Fuel cell electric vehicles – outlook on market potential and industry challenges

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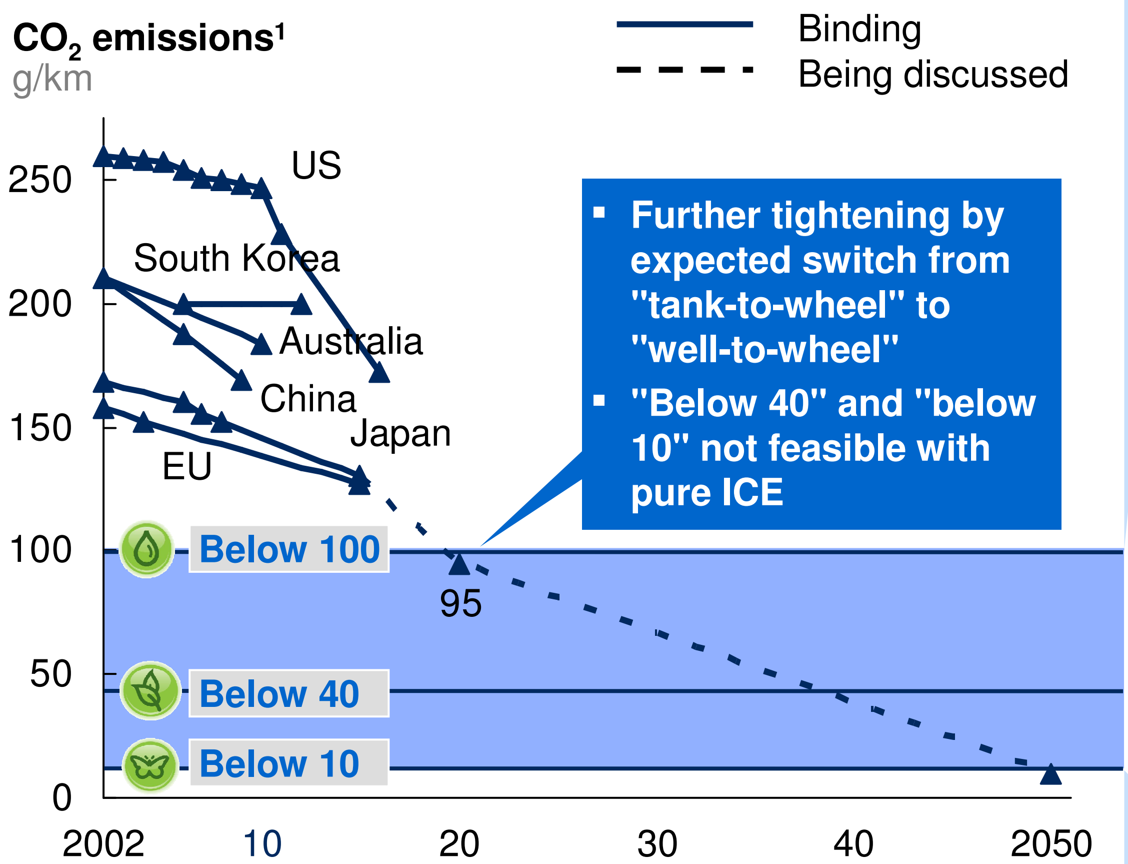
McKinsey&Company

Major driver for alternative powertrains is tightening CO_2 regulation – significant reductions announced until 2020, but uncertainty of outlook

Converging emission regulations across the globe



- Further tightening by expected switch from "tank-to-wheel" to "well-to-wheel"
- "Below 40" and "below 10" not feasible with pure ICE

- Future powertrain market penetration will be mainly driven by CO_2 regulations, TCO, and fit with customer needs
- Regional differences are projected to be substantial (e.g., speed of adoption, public incentives)
- To be in line with the "2°C global warming" target, CO_2 emission reduction to 10 g/km are required in the private road transport sector by 2050

1 Regulation under review by the European Parliament: 2015, 2020, 2025 targets will be determined by 2015

SOURCE: European Commission; McKinsey

A global industry group is evaluating the commercialization of a H_2-infrastructure and fuel cell electric vehicles

	Factual comparison of FCEV within a portfolio of power-trains	H_2 Mobility – Fact-based analysis of roll-out scenarios	H_2 Mobility infrastructure roll-out
Status	Results published Nov 2010	Ongoing	Parties to be defined (from 2011)
Objec-tive	▪ **Fact-based evaluation** of the **market potential** of **FCEV** compared to **BEV**, **PHEV**, **ICE** ▪ Development of an **integrated perspective** across the **H_2 value chain** based on **proprietary industry data**	▪ Assessment of hydrogen retail infrastructure roll-out in GER ▪ Definition of an integrated **roll-out scenario** for **FCEV** market penetration with major car OEMs	▪ Establishment of a **future consortium** for the **H_2 infrastructure** roll-out ▪ Implementation of a **business case**

27 private companies, 1 NGO, and 2 GOs across the value chain evaluated the potential of alternative power-trains for passenger cars in Europe

Core questions

- How do FCEVs, BEVs, and PHEVs compare to ICEs on
  - Cost
  - Emissions
  - Energy efficiency
  - Driving performance?
- What are viable production and supply pathways?
- What are the potential market segments for the different power-train technologies?

Approach and principles

- 3 reference car segments
- Well-to-wheel
- >10,000 company data in a "clean room" environment

Proprietary data were collected on all drive trains and at a granular level

Reference vehicle
- Small (A/B)
- Medium (C/D)
- SUV (J)

Power-trains
- ICE - gasoline
- ICE - diesel
- PHEV
- BEV
- FCEV

Evaluation criteria
- User economics
  - Total cost of ownership
  - Purchase price
  - Running cost
  - Payoff time
- Overall sustain-ability[1]
  - Production
  - Operation
  - End-of-life
- Perfor-mance
  - ...
  - ...
  - ...
  - ...

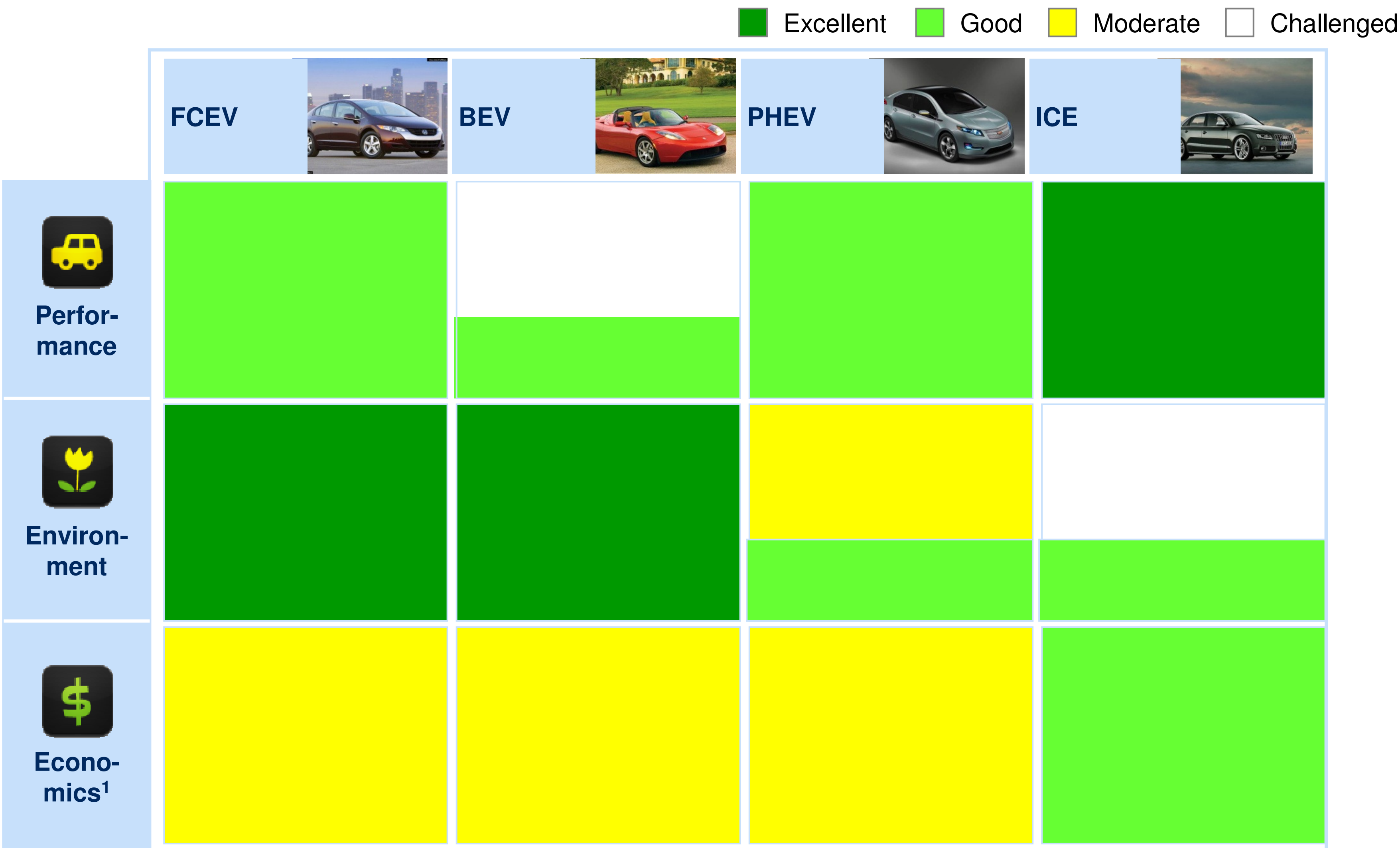
- Potential for biofuels not assessed. Biofuels are assumed to be blended up to 24% CO_2 reduction in 2050
- Power sector will gradually decarbonize from 2010 to 2050
- Oil price slowly increasing to USD 119/ bbl in 2030 (IEA)
- No taxes on purchase price and fuels, no subsidies in base case
- No cherry picking of 'best data'. Frozen input data before sharing results
- Impact of potential technology breakthroughs not included

Key insights

- Electric driving has clear benefits over the combustion engine on CO_2 and local emissions
- Within electric driving, battery electric vehicles are suited for urban driving – small cars and shorter driving ranges
- Plug in hybrids and fuel cell vehicles are suitable for medium and larger cars with higher annual driving distance
- For this segment amounting for 50% of the fleet and 70% of the CO_2 emissions, fuel cell vehicles are an attractive low carbon solution
- After 2025, the total cost of ownership of electric vehicles is comparable to ICEs
- To drive the uptake of fuel cell vehicles, significant infrastructure investments are required in the first decades (~ EUR 3 billion up to 2020)

There is not one technology outperforming others across all dimensions

C/D SEGMENT | 2030

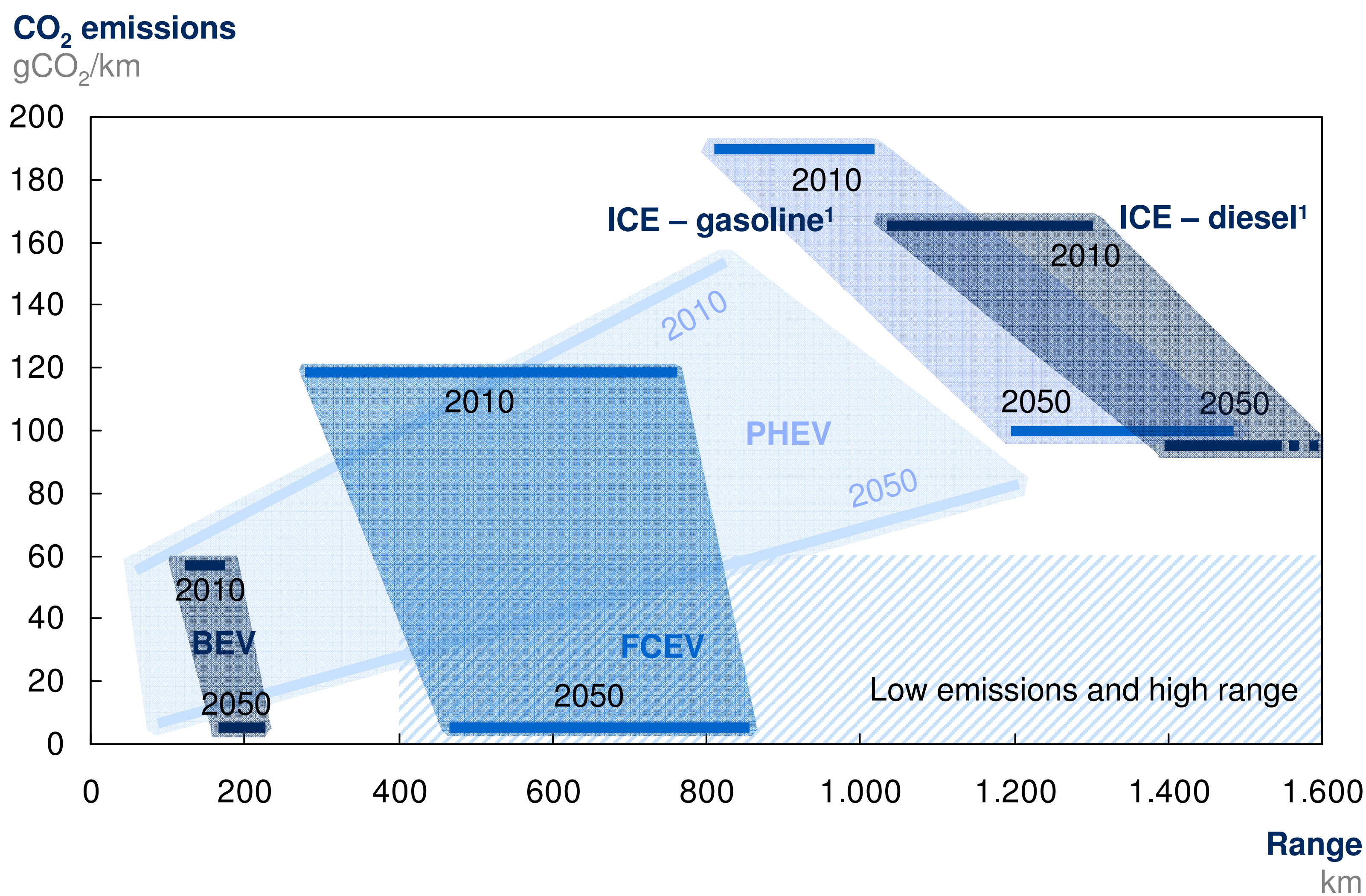


1 Consumer economics can be different, dependent on tax region
2 Fast charging for BEVs implies reduced battery lifetime, lower battery load and higher infrastructure costs than included in this study

SOURCE: Study analysis

BEVs and FCEVs can achieve significantly low CO_2 emissions, with BEVs showing limitations in driving range

C/D SEGMENT

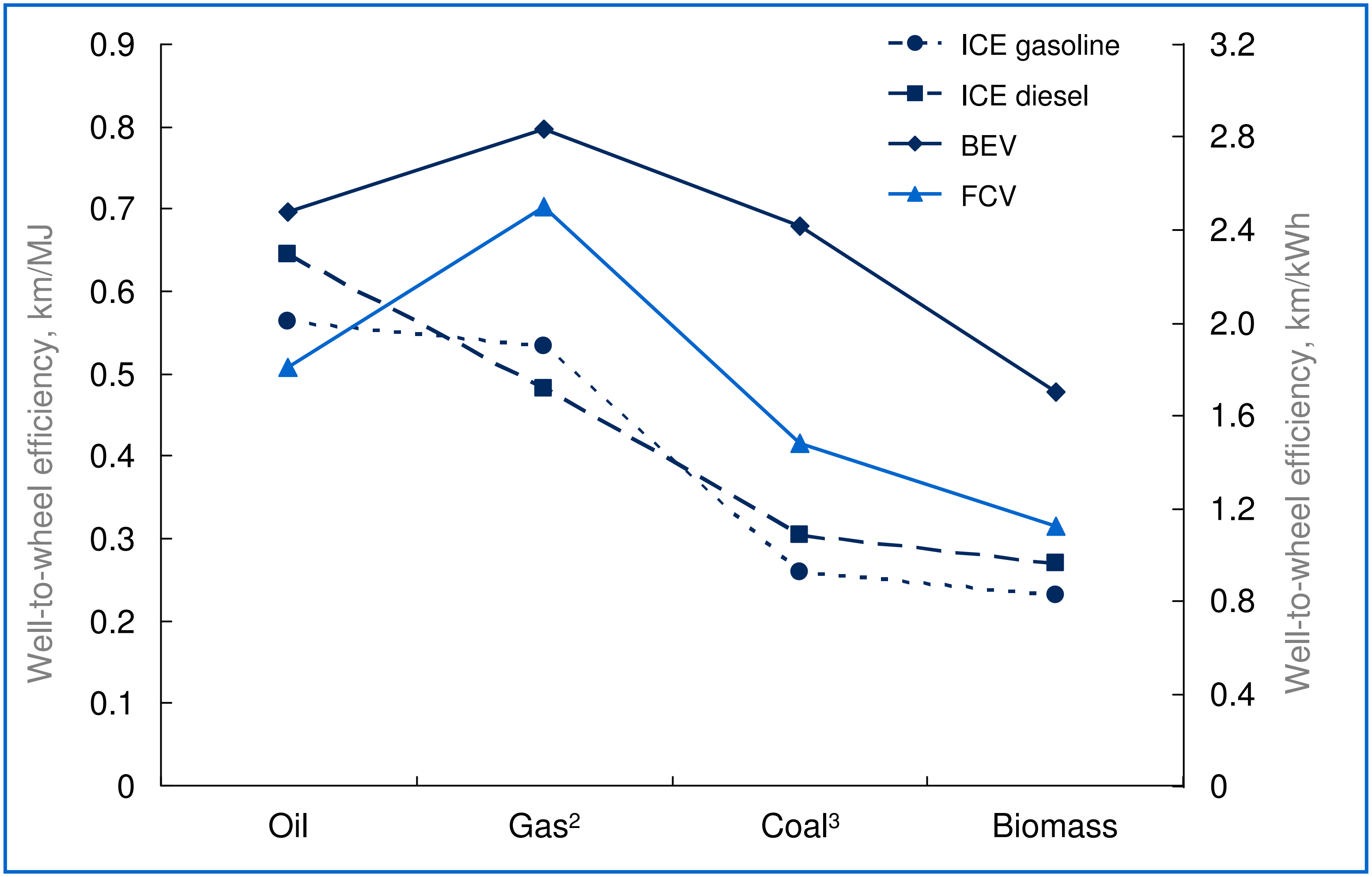


1 ICE range for 2050 based on fuel economy improvement and assuming tank size stays constant. Assuming 6% CO2 reduction due to biofuels by 2020; 24% by 2050

SOURCE: Study analysis

Electric vehicles are more energy efficient than ICEs over a broader range of feedstocks

2020

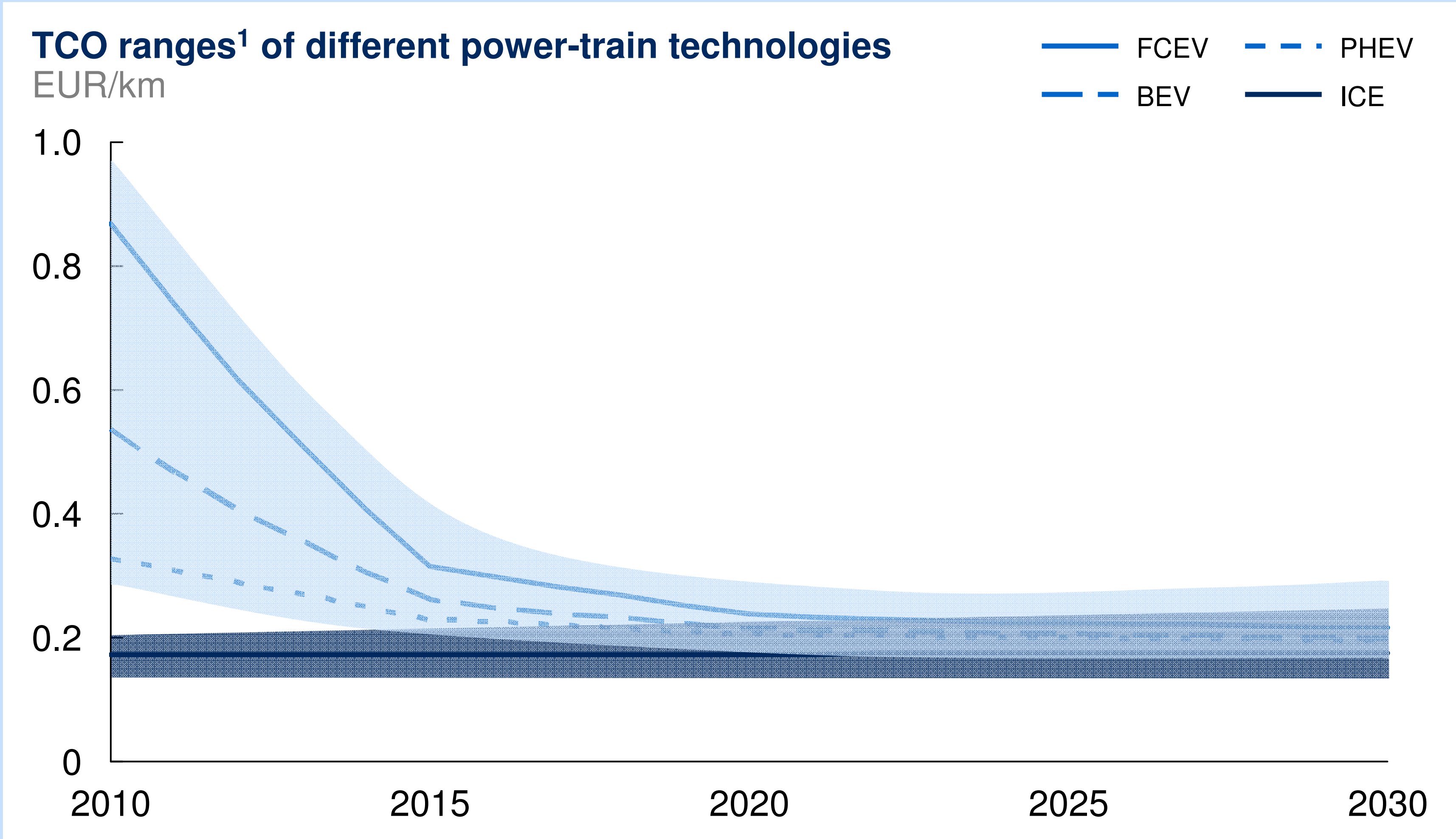


1 All power-trains have different performance criteria and therefore different driving missions
2 CNG used in gasoline ICE; diesel production from natural gas through Fischer-Tropsch process
3 Gasoline and diesel production from coal-to-liquids transformation through Fischer-Tropsch process

SOURCE: CONCAWE-EUCAR JEC-WTW study; study analysis

After 2025, the TCO of all powertrains converge

C/D SEGMENT

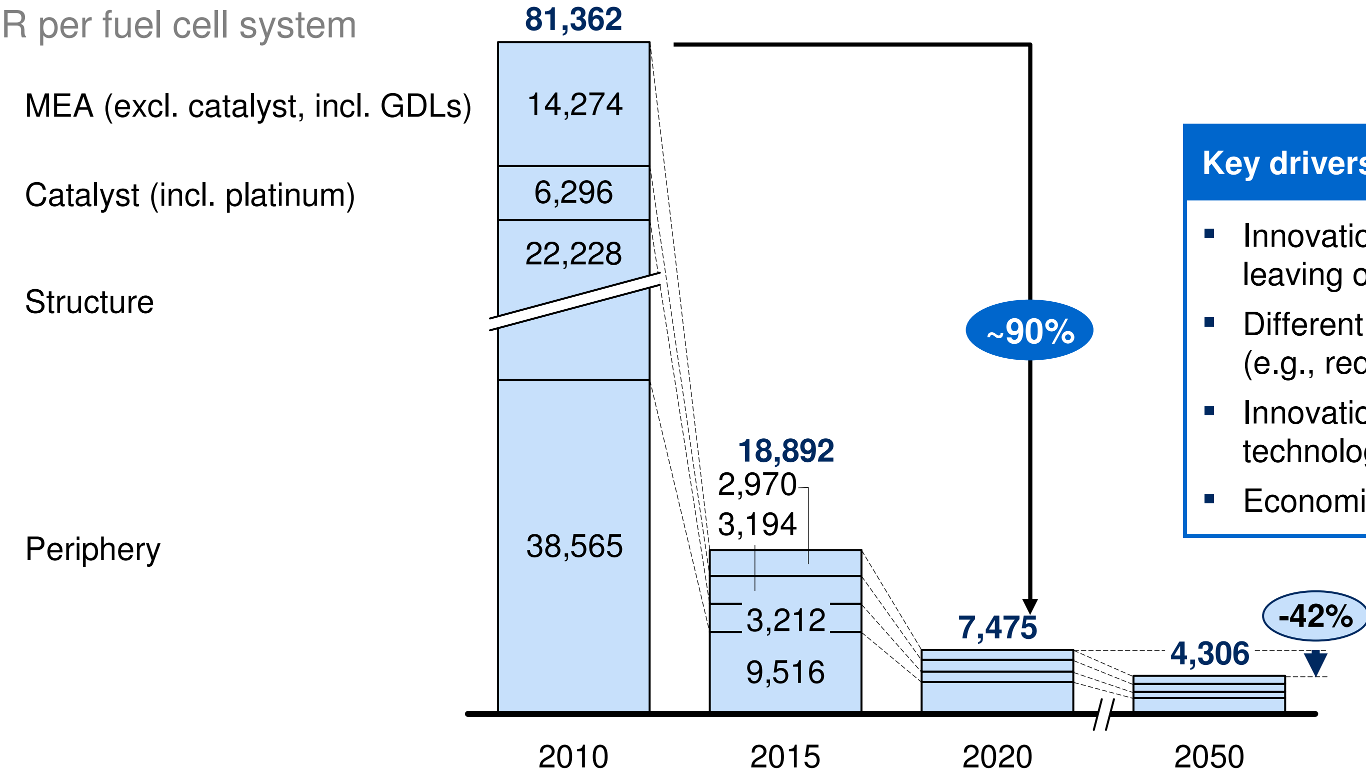


1 Ranges based on data variance and sensitivities (fossil fuel prices varied by +/- 50%; learning rates varied by +/- 50%)

SOURCE: Study analysis

The cost of a fuel cell system is expected to reduce by 90% by 2020 (80% for BEV-specific parts incl. battery and e-motor)

EUR per fuel cell system



Key drivers for cost reduction

- Innovations in design (e.g., leaving out components)
- Different use of materials (e.g., reduced platinum use)
- Innovations in production technology
- Economies of scale

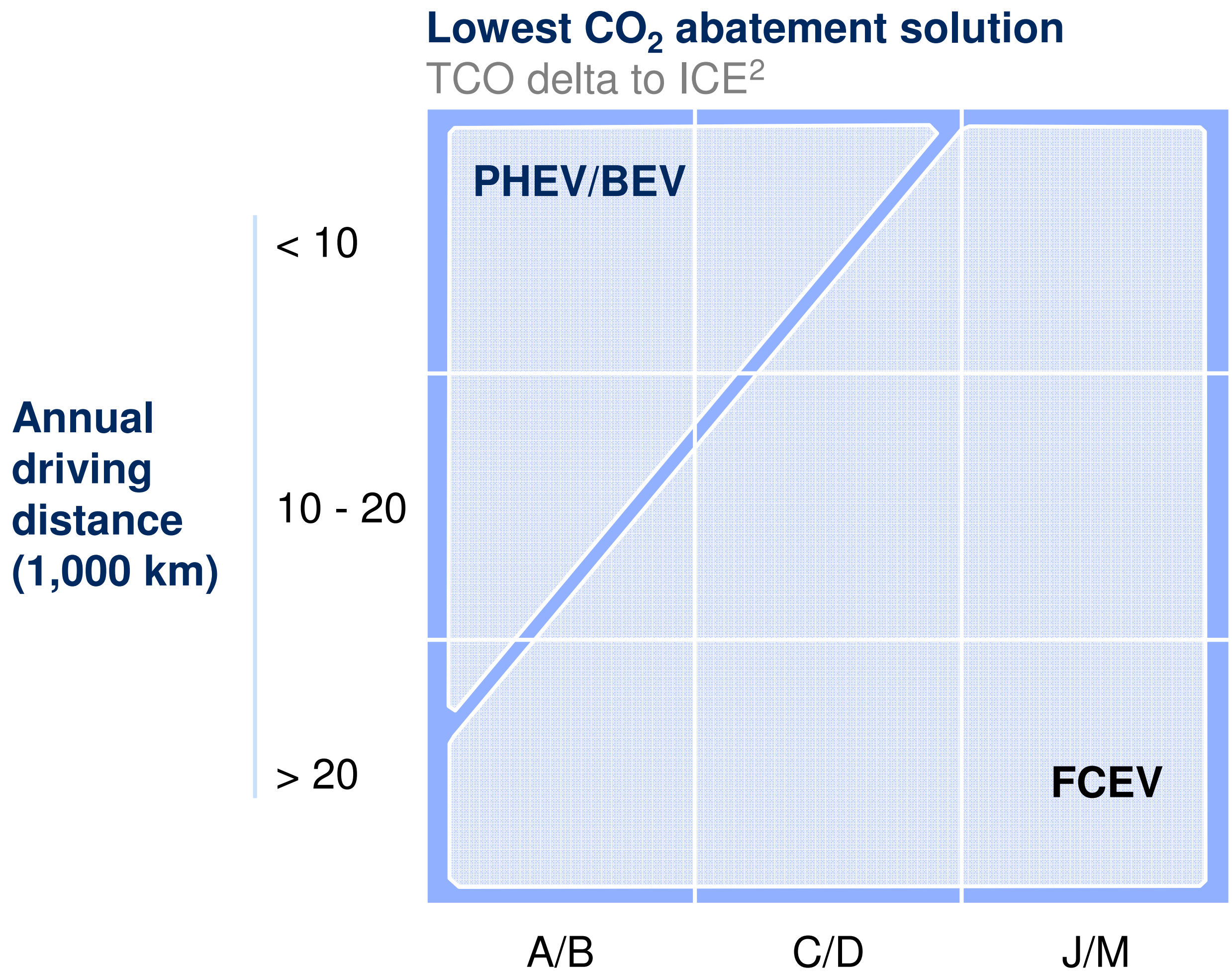
	2010	2015	2020	2050
FC stack lifetime '000 km	115	180	247	290
Platinum use g/kW	0.93	0.44	0.24	0.11
Ø Fuel cell stack cost EUR/kW	500	110	43	
Min	221	42	16	
Max	781	252	98	

SOURCE: Study analysis

In the long run, FCEVs have a TCO advantage over BEVs and PHEVs in the larger car/long distance segments

2050

EUR/year/car[1], assuming no cost of CO_2



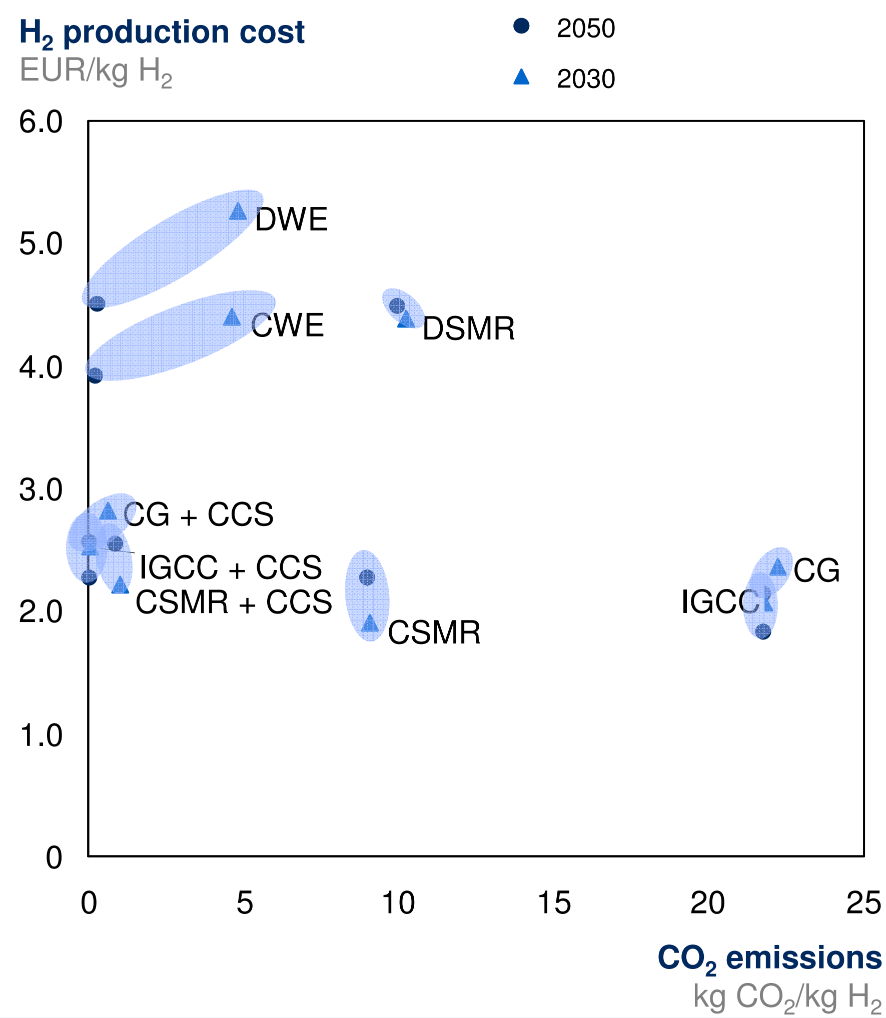
1 Constant lifetime, but different total driving distances (90,000 km; 180,000 km; 360,000 km)
2 Calculated as ICE TCO minus lowest FCEV/BEV/PHEV TCO. Negative numbers indicate a TCO advantage over the ICE

SOURCE: Study analysis

Cost of H2 production and supply differ significantly by technology, in the base case a 70% reduction is projected by 2025

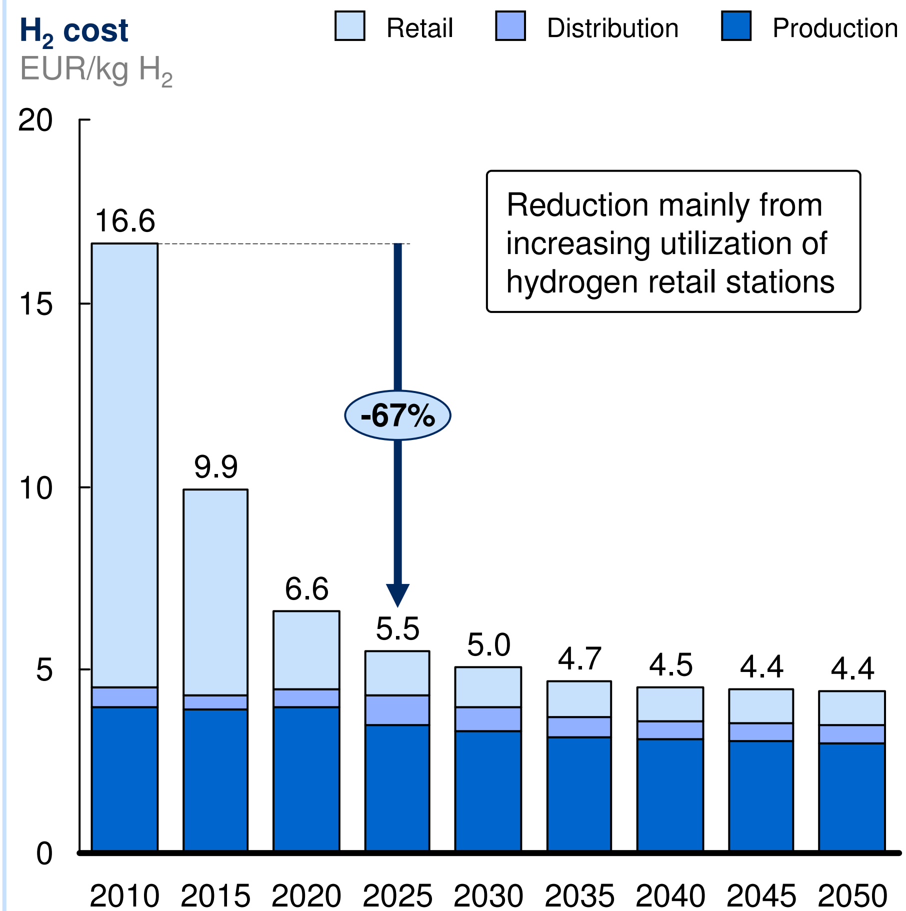
H_2 production methods

Examples



Hydrogen cost in base case (balanced mix)

EUR per kg, delivered at pump, w/o taxes/excises

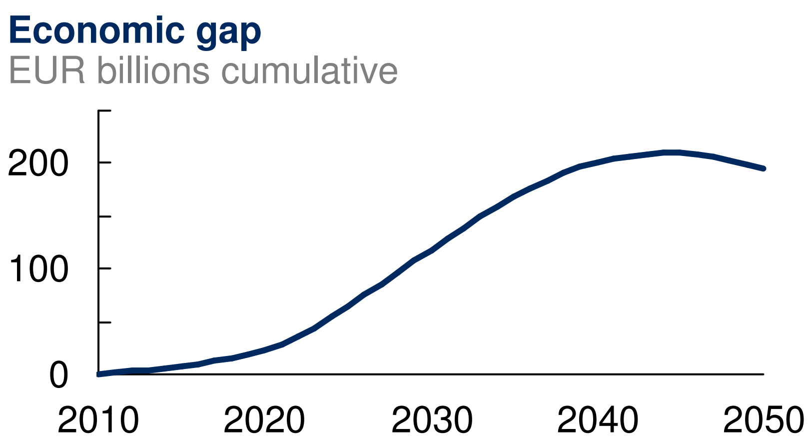


SOURCE: Study analysis

Economic gap and infrastructure buildup require new business and funding models

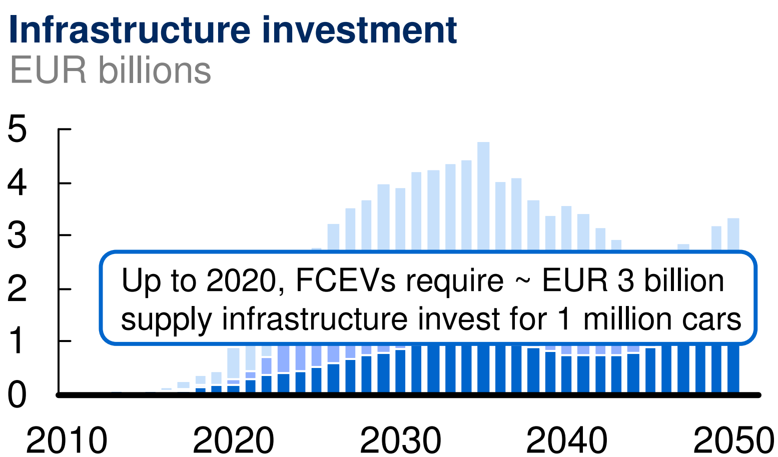
25% FCEV SCENARIO

Economic gap



- Significant economic gap in the early ramp-up phase
- Gap needs to be absorbed by all stakeholders
  - Customer (price premium)
  - OEMs (investment)
  - Infrastructure industry (investment)
  - Public/regulator (taxes, subsidies, incentives)

Investment challenge



- Significant infrastructure investment required (underutilized in ramp-up)
- Industry groups with different risk profiles
- Synchronization of industry investments required
- Investments need require new integrated business models

1 E.g., selling an FCEV below its cost

H_2 Mobility is a second step in evaluating the commercialization of a hydrogen infrastructure and fuel cell electric vehicles

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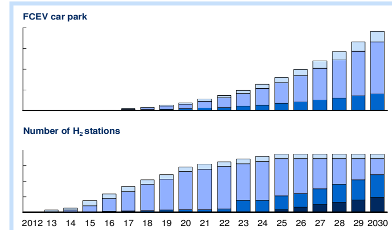
Main achievements and selected end products for pilot market Germany - intermediate results

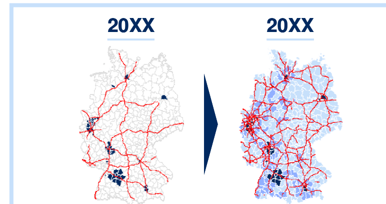
Roll-out scenarios for H_2 station network and FCEVs

- Development of **FCEV roll-out** scenarios with car OEMs via "clean team" based on assumptions (e.g., incentives, market environment)
- Assessment of **H_2 station rollout** and network requirements (e.g., density, sizes)



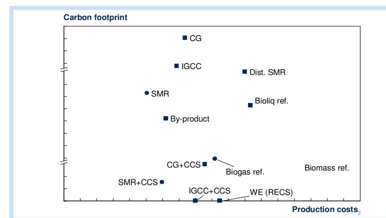
Roll out regions and timing

- Analyses of German **regions** on traffic density, income per capita, car registrations, etc.
- Definition of **"focus regions"** and connecting highways



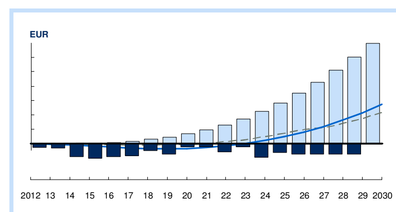
H_2 production and supply road map

- Assessment of **H_2 production technologies** on cost and CO_2 emissions (water electrolysis, steam methane reforming, etc.)
- Definition of H_2 **production and supply mixes** focusing on CO_2 abatement, sustainability, and economic efficiency



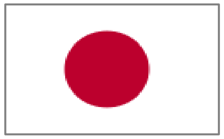
Holistic roll-out cases

- Description of consistent **rollout case** for Germany
- **Financial assessment** of roll-out cases including NPV, investment, payback time
- Evaluation of **risks** and **sensitivities**

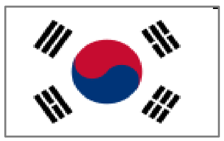


High momentum of H_2 Mobility-related initiatives in other countries

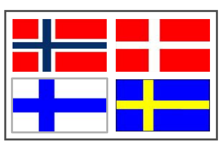
Overview of selected countries



- Announcement by **13 companies** (3 OEMs and 10 energy and infrastructure providers) and the Ministry of Transport to commercialize FCEV
  - Mass production of **FCEV by 2015**
  - **100 HRS operational** in 4 four metropolitan areas and connecting highways planned, **1,000 HRS** in 2020, and **5,000 HRS** in 2030



- South Korea laid out **"Green Car Roadmap"** including action for EV, PHEV, HEV, FCEV, and bio diesel
- Plans to have **168 HRS** and **100,000 FCEV** deployed **by 2020**
- Announced **government support** for **EV** of **up to EUR 20,000** in rebates, tax exemptions, and bonus/malus
- Incentives for **FCEV** will be defined later but are **expected to be comparable** to EV



- Hyundai-Kia signed **MOU** with four **Scandinavian countries** (Norway, Sweden, Denmark and Iceland) for the provisional distribution of FCEV
- FCEV will be used to complement the **Scandinavian Hydrogen Highway Partnership (SHHP) fleet** of 26 FCEV and to be increased to 46 in 2011
- SHHP also plans to **increase number of HRS** from 7 to 15 by 2015

SOURCE: METI; Government of South Korea; DoE