
Presented the DOE Hydrogen and Fuel Cell Technical Advisory Committee (HTAC)  
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www.CleanCarOptions.com
Study Participants

- 10 OEMs
- 5 Energy Companies
- One Utility
- 3 Industrial Gas Companies
- One Wind Energy Company
- 4 Electrolyzer Companies
- One non-government agency
- 2 Government agencies

Proprietary Cost data
New Results/Perspectives

• An overall 80% reduction in GHGs will require a 95% reduction in road transport GHGs

• Larger vehicles represent 50% of all cars in the EU and they generate 75% of all road transport GHGs.
  - [therefore FCEVs will play a large role, since they alone can provide long range and fast refilling for larger vehicles.]
Road Transport will require 95% GHG reduction to achieve overall 80% reduction.

Exhibit 1: In order to achieve EU CO₂ reduction goal of 80% by 2050, road transport must achieve 95% decarbonisation.
Key Results

- FCEVs are ready for commercialization and FCEVs “are the lowest carbon solution for medium/larger cars and longer trips.”
- BEV’s “are ideally suited to smaller vehicles and shorter trips.”
- PHEVs will help to cut GHGs, particularly if combined with biofuels (although biofuel resources are limited.)
- ICEs efficiency can be improved 30%, which will help cut GHGs with biofuels (see above)
Specific Energy Comparison

Note: The Chevy Volt Li-ion battery has 44.1 Wh/kg of useful specific energy. (although PHEVs require much less energy than BEVs)
Batteries Weigh More than Fuel Cell Systems
(Effects of mass compounding)

Structural weight addition: 15%
Useful Energy Density

Useful Energy Density (Wh/liter)

- Pb-A
- NiMH
- Lithium-Ion
- USABC Goal
- 35 MPa H2 Tank, Battery & Fuel Cell System
- 70 MPa H2 Tank, Battery & Fuel Cell System
Batteries also take up more space:

- **EU Range**
- **PbA Battery**
- **NiMH Battery**
- **Li-Ion Battery**
- **Fuel Cell + Hydrogen Tanks (5,000 psi)**
- **(10,000 psi)**
- **DOE H2 Storage Goal**

**Energy Storage System Volume** (liters)

**Range (miles)**

- DOE Storage Goal: 2.7 kWh/Liter
No Silver Bullet !!!
Toyota View of Alternative Vehicle Space:
Market Segments for Each Technologies

Vehicle Size
 EV
 HV & PHEV
 FC

Driving Range

Electricity

Hydrogen

Gasoline

Diesel

Biofuel
Drivetrains for Various Driving Cycles

- **Long Distance**
- **Suburban**
- **Urban**

- Combustion Engine
- Hybridization
- Plug-In/Range Extender
- Electric Drive with Battery
- Electric Drive with Fuel Cell

- Only fuel cell technology is suited equally for both, short and long distance mobility
CO2 emissions vs. range from McKinsey Report

b. BEVs are ideally suited to smaller cars and shorter trips

Exhibit 18: BEVs and FCEVs can achieve significantly low CO₂ emissions, with BEVs showing limitations in range.

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
FCEVs are ready for Commercialization

- Over 500 FCEVs have been road-tested
- 15 million km (9.3 million miles)
- 90,000 refuelings
- 700-bar storage acceptable for long range
- -25°C temperature (or lower) achieved
- Durability improving
FCEVs & PHEVs have ICV-like performance

1 Bars represent range of performance across reference segments
2 Fast charging; implies higher infrastructure costs, reduced battery lifetime and lower battery load
3 The gas tank of a PHEV has the same refueling time as a conventional vehicle

SOURCE: Study analysis
### Alternative Vehicle Mixes Considered:

<table>
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<tr>
<th>Case</th>
<th>FCEVs</th>
<th>BEVs</th>
<th>PHEVs</th>
<th>ICEs</th>
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<td>FCEV Case</td>
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<td>20%</td>
<td>5%</td>
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</tbody>
</table>
Incremental Cost of Alternative vehicles in 2030
(Kromer & Heywood [MIT] vs. McKinsey C/D segment)


($1 = €0.7245)
J-Segment (SUV) total cost of ownership in 2050
TCO 2030 & 2050 for J-segment (SUVs)

- Diesel ICVs
- Gasoline ICVs
- PHEVs
- BEVs
- FCEVs

Total Cost of Ownership (TCO - thousand Euros)

- 2050
- 2030

J-segment cars

McKinsey EU Data.xls Tab 'TCO'; K 26 2/2/2011
Total Cost of Ownership (TCO) – small cars

A-Cars = City Cars (Smart & Hyundai i20)
B-cars = Super-mini (Toyota Yaris & Mercedes A)
Total Cost of Ownership (TCO) – Medium cars

C-Cars = Medium Cars (Honda Civic & Ford Focus)
D-cars = upper Medium (Hondas FCX, Renault Laguna & Mercedes C)

[Bar chart showing total cost of ownership for different types of vehicles (Diesel ICVs, Gasoline ICVs, PHEVs, BEVs, FCEVs) across years 2030 and 2050.]
Total Cost of Ownership for Mixture of 2.1% A/B; 7.5% C/D & 90.4% J (accounting for 50% of vehicles and 75% of GHGs)
Daimler thinks FCEV will not cost more than diesel HEV by 2015

• By 2015, we think a fuel cell car will not cost more than a four-cylinder diesel hybrid that meets the Euro 6 emissions standard. By 2013-2014, we want to bring a four-digit-number of fuel cell vehicles to market.

• Source: Herbert Kohler, head of e-drive and future mobility at Daimler, recently told Automotive News Jan 30th 2011 at 8:15AM
J-Segment (SUV) total cost of ownership in 2050

The chart illustrates the total cost of ownership (TCO) in thousand euros for different vehicle types in 2050. The chart includes:

- ICE diesel
- ICE-gasoline
- PHEV
- BEV
- FCEV

The chart shows the breakdown of costs into Price, O&M, Fuel, and Infrastructure. The FCEV has a notable infrastructure cost compared to other vehicle types.
Hydrogen Infrastructure cost is small and Manageable

- H2 infrastructure is ≈5% of FCEV cost or €1,000 to €2,000 per FCEV
- H2 Infrastructure is €3 billion first decade and €2 billion/year to €3 billion/year thereafter
- Other EU infrastructure: €150 to 180 B/year:
  - Oil & gas infrastructure
  - Telecommunications
  - Roads: each €50 to €60 billion per year
- Cost to decarbonize electricity: €20 to €30 billion per year and €1.3 Trillion total
H2 Infrastructure: €101 Billion over 40 years

1 Current annual capex requirement for the EU

SOURCE: WIIIS Global Insight; OVUM; OECD / International Transport Forum; study analysis
Electric charging infrastructure: €540 Billion over 40 years

Average annual investment of 13+ billion EUR over next 40 years is considerably larger than investment needed for FCEVs, but serves more vehicles (~200 million BEVs/PHEVs\(^1\) compared to ~100 million FCEVs)

\(^1\) Cumulated new builds over 40 years

SOURCE: Study analysis
Average Annual EU Infrastructure Costs over next 40 years

- Roads
- Telecommunications
- Oil & Gas
- Decarbonize Grid
- PHEV
- BEV
- FCEV

Average Annual Infrastructure Expenditures (€ Billions) (over next 40 years)
Total Cumulative Infrastructure Costs over 40 years

- FCEV: 101
- BEV & PHEV: 540
- Decarbonize Grid: 1300

Total Infrastructure Expenditures (€ Billions) (over next 40 years)
Annual Economic Gaps (Vehicles & Infrastructure)

- **FCEV Gaps**
  - €202B by 2050

- **BEV Gaps**
  - €502B by 2050

- **PHEV Gaps**
  - €420B by 2050
Surprise: GHGs Not total well-to-wheels

• They did NOT include “indirect GHG emissions” from:
  – Feedstock exploration & infrastructure buildup, including
    • Mining activities
    • Power plant buildup
  – Nor “so-called CO2-equivalent emissions”
CCS = near-zero GHGs

1 SMR (Steam Methane Reforming) – dependent on natural gas
2 WE (Water Electrolysis) – uses 80% RES pathway for electricity and can offer additional grid stabilisation load leveling benefits
3 CG (Coal Gasification) – relies on domestic coal and when combined with CCS is assumed to be co-fired with 10% biomass
H2 costs decrease from €16.6/kg to €4.40/kg

- Small retail stations operating at low utilization drive high initial cost, but is required to allow vehicle adoption
- High initial price is only necessary for relatively small volume of H₂
- Production costs decrease significantly after 2020 due to IGCC and CG
- Minimal price decrease after 2025 is a result of relatively low learning rates and increase in natural gas price

1 Coverage requirement sets area and retail station density requirements for vehicle adoption
31% of technology improvements for BEVs and PHEVs also apply to FCEVs
Thank You

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