Development of a European Hydrogen Economy: What are the challenges ?

contribution by HyWays - European Hydrogen Energy Roadmap

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Content

HyWays

Partners

Motivation

Project goals/ objectives

Methodology

First preliminary results

Acknowledgement

Partners

Partners

HyWays

Industry

BMW Group

DaimlerChrysler

GM

OPEL

AIR LIQUIDE

AIR PRODUCTS

REPSOL YPF

Linde

Statkraft

GE Oil & Gas

VATTENFALL

TOTAL

EDF Electricité de France

HYDRO

HYGEAR

infraserv höchst

DNV

acciona Biocombustibles

HYDROGENICS CORPORATION

Member states

SenterNovem

cea

dena Deutsche Energie-Agentur

HELLENIC INSTITUTE OF TRANSPORT

INTA

Główny Instytut Górnictwa

dti

VTT

ENEA

Institutes

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

IDMEC Pólo INSTITUTO SUPERIOR TÉCNICO

Fraunhofer Institute Systems and Innovation Research ISI

ludwig bölkow systemtechnik

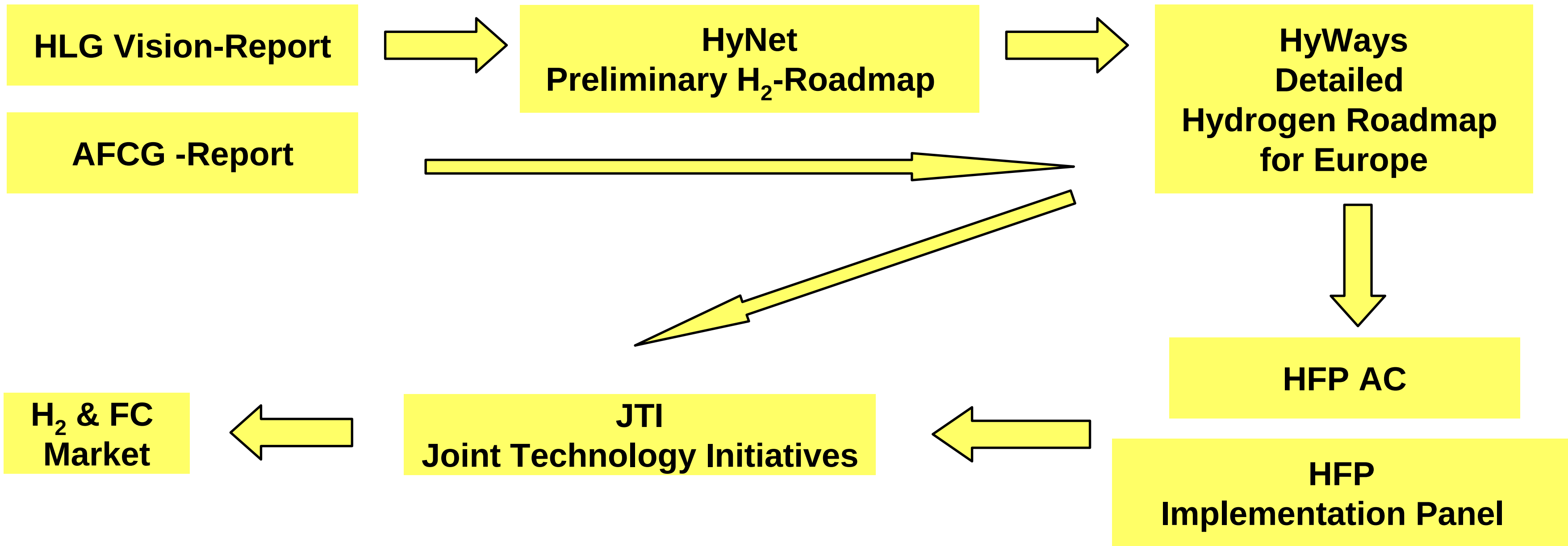
ECN Energy research Centre of the Netherlands

ZEW Zentrum für Europäische Wirtschaftsforschung GmbH

APR 04 - MAR 07 in 2 phases of 18 months each; 7.9 M€ budget and 4 M€ EU funding

Motivation

Need for a European hydrogen energy roadmap as orientation and decision basis for industry, politics and society



Project goals

"If hydrogen has an X share in the future energy system…

- no prediction, no commitment, but plausible assumptions

… then what is the impact...

- on greenhouse gases and other emissions, economy, industry and society (competitiveness, employment)

… and how can we get there?"

- Scenarios for market introduction of hydrogen applications (vehicles, CHP, …), infrastructure build-up and energy diversification (hydrogen production)
- Recommendations to EC, Member States and industry

Methodology

Methodology (1) - Major Tasks and Their Cohesion

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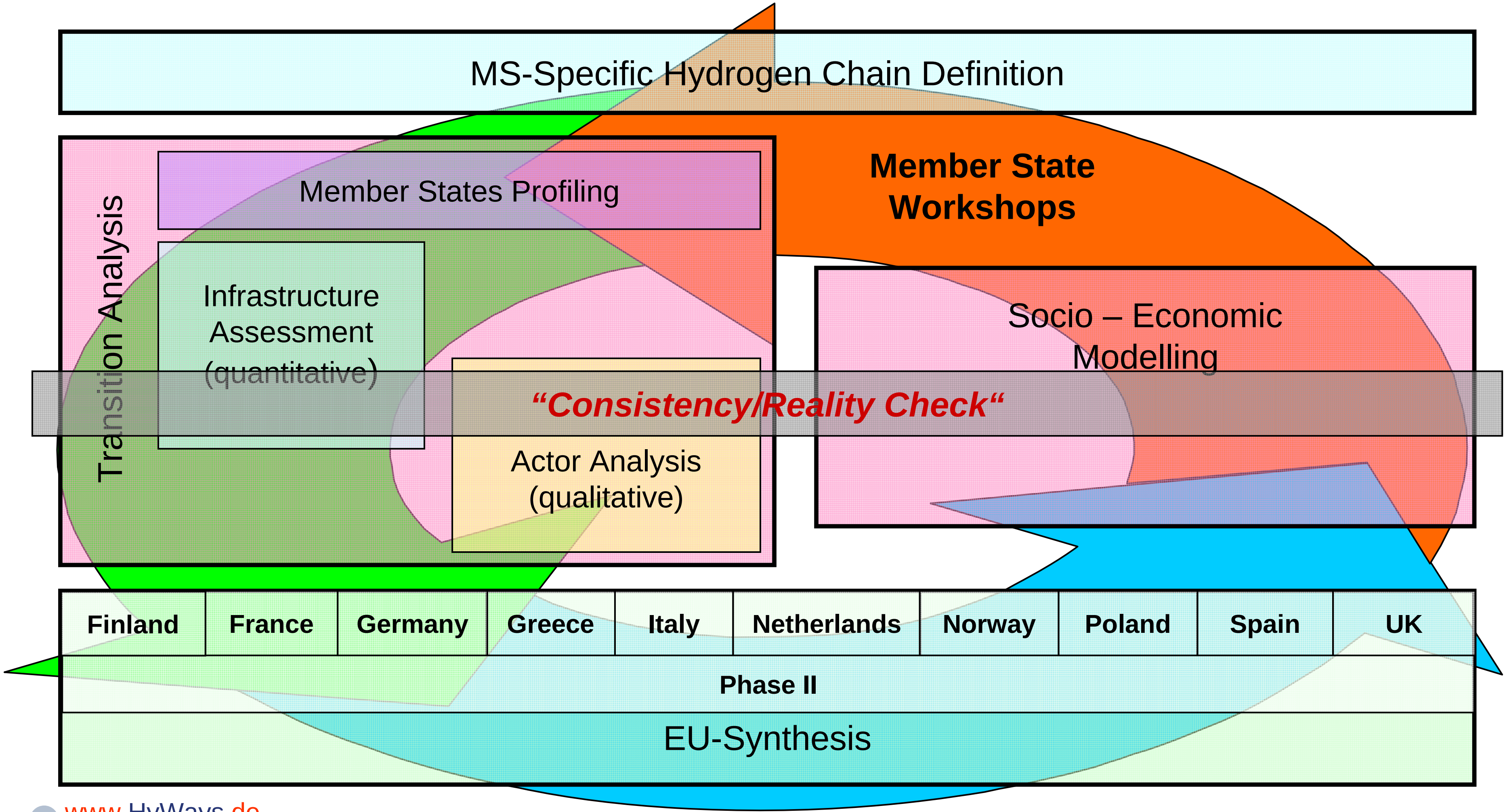
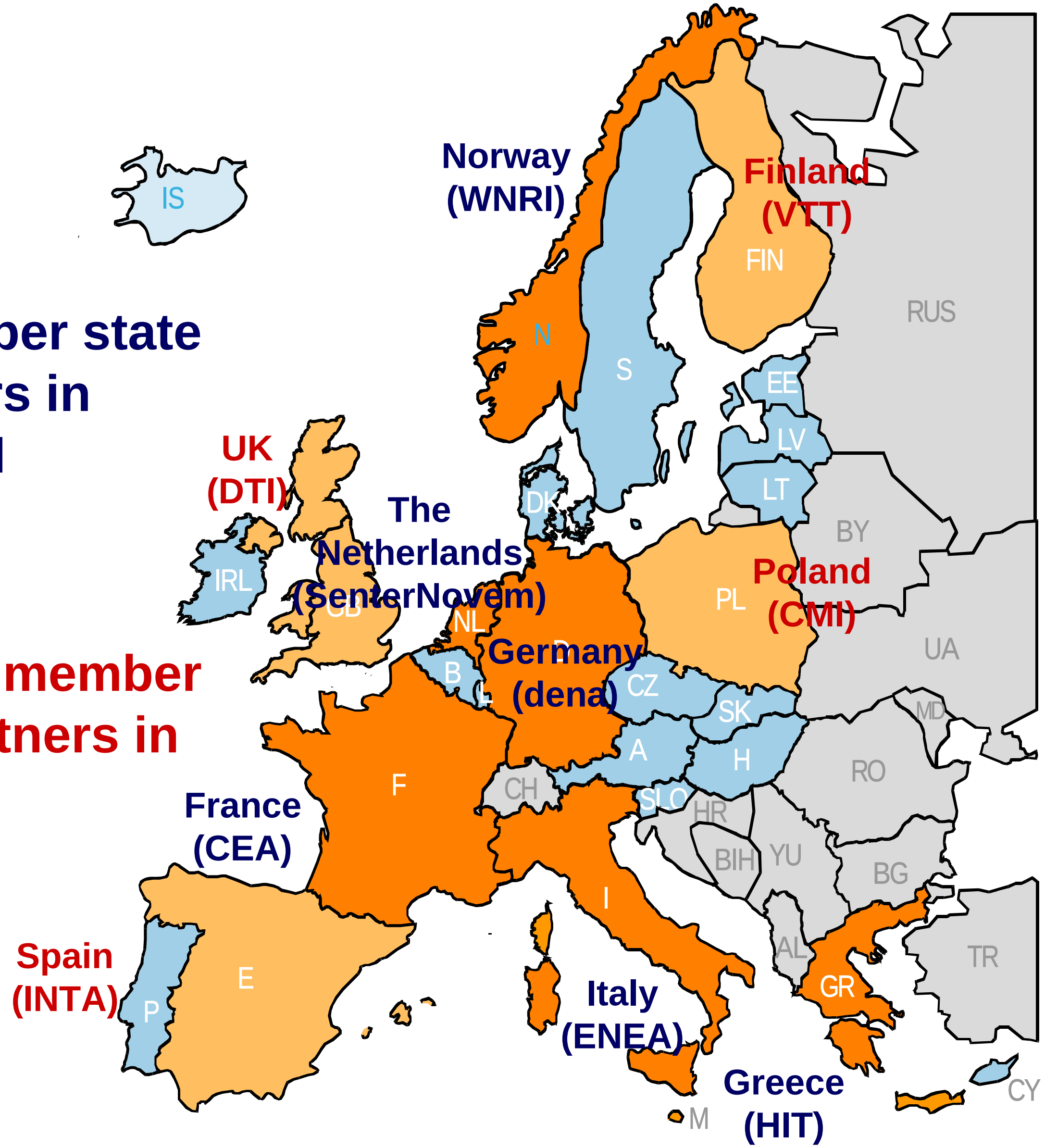


Methodology (2) - Geographical Representation of MS

HyWays

6 member state partners in Phase I

4 further member state partners in Phase II



TIME HORIZON

2010 / 2020 / 2030 / 2050

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

Methodology (3) - Overview: Modelling perspective

HyWays

Input

Stakeholder input

Final vision of a hydrogen economy, H_2 chains, H_2 market penetration scenarios, minimum/ maximum bounds for H_2 feedstocks

Techno-economic data

E.g.
- vehicles (efficiency, investment, life time, drive cycles,….)
- production plants (emissions,…)
- transport and distribution plants (pipeline dimension,…)

Scenario data

E.g.
- primary energy prices forecast
- competitiveness of a country
- environmental constraints (CO_2)

HyWays Modelling Toolbox

Energy pathway analysis (E3), Energy system model (MARKAL), Infrastructure model (MOREHyS), Macro-economic models: Input/Ouput model (ISIS) and General Equilibrium model (Pace-T), Emission model (COPERT)

Outcome

- **Design of the whole energy system**
- **H_2-infrastructure build up: feedstocks, production technologies, transport and distribution, applications**
- **Investments and costs**
- **GDP and employment development**
- **Emission development**
- **…….**

First preliminary results

Hydrogen Deployment in 3 Phases*

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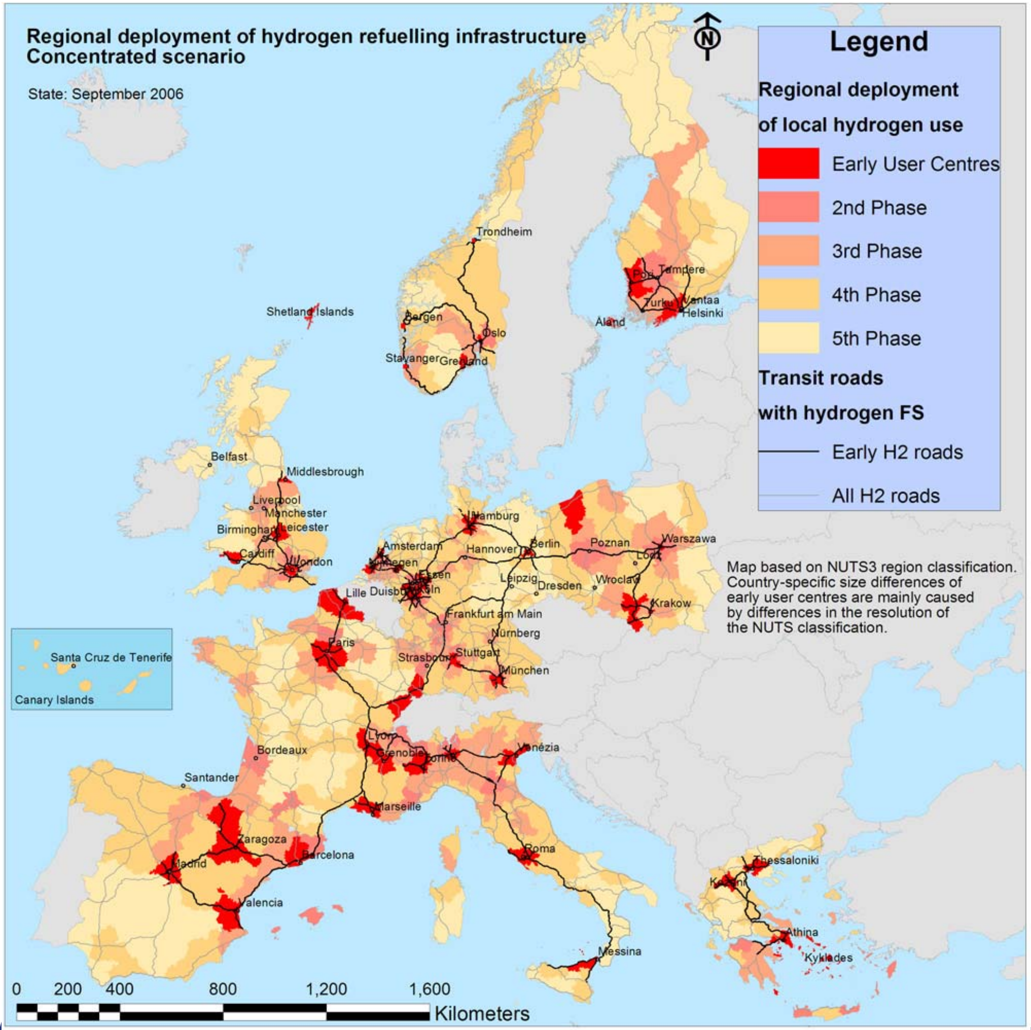
Phase	Vehicles EU-wide	Regional spread of H_2 use
Phase I (LHPs, pre-commercial phase)	10,000	Some large-scale demonstration “**first user centres”** in Europe (LHPs)
Phase II (early commercialisation)	10,000-500,000	2-5 “**early user centres**” per country** (10-25% of total population, emerging simultaneously). 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

* Phase II and Phase III are regarded in HyWays
** Manual selection based on indicators like local pollution, political commitment, experts, demo projects, …

Hydrogen deployment map
“Where and when will hydrogen be used?”

HyWays



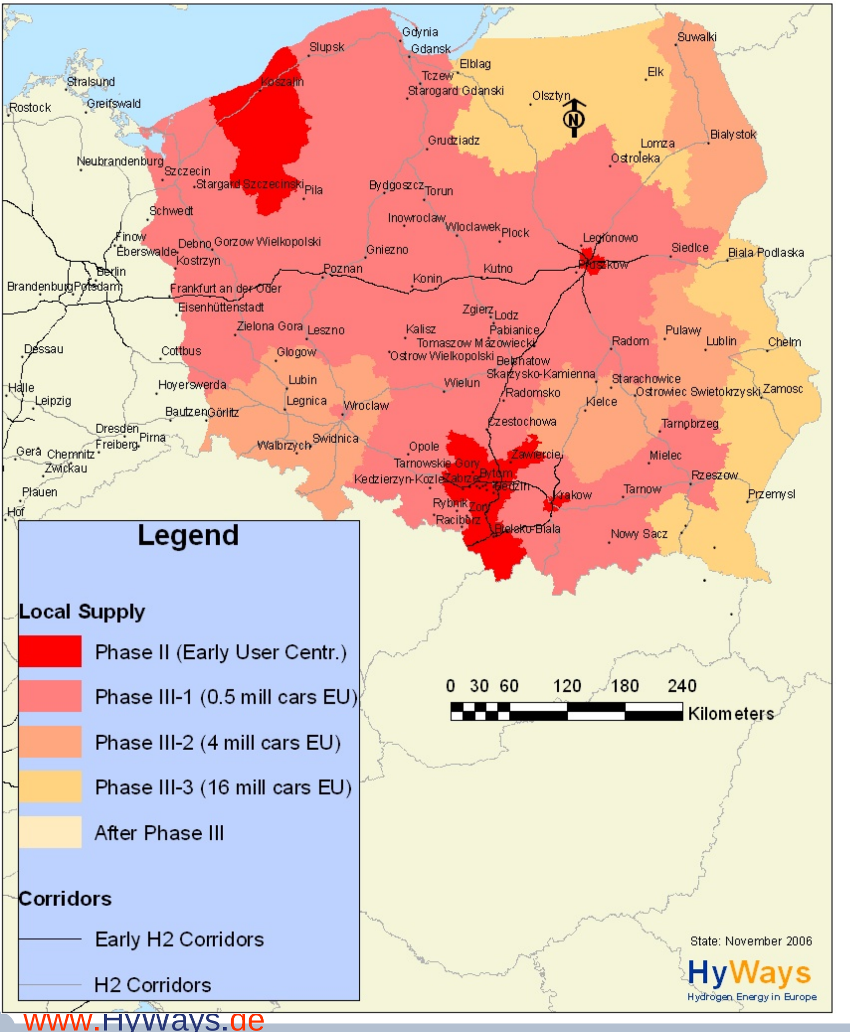
Size of colored areas do NOT represent hydrogen demand intensity but the GIS representation in NUTS 3 classes

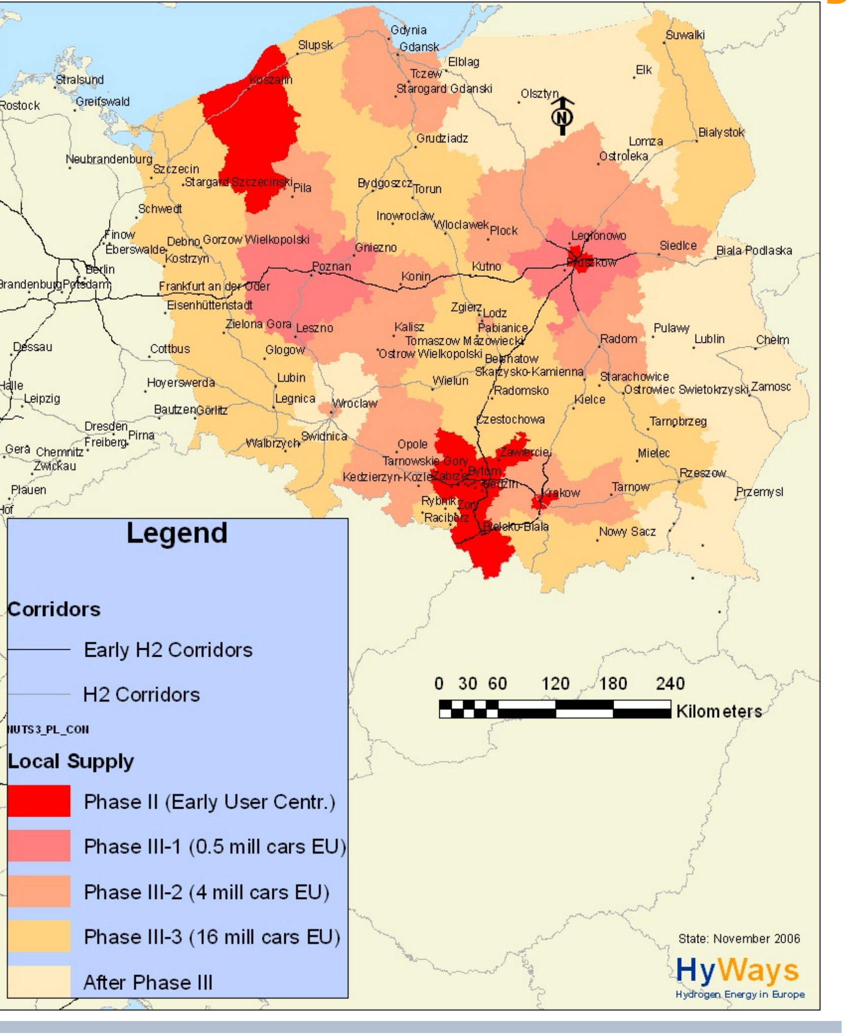
Hydrogen deployment map   Example: Poland

“Where and when will hydrogen be used?”

HyWays

Example: Poland





Hydrogen intensity map - Phase II (10, 000 cars EU- wide)

“Where is hydrogen used at which intensity [GWh/(a km²)]?“

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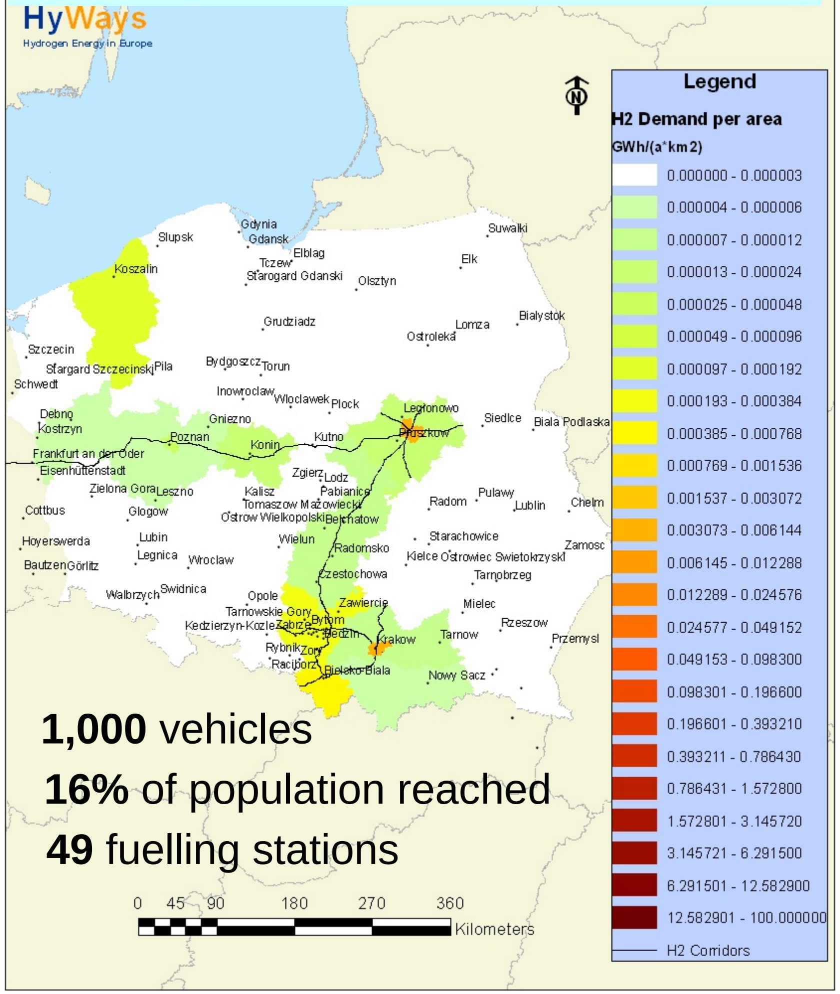
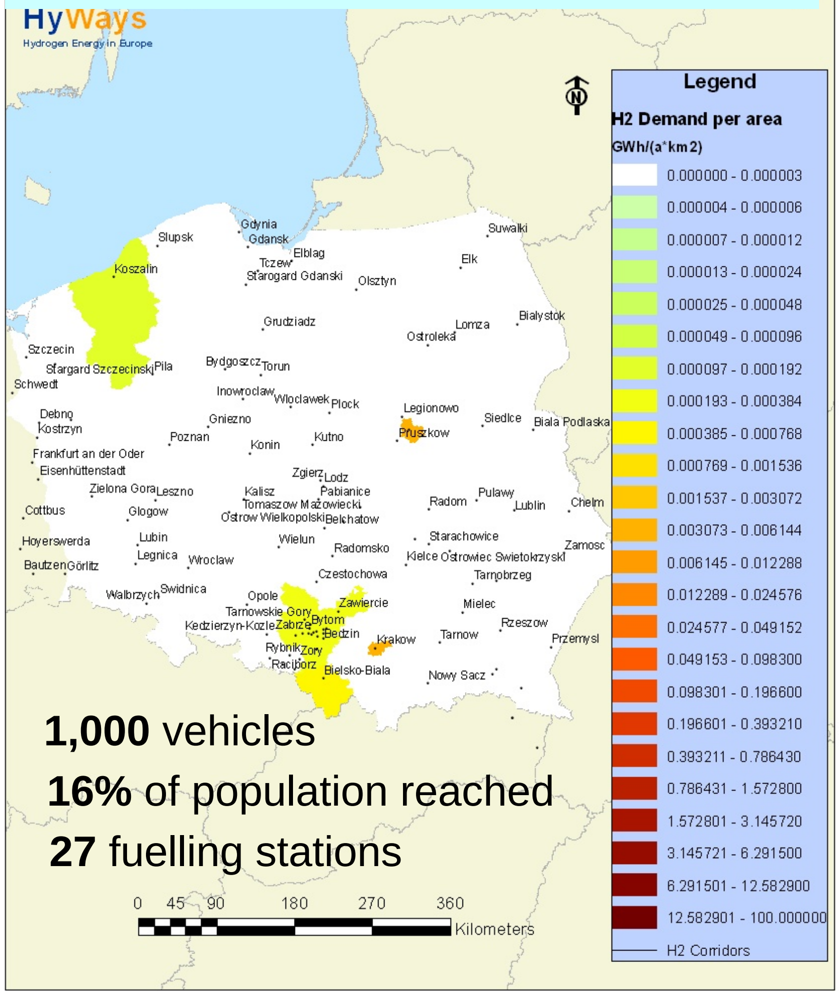
Example: Poland

High penetration - Distributed users - Early network



Low penetration - Concentrated users – Late network



Hydrogen intensity map - Phase III- 1 (500, 000 cars EU- wide)

"Where is hydrogen used at which intensity [GWh/(a km²)]?"

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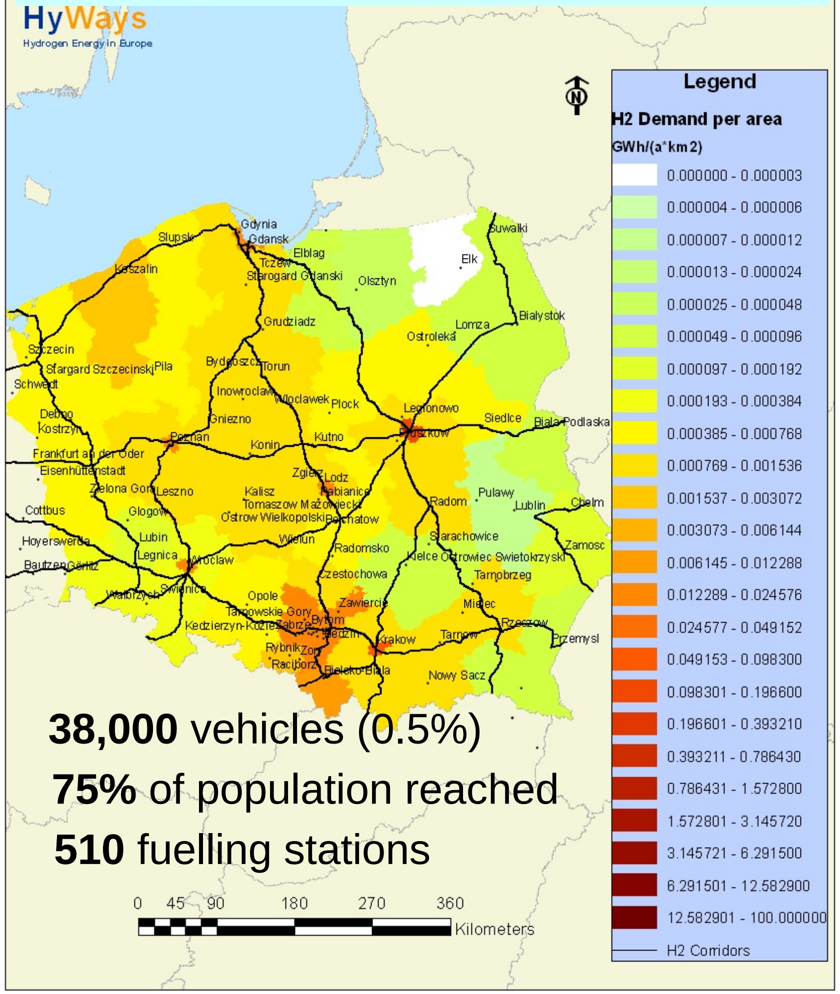
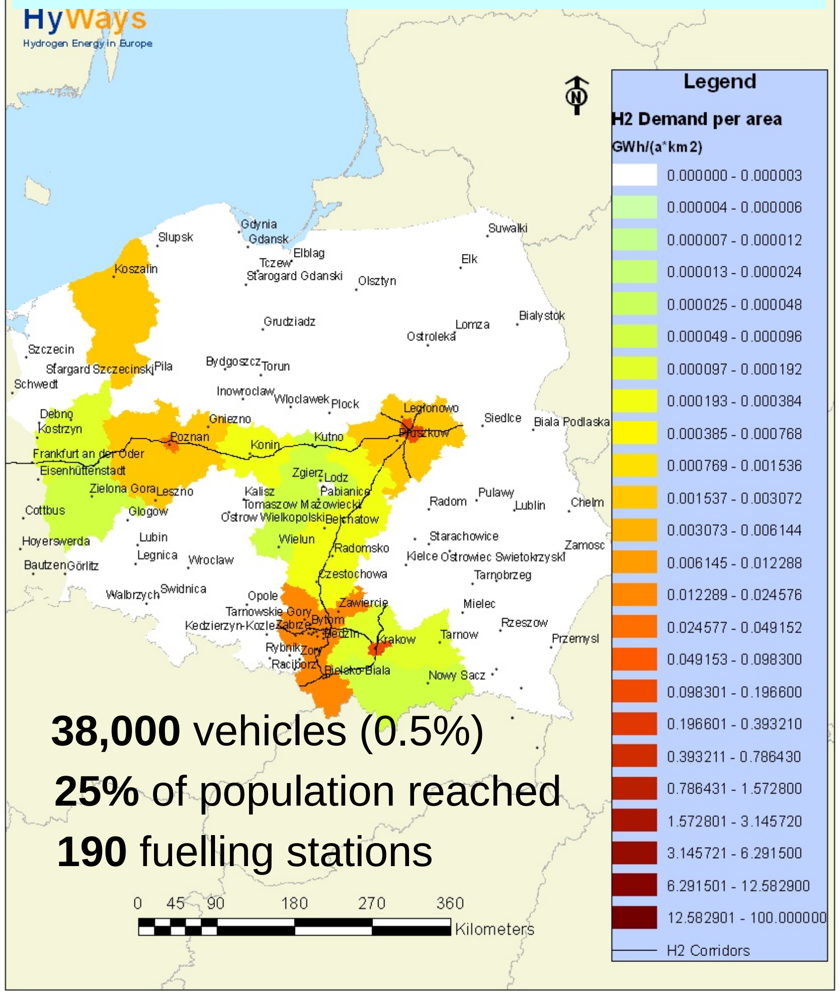
Example: Poland

High penetration - Distributed users - Early network



Low penetration - Concentrated users – Late network



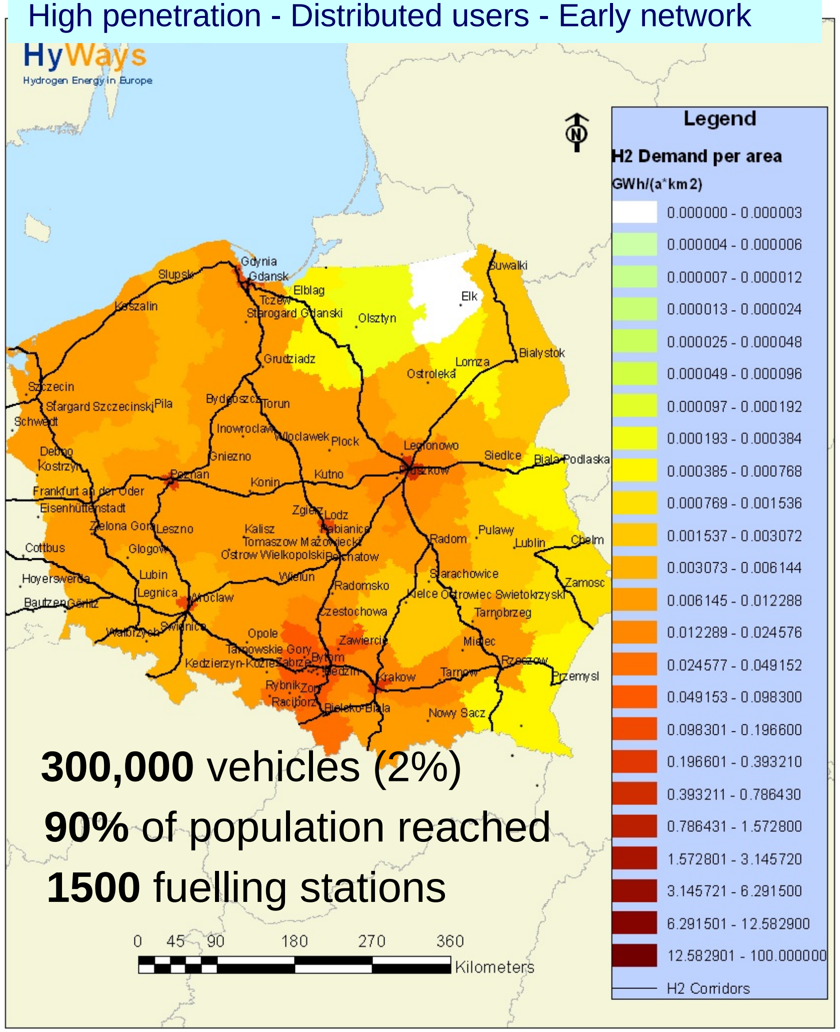
Example: Poland

Hydrogen intensity map - Phase III- 2 (4 mill. cars EU- wide)

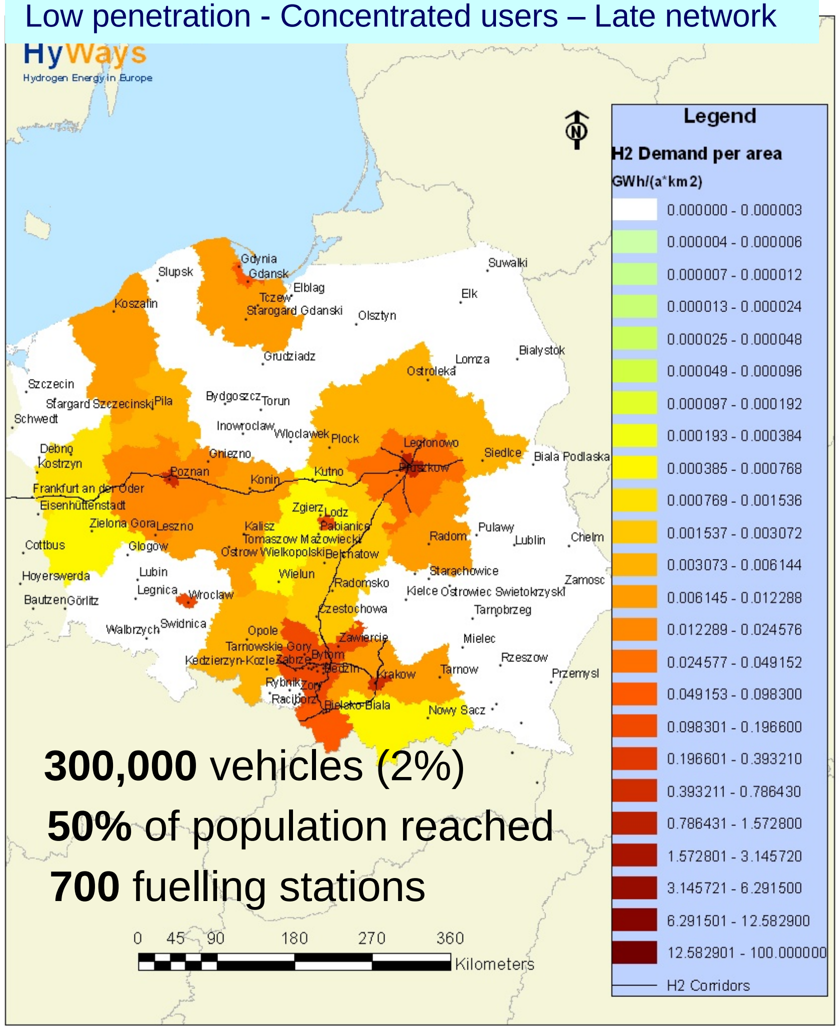
"Where is hydrogen used at which intensity [GWh/(a km²)]?"

HyWays

High penetration - Distributed users - Early network



Low penetration - Concentrated users – Late network



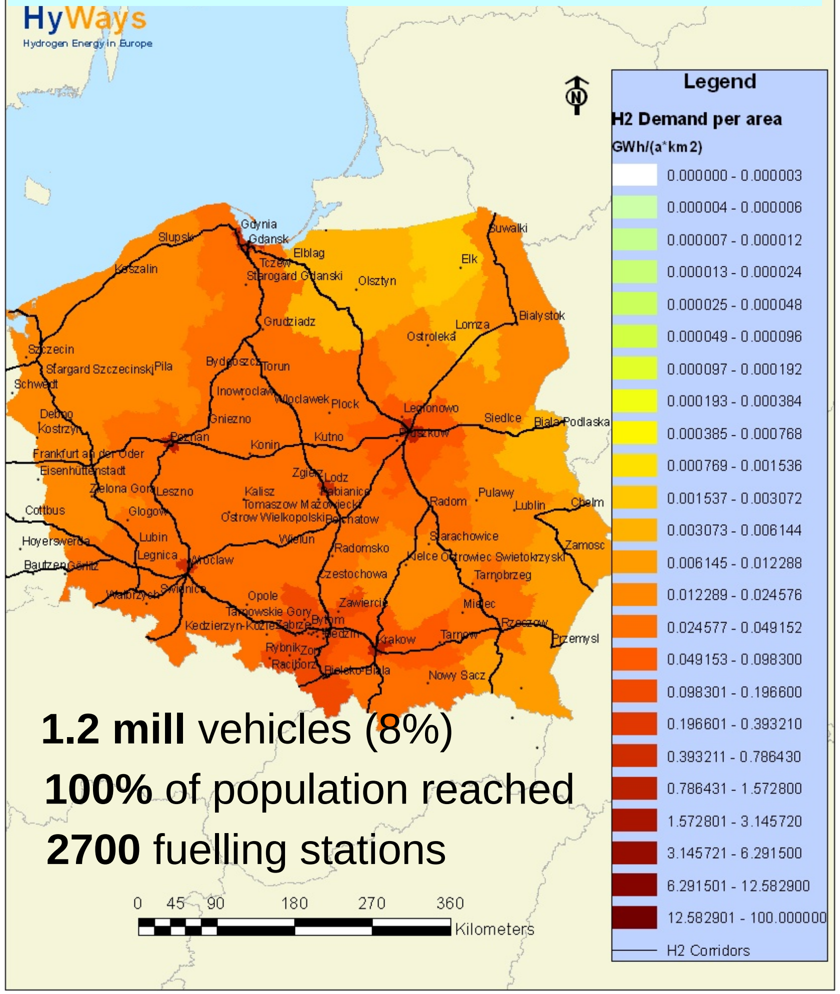
Hydrogen intensity map - Phase III- 3 (16 mill cars EU- wide)

"Where is hydrogen used at which intensity [GWh/(a km²)]?"

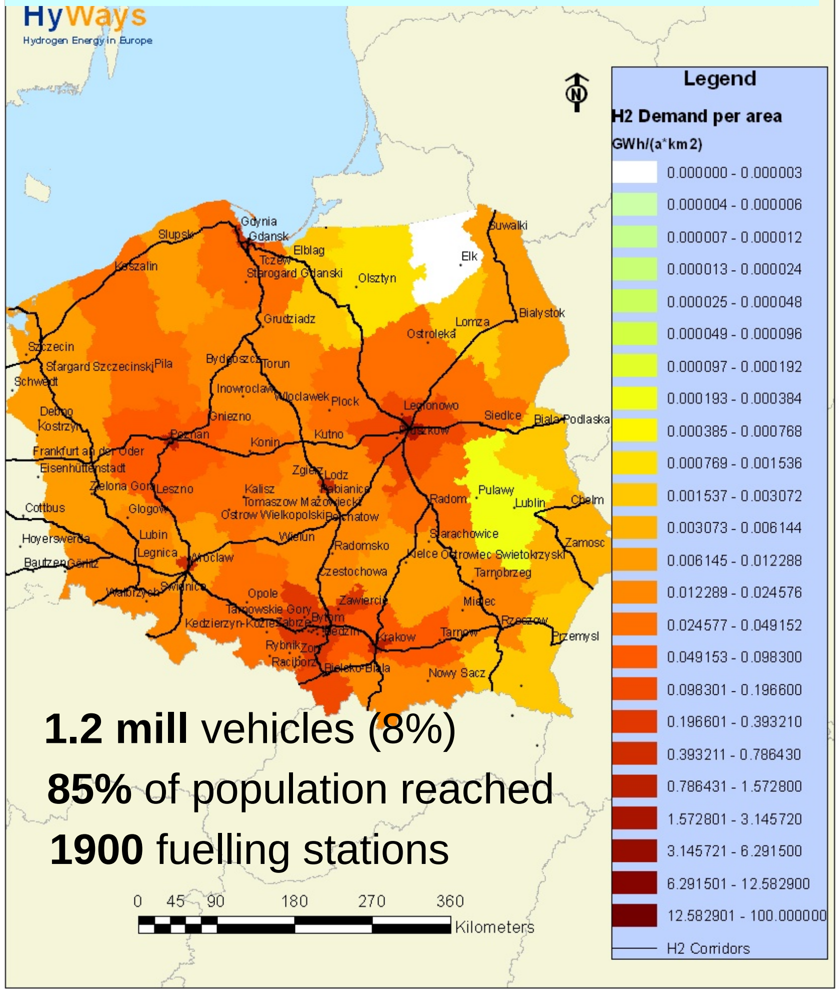
HyWays

Example: Poland

High penetration - Distributed users - Early network

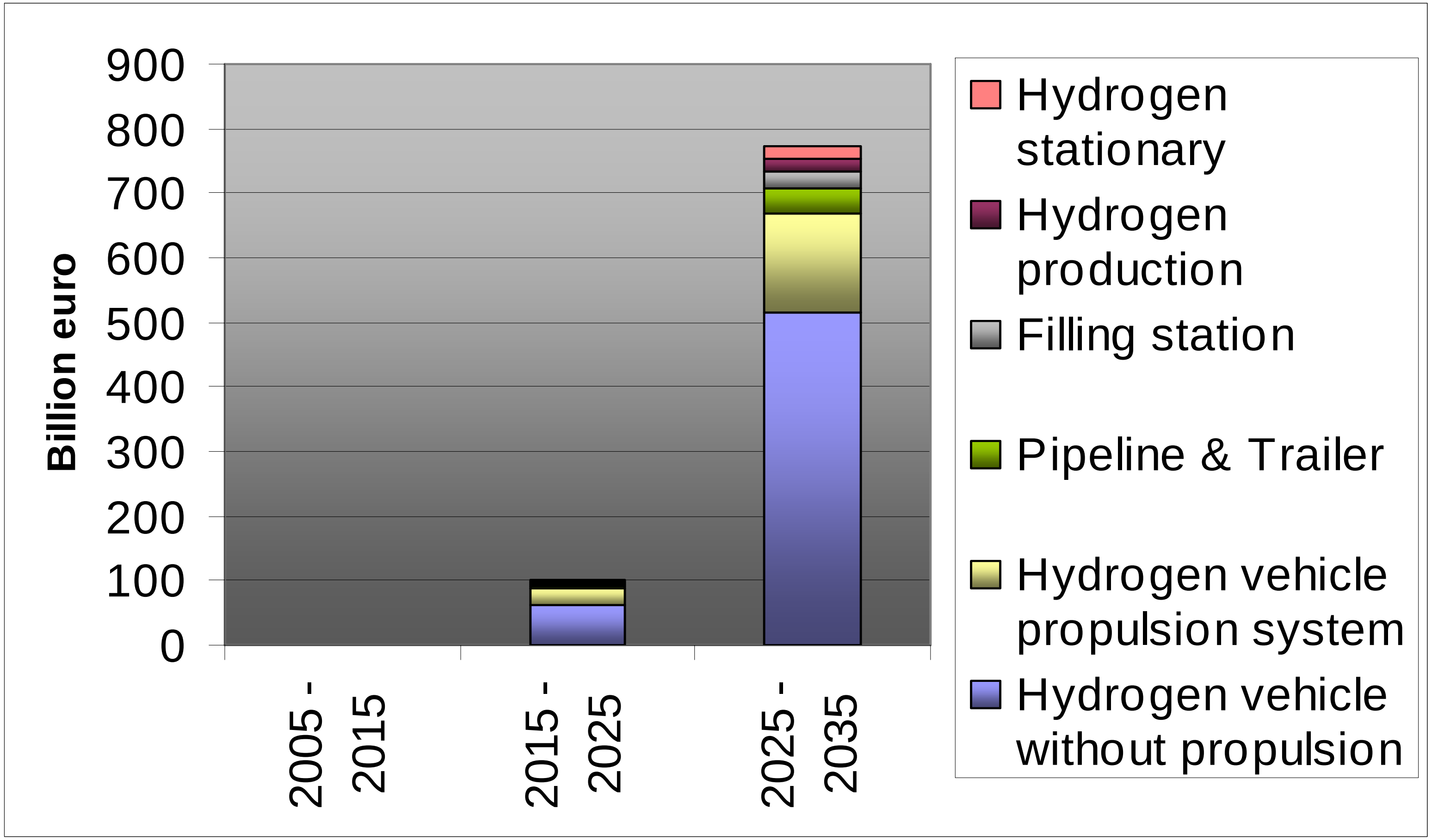


Low penetration - Concentrated users – Late network



Structure of the investments in a hydrogen economy of the six HyWays countries

HyWays



(cumulative investments for a ten-year period, hydrogen high penetration scenario)

HyWays

- After the full commercialisation phase has been reached, the hydrogen costs at the filling station in comparison to oil-based fuels do not seem to be a relevant barrier to the use of hydrogen as a fuel as long as the crude oil price does not fall significantly under 50 $/b. The introduction phase with sub-capacity use is critical.
- However, it should be kept in mind that the costs of the powertrain (and perhaps the development costs of innovative vehicles designed specifically to run on hydrogen) have by far the largest influence on any evaluation of economic efficiency which includes hydrogen applications. The costs for the powertrain still have to be significantly reduced, but this is considered feasible by HyWays' automobile partners.
- All the results of the infrastructure analysis are very sensitive with regard to primary energy prices, which make up the main cost fraction (production costs constitute approx. 60 to 70 % of the infrastructure costs and primary energy prices alone 70 to 90 % of these).

Role of feedstock and production technologies

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- **In the first phase of infrastructure construction, the following appear to play a significant role:**
  - Hydrogen occurring as a by-product in the chemical industry (e. g. in chlor-alkali electrolysis), for which questions concerning the potential and the purity of the hydrogen still have to be answered among others,
  - hydrogen from the steam reforming of natural gas in decentralised installations at the filling stations which must take into account licensing questions, the required building space and local emissions, and
  - possibly hydrogen from electrolyzers at the filling station (due to the electricity prices currently a comparatively expensive way of producing hydrogen, but with advantages such as the use of renewable electricity).
- **Once full commercialisation is achieved, central plants could increasingly gain market shares**
  - In some countries it could be coal gasification provided that CO_2 separation and storage prove to be economically feasible and there are no barriers such as acceptance problems among residents, and
  - In others it could by nuclear (some questions regarding barriers)

Overview of Member States Pathway Selection

Chain (fossil pathways mostly with CCS; stationary and CGH2 truck pathways not shown)	DE	ES[1]	FR	FI[1]	GR	IT	NO[1]	NL	PL	UK[1]
NG – pipeline – central SMR – H_2-pipeline – CGH_2 fuelling station[2]	X	X	X	X	X	X	X	X	X	X
NG – pipeline – central SMR – liquefaction – LH_2 truck – $LCGH_2$ fuelling station[3]	X	X	X			X		X		X
NG – pipeline – on-site SMR – CGH_2 fuelling station[2]	X	X		X		X		X	X	X
NG – pipeline – central SMR – CCGT (Power station)						X				
NG – pipeline – central SMR – Mix NG/H_2-pipeline – CGH_2 fuelling station[2]			X		X[4]					
NG – liquefaction – LNG-ship – regional SMR – H_2-pipeline - CGH_2 fuelling station[2]		X					X			X
NG – liquefaction – LNG-ship – onsite SMR – CGH_2 fuelling station[2]		X								
El-mix – central electrolysis – H_2-pipeline – CGH_2 fuelling station[2]	X		X							
El-mix – on-site electrolysis - CGH_2 fuelling station[2]	X	X	X	X		X	X			X
Nuclear electricity – central electrolysis – liquefaction – LH2 truck – LCGH2 FS				X						
Nuclear power – HT electrolysis – H_2-pipeline – CGH_2 fuelling station[2]			X							
Nuclear power – HT nuclear thermocycles – H_2-pipeline – CGH_2 fuelling station[2]		X		X					X	X
Offshore-wind-El - central electrolysis – pipeline - CGH_2 fuelling station[2]	X	X						X		X
Offshore-wind-El - on-site electrolysis – CGH_2 fuelling station[2]	X		X	X		X	X		X	
Onshore-wind – central electrolysis - H_2-pipeline – CGH_2 fuelling station[2]		X			X					
Onshore-wind – on-site-electrolysis - CGH_2 fuelling station[2]	X	X			X		X		X	
Biomass (farmed/residual/waste wood) – gasification – H_2-pipeline – CGH_2 fuelling station[2]	X	X		X	X		X	X	X	X
Biomass (farmed/residual/waste wood) – decentral gasification – CGH_2 fuelling station[2]			X			X				
Municipal waste – onsite gasification – CGH_2 fuelling station[2]						X				
Solar –thermal HT conversion – H_2 pipeline - CGH_2 fuelling station[2]		X								X
H_2-by-product – pipeline - CGH_2 fuelling station[2] (Poland: large-scale coke-oven gas)	X	X	X				X		X	X
Hard-coal – gasification – liquefaction – LH_2 truck – $LCGH_2$ fuelling station[3]	X			X						X
Hard-coal – gasification – H_2 pipeline – CGH_2 fuelling station[2]	X	X		X	X	X		X	X	X
Hard-coal – in-situ gasification – H_2 pipeline - CGH_2 fuelling station[2] (only Poland)									X	
Lignite – gasification – pipeline/liquefaction – (L)CGH_2 fuelling station[2] (only Poland)									X	

1) Spain, Finland, Norway and UK have also CGH_2 truck delivery pathways. These are not shown here for simplicity

2) CGH_2 re-fuelling station: can refill ICE or FC cars and buses with CGH_2, can also be replaced by or combined with local micro-grid to supply stationary users such as fuel cells

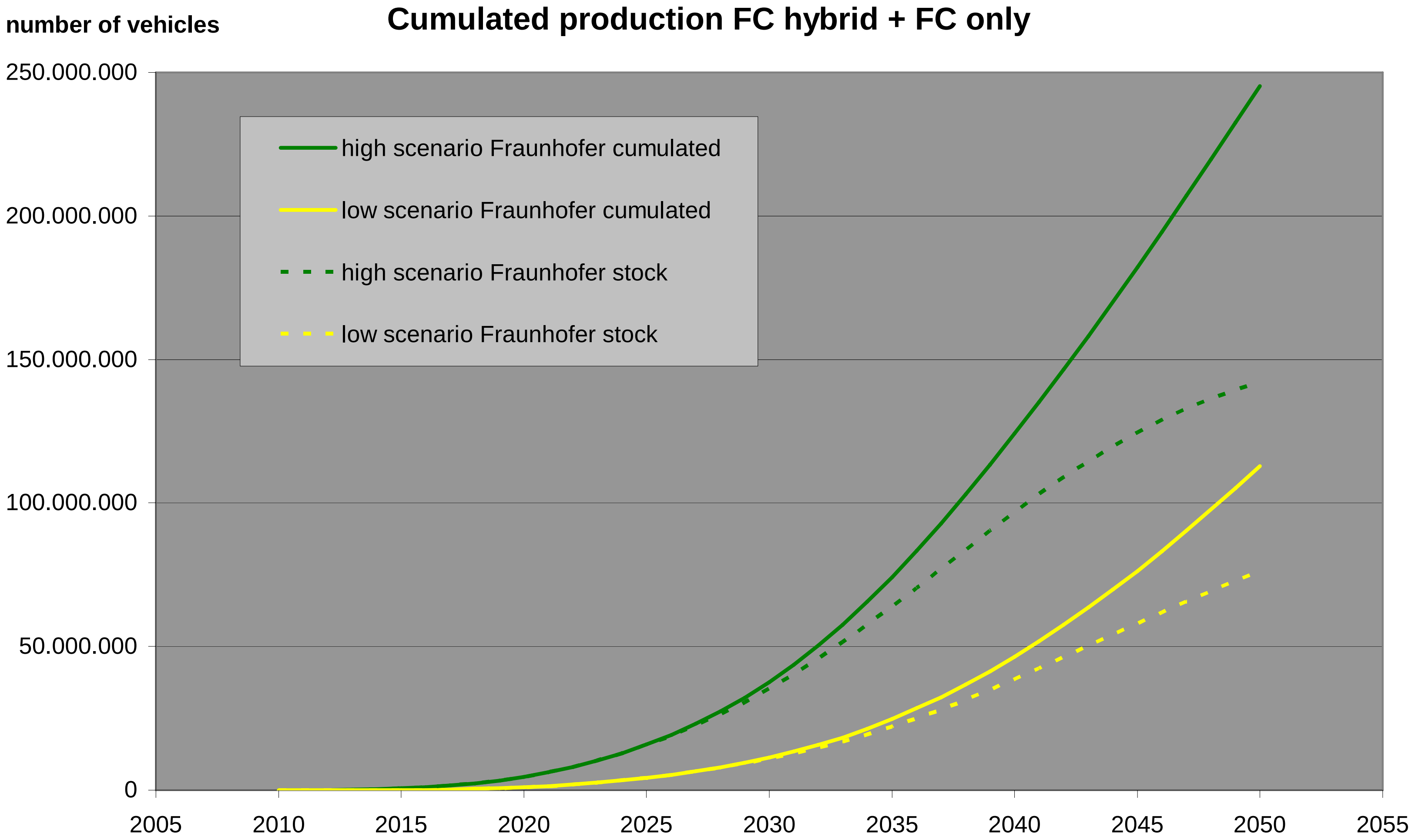
3) $LCGH_2$ re-fuelling station: can refill ICE or FC cars and buses with LH_2 or CGH_2, can also supply stationary users after gasification

4) For Greece, a mix stream NG-GH_2 is thought to be used only in stationary applications (boiler). This chain has been selected as a possibility, but it is probably not a part of the vision for Greece (and Europe).

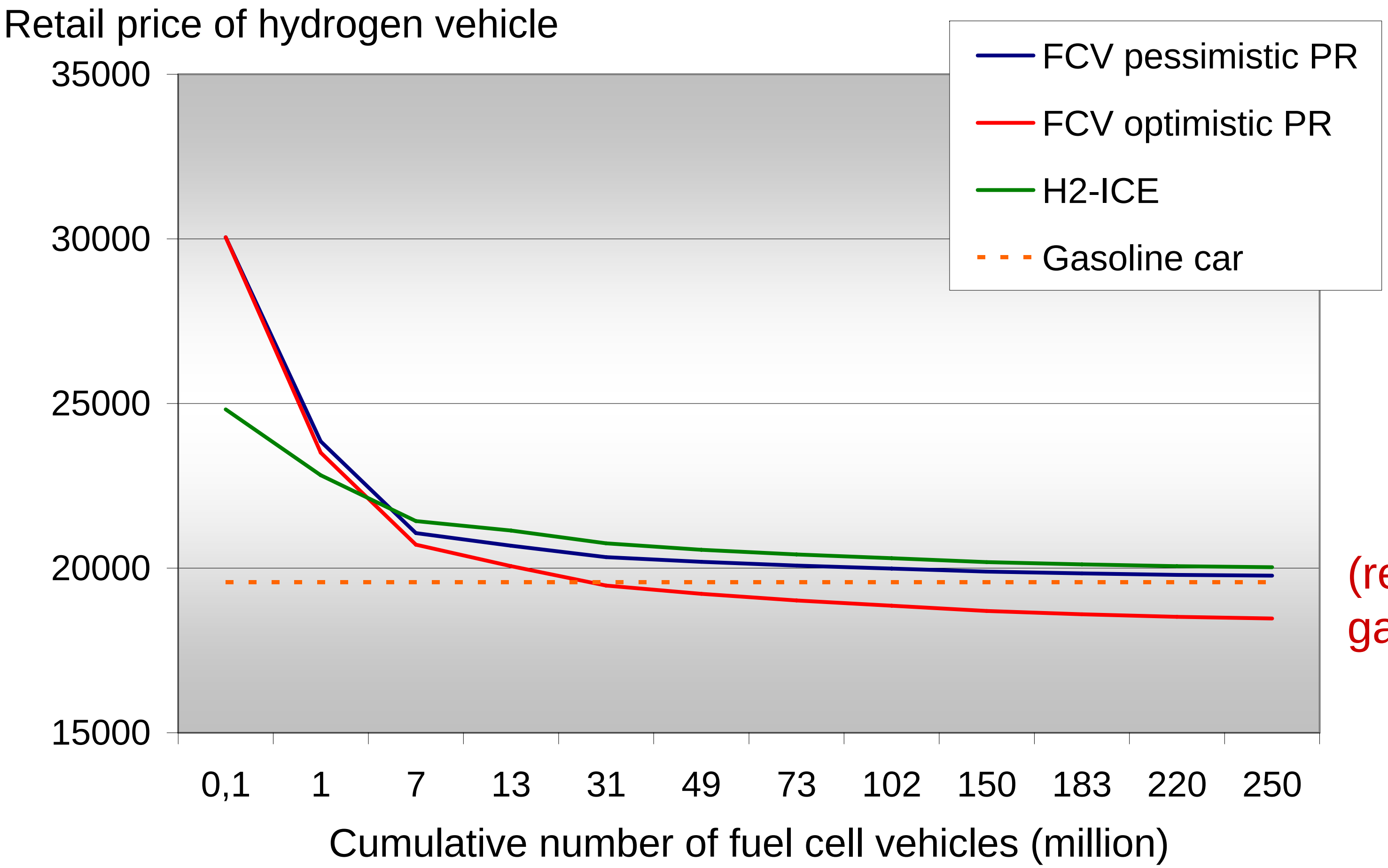
Chains added in Phase II are marked in red

Production curve of FC cars

HyWays



Cost reduction of hydrogen cars (only medium class cars) shown for two progress ratio scenarios

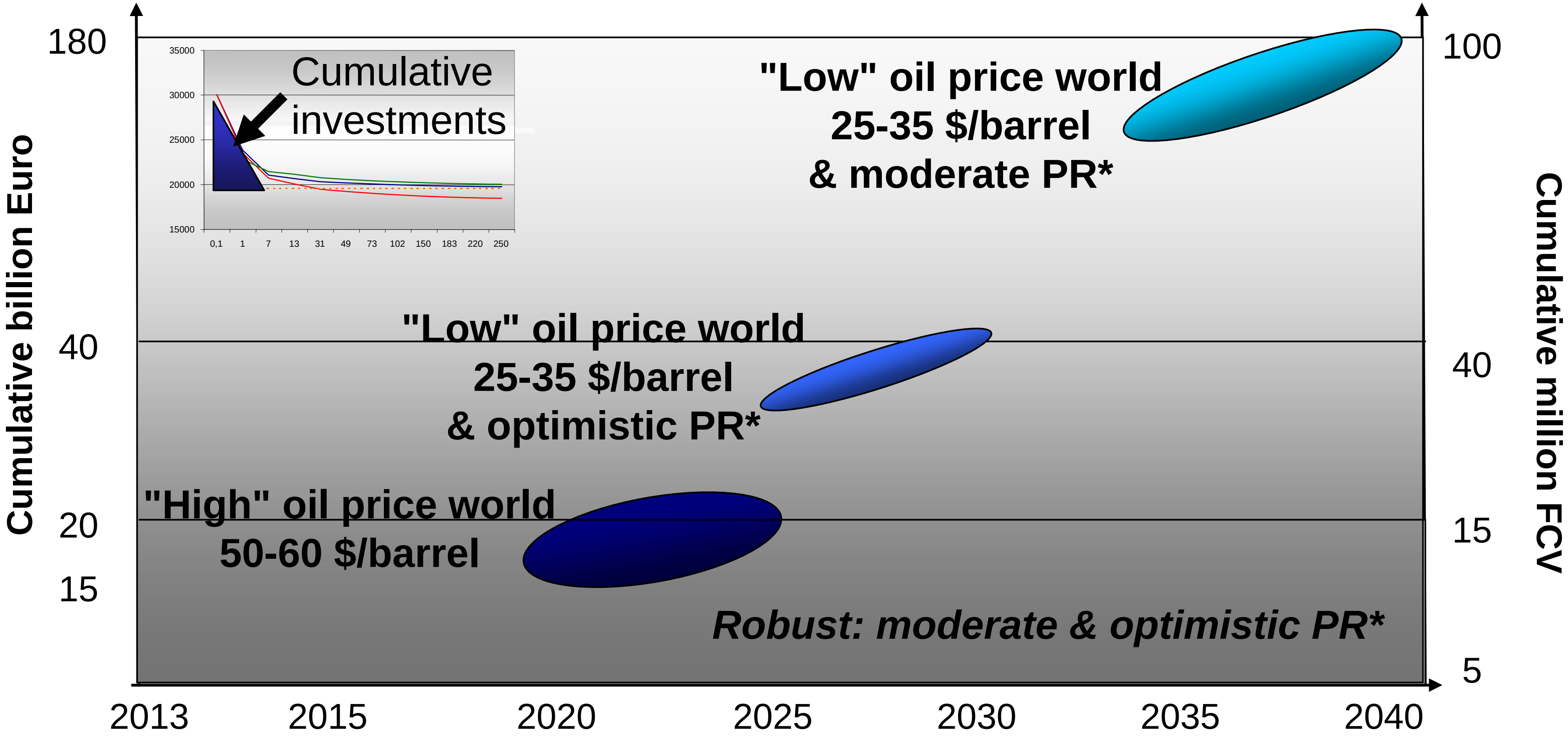


(reference is 2010 gasoline car)

Accumulated investments in hydrogen vehicles and number of cars until cost-competitiveness of FCV is reached

HyWays

Cumulative investments and car numbers to reach competitiveness of FCVs (global, assuming mass production)



* **PR** = **P**rogress **R**atio describes the speed of cost reduction over the cumulative output (without externalities and interest rate, from the beginning of mass production {€ 10,000 more for a fuel cell car}, worldwide)

Specific additional cost and savings of a FCV compared with a conventional vehicle

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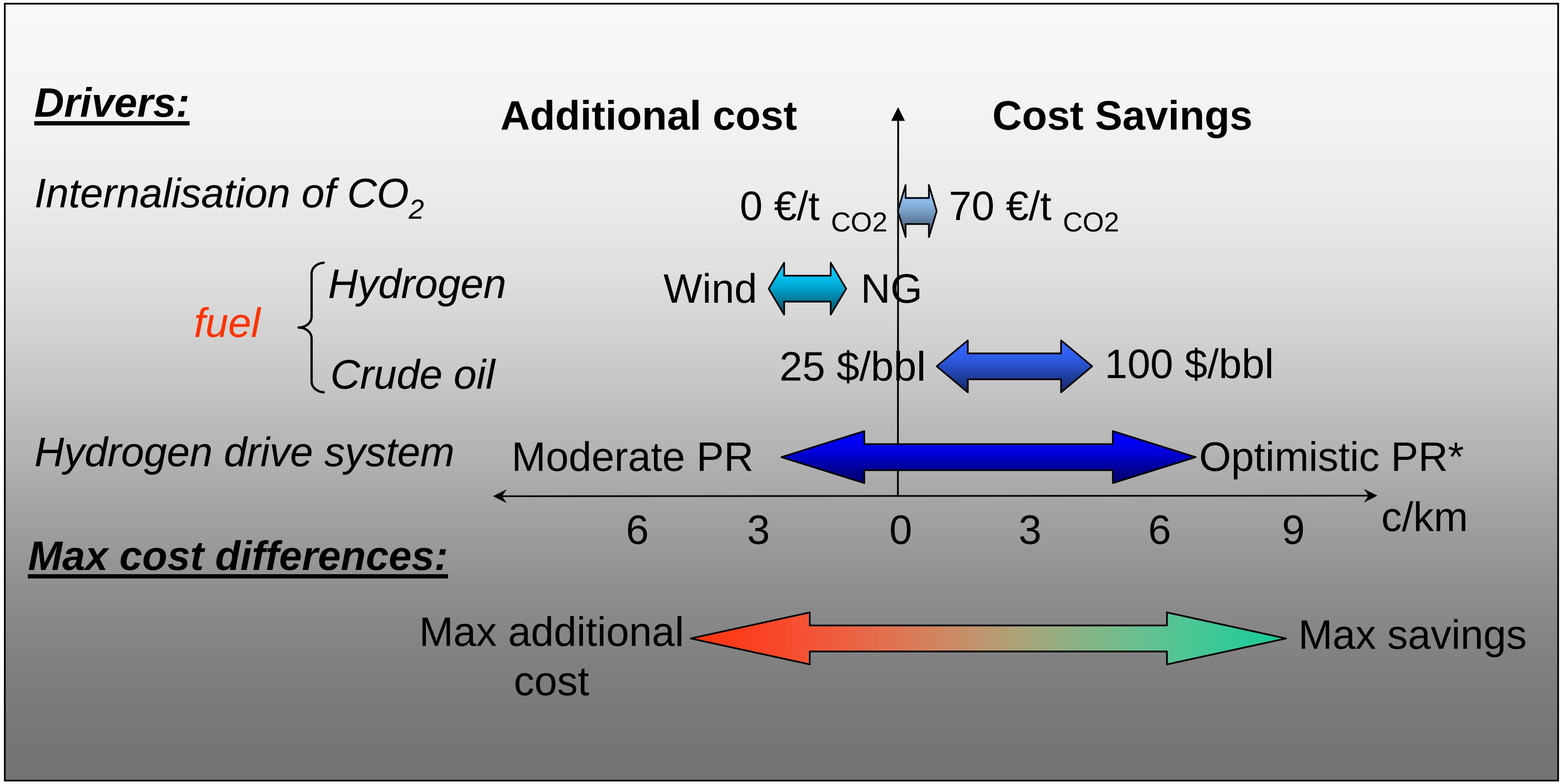
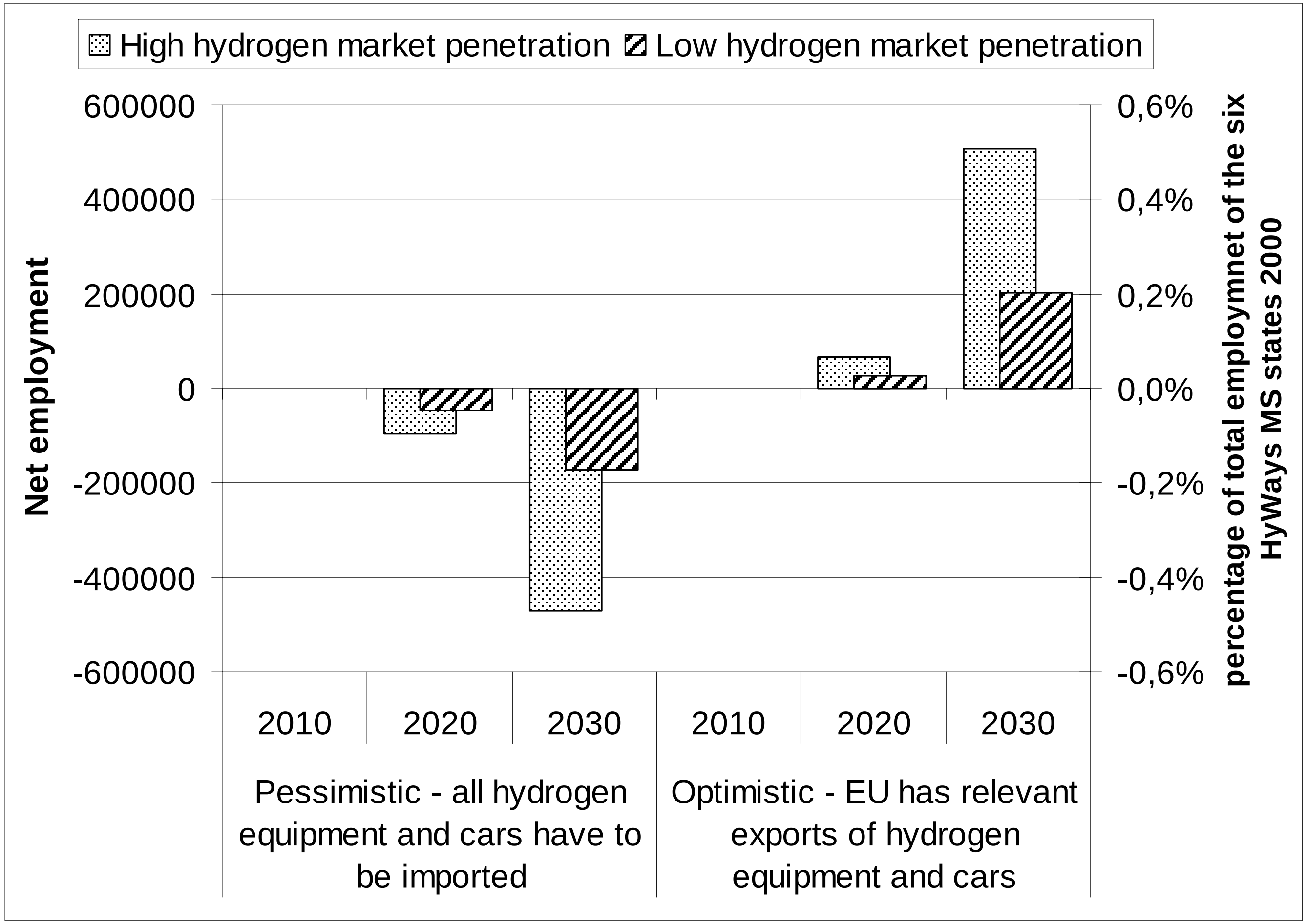
Spec. additional costs/savings of FCVs compared with conventional cars without tax



* **PR** = **P**rogress **R**atio describes the speed of cost reduction over the cumulative output

Net employment effects for two penetration scenarios (low and high) for 2010 - 2030

HyWays



Net employment effects for the "hydrogen high penetration" and "hydrogen low penetration" scenarios with high learning rates for hydrogen passenger cars for the years 2010-2030. Shown are the net employment effects for the six HyWays Phase I countries in two import/export scenarios (HyWays calculations)

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