# DOE Hydrogen and Fuel Cell Technical Advisory Committee

# McKinsey Report Overview – Process & Outcomes

February 18, 2011

Dennis Hayter
Vice President, Business Development

# Background: Intelligent Energy

- A **clean power systems** company with **globally scalable** business with operating bases in the UK and US (CA)
- Creating bespoke power systems for OEMs and their **global mass markets** from our proprietary "clean engine building blocks"
- **Fuel cells:** proprietary PEM fuel cells that are versatile, robust, efficient, compact, power-dense and designed from inception for **low cost**, **high volume manufacturing**
- **Smart power management software:** we have important integration, balance of plant and systems capabilities for technology insertion, hybridisation and Smart Grids
- **History**:
  - Formed in 2001 but with over a 20 year history of fuel cell innovation
  - First UK PEM fuel cells built at Loughborough University
  - First UK company established specifically to commercialise PEM fuel cells – Advanced Power Sources Ltd in 1995
  - Circa 180 staff, HQ in Loughborough (UK), facility in Long Beach (US).
  - Commercial offices in Osaka (Japan), Bangalore (India) and London (UK)



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# Background: Intelligent Energy Activities

**BOEING**

World's first manned flight in H2 fuel cell propelled aircraft, Feb 2008

**LOTUS**

IE 30kW powered taxi outperforms diesel performance, Jul 2010

**SUZUKI**

World's first H2 fuel cell motor bikes, first unveiled in 2005

**AIRBUS**

Opening of IE's 30kW APU (multi-functional power system) test rig in Airbus Hamburg, Aug 2009

**PSA PEUGEOT CITROËN**

10kW FC Hybrid delivery vehicle with 300km range, -20/+40ºC 3min refuel, no loss of capacity

Defence Systems Co

UAV and Dis-mounted soldier applications

**Scottish and Southern Energy**

Commercial (10-20kW) and residential (0.5-2kW) CHP JV formed between SSE and IE, Mar 2008

Global Consumer Electronics Co

Production fuel cell system in development step-changes battery performance for handheld electronic devices

Tier 1 Indian Telco

Backup power systems that deliver lower cost /kWh than diesel

# McKinsey framework: EU and FCH JU HFC pursuits

**WORK PROGRAMME 2011**

**COOPERATION**

**THEME 7**

**TRANSPORT (INCLUDING AERONAUTICS)**

New Energy World JTI

**FUEL CELLS AND HYDROGEN JOINT UNDERTAKING (FCH JU)**

**Multi - Annual Implementation Plan 2008 - 2013**

# McKinsey framework: EU FP6 & FP7

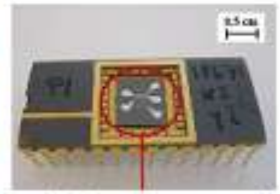
## Fuel Cell Vehicle System Component Development: EU Project HySYS (FP6)


Fuel cell vehicle (validator)


Electrical turbo charger


Integrated air sensor


Humidifier


Hydrogen sensor


Hydrogen metering device

**Coordinator:** Daimler AG
**Total budget:** 22.7 M€
**EC-Funding:** 11.2 M€
**Partners:** 28 (6 OEMs, 13 Suppliers, 4 Institutes, 5 Universities)
**Countries:** 8 EC Member States and Switzerland
**Duration:** 01.12.2005 – 30.11.2010

| Vehicle Data | |
|---|---|
| Vehicle Type | Mercedes-Benz Sprinter |
| Fuel Cell System | PEM, 80 kW |
| Engine | IPT Engine Output (Continuous/ Peak) 70kW / 100kW (136hp)<br>Max. Torque: 290 Nm |
| Fuel | Compressed Hydrogen (70 MPa / 10,000 psi) |
| Range | > 300 km |
| Top Speed | 130 km/h |
| Battery | Li-Ion, Output:40 kW ; Capacity 6.8 Ah, 1.9 kWh |


DC/DC converter


Electric motor


Li-Ion battery

**Achievements**

| Component | Result |
|---|---|
| Electrical Turbo Charger | Low weight, small size, low noise, high efficiency, high dynamics, |
| Integrated Air sensor | Automotive sensor combining pressure, temperature and mass flow |
| Humidification | Lab scale hollow fibre humidifier for air humidification |
| Hydrogen Sensors | First prototype sensors of a promising new hydrogen sensing principle |
| Hydrogen Supply | Automotive hydrogen metering device with high maturity for mass production |
| Power Electronics | Automotive inverters and DC/DC Converters with high efficiency |
| Electrical Motors | High efficient and dynamic e-motors for electric drive trains |
| Battery | High power Li-Ion Batteries |

# McKinsey framework: Multi-country regional programmes

H2moves.eu
SCANDINAVIA

**Status of the first European Lighthouse Project to demonstrate hydrogen fuel cell cars in Scandinavia**

# McKinsey framework:  Multi-country regional programmes

**NextHyLights**

**Supporting Action to Prepare Large-Scale Hydrogen Vehicle Demonstration in Europe**

**NEXTHYLIGHTS**

Preliminary inputs for MAIP revision / AIP development

# McKinsey framework: National programmes - NOW

NOW Conference: First Public Status Reports of the Electromobility Model Regions and the NIP Mobility Projects
Berlin, 09/16/2010

- "Batteries and fuel cells are key technologies of emission-free mobility of the future. With the market preparation programmes of the Electromobility Model Regions of the Federal Ministry of Transport, Building and Urban Development (BMVBS) as well as the Government's National Innovation Programme Hydrogen and Fuel Cell Technology (NIP), we are very well-positioned in Germany," said Dr. Klaus Bonhoff, …

DAIMLER Ford GM OPEL HONDA

KIA RENAULT NISSAN TOYOTA

## Letter of Understanding

## on the Development and Market Introduction of Fuel Cell Vehicles

To: Oil and Energy Companies, Government Organizations and NOW GmbH

From: Daimler, Ford, GM/Opel, Honda, Hyundai/KIA, the Alliance Renault/Nissan, Toyota

Development and Production Plan for Fuel Cell Vehicles

Based on current knowledge and subject to a variety 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 (100.000) units over life cycle on a worldwide basis.

All OEMs involved will implement their own specific production and commercial strategies and timelines, and, as a consequence, depending on various influencing factors, the commercialisation of fuel cell vehicles may occur earlier than in the above-mentioned expected year.

Press Release

**Joint Press Release of Linde, Daimler, EnBW, NOW, OMV, Shell, Total and Vattenfall**

## Initiative "H2 Mobility" – Major companies sign up to hydrogen infrastructure built-up plan in Germany

- Leading industrial companies agree upon a built-up plan for a nationwide infrastructure
- Significant expansion of hydrogen fuelling stations network by the end of 2011
- Important milestone on the way to emission-free mobility
- Leading vehicle manufacturers pursue the development and Commercialisation of electric vehicles with fuel cell. Commercialisation with several hundred thousand units anticipated from 2015 onwards

# McKinsey framework: CO2 targets

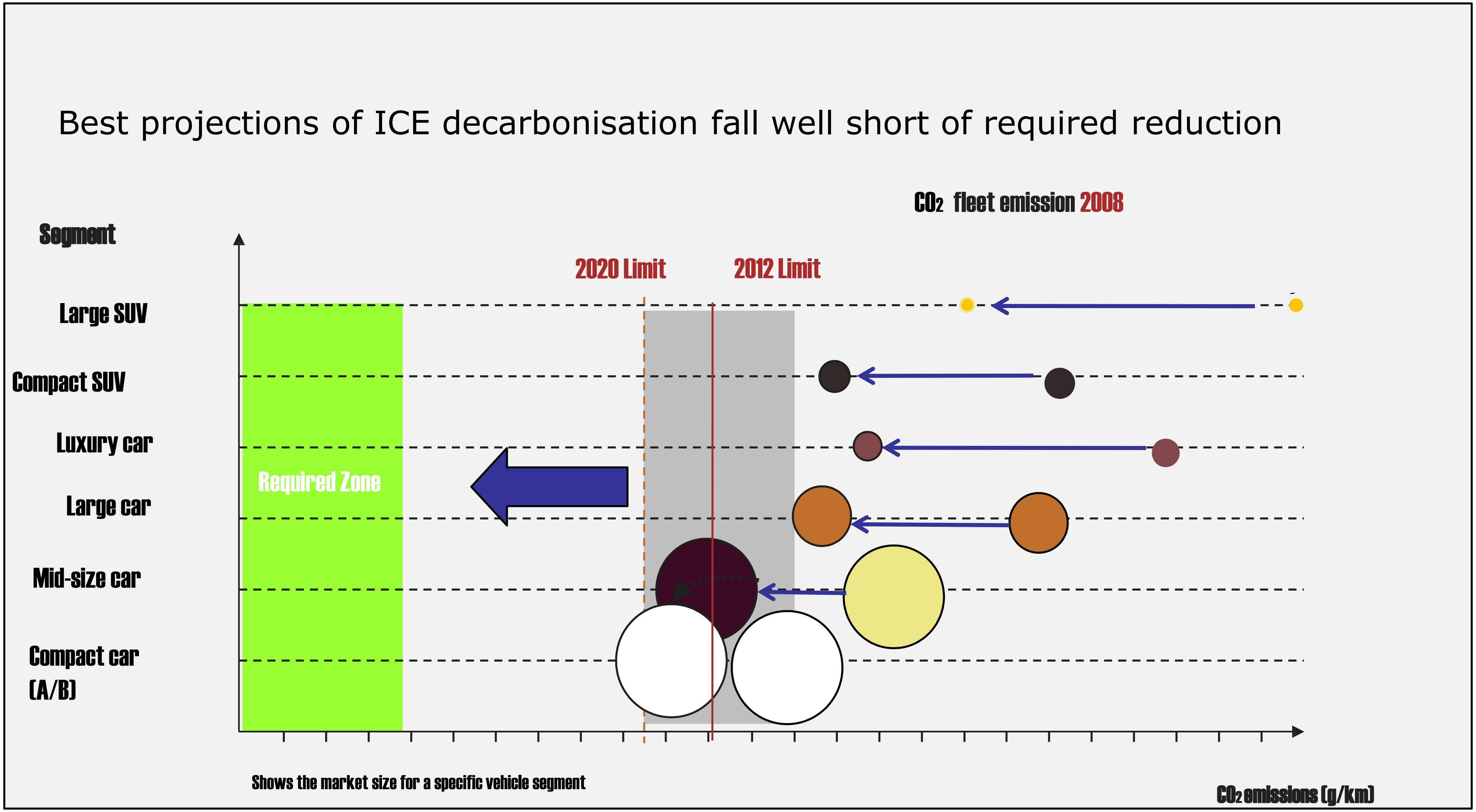
In September 2009, both the European Union (EU) and G8 leaders agreed that $CO_2$ emissions must be cut by **80%** by 2050 if atmospheric $CO_2$ is to stabilise at 550 parts per million – and global warming stay below the safe level of 2ºC.

## 80% Decarbonisation by 2050 requires 95% Decarbonisation of the road transport sector

*"Success, indeed survival, in tomorrow's automobile industry will depend on how individual auto companies meet rapidly growing worldwide concerns over environmental quality and scarce energy resources"*

**William Duncan, General Director, Japanese Auto Manufacturers Association, US**

# European $CO_2$ fleet emissions – 2008 and forecast for 2020




JD Power and RBSC forecast 2020 Source: JD Power; Roland Berger

# FC coalition McKinsey report

***Brussels, 8 November 2010* – Unprecedented study concludes that a combination of engines - battery, fuel cell and plug-in hybrid electric vehicles - is needed to reach a 95% reduction of $CO_2$ emissions of the road transport sector by 2050.**

**The study “A portfolio of power-trains for Europe: a fact-based analysis” was launched today in Brussels by a consortium of around thirty organisations including global companies across the passenger car value chain, an NGO and Government Organisations. The analysis compares the economics, sustainability and performance of four different types of vehicles in helping achieve the overall 80% decarbonisation goal by 2050 set by the European Union.**

# 27 private companies, 1 NGO, and 2 GOs across the value chain performed a fact-based analyses in a "clean room" environment

## Industry participants

| | |
|---|---|
| Car OEMs | DAIMLER, HONDA, HYUNDAI, KIA MOTORS, GM, NISSAN, Ford, RENAULT, VW, BMW, TOYOTA |
| Oil and gas | Eni, OMV, Shell, TOTAL, galp energia |
| Utilities | EnBW, VATTENFALL |
| Industrial gas companies | AIR PRODUCTS, AIR LIQUIDE, Linde |
| Equipment OEMs | INTELLIGENT ENERGY (Clean fuel and power), Powertech |
| Wind | NORDEX |
| Electrolyser companies | HYDROGENICS (Advanced Hydrogen Solutions), PROTON ENERGY SYSTEMS, ELT Elektrolyse Technik, Hydrogen Technology |
| NGOs, GOs | European Climate Foundation, NOW (Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie), New Energy World |

## Approach and principles

- All relevant powertrains (ICE, BEV, PHEV, FCEV)
- 3 reference car segments
- Cost, emissions, energy efficiency, driving performance
- Well-to-wheel
- >10,000 company data in a "clean room" environment

# FC coalition & McKinsey report - Process

- Fact based - portfolio of power trains analyses with:
    - Unprecedented scale, most accurate to date – access to over 10,000 proprietary data points
    - rigorous data collection and analysis process
    - not based on speculations
    - only based on vehicle technologies which are
        - proven and demonstrated today, thus capable to scale-up for a commercial deployment
        - capable of meeting the EU's 2050 $CO_2$ reduction goal for 2050
- Based on granular and proprietary data provided by key industry players
- True comparison of all the power-trains with all underlying assumptions clearly stated
- No cherry picking of most favourable data and conclusion based on average data
- To avoid bias towards any particular power train, balanced mix of car sizes
- When all output data signed off it was 'frozen' and only then analysis of the power-trains began

# Data collected on all drive trains at a highly granular level

| Reference vehicle | Power-trains | Evaluation criteria | |
|---|---|---|---|
| Small (A/B) | ICE - gasoline | User economics | Total cost of ownership |
| | | | Purchase price |
| | ICE - diesel | | Running cost |
| | | | Payoff time |
| Medium (C/D) | PHEV | Overall sustain-ability1 | Production |
| | | | Operation |
| | BEV | | End-of-life |
| SUV (J) | FCEV | Perfor-mance | ... |
| | | | ... |
| | | | ... |
| | | | ... |

- 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 $119/bbl in 2030 (IEA)
- No taxes on purchase price and fuels, no subsidies in base case
- Like for like evaluation of different power trains, no cherry picking of 'best data'. Frozen input data before sharing results
- Impact of potential technology breakthroughs not included
- Industry consensus through "clean room" environment based on more than 10,000 data points

# FC coalition & McKinsey report - Process

- Over 30 “stakeholders” came together to develop a factual evaluation of the economics, sustainability and performance of the drive trains

  - Many stakeholders having an equal interest in all four power-trains, namely, ICE, BEV, PHEV, FCEV

- Results of the study take into account significant improvement in fuel economy of ICEs by 2020

- Assumption robust to significant variations … in cost reduction rates and cost of fossil fuels

- Different scenarios (not forecasts) were considered with different “worlds”
E.g. only 5% penetration rates for FCEVs might be expected to be uncompetitive but this is not the case (5% to 25% increase yields a 7.3% increase in total cost of ownership for a C/D – Golf type car)

- So even with variations of +/-50% in oil prices and cost reduction rates, by 2030, there is only a small difference of -1 to +3 EURO cents per km based on a pre-tax cost of 18 cents per km

# FC coalition & McKinsey report - Process

Energy Mix:

- Electric vehicles (BEV, FCEV and PHEV in electric drive) can be fuelled by variety of primary energy sources

- Reducing oil dependency and enhancing security of energy supply – energy diversity is energy security

- A balanced production mix for hydrogen from different sources using different technologies is assumed which is robust to energy shocks

- Hydrogen can be produced, distributed and retailed cost effectively by 2020 from a variety of feedstocks to suit local market conditions
(but even with a full renewable only mix, increases the total cost of ownership by circa 5% for a C/D – Golf type car)

- Some of the technologies such as water electrolysis and IGCC could provide a key role in supporting the electricity grid and provide a load balancing service increasingly demanded by electricity grids which include high percentages of renewable generation

# FC coalition & McKinsey report

Technology improvement:

- Whilst ICE still have 30% further to improve, electric vehicles (BEV, FCEV and PHEV in electric drive) have the potential to significantly reduce CO2 and local emissions

- Battery electric vehicles, given their limited energy storage capacity, shorter driving range (150-250km range in the medium term; or by 2020 150km trip at 120km/h constant speed – all for C/D type- Golf car) and relatively long recharging times are ideal for smaller cars and shorter trips – i.e. urban driving

- Plug-in hybrids are a good transition technology combining the battery electric benefits for short distances with the traditional combustion engine characteristics for long distant driving and where sustainably produced biofuels are available.

- Fuel cell electric vehicles have a driving range and performance comparable to internal combustion engines are the lowest-carbon solution for long distance driving and family-size cars which represent 50% of all cars and 75% of all emissions.

- FCEVs are therefore effective low-carbon solution for a large proportion of the car fleet and have clear benefits in a CO2 constrained world.

# FC coalition & McKinsey report

Fuelling:

• Several infrastructure systems are required such as those for BEVs, PHEVs and ICE (CNG, LPG, biofuels) as well as FCEVs

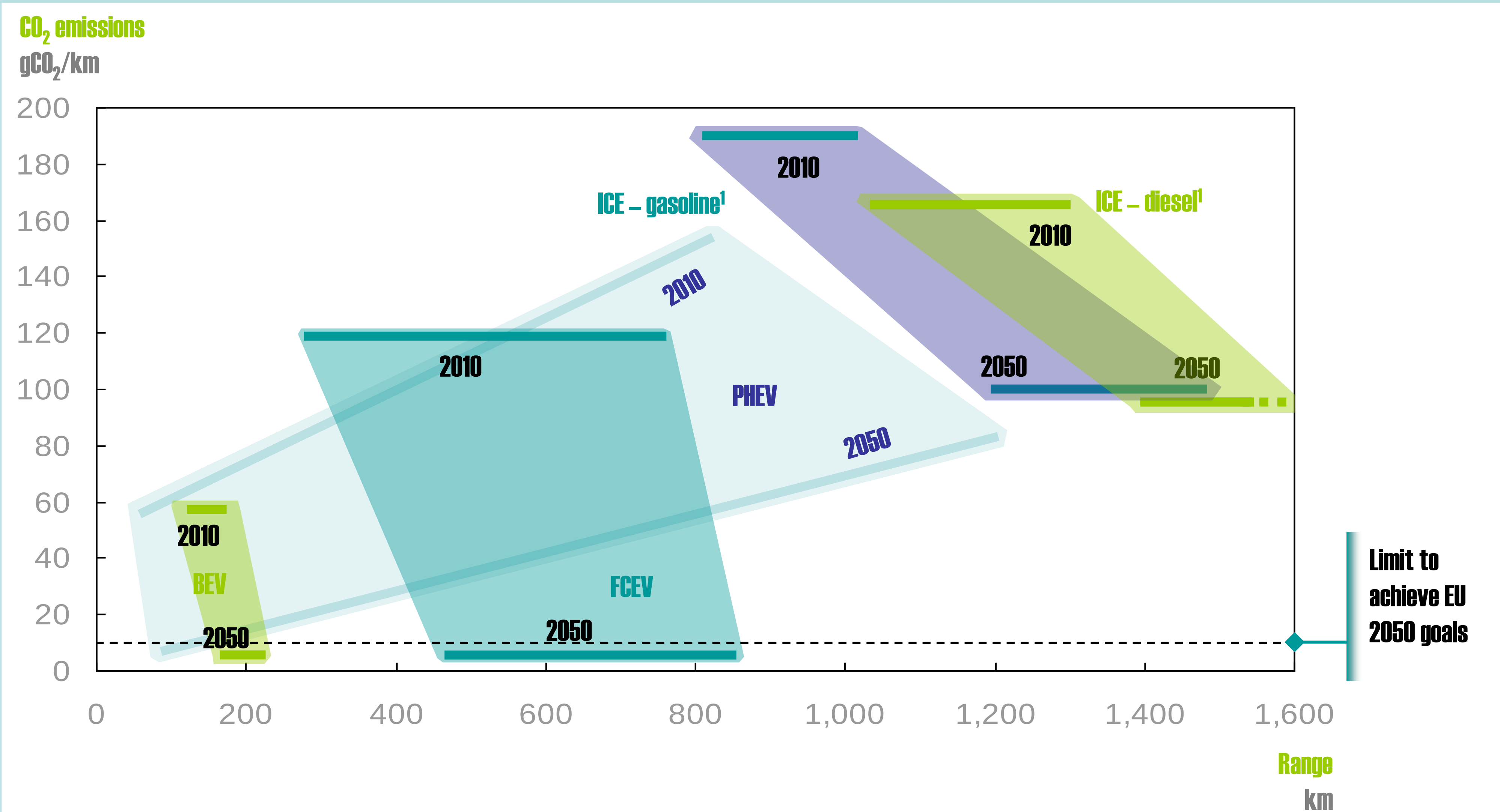
• Costs of hydrogen infrastructure is affordable:

- relatively low compared at 5% of the vehicles total cost of ownership owing to their modular nature, electrical infrastructures are easier to build up, but after 2020, infrastructure costs for FCEVs are less than those of BEVs as the number of public charging remains commensurate with the number of cars due to the lengthy recharging time. In contrast, once a territory is covered, no further investment is needed in hydrogen infrastructure regardless because of the short refuelling times. By 2030 BEVs infrastructure costs 1.5-2.5 cents per km compared with 1.5 cents per km for FCEVs…

- comparable to other fuels and technologies such as charging infrastructures for BEV and PHEVs (hydrogen can be produced cost-effectively on both small and large scales (0.4 to 1000 tonnes per day), centralized or decentralized production)

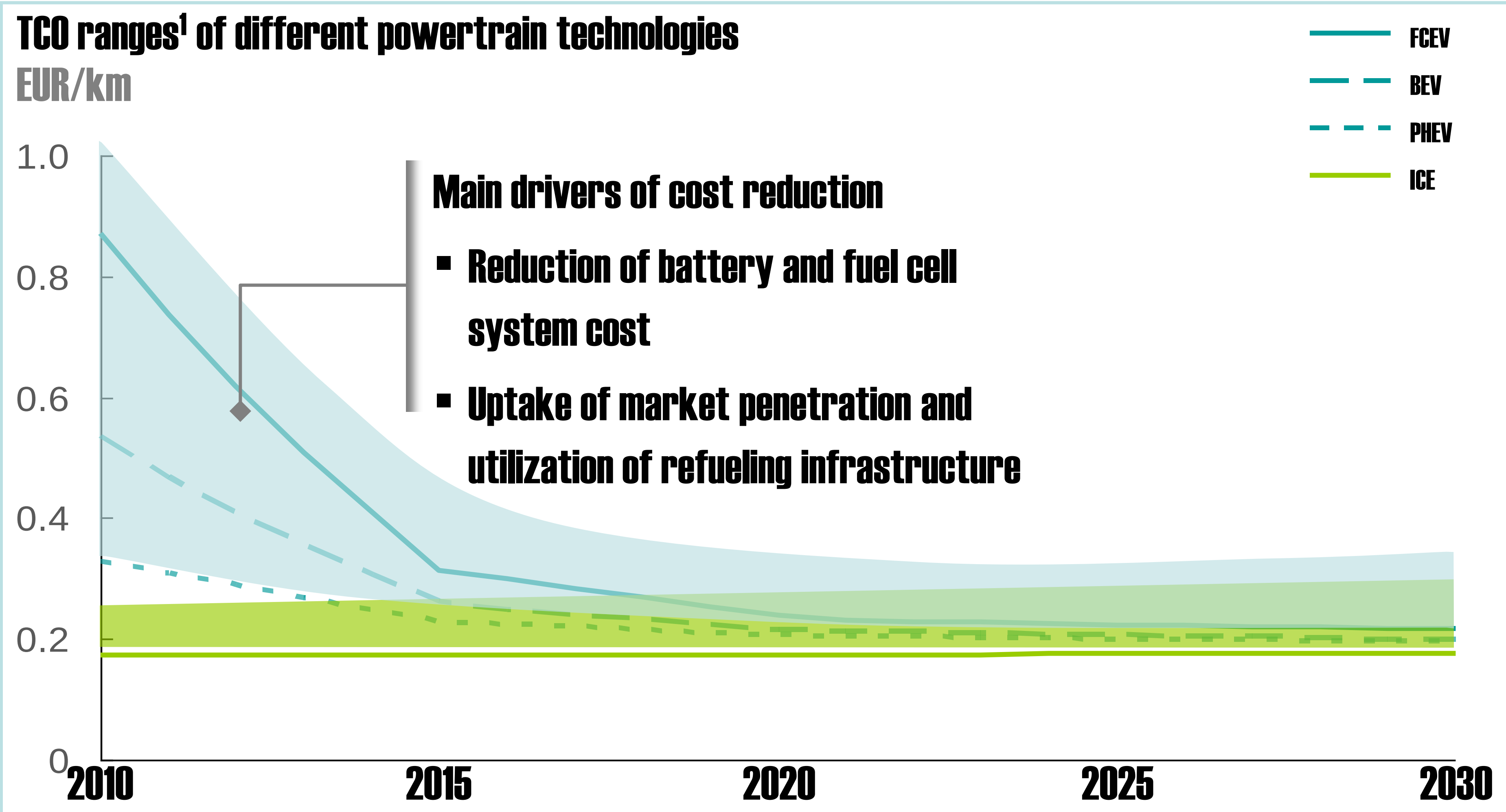
# Only electric vehicles (BEV, PHEV, FCEV) can achieve the required $CO_2$ emissions






1 ICE range for 2050 based on fuel economy improvement and assuming tank size stays constant

# Total cost of ownership of alternative powertrains will converge with ICE after 2020




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

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

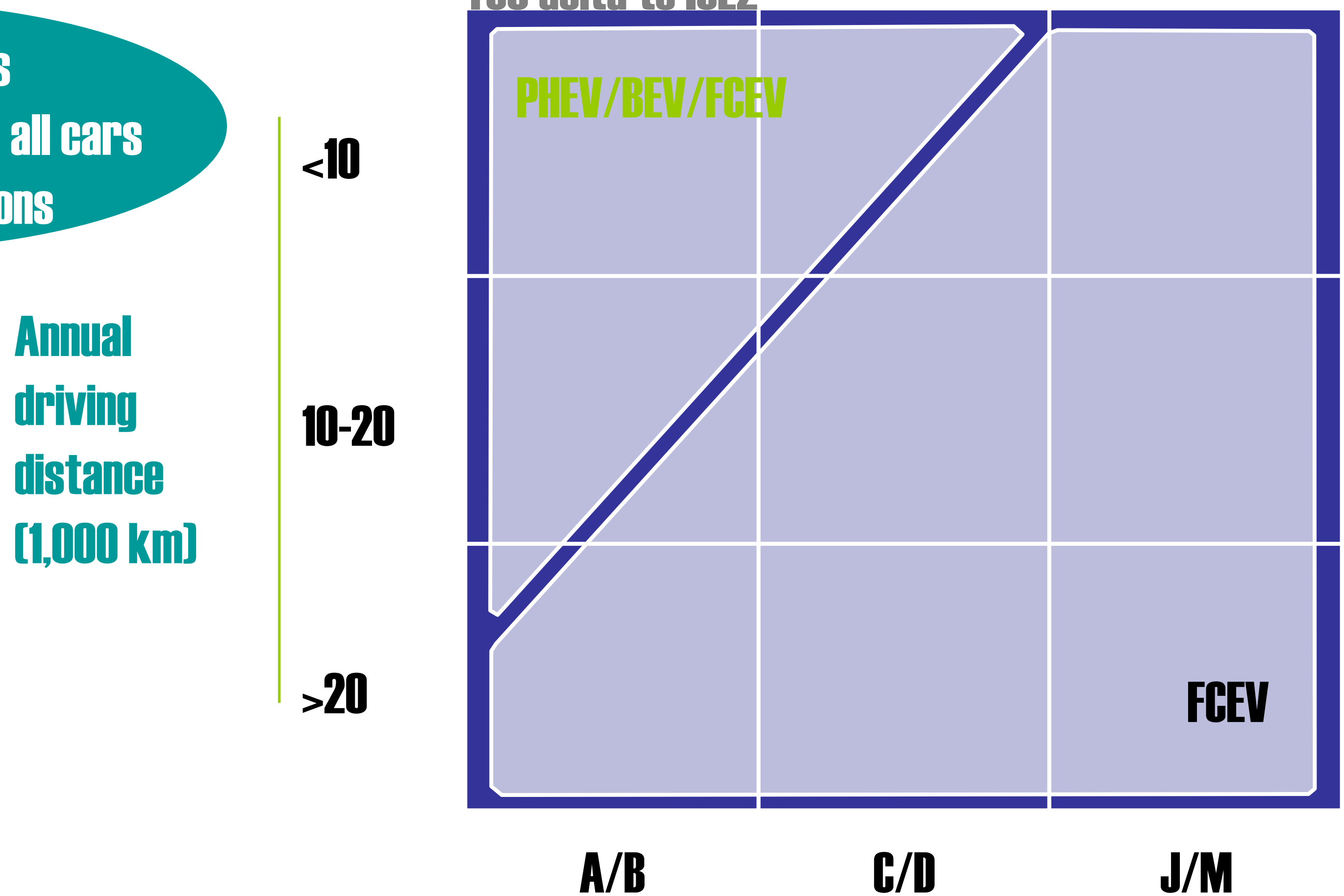
2050

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

**Family sized cars (medium/large) = 50% of all cars & 75% of $CO_2$ emissions**

## Lowest $CO_2$ abatement solution

TCO delta to ICE2




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



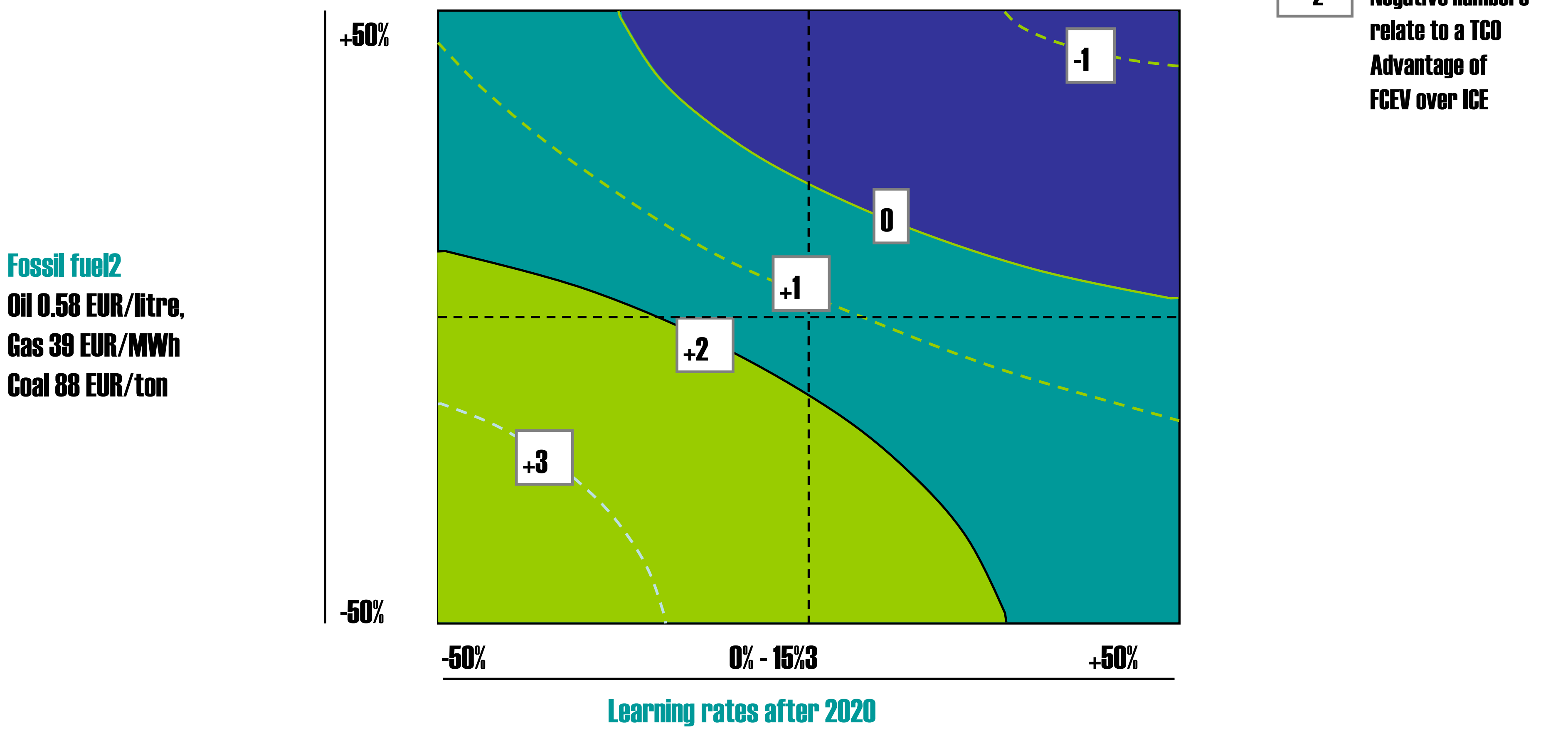
SOURCE: Study analysis

# Conclusions are robust to significant variations in learning rates and the cost of fossil fuels

C/D SEGMENT

**TCO delta between FCEV and ICE-gasoline1**

EURct/km, 2030




1 Assuming 15 year lifetime and annual driving distance of 12,000 km

2 No taxes included, e.g. excise tax, CO2 tax, VAT

3 Fuel cell membranes: 15% pdc (per doubling of capacity); non-platinum catalyst: 15% pdc; FC structure: 15% pdc, EV-specific parts: 4.0%/1.5% p.a.; FC periphery 4.0%/1.5% p.a.; glider cost (FCEV & ICE): 0%; ICE basic power-train parts: 0%; technology packages: 1.5% p.a.



SOURCE: Study analysis

# FCEVs can play a significant role

- FCEVs are technologically ready and, in the medium to long term, are the best low-carbon substitute for family size cars
- The costs for a hydrogen infrastructure are approximately 5% of the overall costs of FCEVs over coming decades, comparable to rolling out a charging infrastructure for BEVs and PHEVs
- In addition to BEV and PHEV infrastructures, a dedicated hydrogen infrastructure is therefore justified and doable, but investment cycles in infrastructures can be lengthy

  ➲ Hydrogen infrastructure and scale up should be initiated now to achieve a broad market uptake beyond 2020.

  ➲ Infrastructure: Market failure of early mover disadvantages must be bridged with adequate policies

  ➲ Vehicles: Incentives could make FCEVs cost-competitive with ICE as early as 2020

# FC coalition & McKinsey report

Overall:

Results highlighted that the four vehicle types are complementary, given unique characteristics that makes each ideal for serving different car segments and driving behaviour:

•**Battery electric vehicles**, given their limited energy storage capacity and driving range (150-250km) are ideal for urban locations/settings

•**Fuel cell electric vehicles**, which have a driving range and performance comparable to internal combustion engines, become the lower-carbon solution for longer trips and family-size cars

•**Plug-in hybrids** are a good transition technology combining the battery electric benefits for short distances with the traditional combustion engine characteristics for longer drives

•**Internal combustion engines** are expected to reduce $CO_2$ emission through improved technology and biofuels, but after 2020, further engine efficiency improvements in this technology are expected to be limited and relatively costly, while availability of biofuels may also be an issue

The study also demonstrated the commercial case for electrification of passenger transport, as the total cost of ownership of the different vehicles will converge after 2020.

*The mission of this study was to help define the way towards the long-term sustainability of road transport. The study reinforces our belief that this will only be possible if Europe immediately begins to prepare the infrastructure required for a sustainable electric vehicles market.”*

*Bringing electric vehicles to market has a cost. This cost is not prohibitive and comparable for all types of electric vehicles. However, the risk is high for first-movers. Governments need to support investment through legislation, coordination and public funding to achieve our climate goals”.*

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nis.hayter@intelligent-energy.com
47958066928

# Thank You