HyWays – The European Hydrogen Energy Roadmap

Current status and Socio-Economic Aspects

Reinhold Wurster
Ludwig-Bölkow-Systemtechnik GmbH (LBST)
on behalf of the HyWays consortium

1st MOBIDAYS Conference on
Socio-economic Barriers to Sustainable Transport
Prague, 18 June 2007

Outline

HyWays

- Introduction and current status
- Key assumptions
- Hydrogen deployment in Europe
- Key Changes and Actor Mapping (KCAM)
- Costs of infrastructure and vehicles
- Macroeconomic Effects
- Key messages from roadmap and action plan

Project goals / objectives

HyWays

Goal: Development of a harmonised European Hydrogen Roadmap and Action Plan

Participation: HyWays partners and relevant other stakeholders from industry, research and politics via workshops in each of the 10 participating countries

Discussions: facilitated through standard procedure comprising

- Vision building (2050, backcasting)
- Country profiling
- Modelling of hydrogen energy chains, energy markets, socio-economic and employment effects and policy measures
- Actor analysis to identify the implications for stakeholders and necessary actions
- Infrastructure analysis (hydrogen demand allocation and supply infrastructure build-up by forecasting)
- Benefits assessment

Participating countries

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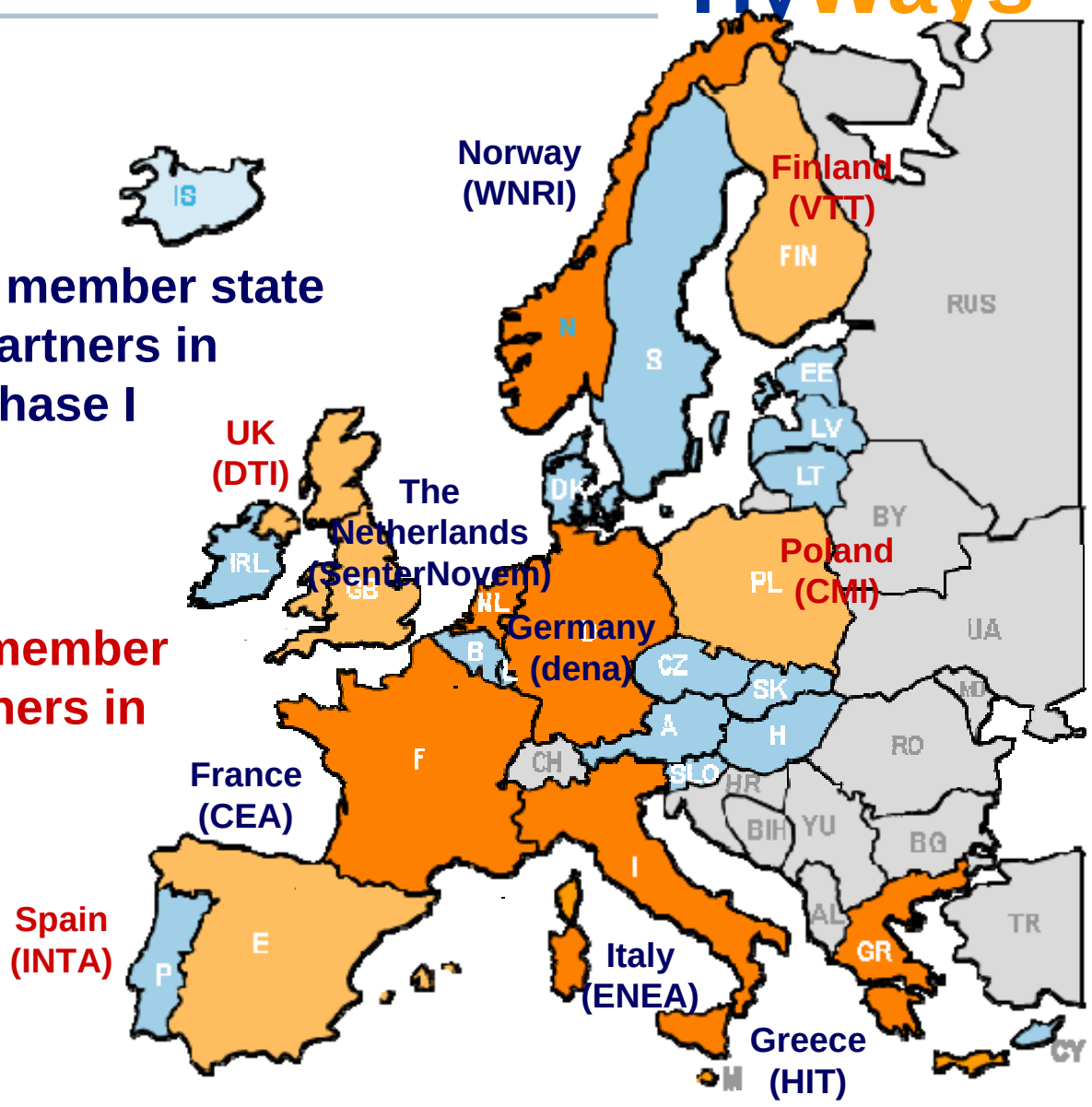
	Coverage [%] by	
	land area	population
Phase I	49,7	39,2
Phase I+II	80,5	71,4



6 member state partners in Phase I

4 further member state partners in Phase II

TIME HORIZON

2010 / 2020 / 2030 / 2050

Methodology

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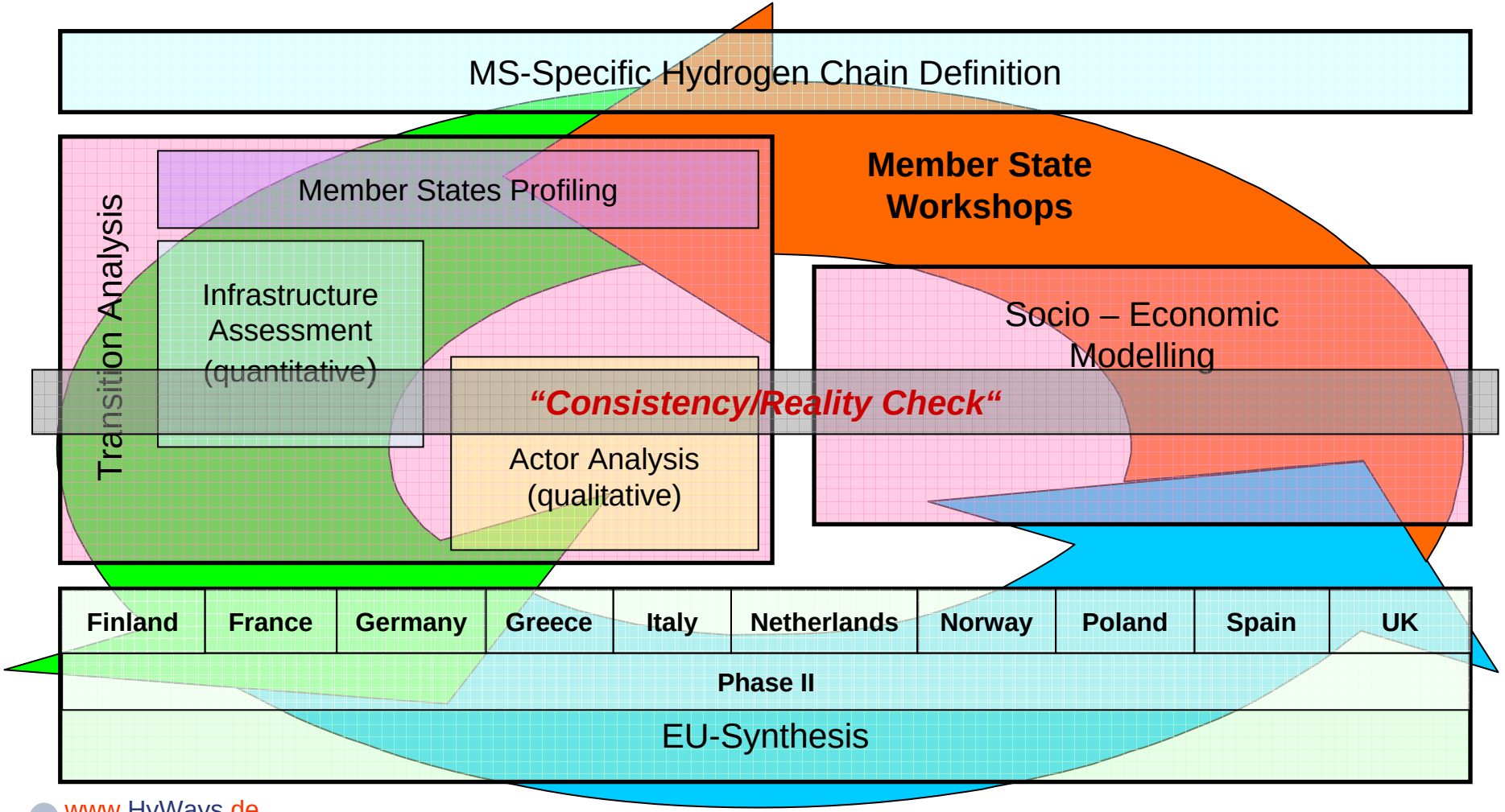

Partners

HyWays

Industry

BMW Group

DaimlerChrysler

GM

Opel

Air Liquide

Air Products

Repsol YPF

THE LINDE GROUP

Statkraft

GE Oil & Gas

VATTENFALL

Total

EDF Electricité de France

HYDRO

HYGEAR

infraserv höchst

DNV

acciona Biocombustibles

HYDROGENICS CORPORATION

Member states

SenterNovem

dena Deutsche Energie-Agentur

dti

HELLENIC INSTITUTE OF TRANSPORT

INTA

gig Główny Instytut Górnictwa

VTT

ENEA

Institutes

cea

Bureau d'économie théorique et appliquée (BETA) UMR 7522

IDMEC Pólo INSTITUTO SUPERIOR TÉCNICO

Fraunhofer ISI Institute Systems and Innovation Research

Ludwig-Bölkow-Systemtechnik

ECN Energy research Centre of the Netherlands

ZEW Zentrum für Europäische Wirtschaftsforschung GmbH

Current status

- Project to finish after 39 months by 30 June 2007
- Member state workshops completed (app. 50)
- Modeling work completed
- Most deliverables finished
- Roadmap and Action Plan in preparation

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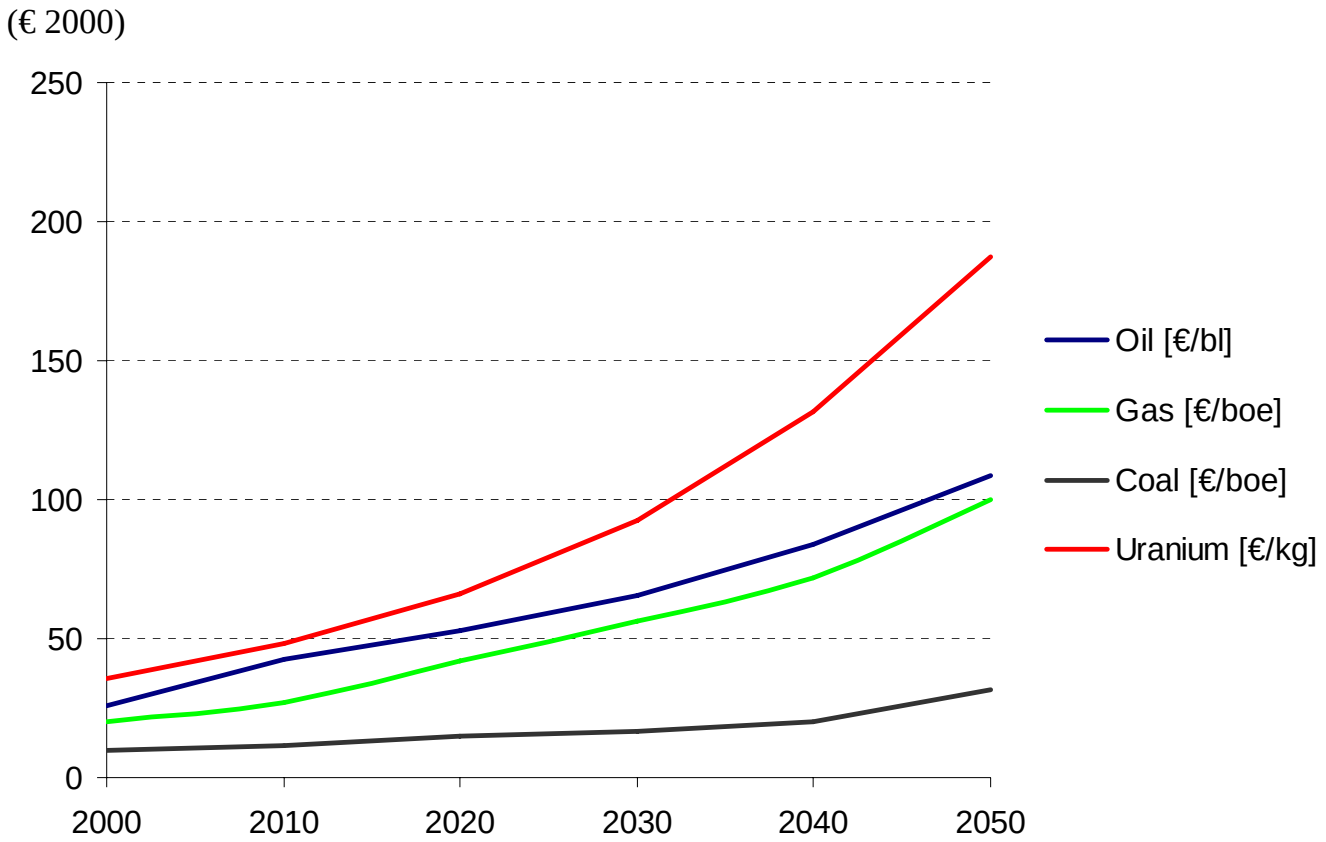
Development of energy prices



Basis: HyWays phase I: prices based on Energy Trends 2030 (low oil price)
HyWays phase II: WETO-H2 study (update of Energy Trends 2030)

Hydrogen demand in road transport

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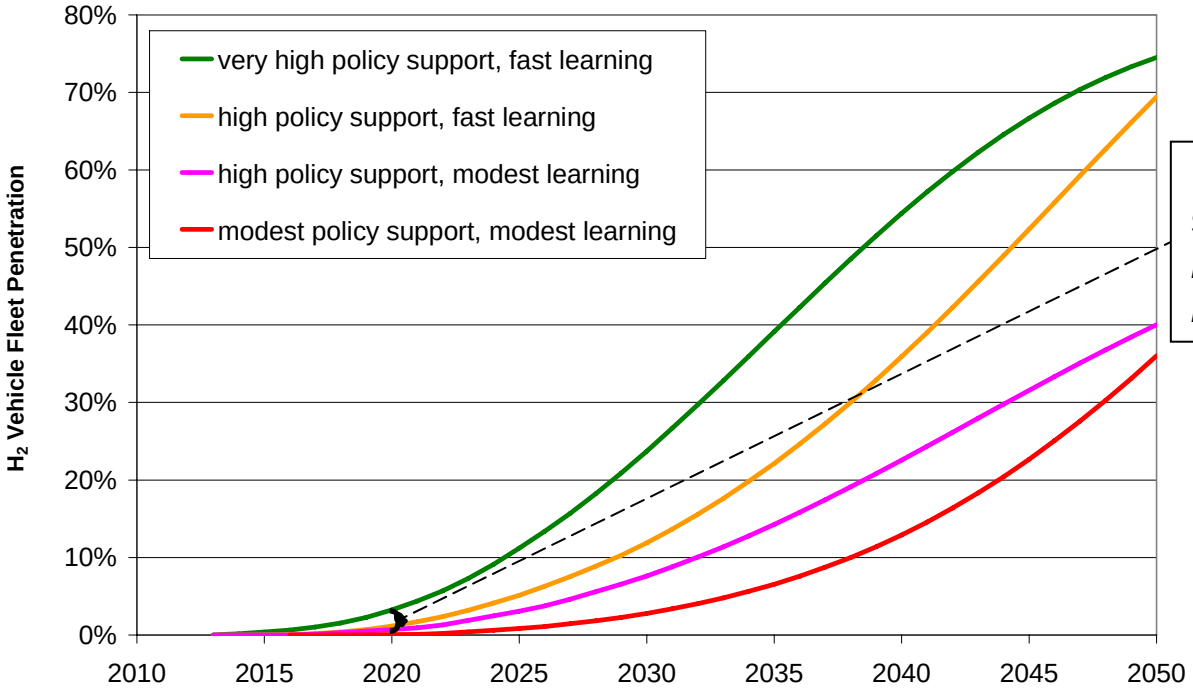

HFP Snapshot 2020 is spanned by scenarios *very high policy support, fast learning* and high policy support, *modest learning*!

Scenario build-up with 2 parameter

- **"policy support"**
- **"technical learning"**

a) Very high policy support, fast learning
b) High policy support, fast learning
c) High policy support, modest learning
d) Modest policy support, modest learning

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Market penetration phases

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Phase	Vehicles EU-wide	Regional spread of H_2 use
Phase I (LHPs, JTI) pre-commercial phase)	10,000	Some large-scale demonstration "**first user centres"** in Europe (LHPs)
Phase II (early commercialisation)	10,000-500,000	2-5 "**early user centres**" per country** (10-25% of total population, emerging simultaneously). Possibly also a **network of transit roads** for commuters out of early user centres and between them (considered by various deployment scenarios, focus: on private cars or captive fleets)
Phase III (full commercialisation)	>500,000 **Step 1:** 500k **Step 2:** 4M **Step 3:** 16M	**Extension of existing** user centres and **development of new** hydrogen regions; dense network installed by 2030; vehicles EU-wide: one distributed and one concentrated users deployment scenario in all steps

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Early user centres and early H_2 corridors

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- Based on stakeholder consensus
- Early user centres: most population centres (but also less densely populated areas)
- Early corridors (highways): ~25,000 km to connect user centres and catchment areas

Regional H_2 demand development

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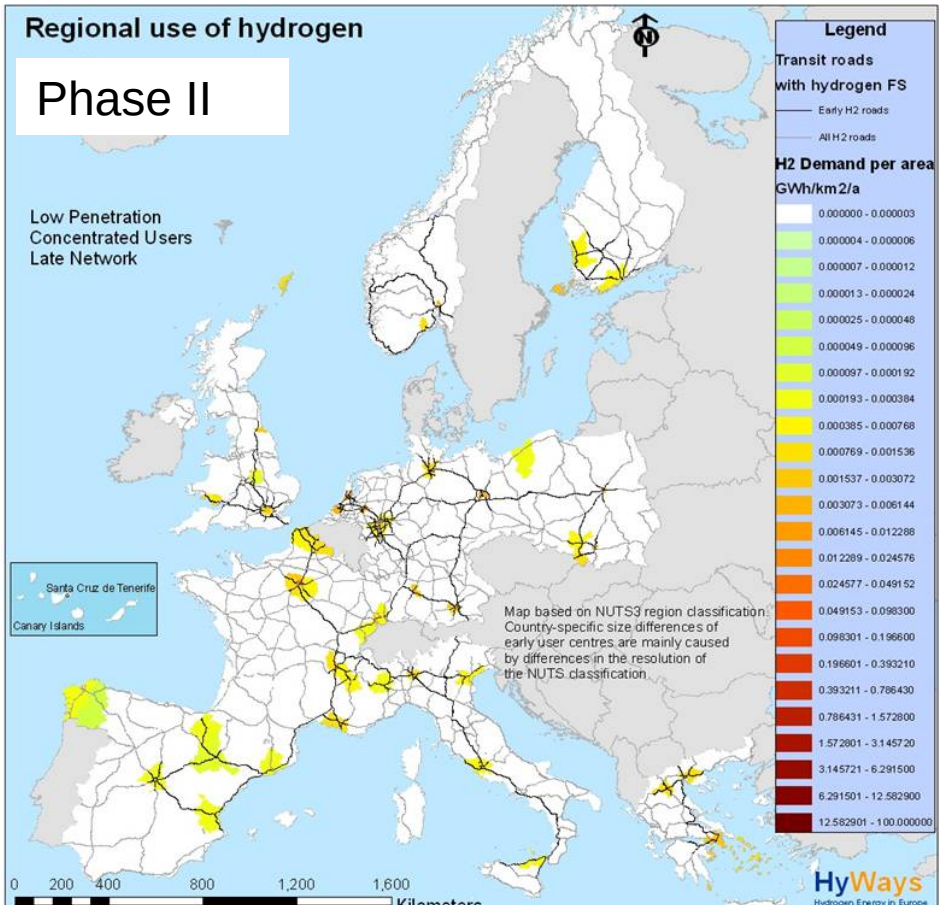
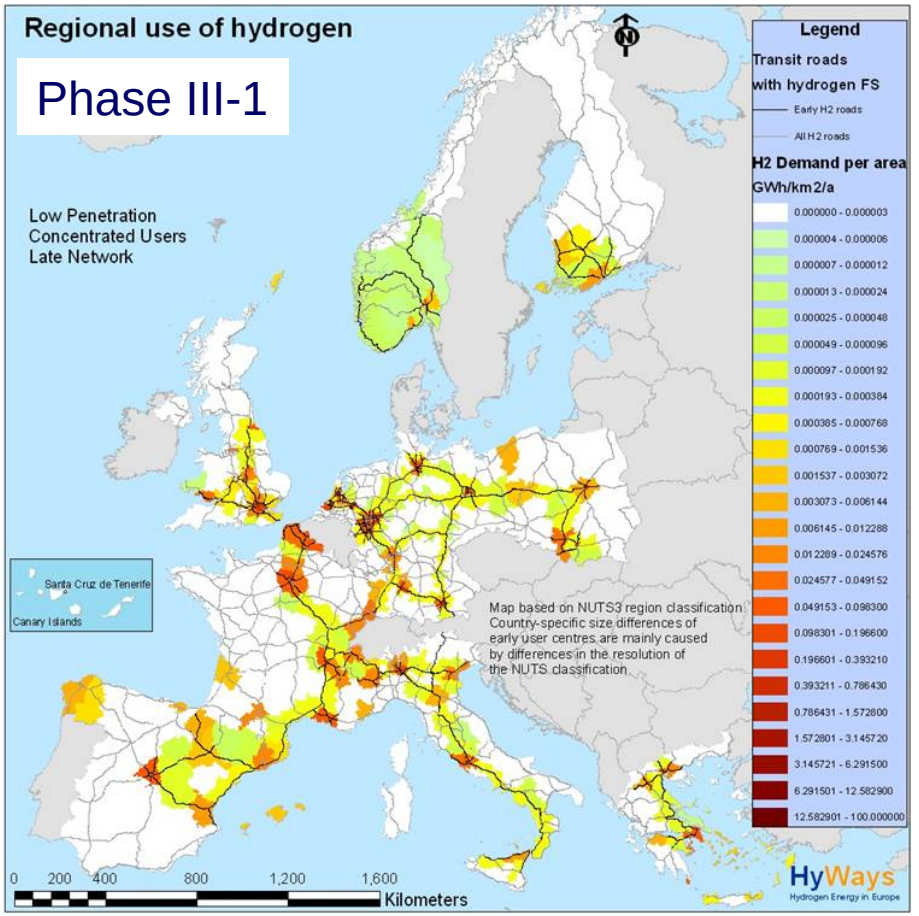
Scenario: Focus on populated areas - Late extension of corridors



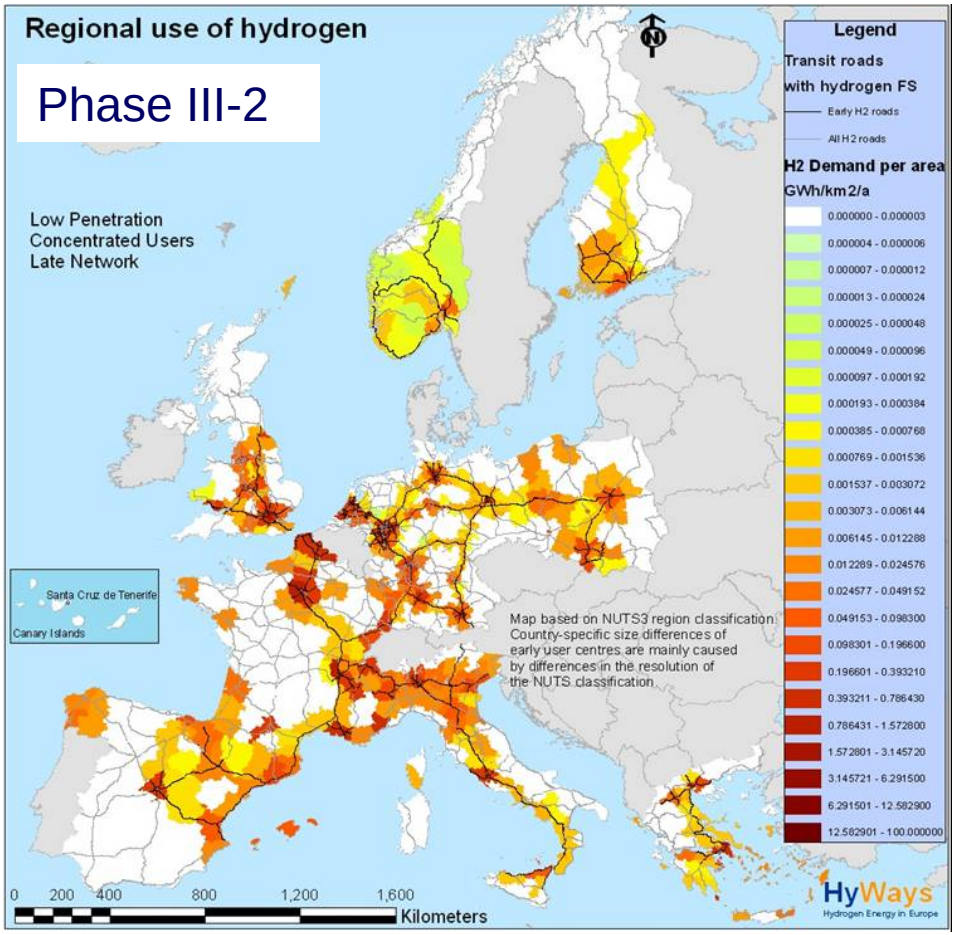


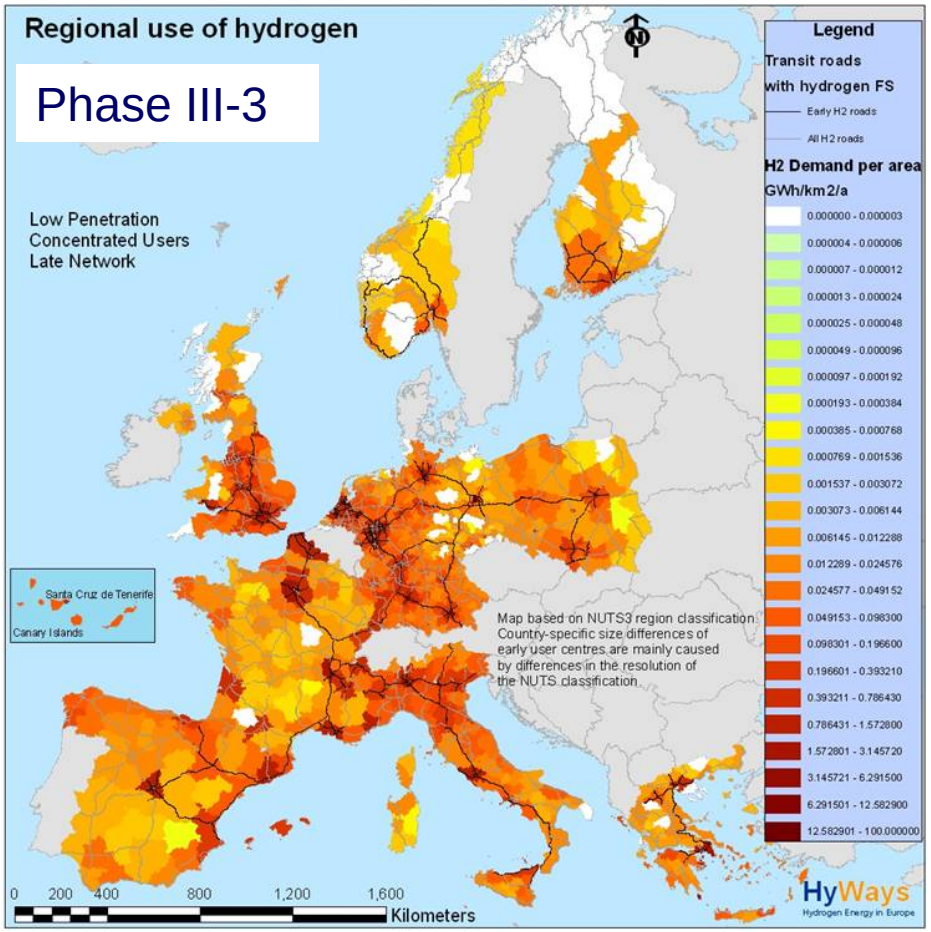
Further regional deployment: Based on demographic indicators like population density ⇒ extension of existing and build-up of new user centers (**organic growth**)

Regional H_2 demand development

HyWays

Scenario: Focus on populated areas - Late extension of corridors





European synthesis

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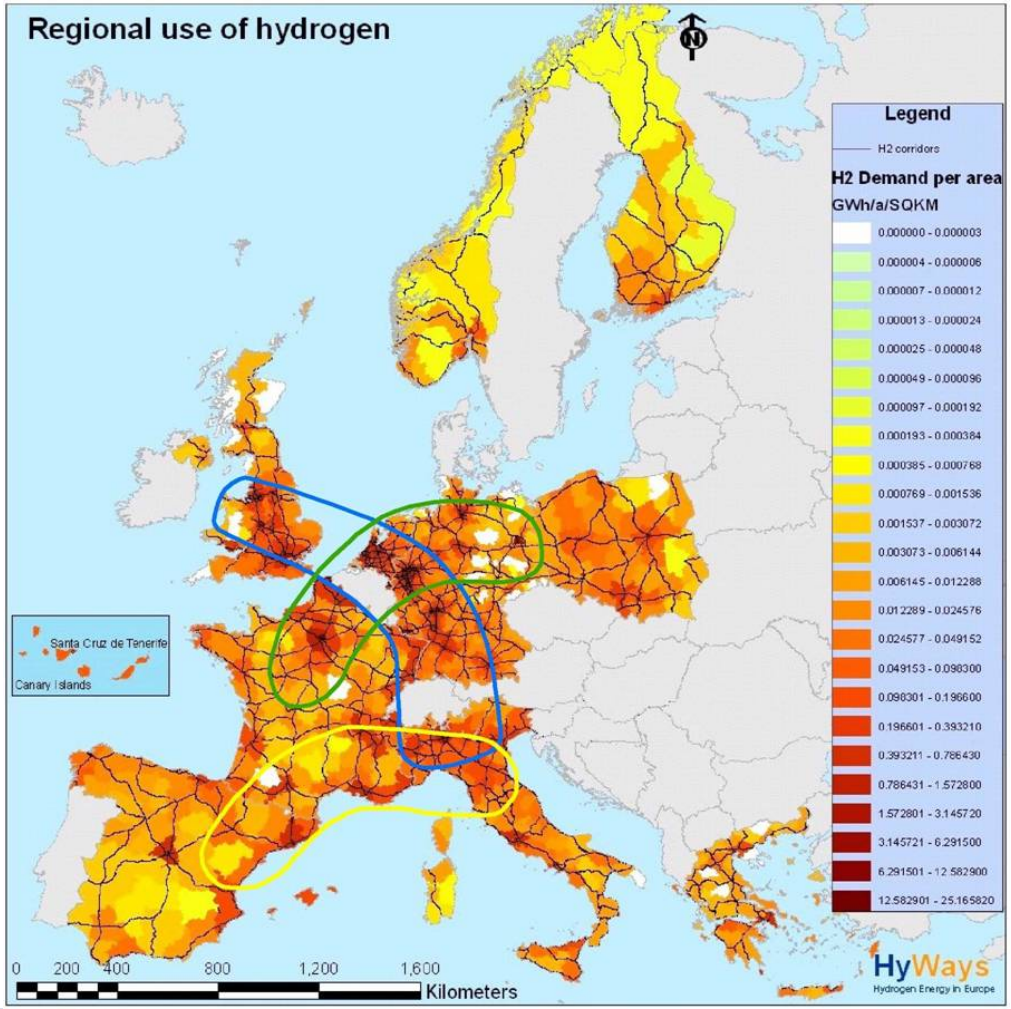
- Build up of a European hydrogen synthesis could follow the so-called *Blue Banana* region
  - *Blue Banana*: 40% of European people, most European cities, well developed infrastructure, relevant industries
- Followed by other attractive regions and hot spot areas



Infrastructure scenario overview

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Phase		II	III-1	III-2	III-3
Hydrogen vehicles in EU27		10,000	500,000	4 mill.	16 mill.
Years these vehicle number will be realised					
Penetration scenarios	Very high policy support, high learning	2012	2015	2019	2024
	High policy support, high learning	2014	2017	2021	2027
	Modest policy support, modest learning	2017	2021	2028	2036
% of population in areas with hydrogen fuelling stations					
Local use scenarios	Distributed users	26%	32%	52%	85%
	Concentrated users	26%	75%	90%	100%
Long-distance road network supplied (10 MS)					
Long-distance road scenarios	Early road network	25,000 km	70,000 km	70,000 km	70,000 km
	Late road network	0 km	25,000 km	25,000 km	70,000 km

Spatial coverage of fuelling stations

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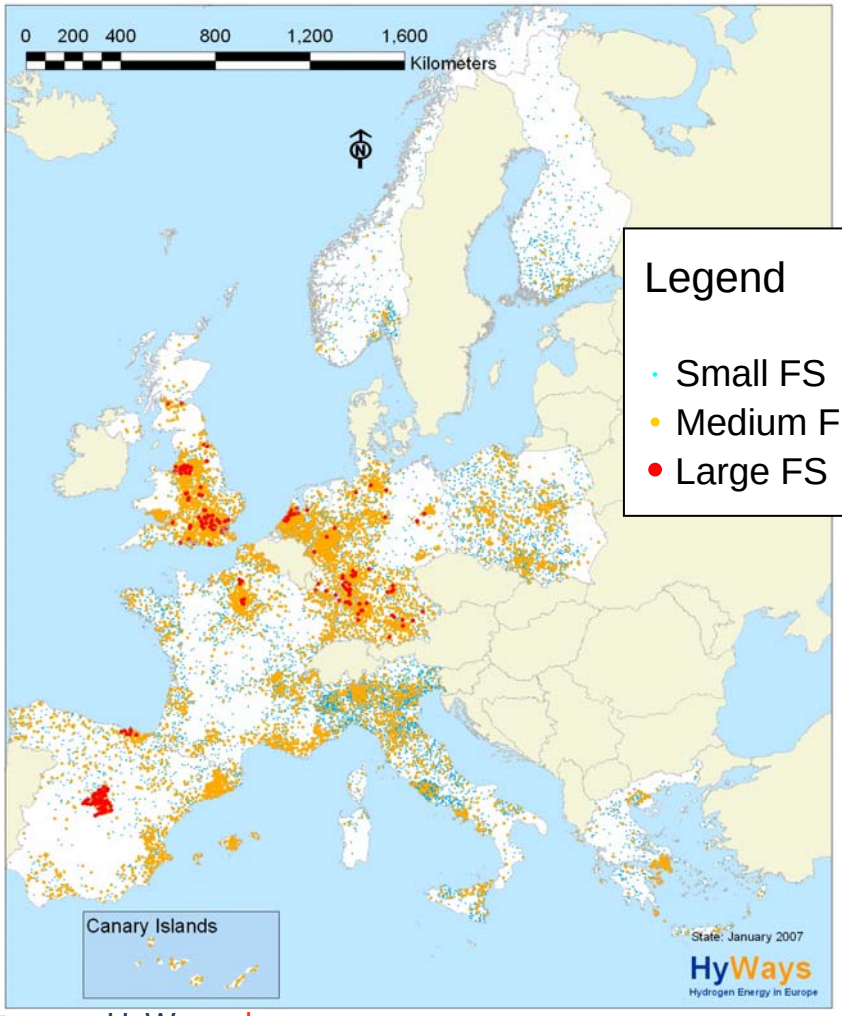

- First phase (2010-2015):
  - A limited number (400) of small H_2 stations
  - serving around 10.000 H_2 cars (25 cars/station in average)
  - for corridors another app. 500 small fuelling stations would be required
- Demand develops (2015 – 2025):
  - also bigger filling stations will come in
  - between 13,000 and 20,000 H_2 stations and 10 mill. H_2 vehicles in Europe.
- Massive rollout of H_2 (post 2025):
  - Gradually, same patterns as today's conventional refuelling network is reached

Example: fuelling stations spatial coverage for 8% vehicle penetration

Selected hydrogen energy chains per country

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Chain (central fossil pathways mostly with CCS; stationary and CGH_2 truck pathways not shown)	D	E[1]	F	FIN[1]	GR	I	N[1]	NL	PL	UK[1]
NG – pipeline – central SMR – H_2-pipeline – CGH_2 FS[2]	X	X[4]	X	X[5]	X	X	X[6]	X[4]	X	X[4]
NG – pipeline – central SMR – liquefaction – LH_2 truck – $LCGH_2$ FS[3]	X	X[4]	X	X[5]		X		X		X
NG – pipeline – on-site SMR – CGH_2 FS[2]	X	X		X		X		X	X	X
NG – pipeline – central SMR – CCGT (Power station)						X				
NG – pipeline – central SMR – NG/H_2-pipeline – CGH_2 FS[2]			X		X					
NG – liquefaction – LNG-ship – regional SMR – H_2-pipeline - CGH_2 FS[2]		X[4]					X			X
NG – liquefaction – LNG-ship – onsite SMR – CGH_2 FS[2]		X								
El-mix – central electrolysis – H_2-pipeline – CGH_2 FS[2]	X		X							X
El-mix – on-site electrolysis - CGH_2 FS[2]	X	X	X	X		X	X			X
Nuclear electricity – central electrolysis – pipeline - CGH_2 FS[2]				X						X
Nuclear electricity – onsite electrolysis – CGH_2 FS[2]									X	
Nuclear power – HT electrolysis – H_2-pipeline – CGH_2 FS[2]		X	X							
Nuclear power - HT nuclear thermocycles - H_2-pipeline - CGH_2 FS[2]		X		X					X	X
Offshore-wind-El - central electrolysis – pipeline – CGH_2 FS[2]	X	X						X		X
Offshore-wind-El - on-site electrolysis – CGH_2 FS[2]	X		X	X		X	X		X	
Onshore-wind – central electrolysis – pipeline – CGH_2 FS[2]		X			X					X
Onshore-wind – on-site-electrolysis - CGH_2 FS[2]	X	X			X	X	X		X	X
Biomass (farmed/residual/waste wood) – gasification – H_2-pipeline – CGH_2 FS[2]		X	X		X			X	X	X
Biomass (farmed/residual/waste wood) – truck transport - decentral gasification – CGH_2 FS[2]	X			X		X	X			
Biomass (farmed/residual/waste wood) – train transport - decentral gasification – CGH_2 truck - CGH_2 FS[2]				X						
Biogas – onsite SMR – CGH_2 FS[2]									X	
Municipal waste – onsite gasification – CGH_2 FS[2]						X				
Solar –thermal HT conversion – H_2 pipeline – CGH_2 FS[2]		X				X				
H_2-by-product – pipeline - CGH_2 FS[2] (Poland: large-scale coke-oven gas)	X	X	X				X		X	
H_2-by-product – liquefaction – LH_2 truck - $LCGH_2$ FS[2]						X				
Hard-coal - gasification - liquefaction - LH_2 truck - $LCGH_2$ FS[3]	X			X[5]					X	
Hard-coal – gasification – H_2 pipeline – CGH_2 FS[2]	X	X[4]		X[5]		X		X	X	X
Hard-coal – in-situ gasification – H_2 pipeline - CGH_2 FS[2]									X	
Lignite – gasification – pipeline/liquefaction – (L)CGH_2 FS[2]					X				X	

Natural gas reforming

Nuclear and grid-mix electricity

Wind

Biomass

Solar

By-product H2

Coal

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Synthesised visions of stakeholders

Choice of hydrogen energy chains strongly influenced by stakeholder preferences and country specific characteristics

Diversified H_2 production mix found

Share of (sustainable) fossil fuels varies, decreases in time while share of renewable energy goes up

No unambiguous choice of H_2 infrastructure (no clear winner)

CCS, electrolysis, biomass gasification and SMR are key technologies in (almost) all MS visions

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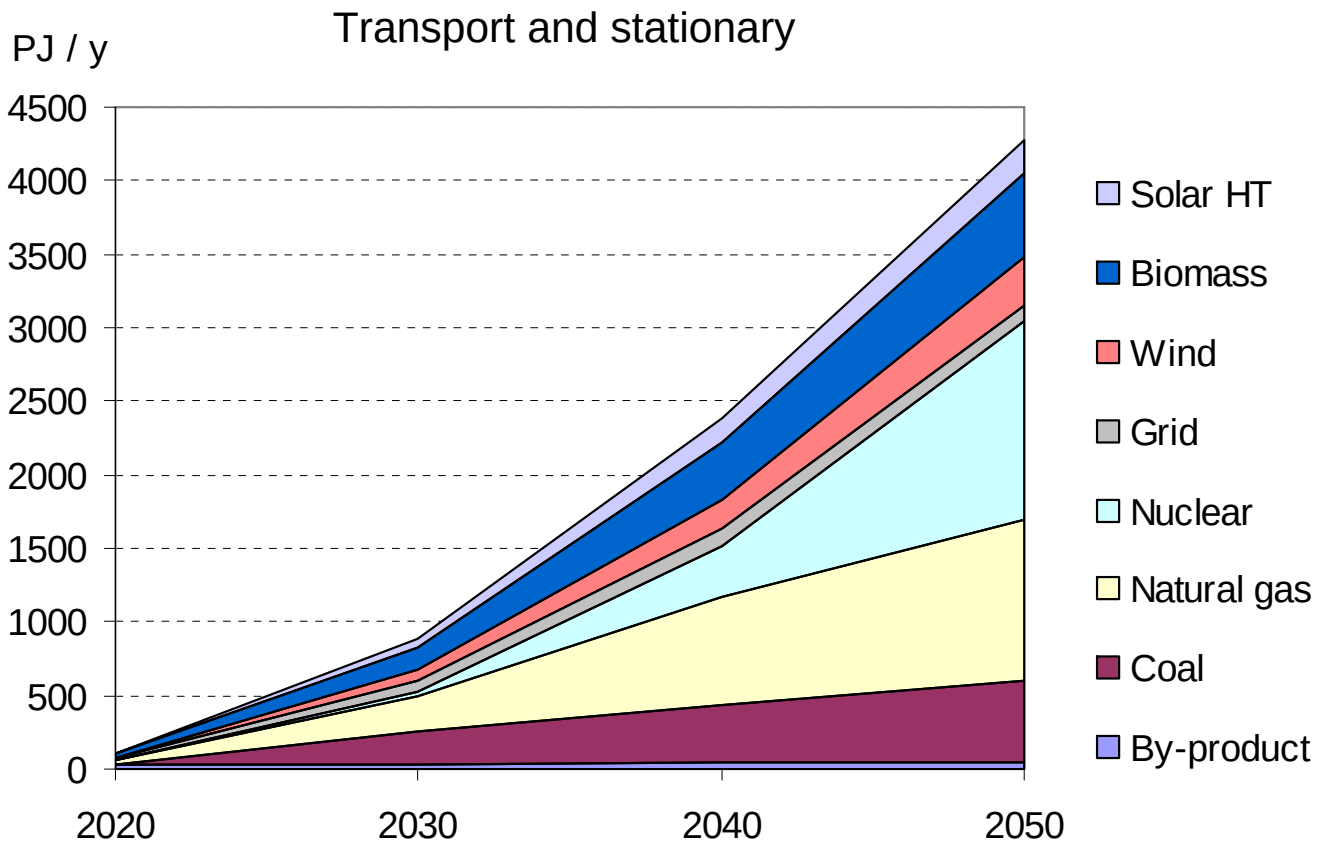
Hydrogen production mix: MS bounds



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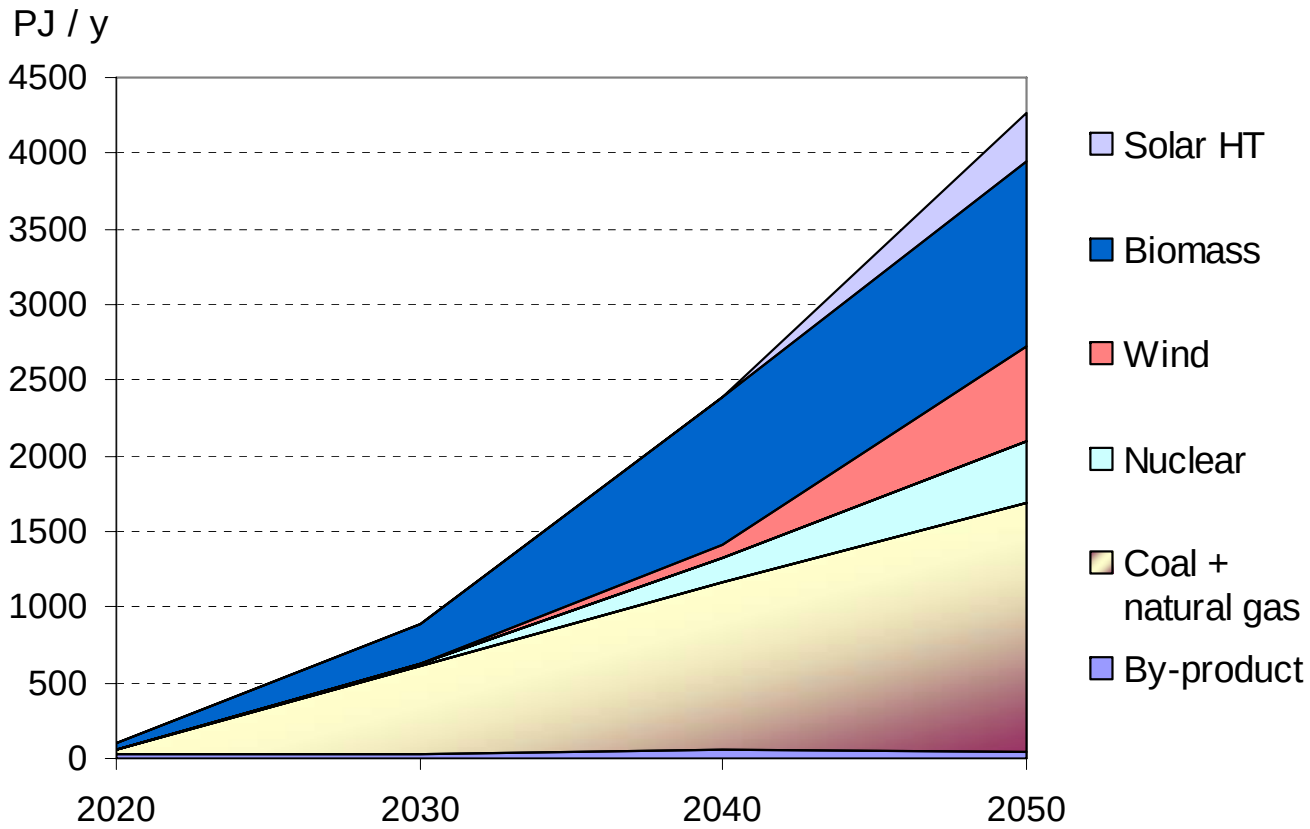
Hydrogen production mix: least cost solution



Sensitivity analysis H_2 production mix

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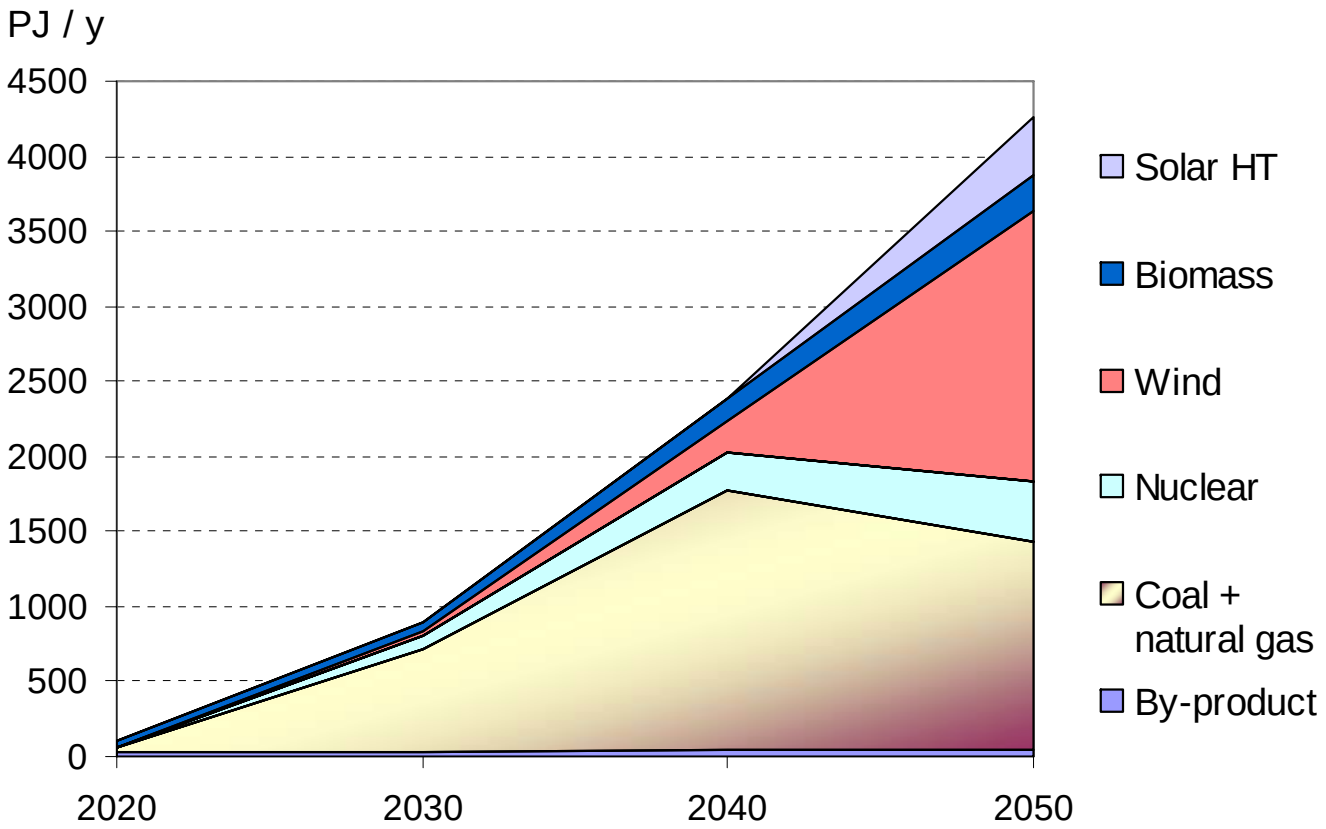
Hydrogen production mix: -80% CO_2 reduction



Sensitivity analysis H_2 production mix

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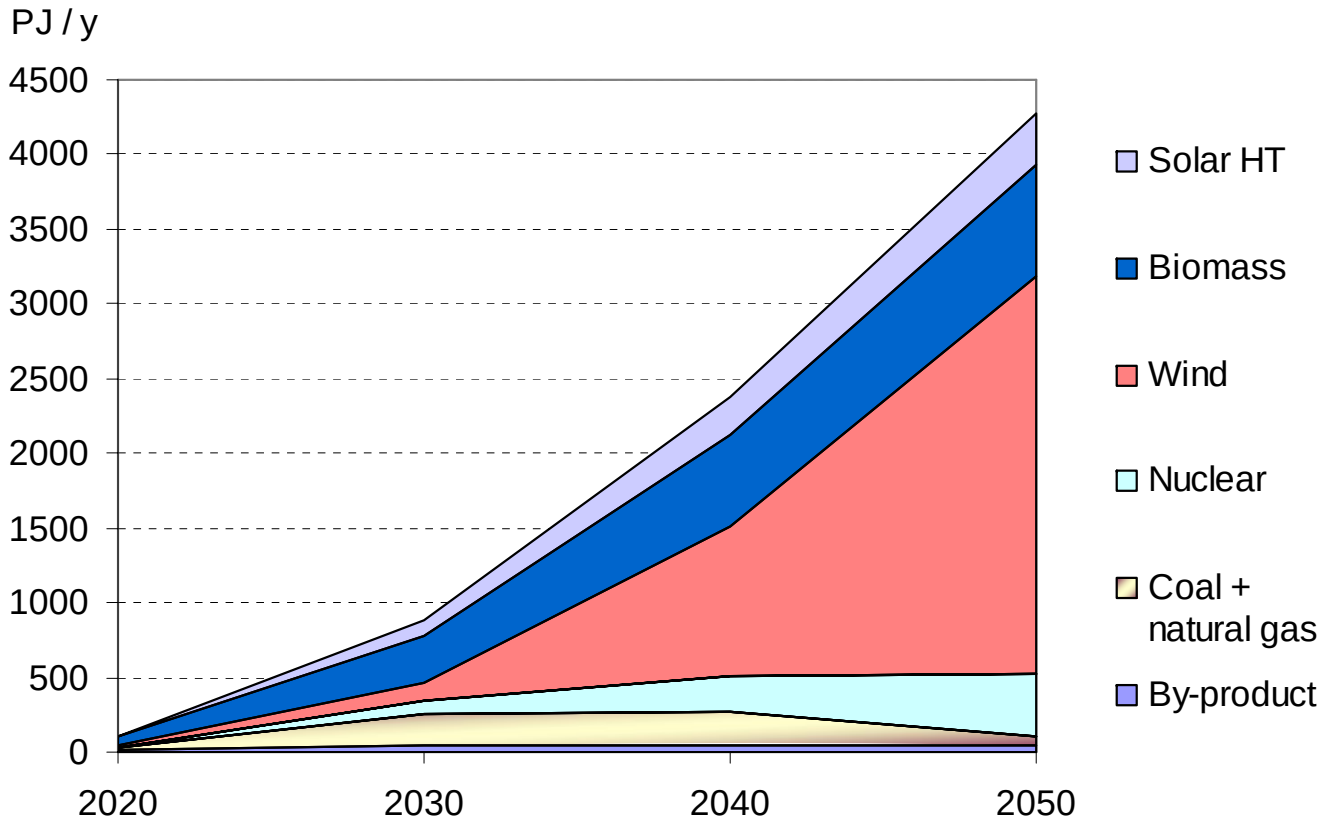
Hydrogen production mix: failure of CCS



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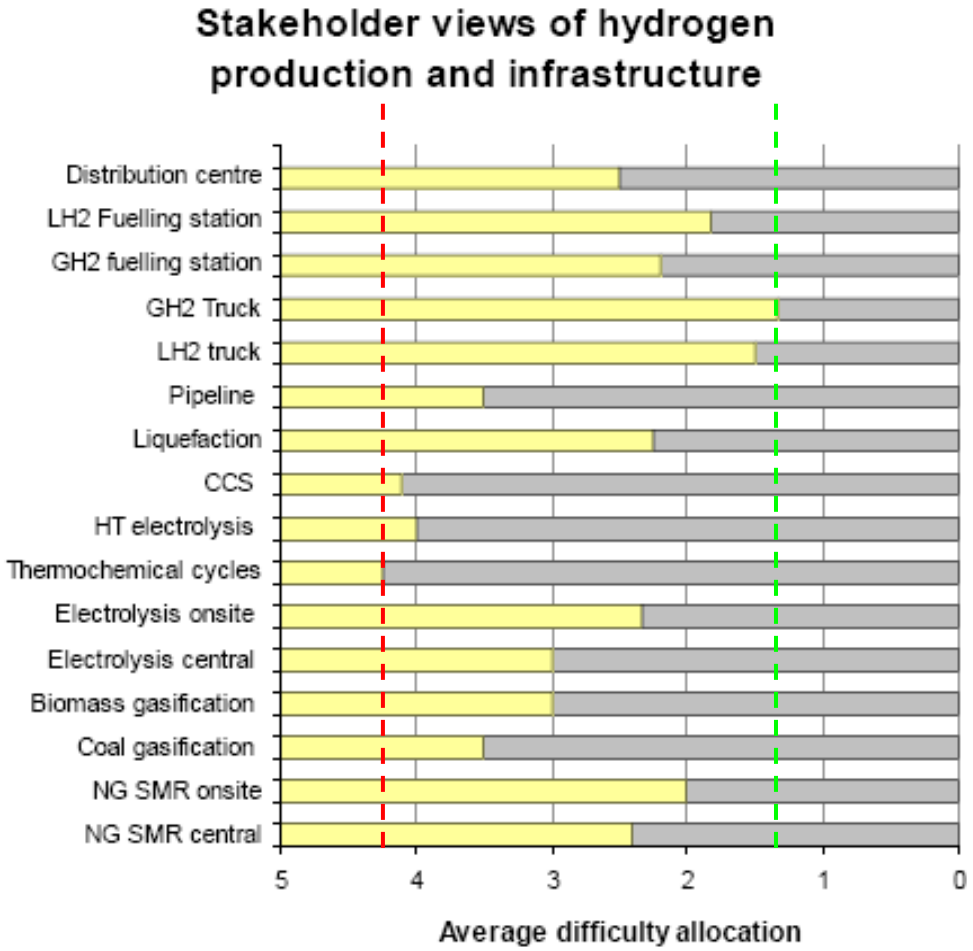
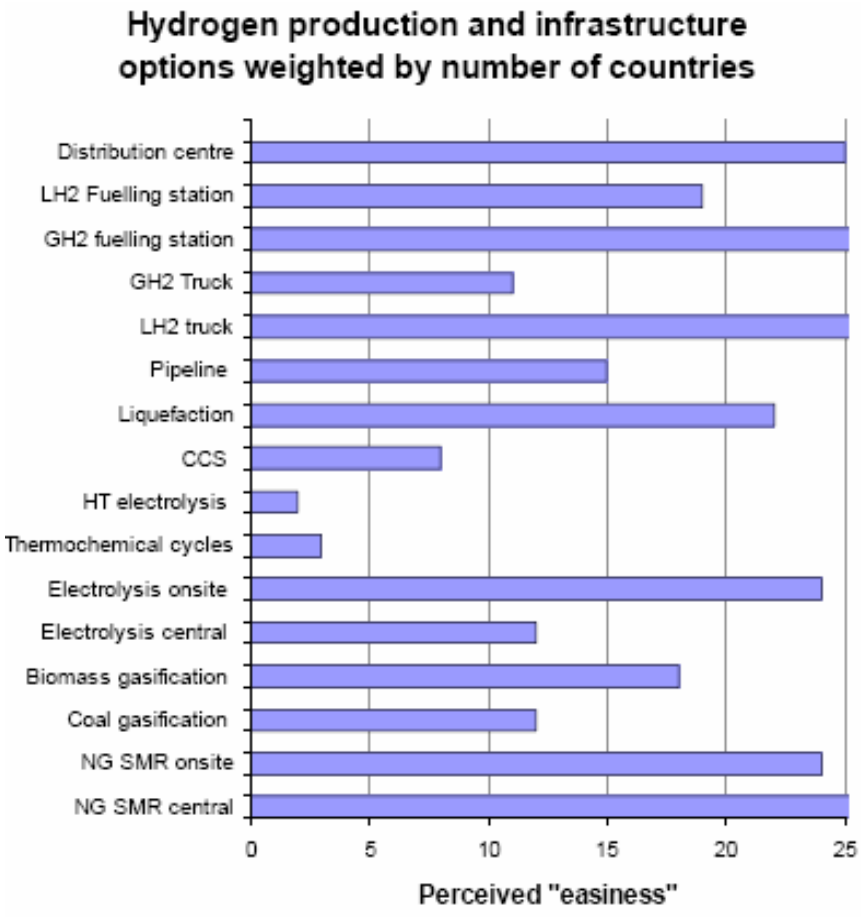
KCAM - Hydrogen Production Difficulty Allocations

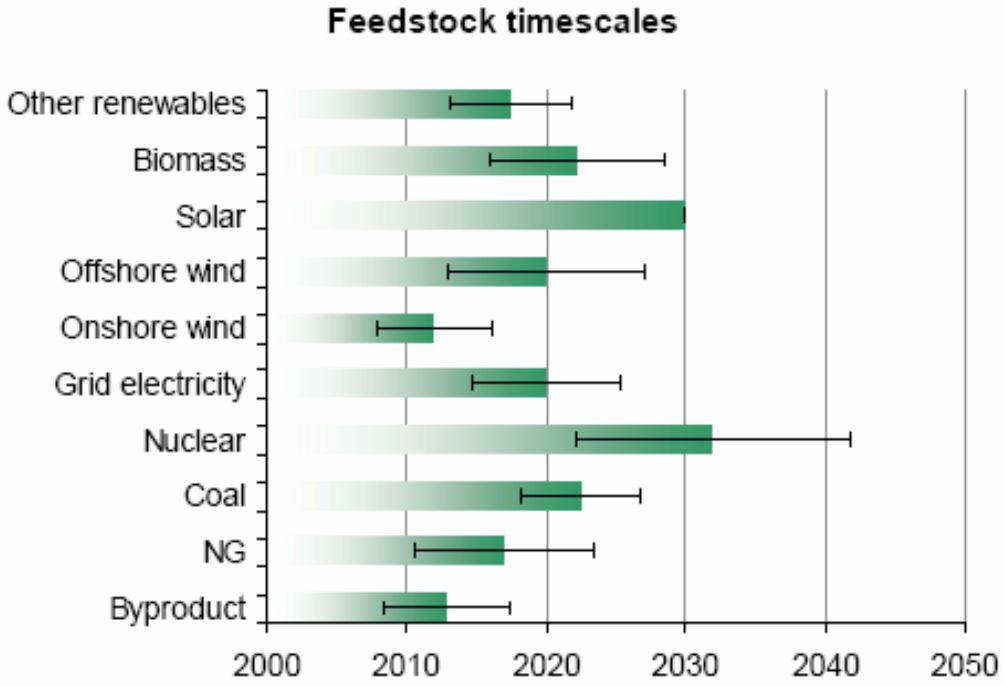
HyWays

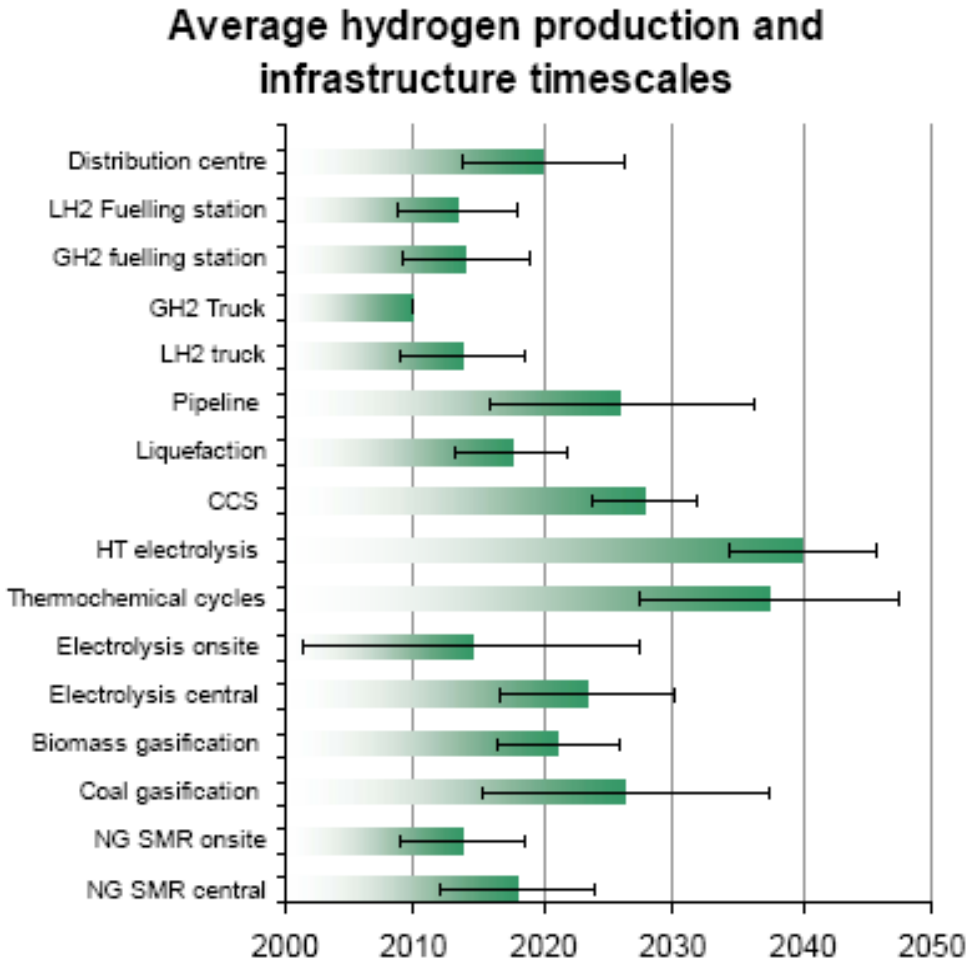




KCAM - Timescales and Difficulty Allocations

HyWays





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Costs of infrastructure build-up

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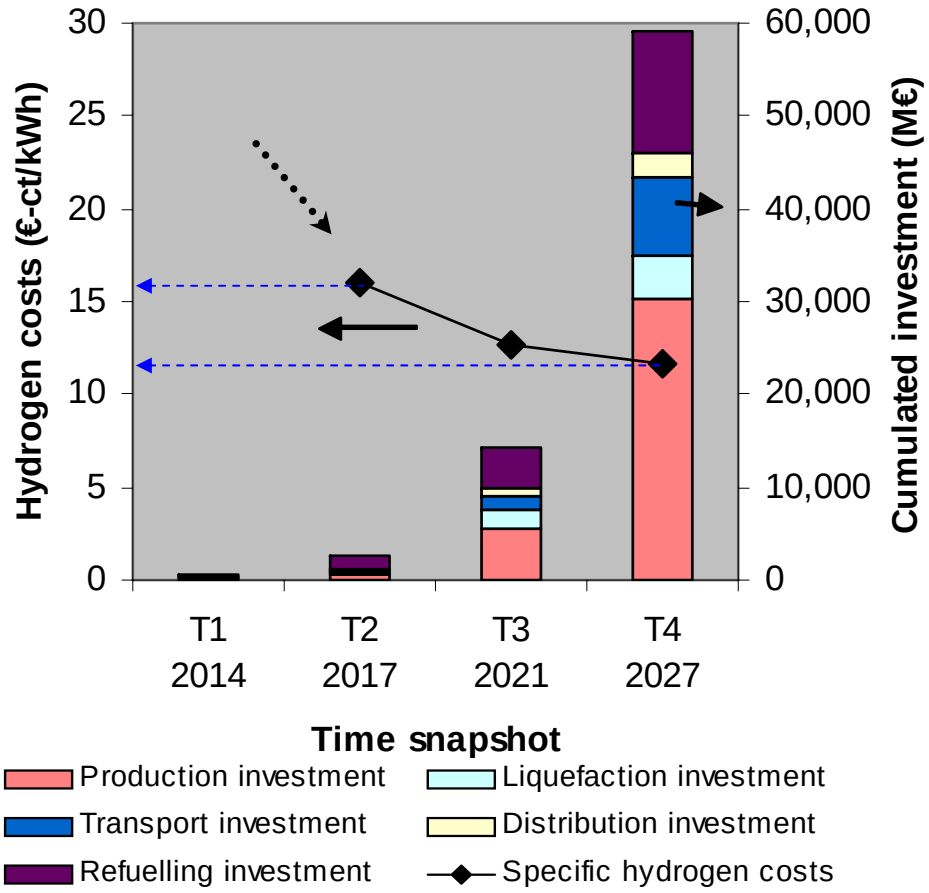
Cumulated investment and specific H_2 costs



- High initial costs (due to under-utilization of plants and fillings stations)
- But: quick reduction to 1.1-1.6 €/ liter Diesel equivalent) from second phase
- Relevant variation of cost between countries (depending on availability of feedstock, stakeholder selection of hydrogen pathways, car and population density)
- Transport, distribution and refuelling contribute significantly to investment

Sensitivity of cost factors

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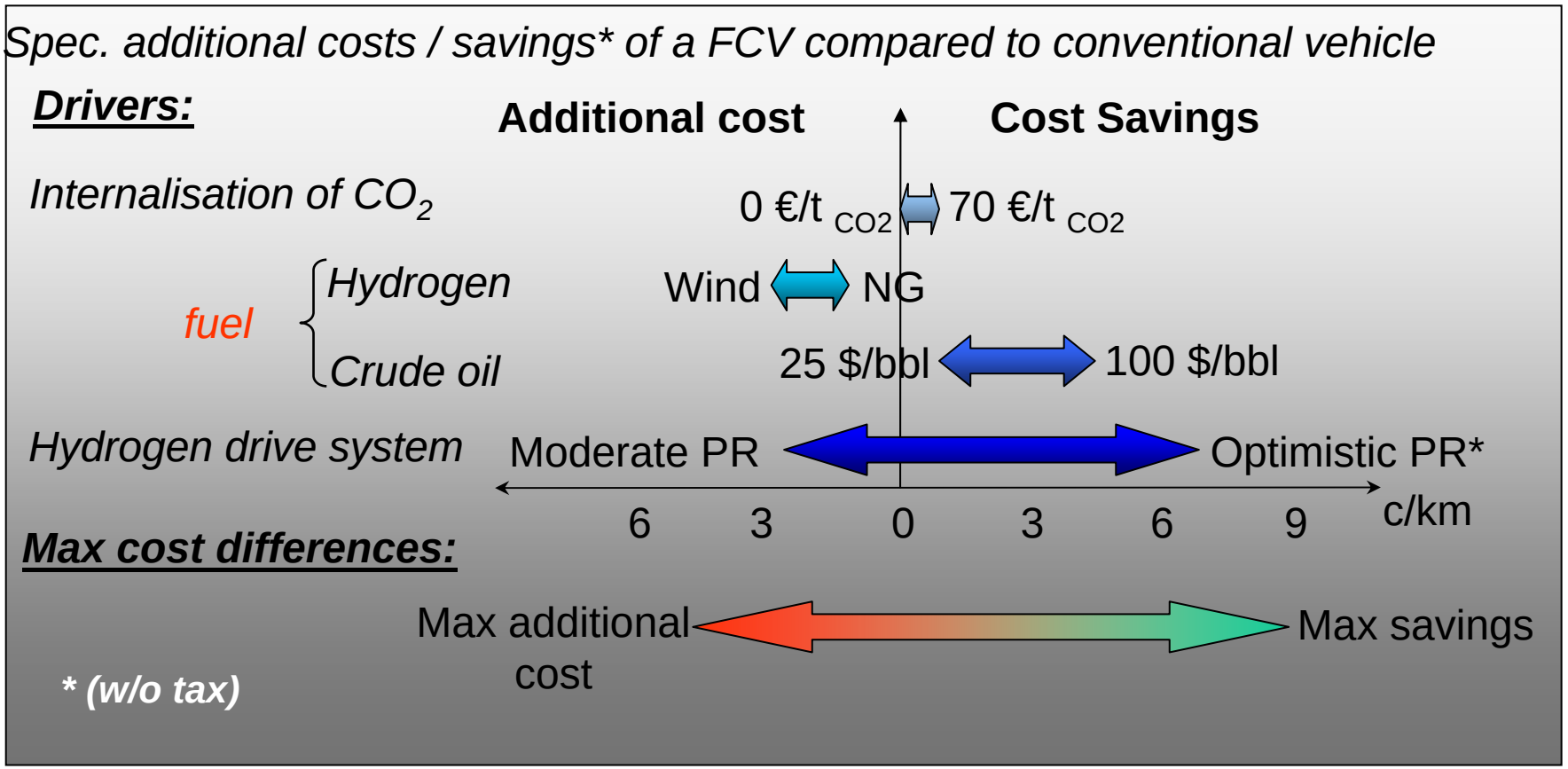

⇒ Powertrain costs

- have by far the largest influence on economic efficiency.
- still have to be significantly reduced (to reach cost level of conventional diesel cars), which is considered feasible by HyWays's automobile partners.

Total cash flow (fuel and fleet cash flow) analysis for two extreme scenarios

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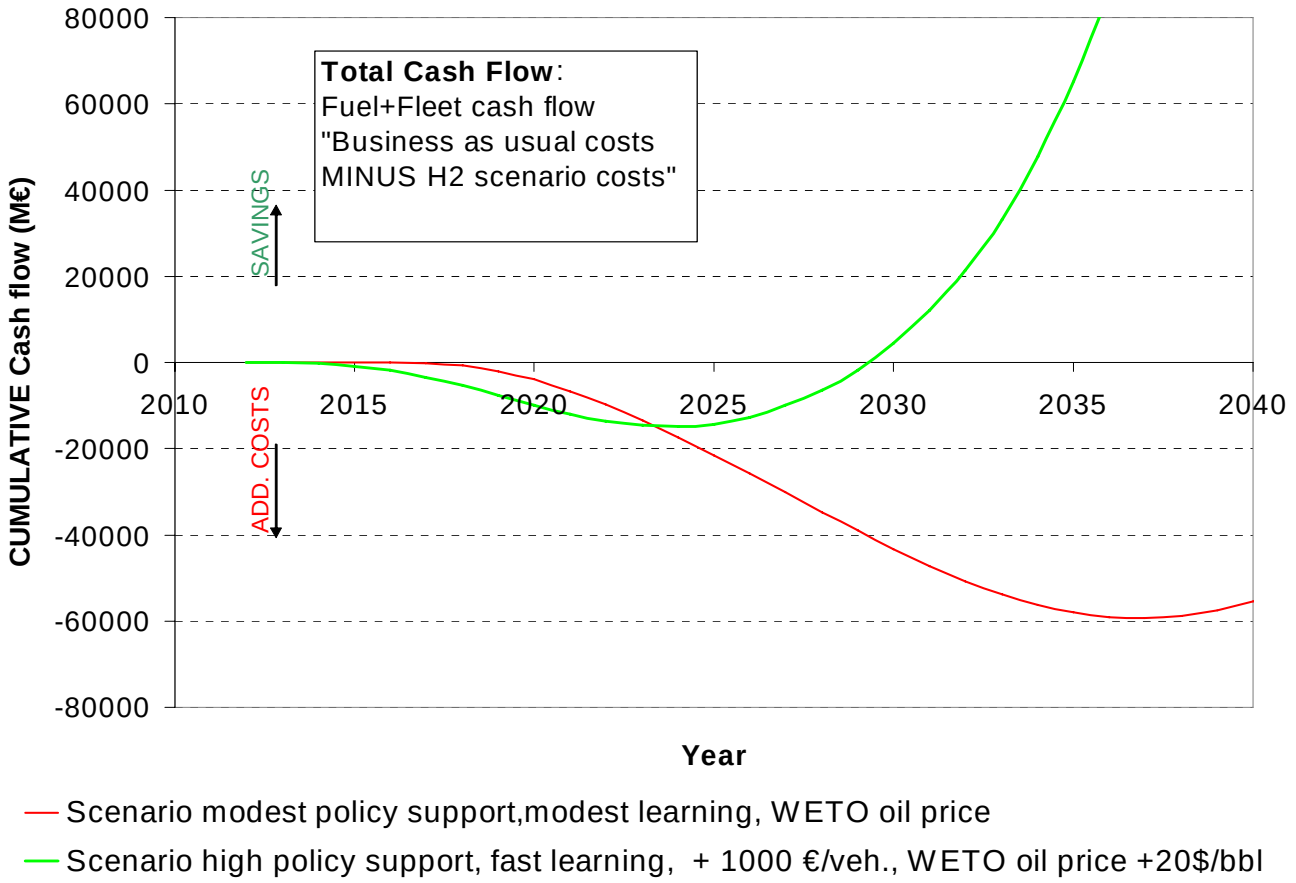
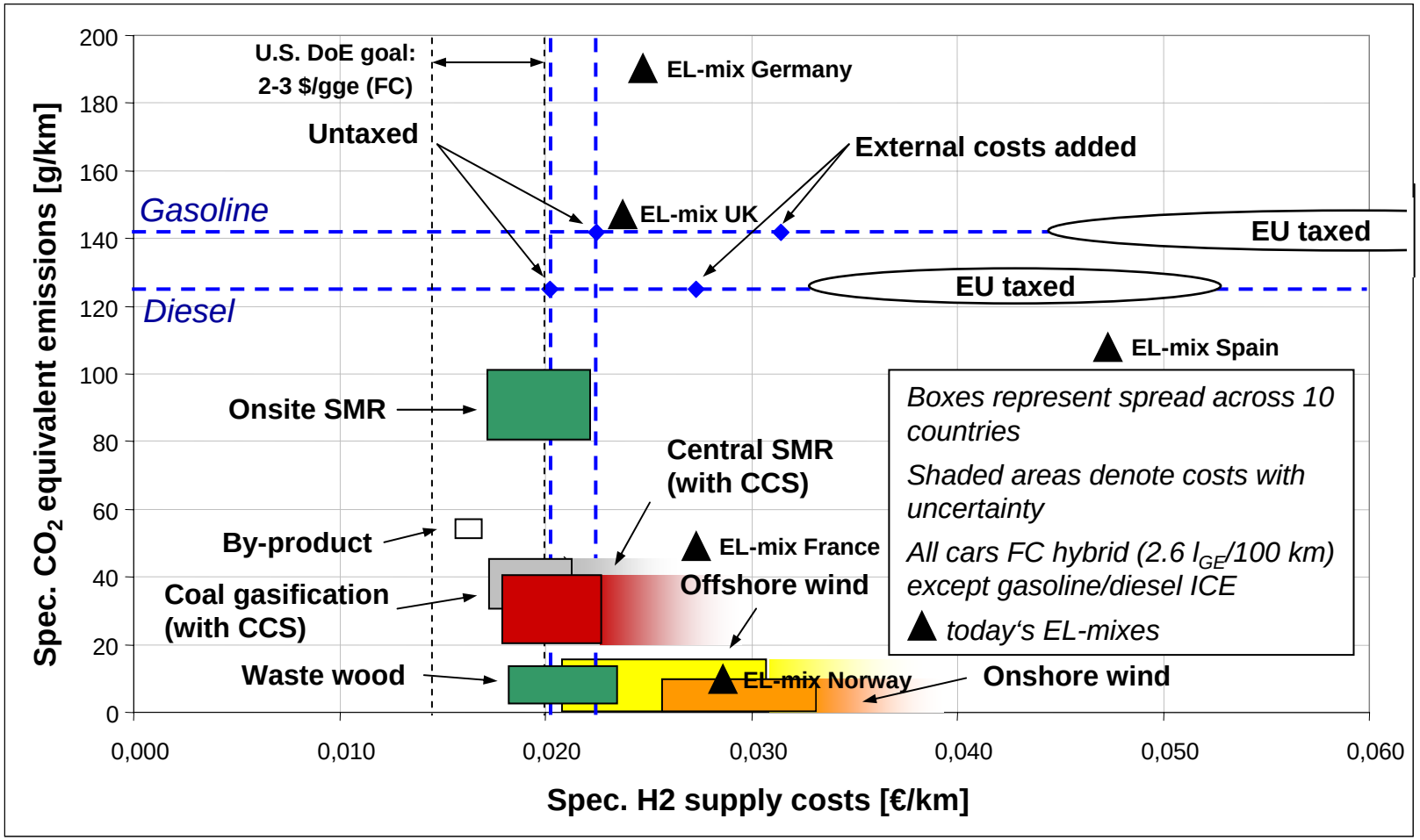


Selected hydrogen WTW pathway portfolio for 10 countries (2030)

HyWays



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Economic impacts – Employment effects

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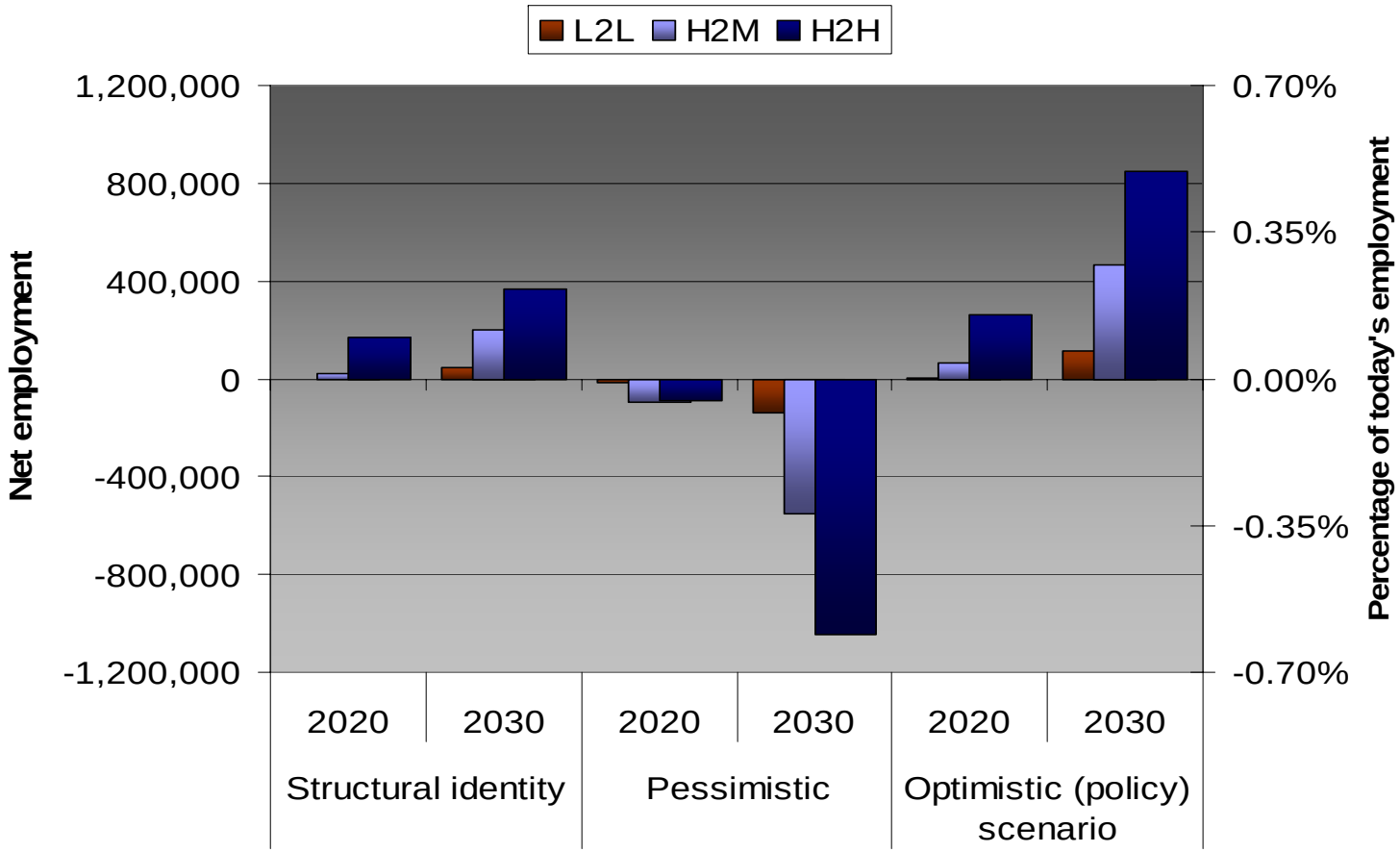
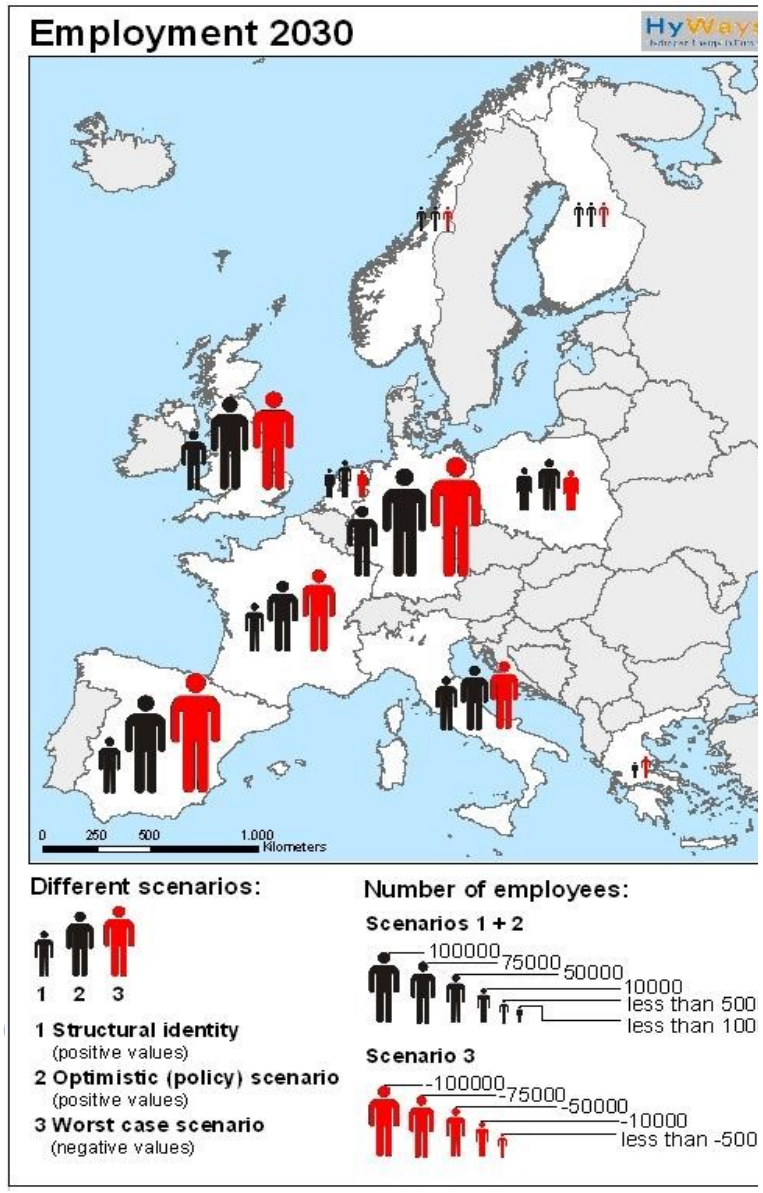


Overall net employment effects for the ten HyWays countries three import and export scenarios for different market penetration scenarios

Economic impacts – Employment effects

HyWays



- Critical issue for EU27
  - Today 25% of all vehicles are produced in Europe, the transport sector counts for 10% of total GDP in EU27, important plant manufactures are located in EU27)
- Dilemma for large automotive countries:
  - GDP and job losses (0.7% in 2030 for pessimistic scenario) could be drastic if these country lose market shares due to a late market entry
  - Uncertainties regarding market success of H_2 cars and potential risk of losing several billion Euro due to investments in premature H_2 infrastructure and H_2 car development
- Other countries could see it more relaxed; by following the "right strategies" additional wins in GDP and employment can be obtained

Economic Impacts – Emission reduction costs

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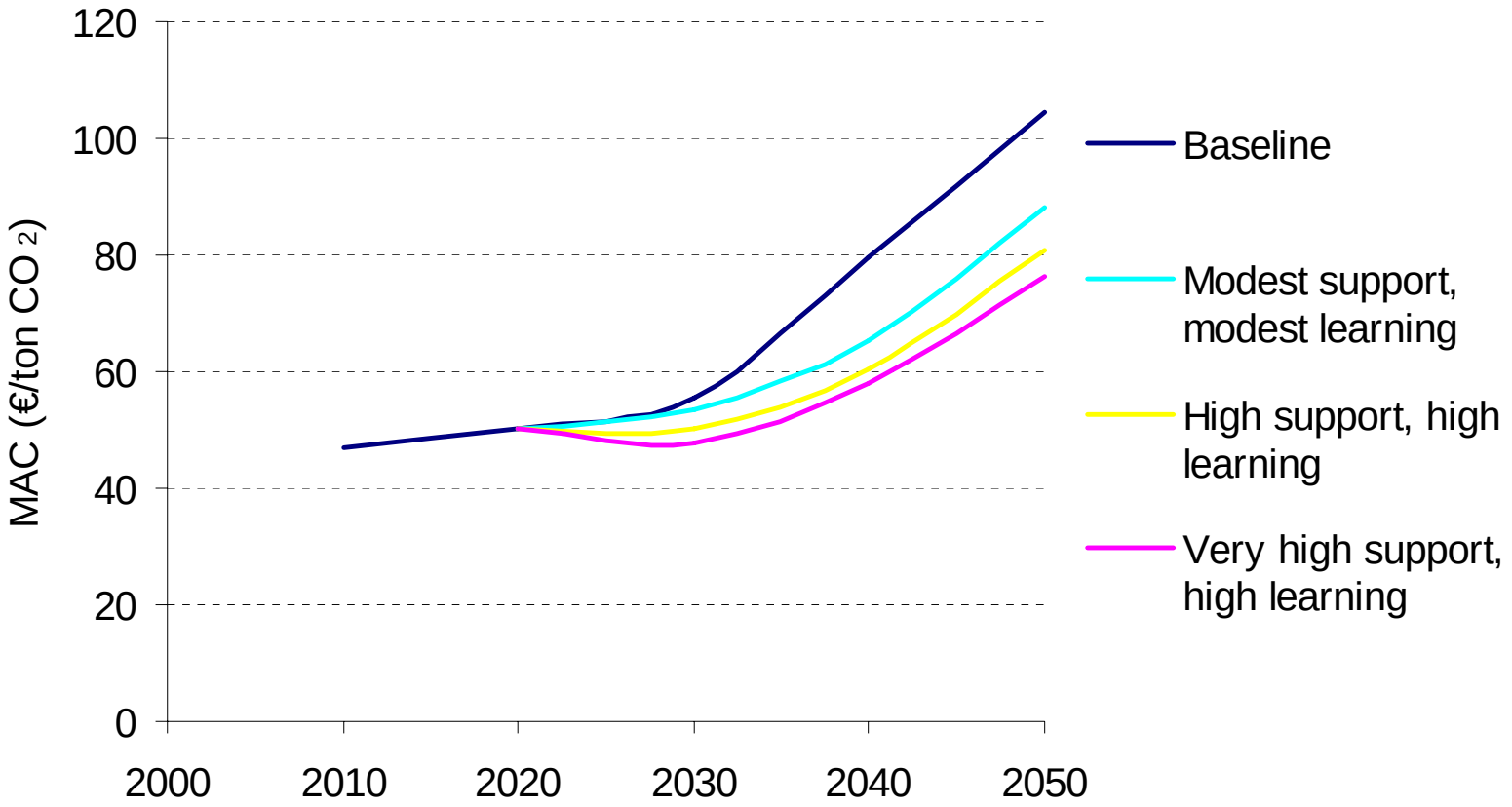
Marginal abatement costs (MAC) for CO_2 emission reduction (Europe)



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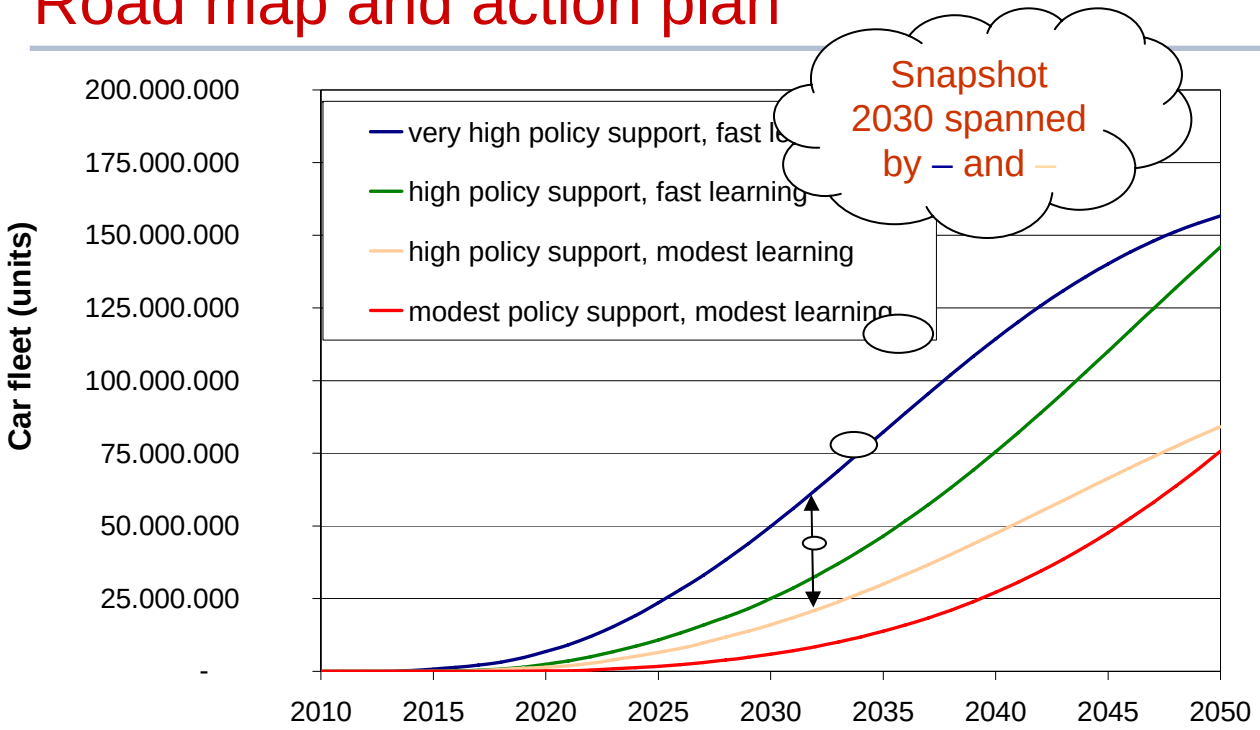
Roadmap contents

HyWays

- Proof that hydrogen offers value added
  - Economy (GDP, competitiveness, labour)
  - Environment (emissions)
  - Security of supply (diversification)
- Describe the changes for the energy system
  - Hydrogen pathways (emissions, costs), infrastructure development, hydrogen sources, end use applications
  - Identification of key technologies
- Barriers that hamper introduction
  - Technology gaps (performance)
  - Economic gaps (cost reductions)

Road map and action plan

HyWays



Vehicle fleet targets: Snapshots 2020 & 2030

HyWays passenger car fleet targets for EU15	„Snapshot 2020“ (HFP)	„Snapshot 2030“ (HyWays Proposal)
Lower bound Requires high policy support!	1 million	15 million
Upper bound Requires extreme policy	5 million	50 million
What could happen with modest policy support	*0.1 million*	*5 million*

HFP Snapshot 2020: Road Transport

- In **2020**, hydrogen & fuel cell vehicles are likely to account for only a few percent of the overall vehicle fleet
- For **2020**, the primary objective is availability of a significant choice of hydrogen & fuel cell vehicles, with an appropriate infrastructure
- The best case estimate for hydrogen fuelled vehicles in **2020** is in the range of 0.4 million - 1.8 million units sold per annum and 1 million to 5 million in vehicle population
- Even at the lower end of this estimate, a few thousand hydrogen filling stations will be required to service cars sold, probably in urban clusters

HyWays Snapshot 2030: Road Transport

- In 2030 H_2 & FC technologies for road transport (passenger vehicles + LDV) will likely be in the growth phase
- S-Curve model with exact “take-off point” is partially misleading in terms of absolute figures (deviation of some years causes drastic changes in absolute figures)
- HyWays scenarios *very high policy support, fast learning* and *modest policy support, modest learning* define (from today‘s best knowledge) a theoretical level playing field

A European hydrogen roadmap

HyWays

	Phases	Targets (minimum)	Impact on Policy Goals	Proposed Actions
tentative time line	**Phase I** Technology development & cost reduction			**Large-scale demos & supporting R&D** • "Lighthouse Projects" • accompanying phases I &II
2010	**Phase II** Pre-commercial technology refinement & market preparation			**H2 friendly framework** • Fiscal incentives • Public procurement • Long term security for investing stakeholders
2015	**Phase III** Start of commercialisation		**materialisation of first impacts** • New hydrogen supply capacities fully based on renewable/ low carbon sources • Early user centres in large cities lead to further improvement in local air quality • Creation of new jobs/ safeguarding existing automotive & energy jobs	
2020	**HFP Snapshot 2020**	**H2: 3 €/kg** **FC: 100 €/ kW** **Tank: 10 €/kWh**		**H2 is fully competitive** • Phase out of incentives completed
2030	**HyWays Snapshot 2030**	**H2: 2 €/kg** **FC: 50 €/ kW** **Tank: 5 €/kWh**		
2050	**Vision** Hydrogen & FC dominant technologies in passenger car transport		**high impact** • Most cars fuelled with renewable hydrogen • reaching more than 80% CO_2 reductions in passenger car transport	

Acknowledgement

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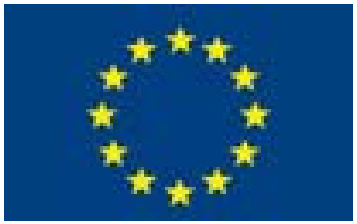

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