better global efficiency than with hydrogen (500 Mtoe less than « H2+ » by 2100)



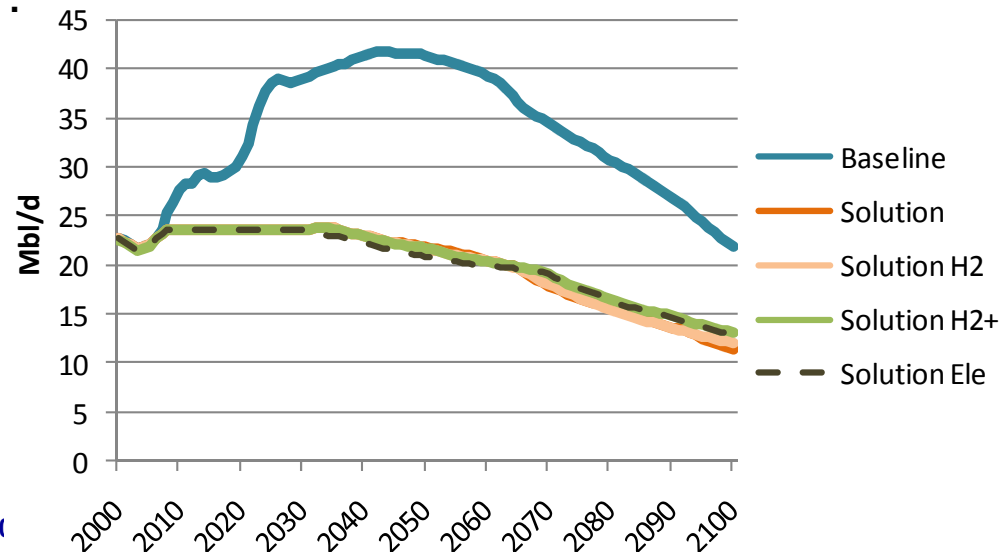
3. Oil supply constraint scenarios : The potential role of hydrogen on international oil markets

Oil supply constraints in the Challenge and Solution scenarios

- > Oil production capacity in Gulf countries limited to 23 Mbl/d :
=> short/medium-term impact on oil markets
- > Long-term recoverable oil resources halved compared to Baseline:
in 2000: 2000 Gbl against 4000 Gbl (assumption);*
in 2100: 400 Gbl against 1400 Gbl (result from POLES)
=> long-term impact on oil markets

* corresponds to long term URRs including EOR

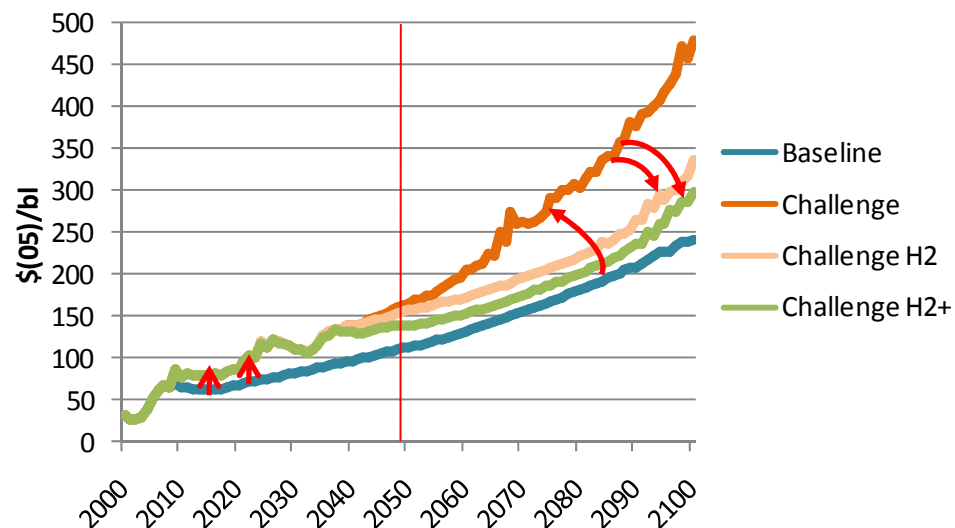
**Oil production capacity in Gulf Persian countries
in the Solution variants :**



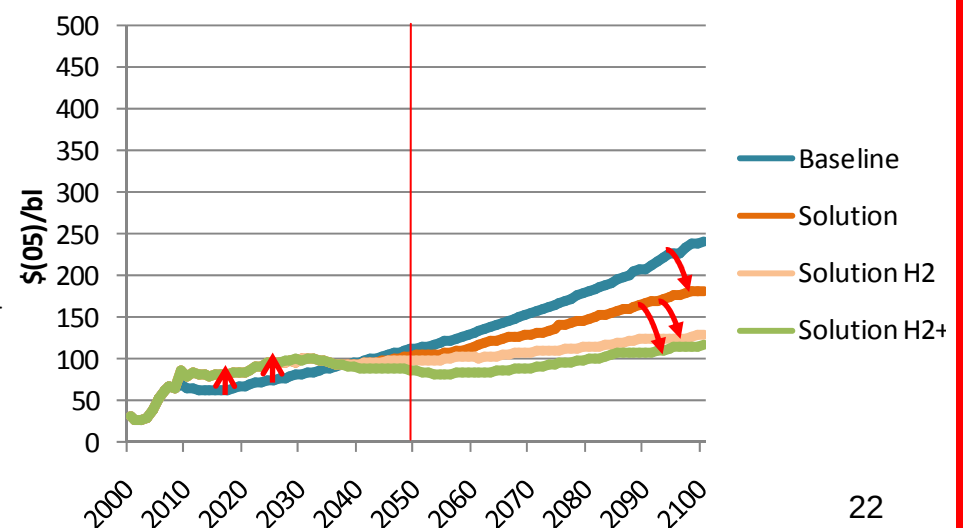
International oil price in the PROTEC-H2 scenarios

- > **In the short term (< 2020):** the equilibrium price for oil in Challenge and Solution variants is 20\$ over the Baseline due to oil supply constraint
- > **In the medium term (2020-2035):** high volatility of price due to oil supply constraint in Challenge but not in Solution thanks to the carbon constraint ; still no impact of hydrogen
- > **In the longer term (>2035):** massive development of hydrogen allows limiting the dramatic oil price increase in Challenge ; but only the carbon constraint (Solution) allow stabilizing oil price and limits its volatility

International oil price – « Challenge » variants

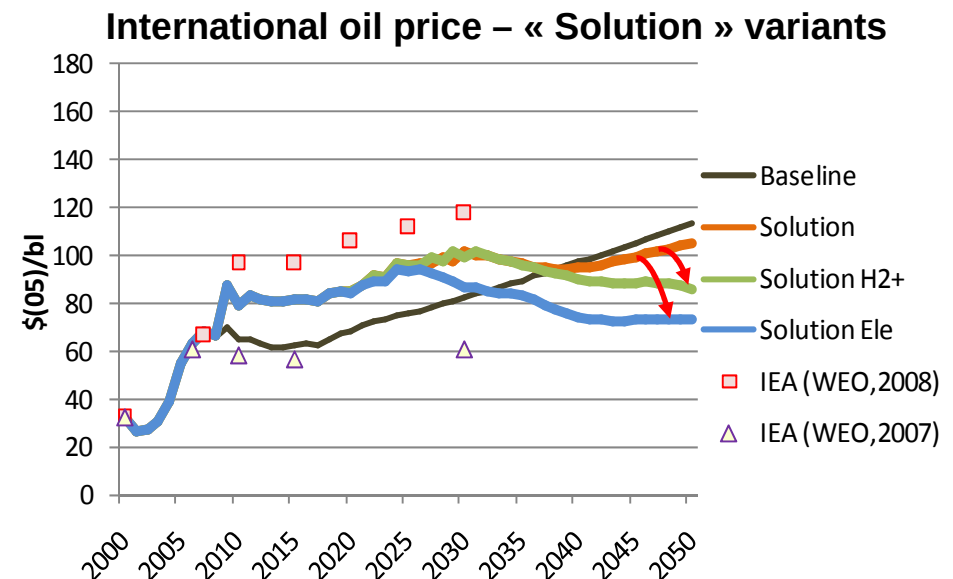
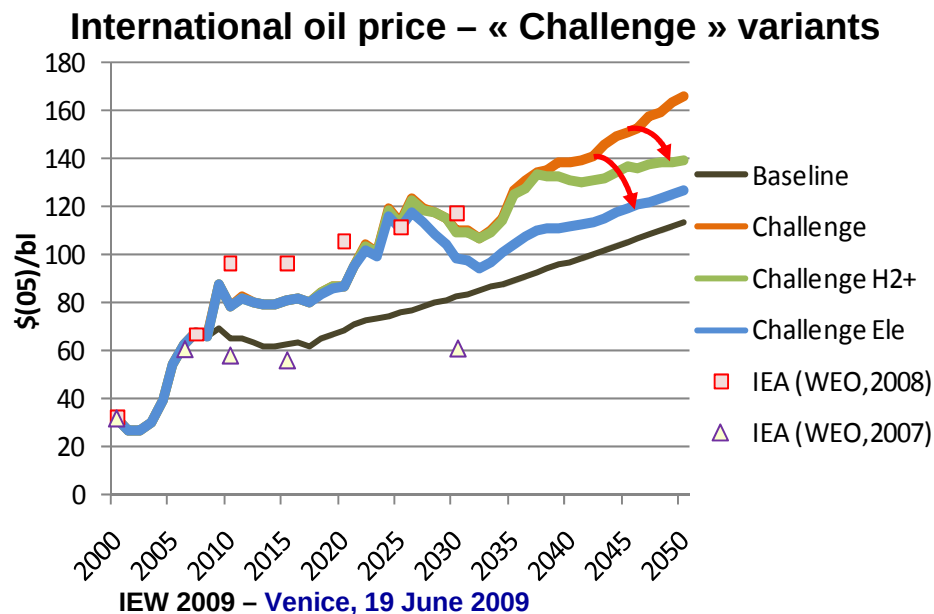


International oil price – « Solution » variants



The role of hydrogen and electricity on oil markets

- > **Hydrogen clearly pacifies oil markets** and allow containing price volatility and increasing trends, overall in the long-term
- > However, when comparing to electricity variants, the **impact of hydrogen is delayed** by 10 to 20 years
- > After 2050, the hydrogen role on oil market is more important and could even be larger than the electricity



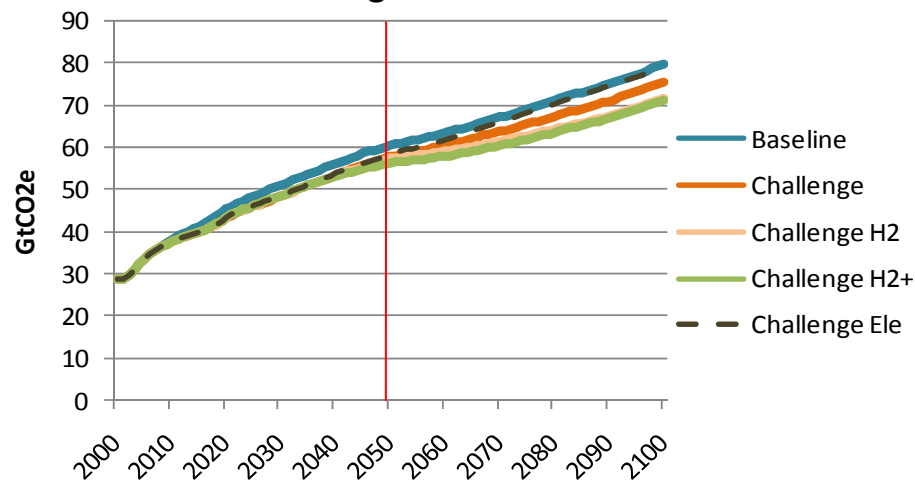
4. Climate policy scenarios :

The potential role of hydrogen on mitigation strategies

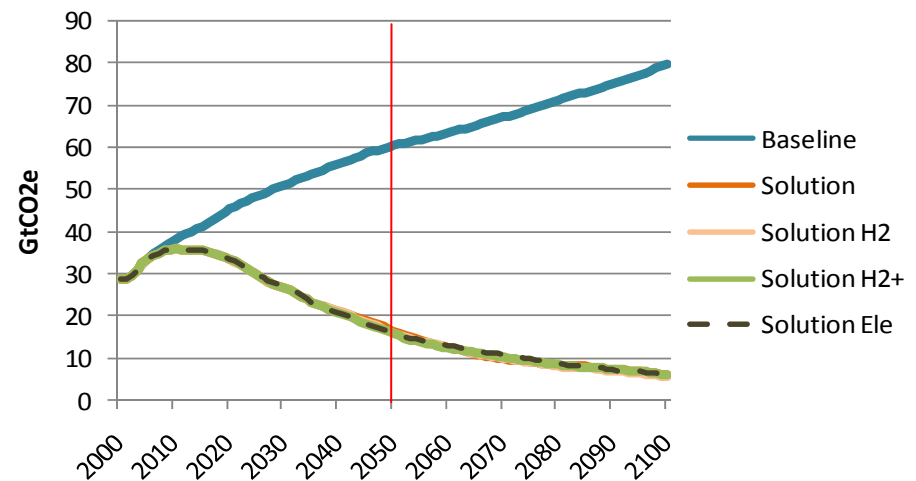
World GHG emissions

- > Solution scenario aims at stabilizing concentration at 450 ppm CO₂e ; **only the carbon constraint allow reducing dramatically GHGs emissions**
- > Without carbon constraint, some **transport fuel substitution effect**, allows reducing slightly GHG emissions in the Challenge « H2 » variants

World GHG emissions path
« Challenge » variants



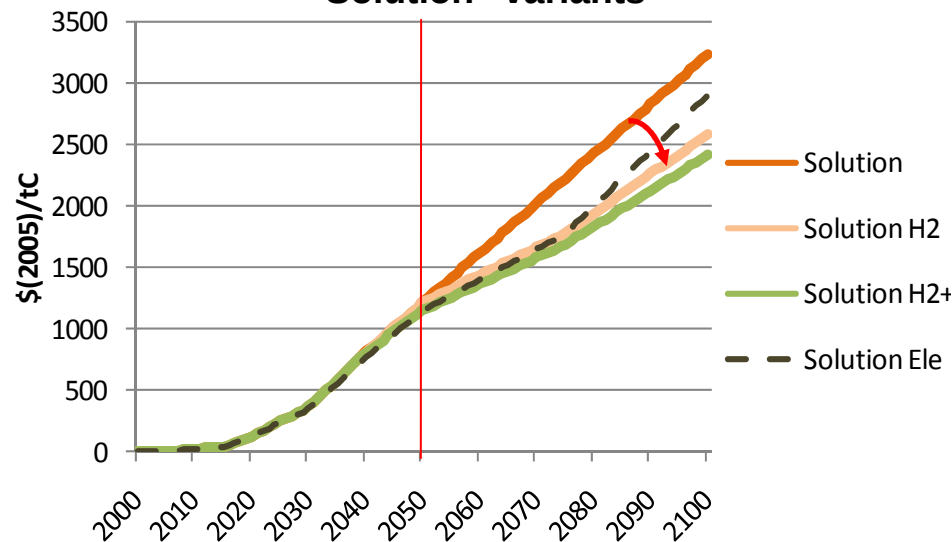
World GHG emissions path
« Solution » variants



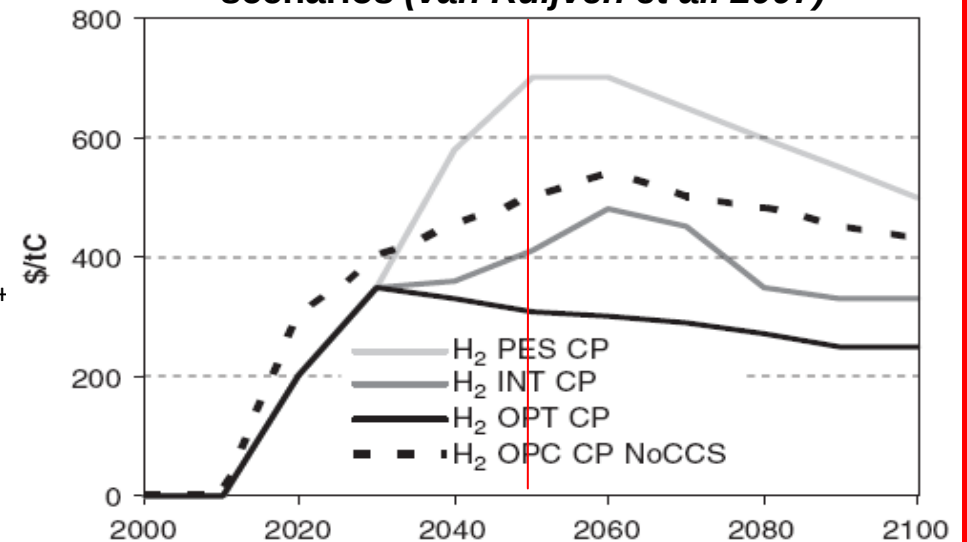
Carbon constraint in the « Solution » variants

- > The carbon value is around 300-350 \$/tCO₂ in 2050
- > *van Ruijven et al (2007)* provides a similar result to PROTEC-H2: **the more hydrogen diffuses, the lower the carbon value** to reach the same concentration target
- > However in POLES, hydrogen diffusion shows a lower impact on the carbon value and the marginal mitigation costs are higher

Carbon value in the PROTEC-H2
“Solution” variants

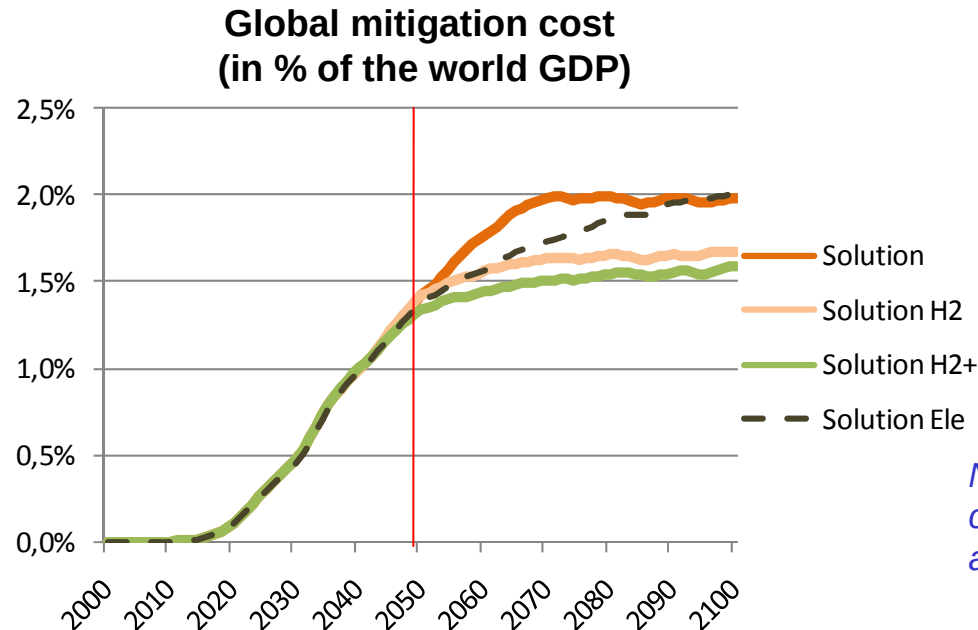


Carbon value in various 450ppm hydrogen
scenarios (*van Ruijven et al. 2007*)



Global mitigation cost in the « Solution » variants

- > The global cost in the energy sector to reach the long-term concentration target illustrates the **possible advantage of hydrogen on electricity in the very long-term**
- > This reveals it could be **more efficient to build “greenfield” hydrogen capacities** than transforming existing patterns which are beard by historical investment decisions

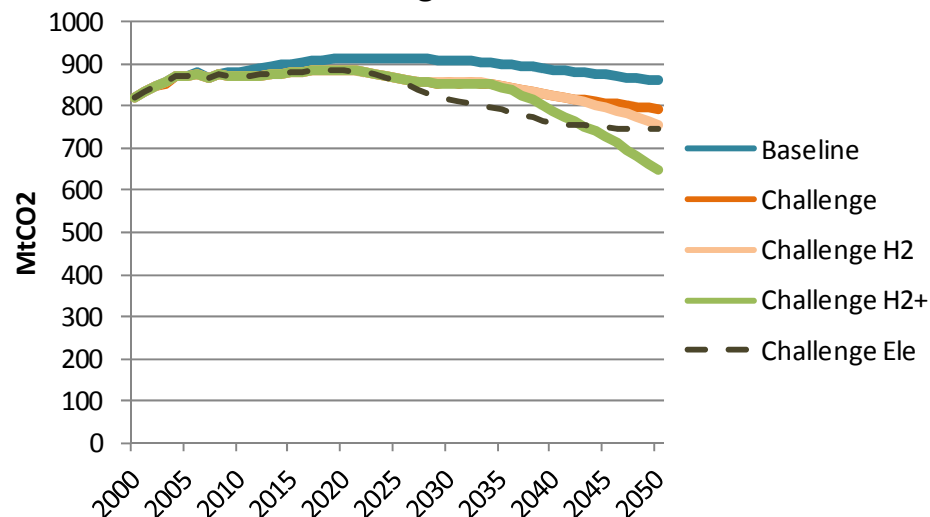


NB : global mitigation cost is calculated by integrating the marginal abatement cost curves

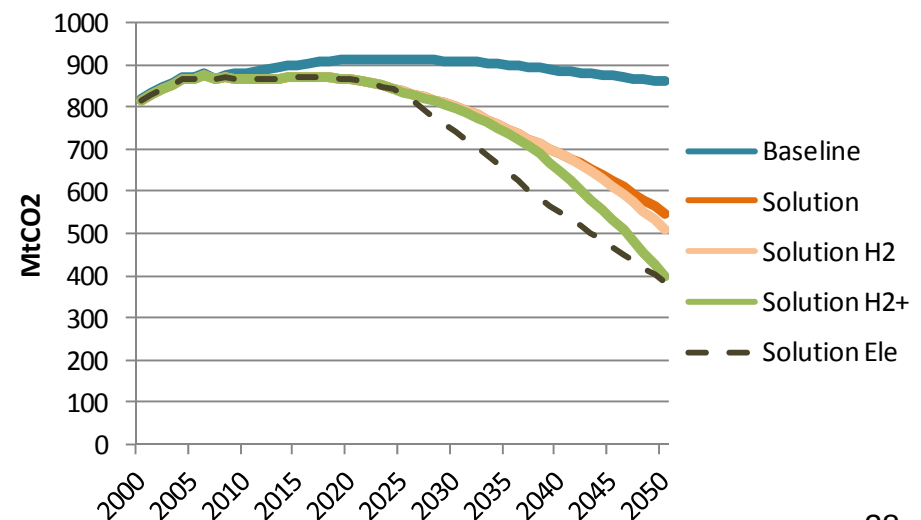
Total CO2 emissions from transport in EU27 (including indirect emissions)

- > New energy carriers in road transport allow reducing final energy demand
- > **Hydrogen like electricity allow reducing total emissions** (direct + indirect emissions) in a constrained scenario (Factor 2 by 2050)
- > The more new energy carriers diffuse, the easier to reduce total emissions in transport (concentrated emissions vs diffused emissions)

Total EU27 emissions of road transport
« Challenge » variants

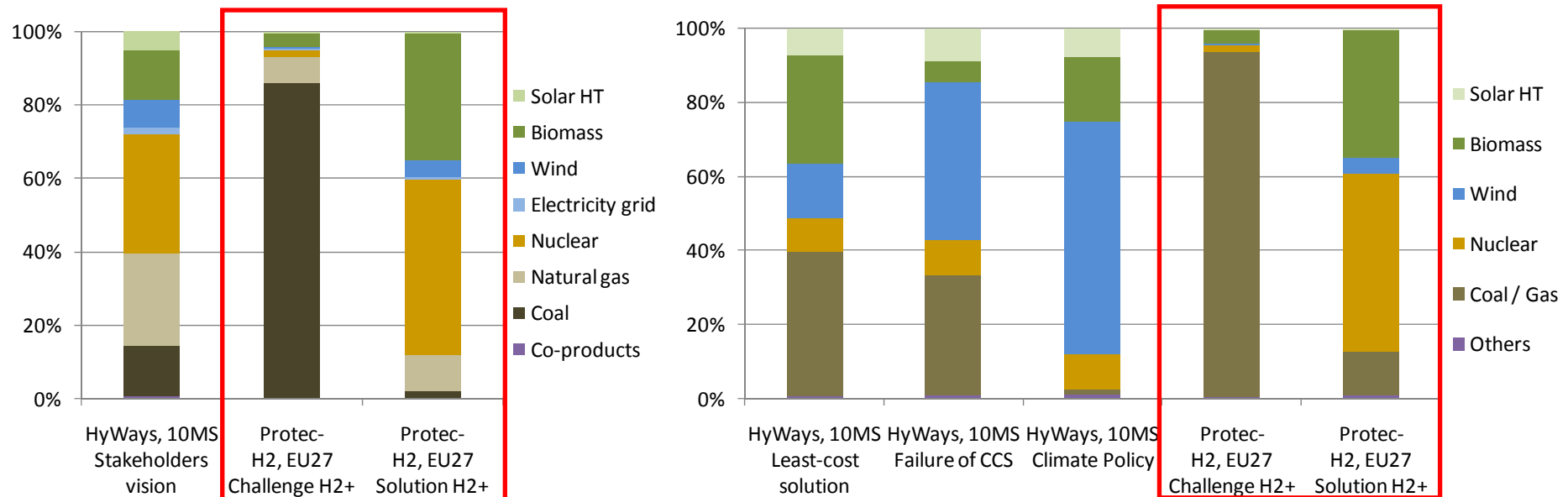


Total EU27 emissions of road transport
« Solution » variants



Hydrogen production mix in 2050 – Comparison with *HyWays*

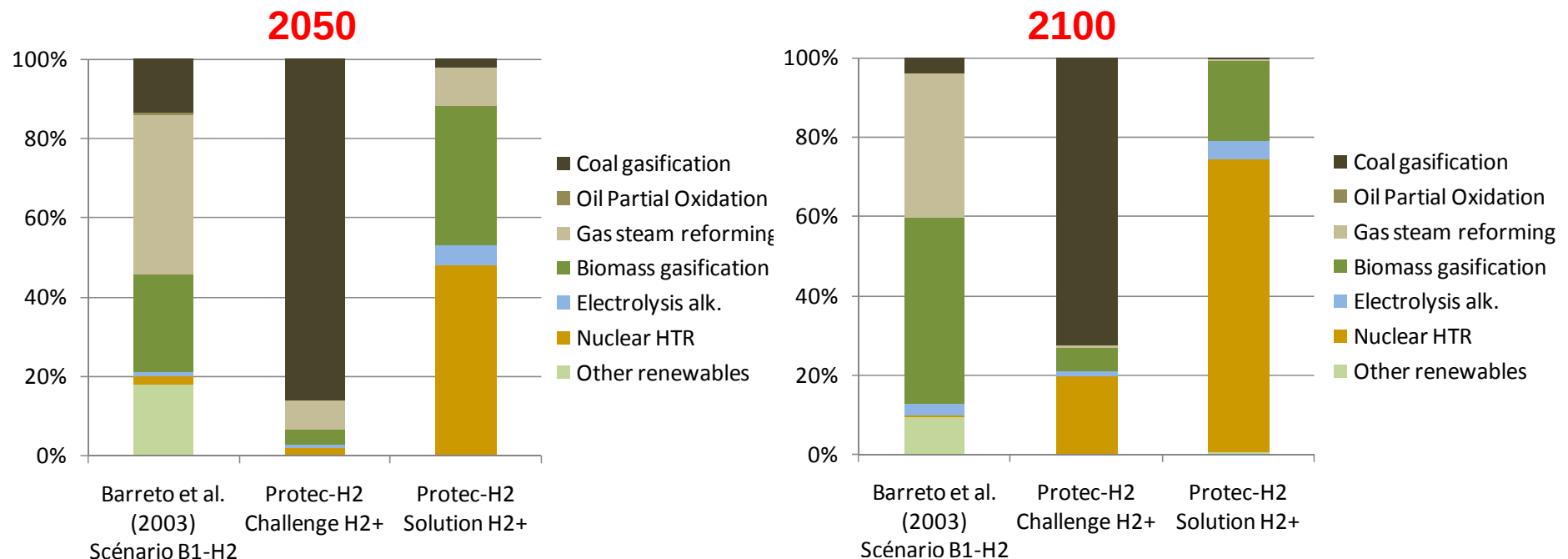
- > PROTEC-H2 scenarios are **close to the HyWays « Stakeholders vision »**
- > MARKAL's response to the carbon constraint is a massive development of hydrogen based on wind energy



NB : all HyWays scenarios assumes 35% emissions reduction over the 1990-2050 period, which is an intermediate objective to the Challenge et Solution scenarios; only the HyWays Climate Policy scenario considers 80% emission reduction on the 1990-2050 period (close to Solution)

Hydrogen production mix in 2050 – Comparison with *Barreto et al. (2003)*

- > In Barreto et al. (2003), hydrogen based on natural gas and biomass (+solar) contributes emission mitigation in transport
- > For POLES, dedicated HT nuclear (electrolysis and thermo-chemical cycles) and biomass gasification are the preferred technologies for hydrogen production in a climate policy scenario



Conclusion

The potential role of hydrogen in long-term energy system

The study showed a potential role of hydrogen in the long-term energy system, which can be twofold:

Role on oil markets :

Hydrogen could potentially stabilize international markets in the very long-term, both in terms of volatility and increasing trend ; however in the short term electricity could have a larger impact on oil price

Role in global emissions mitigation :

- Without climate policy, hydrogen do not participate to the resolution of the climate change issue
- However hydrogen could help reducing global mitigation costs in a constrained world, and could even be more efficient than electricity in the long-term

Long-term hydrogen diffusion in road transport

- > The prospective analysis allowed stressing **numerous barriers to massive diffusion of hydrogen in transport**, which may stand in:
 - Demand **technologies** cost and performance (Fuel Cells)
 - **Infrastructure** development (storage and T&D chains)
 - Availability of **primary materials** (like platinum in FC)
 - Other **social barriers**
- > In a larger perspective, **electricity and hydrogen are possibly complementary in transport**, for instance through integration in electric vehicles or H2 Fuel-Cells, used as *range-extendors*
- > **Demand-side system innovations**, which can be organizational or institutional, could also favor new energy carriers in transport, e.g. through the large scale emergence of new “light urban” vehicles (*downsizing* of the demand)

Selection of recent research projects and studies

- > **PACT** (2008-2011). PAtHways for Carbon Transition. EC – 7th FP. <http://www.pact-carbon-transition.org> .
- > **ADAM** (2006-2009). ADaptation And Mitigation. EC - 6th FP. <http://www.adamproject.eu> .
(Final report published in May 2009).
- > **WEC** (2006-2007). World energy forecasts scenarios by world region. Report for the World Energy Council.
http://www.worldenergy.org/publications/energy_policy_scenarios_to_2050/default.asp .
- > **PROTEC-H2** (2005-2008). PROspective TEChnological and Economic Outlook of Hydrogen-energy. French ANR project. PAN-H program - Edition 2005.
- > **IDDRI-EpE** (2004-2008). Scenarios under carbon constraint : What's at stake for heavy industries? Report for IDDRI-EpE. <http://www.iddri.org/Publications/Rapports-and-briefing-papers/Scenarios-for-transition-towards-a-low-carbon-world-in-2050-What%27s-at-stake-for-heavy-industries>
- > **WETO-H2** (2004-2005). World Energy Technology Outlook to 2050, for EC - DG-RTD, http://ec.europa.eu/research/fp6/ssp/weto_h2_en.htm (published in 2007).

Thank you for your attention

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