General Motors/Opel
Fuel Cell Activities
Global Perspectives Require Balanced Solutions

Energy Security and Availability

Transportation Economics

Environment

Sustainable Mobility
Commitment of the European Automotive Industry about the reduction of CO₂-Emissions

Interim Goal for 2003:
(165g - 170g CO₂/km)

Further Measures:
(CNG, fuel cell)

Vehicle Measures

Powertrain Measures

Current line of reduction of the European industry

2001: 164 g CO₂/km

25% Reduction

Commitment for 2008:
140 g CO₂/km

EU Target for 2012:
120 g CO₂/km

Origin: 185 g CO₂/km
Well-to-Wheel Pathways – Traditional and Renewable Feedstocks

Well-to-Tank

Tank—to-Wheel

H₂
Well-to-Wheel Greenhouse Gas Emissions Using Fossil Fuels

Internal Combustion:
- 2002 Gasoline Engine
- DI Engine, Gasoline
- DI Engine, Diesel
- SI Engine, CNG, EU NG-mix
- SI Engine, LH₂, EU NG-mix

Fuel Cell:
- MeOH + Reformer, EU NG-mix
- LH₂, EU NG-mix
- CH₂, EU NG-mix

Graph showing greenhouse gas emissions (gCO₂ Equivalent/km) for different fuel types:
- Well-to-Tank
- Tank-to-Wheel

Legend:
- * : Hybrid
Well-to-Wheel Greenhouse Gas Emissions Using Renewable Fuels

**Hydrocarbons:**
- DI Eng., Diesel, Residual Wood
- SI Engine, Biogas
- FC + Reform., MeOH, Res. Wood

**Hydrogen:**
- SI Eng., LH₂, Electrolysis, Wind
- FC, LH₂, Electrolysis, Wind
- FC, CH₂, Electrolysis, Wind
- FC, CH₂, Biomass

Gaseous emissions, gCO₂ Equivalent/km

- Well-to-Tank
- Tank-to-Wheel

-150 -100 -50 0 50 100 150

Greenhouse Gas Emissions (gCO₂ Equivalent/km)
Conclusions of the Study

On a Well-to-Wheel basis, several pathways offer improved greenhouse gas emissions and energy consumption:

• Advanced ICE powertrains using conventional diesel and biofuels
• Fuel cell powertrains using hydrogen

Long term, fuel cells and hydrogen from renewable sources are the most attractive option due to:

• Fuel economy
• Local and global emissions
• Feed stock diversity / security of supply
GM Fuel Cell Activities

Warren
(MI, USA)

Rochester
(NY, USA)

Mainz-Kastel
(Deutschland)

Torrance
(CA, USA)

Tokyo
(Japan)
Fuel Cell Vehicle “HydroGen1”

- Fuel Cell Stack (200 cells):
  - Power: 80 kW
  - Start-up: 30 s at -20° C
- Elektromotor: 55 kW
- Top speed: 140 km/h
- Fuel: 5 kg LH₂
- Range: 400 km (EDC)
Great success for “HyroGen1” at competition for alternative propulsion vehicles:

- Only fuel cell passenger vehicle to cover the whole distance
- Best scores in disciplines emissions, handling, noise
- Design trophy for outstanding integration of fuel cell system
Milestones achieved with “HydroGen3”

Improved performance and day-to-day practicality compared to “HydroGen1”:

• No high-performance buffer battery
• Increased fuel cell unit power density, no external humidification devices
• Compact propulsion module
• Air conditioning system, diagnostic system
• Same loading space as production model
“HydroGen3” – Liquid and Compressed

- Fuel cell stack (200 cells):
  - Power: 94 kW
  - Start-up: 30 s at -20° C (-4° F)
- Electric motor: 60 kW
- Top speed: 160 km/h (100 mph)
- Fuel: 4.6 kg LH₂ or 3.1 kg CH₂
- Range: 400 or 270 km (EDC)
  - 250 or 170 miles (EDC)
Detroit Motor Show 2002:
Presentation of “GM AUTOnomy”

Concept vehicle with “skateboard”-chassis developed based on advantages of fuel cell and “x-by-wire technology”
Efficiency Comparison

European Driving Cycle (EDC):
- Efficiency: 36% / 22%
- CO₂-Emissions: 0 g/km / 177 g/km
Fuel Cell Technology will be competitive with internal combustion engine powertrains:

- Fuel cell system performance superior to internal combustion engine
- Vehicle integration is feasible
- No functional vehicle restrictions for customers
  → “Fun to drive”
Key Challenges for Commercialization

- Fuel cell system cost
- High performance hydrogen storage system
- Infrastructure Development
- Fuel processing
Energy Storage Comparison

- Advanced LH₂-Tank + 10.9%
- Advanced CGH₂ Tank 700 bars 5.6 SysWt%
- LH₂ 5.3 SysWt%
- CNST (DoE-Goal: Material: 6.5 Wt%) 5.7 SysWt%
- Zafira Tank (equiv. to 14.8 kg H₂) equiv. to 31 H₂-SysWt%
- Zafira Tank + Reformer (long-term) equiv. to 12.0 H₂-SysWt%
- Zafira Tank + Reformer (short-term) Equiv. to 4.2 H₂-SysWt%
- HT-/MT-Metal Hydrids + 3.3 – 3.4%
- LT-Metal Hydrids +1.2%
- CGH₂ 700 bar + 5.0%
Liquid Hydrogen Storage – Challenges

- Mechanization
- Costs
- Design / package
- Parking / boil-off:
  - heat transfer into tank leads to H₂ losses (boil-off)
  - cannot be prevented completely
  - boil-off Hydrogen converted into water
HydroGen3 Compressed Hydrogen Storage System

- Capacity: 3.1 kg $\text{H}_2$ at 700 bar
- Weight: 95 kg
- Service life: 2.5 years
- Certification: TÜV (EIHP “Draft No. 7”; NGV-2)
- Carbon fiber: T1000
- Pressure regulation: in-tank, two-stage
Hydrogen Infrastructure

• Automotive companies cannot develop hydrogen infrastructure alone

• Strong support, commitment and leadership are required from energy companies and governments to jump-start the infrastructure buildup

• Potential of hydrogen economy must be considered under economic aspects and perspectives of energy security
GM is in discussions with all stakeholders in various regions and actively participating in:

- California Fuel Cell Partnership (CaFCP)
- Transport Energy Strategy (VES), Germany
- Clean Energy Partnership (CEP)
- European Integrated Hydrogen Project (EIHP)
- National Hydrogen Association of U.S. (NHA)
- International Hydrogen Infrastructure Group (IHIG)
- International Standards Organization (ISO)
- Society of Automotive Engineers (SAE)
- Japan Hydrogen and Fuel Cell Demonstration Projekt (JHFC)
Conclusions (I)

- Goal is to take automobile out of environmental debate
- Hydrogen from renewables is the future fuel
- Fuel cell system offers best propulsion system for hydrogen
- Hydrogen storage technology has key function
- Activities to develop hydrogen infrastructure must be significantly increased
Conclusions (II)

• Automotive industry is engaged in developing solutions, but needs active support from governments and energy companies

• On-board fuel processing could offer interim solution, but should not hinder implementation of hydrogen economy

• All activities must be accompanied by encouragement of customer acceptance with regard to new product “fuel cell vehicle” and new retail fuel “hydrogen”