Peter Mock
German Aerospace Center (DLR), Institute of Vehicle Concepts

Market Prospects of Electric Passenger Vehicles and Their Effect on CO₂ Emissions up to 2030 (VECTOR21)

PHEV’09 – Plug-In Hybrid and Electric Vehicles
Montreal, Sept. 29, 2009
Introduction
German Aerospace Center (DLR)

- 5,700 employees at 29 research institutes and facilities in 13 locations
- Offices in Brussels, Paris and Washington D.C.
- 4 main research fields:
  - Aeronautics
  - Space
  - Transport
  - Energy
Introduction
Motivation and framework

What are the vehicle technologies and fuels of the future?

- complex system of concurrency / prospects of success unknown
- to be taken into account:
  - technology costs
  - energy prices
  - taxation
  - customer decision process, …
- new computer model for market scenarios up to 2030: VECTOR21
Overview
3-step approach

1. Set up a technology database
2. Develop a model to reflect the market
3. Apply the model to get to scenarios of the future
Vehicle types currently included in the analysis

- conventional gasoline and gasoline hybrid electric (HEV) vehicles
- conventional diesel and diesel HEV vehicles
- conventional compressed natural gas (CNG) and CNG HEV vehicles
- extended range electric vehicles (EREV)
- battery electric vehicles (BEV)
- fuel cell hybrid electric vehicles (FCHEV)
### Technology cost and energy consumption assessment

**Example medium size gasoline vehicle**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Start</th>
<th>End</th>
<th>Packages</th>
<th>Energy Cons.</th>
<th>Production</th>
<th>Markup</th>
<th>Retail</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9,360 €</td>
<td>35%</td>
<td>15,021 €</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
<td><strong>Euro5</strong> (Euro 5 Compliance)</td>
<td>50 €</td>
<td>95%</td>
<td>80 €</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td></td>
<td></td>
<td><strong>Euro6</strong> (Euro 6 Compliance)</td>
<td>50 €</td>
<td>95%</td>
<td>80 €</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5,450 €</td>
<td>35%</td>
<td>15,101 €</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technology</th>
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<th>Production</th>
<th>Markup</th>
<th>Retail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced engine friction losses</td>
<td>2009</td>
<td></td>
<td><strong>X</strong></td>
<td>-3.0%</td>
<td>70 €</td>
<td>35%</td>
<td>112 €</td>
</tr>
<tr>
<td>Direct injection: homogeneous charge</td>
<td>2010</td>
<td></td>
<td><strong>X</strong></td>
<td>-2.0%</td>
<td>150 €</td>
<td>95%</td>
<td>241 €</td>
</tr>
<tr>
<td>Direct injection: stratified charge</td>
<td>2013</td>
<td></td>
<td><strong>X</strong></td>
<td>-8.0%</td>
<td>700 €</td>
<td>95%</td>
<td>1,126 €</td>
</tr>
<tr>
<td>Medium downsizing with turbocharging</td>
<td>2010</td>
<td></td>
<td><strong>X</strong></td>
<td>-5.0%</td>
<td>200 €</td>
<td>95%</td>
<td>321 €</td>
</tr>
<tr>
<td>Strong downsizing with Turbocharging (Twincharger)</td>
<td>2011</td>
<td></td>
<td><strong>X</strong></td>
<td>-8.0%</td>
<td>450 €</td>
<td>95%</td>
<td>723 €</td>
</tr>
<tr>
<td>Variable Valve Timing</td>
<td>2010</td>
<td></td>
<td><strong>X</strong></td>
<td>-3.0%</td>
<td>150 €</td>
<td>95%</td>
<td>241 €</td>
</tr>
<tr>
<td>Variable Valve Control</td>
<td>2012</td>
<td></td>
<td><strong>X</strong></td>
<td>-7.0%</td>
<td>350 €</td>
<td>95%</td>
<td>552 €</td>
</tr>
<tr>
<td>Start Stop</td>
<td>2009</td>
<td></td>
<td><strong>X</strong></td>
<td>-4.0%</td>
<td>200 €</td>
<td>95%</td>
<td>321 €</td>
</tr>
<tr>
<td>Start Stop + Regenerative Braking (Multi Hybrid)</td>
<td>2011</td>
<td></td>
<td><strong>X</strong></td>
<td>-7.0%</td>
<td>600 €</td>
<td>95%</td>
<td>954 €</td>
</tr>
<tr>
<td>Low friction tires</td>
<td>2009</td>
<td></td>
<td><strong>X</strong></td>
<td>-2.0%</td>
<td>30 €</td>
<td>95%</td>
<td>48 €</td>
</tr>
<tr>
<td>Optimized cooling circuit, electric water pump</td>
<td>2011</td>
<td></td>
<td><strong>X</strong></td>
<td>-2.0%</td>
<td>120 €</td>
<td>95%</td>
<td>150 €</td>
</tr>
<tr>
<td>Exhaust heat recovery</td>
<td>2012</td>
<td></td>
<td><strong>X</strong></td>
<td>-1.0%</td>
<td>50 €</td>
<td>95%</td>
<td>80 €</td>
</tr>
<tr>
<td>Improved aerodynamic efficiency</td>
<td>2012</td>
<td></td>
<td><strong>X</strong></td>
<td>-1.5%</td>
<td>75 €</td>
<td>95%</td>
<td>120 €</td>
</tr>
<tr>
<td>Electrically assisted steering, auxiliary power steering</td>
<td>2010</td>
<td></td>
<td><strong>X</strong></td>
<td>-2.0%</td>
<td>100 €</td>
<td>95%</td>
<td>181 €</td>
</tr>
<tr>
<td>Improved transmission (e.g. Dual-Clutch)</td>
<td>2011</td>
<td></td>
<td><strong>X</strong></td>
<td>-4.0%</td>
<td>350 €</td>
<td>95%</td>
<td>552 €</td>
</tr>
<tr>
<td>Weight reduction package 1 (medium) = 1.5% veh. weight (20 kg)</td>
<td>2010</td>
<td></td>
<td><strong>X</strong></td>
<td>-1.0%</td>
<td>120 €</td>
<td>95%</td>
<td>150 €</td>
</tr>
<tr>
<td>Weight reduction package 2 (medium) = 1.5% veh. weight (50 kg)</td>
<td>2011</td>
<td></td>
<td><strong>X</strong></td>
<td>-2.0%</td>
<td>300 €</td>
<td>95%</td>
<td>482 €</td>
</tr>
<tr>
<td>Weight reduction package 3 (strong) = 0.5% veh. weight (120 kg)</td>
<td>2013</td>
<td></td>
<td><strong>X</strong></td>
<td>-5.0%</td>
<td>720 €</td>
<td>95%</td>
<td>1,157 €</td>
</tr>
</tbody>
</table>

**Best available vehicle**

<table>
<thead>
<tr>
<th>Start</th>
<th>End</th>
<th>Packages</th>
<th>Energy Cons.</th>
<th>Production</th>
<th>Markup</th>
<th>Retail</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td></td>
<td><strong>X</strong></td>
<td>1,500 km</td>
<td>12,465 €</td>
<td>35%</td>
<td>20,539 €</td>
</tr>
</tbody>
</table>

**Note:**
- $0.74/kWh/km = 4.13/100 km
- $0.41/kWh/km = 4.91/100 km

*Institute of Vehicle Concepts*
Technology cost and energy consumption assessment
Learning curve approach for electric vehicles

- **Internal combustion engines**
  - manufacturing costs / retail prices for **baseline vehicles**
  - individual technical measures summarized into **fuel economy packages**
  - **potential for future fuel economy improvements** taken into account

- **Electric vehicles**
  - identification of **learning curves**, costs dependent on production volume
Overview

3-step approach

1. Set up a technology database ✔
2. Develop a model to reflect the market
3. Apply the model to get to scenarios of the future
Scenario model (VECTOR21)
Modeling technology supply and customer demand

- energy consumption
- technology costs
- fuel prices, taxes, ...

**Computer model**
- fuel economy packages
- powertrain concept
- type of fuel
- vehicle size
- technical parts
- vehicle
- customer (900 types)
- annual mileage
- adopter group
- willingness-to-pay
- sales / market shares
- CO₂ emissions

Institute of Vehicle Concepts
Scenario model (VECTOR21)
Relevant cost of ownership as main purchase criteria

Total cost of ownership (TCO) = all costs

Relevant cost of ownership (RCO):

<table>
<thead>
<tr>
<th></th>
<th>vehicle price</th>
<th>-</th>
<th>subsidies</th>
<th>+</th>
<th>penalties</th>
<th>purchase price</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>vehicle tax</td>
<td></td>
<td>time for break-even (4 years)</td>
<td></td>
<td></td>
<td>annual costs</td>
</tr>
<tr>
<td>+</td>
<td>fuel costs per km</td>
<td></td>
<td>annual mileage</td>
<td></td>
<td>time for break-even</td>
<td>mileage depending costs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Innovator</th>
<th>Early Adopter</th>
<th>Early Majority</th>
<th>Late Majority</th>
<th>Laggard</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>10 %</td>
<td>7 %</td>
<td>3 %</td>
<td>1 %</td>
<td>0 %</td>
</tr>
</tbody>
</table>

- assumption: purchase decision within vehicle category rational
- basis for decision: relevant cost of ownership (RCO)
- additional willingness-to-pay depending on customer type
Scenario model (VECTOR21)
Illustration of selection process

- vehicle variants (combination of vehicle technology and fuel)
1. step 1: filter for vehicle size category and general compulsory requirements
2. step 2: choose lowest Relevant Cost of Ownership (RCO)
3. step 3: choose lowest well-to-wheel CO₂ emissions
Scenario model (VECTOR21)
Model results vs. real historical developments
Overview

3-step approach

1. Set up a technology database ✓
2. Develop a model to reflect the market ✓
3. Apply the model to get to scenarios of the future
Scenario calculations

Scenario 1 (Baseline) – New vehicle fleet

- **Small**
  - Key technologies: FCV, CNG, D, D-HEV, BEV

- **Medium**
  - Key technologies: EREV, CNG-HEV, BEV

- **Large**
  - Key technologies: D-HEV, CNG, EREV

- **All**
  - Key technologies: FCV, CNG-HEV, BEV
Scenario calculations
Scenario 2 (Climate Protection) – New vehicle fleet
Scenario calculations
Scenarios A&B – New vehicle fleet (all vehicles)
Scenario calculations
All scenarios – New vehicle fleet (all vehicles)
Conclusion / Outlook

 VECTOR21 allows taking into account many influencing factors.

 Future market shares of electric vehicles strongly dependent on calculation assumptions:

 - CO₂ target values a key factor
 - Oil price less significant for customer decision
 - Electricity and hydrogen from renewable sources important for sustainable reduction of CO₂ emissions

 Recent applications of VECTOR21:
 - analysis carried out for German automotive manufacturer
 - detail analysis carried out for German electricity supplier
 - extended study on behalf of the German Ministry of Economic Affairs

 Expansion of assessment planned for other markets (e.g. China, U.S., Europe) and time horizon (2050), depending on funding and data availability.
Further information

→ please ask for information brochure on VECTOR21:

→ recent publications:


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