Market shares of passenger vehicle technologies and their influence on CO₂ emissions up to the year 2030

Peter Mock, German Aerospace Center (DLR), Institute of Vehicle Concepts, Germany
EU-commitment: reduce greenhouse gas emissions (-20 / 30 % by 2020)
- transport responsible for 24 % of all CO₂ emissions in the EU
- mostly cars and light duty vehicles

Market shares of vehicle technologies ...
Peter Mock, German Aerospace Center (DLR)
Focus of the analysis

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, …
- new computer model for market scenarios up to 2030: VECTOR21

Types of vehicles covered by 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)

Market shares of vehicle technologies ...

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### Vehicle energy consumption

#### Baseline Vehicle

<table>
<thead>
<tr>
<th>Measure</th>
<th>Fuel Econ. Packages</th>
<th>Energy Cons.</th>
<th>Production Cost</th>
<th>Retail Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced engine friction losses</td>
<td>X XX XX X</td>
<td>-3.0%</td>
<td>70 €</td>
<td>112 €</td>
</tr>
<tr>
<td>Direct injection: homogeneous charge</td>
<td>X XX</td>
<td>-2.0%</td>
<td>150 €</td>
<td>241 €</td>
</tr>
<tr>
<td>Direct injection: stratified charge</td>
<td>X</td>
<td>-8.0%</td>
<td>700 €</td>
<td>1.125 €</td>
</tr>
<tr>
<td>Medium Downsizing with turbocharging</td>
<td>X X</td>
<td>-5.0%</td>
<td>200 €</td>
<td>321 €</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measure</th>
<th>Fuel Econ. Packages</th>
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<th>Production Cost</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Improved transmission (e.g. Dual-Clutch)</td>
<td>X X X</td>
<td>-4.0%</td>
<td>350 €</td>
<td>562 €</td>
</tr>
<tr>
<td>Weight reduction: package 1 (mild)</td>
<td>X</td>
<td>-1.0%</td>
<td>120 €</td>
<td>193 €</td>
</tr>
<tr>
<td>Weight reduction: package 2 (medium)</td>
<td>X</td>
<td>-2.0%</td>
<td>300 €</td>
<td>482 €</td>
</tr>
<tr>
<td>Weight reduction: package 3 (strong)</td>
<td>X</td>
<td>-5.0%</td>
<td>720 €</td>
<td>1.157 €</td>
</tr>
</tbody>
</table>

#### Fuel-Economy Packages

<table>
<thead>
<tr>
<th>Package</th>
<th>Fuel Econ. Packages</th>
<th>Energy Cons.</th>
<th>Production Cost</th>
<th>Retail Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>G_FE#01</td>
<td>X</td>
<td>-8.0%</td>
<td>300 €</td>
<td>482 €</td>
</tr>
<tr>
<td>G_FE#02</td>
<td>X</td>
<td>-17.0%</td>
<td>870 €</td>
<td>1.398 €</td>
</tr>
<tr>
<td>G_FE#03</td>
<td>X</td>
<td>-24.0%</td>
<td>1.490 €</td>
<td>2.394 €</td>
</tr>
<tr>
<td>G_FE#04</td>
<td>X</td>
<td>-34.0%</td>
<td>2.645 €</td>
<td>4.249 €</td>
</tr>
<tr>
<td>G_FE#05</td>
<td>X</td>
<td>-40.0%</td>
<td>3.615 €</td>
<td>5.807 €</td>
</tr>
</tbody>
</table>

**Best available vehicle (medium size gasoline, no hybrid)**

<table>
<thead>
<tr>
<th></th>
<th>Fuel Econ. Packages</th>
<th>Energy Cons.</th>
<th>Production Cost</th>
<th>Retail Price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>1.59 MJ/km</td>
<td>12,952 €</td>
<td>20,807 €</td>
</tr>
</tbody>
</table>

- **3 size categories:** small, medium, large
- **data from literature and in-house simulations**
- **fuel-economy packages as add-ons for baseline vehicles**

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**Market shares of vehicle technologies ...**

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Vehicle energy consumption

Market shares of vehicle technologies …
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Production costs for batteries

- learning curve approach for “new” technologies
- potential for cost reduction: improved materials (electrodes, conducting salts), optimization of production processes, economies of scale

Market shares of vehicle technologies ...

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Market shares of vehicle technologies ...

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Market shares of vehicle technologies …
Peter Mock, German Aerospace Center (DLR)
### Demand side (customers)

<table>
<thead>
<tr>
<th>vehicle size category</th>
<th>adopter type</th>
<th>annual mileage category</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>new vehicle market</strong></td>
<td>innovator</td>
<td>1,000 km/a</td>
</tr>
<tr>
<td>small</td>
<td>early adopter</td>
<td>2,000 km/a</td>
</tr>
<tr>
<td>medium</td>
<td>early majority</td>
<td>...</td>
</tr>
<tr>
<td>large</td>
<td>laggards</td>
<td>59,000 km/a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60,000 km/a</td>
</tr>
</tbody>
</table>

= 900 customer types

**Market shares of vehicle technologies ...**

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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>+</td>
<td>vehicle tax</td>
<td>x</td>
<td>time for break-even (4 years)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>fuel costs per km</td>
<td>x</td>
<td>annual mileage</td>
<td>x</td>
<td>time for break-even</td>
</tr>
</tbody>
</table>

- Innovator + 10 %
- Early Adopter + 7 %
- Early Majority + 3 %
- Late Majority + 1 %
- Laggard 0 %

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

- **vehicle variants** (combination of vehicle technology and fuel)
- **step 1:** filter for vehicle size category and general compulsory requirements
- **step 2:** choose lowest total cost of ownership (TCO)
- **step 3:** choose lowest well-to-wheel CO₂ emissions

Market shares of vehicle technologies ...

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- Oracle database for handling large data sets
- User-friendly input / output interface

Market shares of vehicle technologies ... Peter Mock, German Aerospace Center (DLR)
Verification of results

- case study: diesel proportion new cars in Germany (1995 to 2008)
- very good model results for medium and large size category
- customer reaction delayed by one year
Market shares of vehicle technologies ...

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**Scenario assumptions**

### Focus on German passenger car market
- moderate oil price increase, electricity and hydrogen from national mix (scenario 1) / renewables (scenario 2), strict regulations for CO₂

### Table: Scenario assumptions

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1</th>
<th>Scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2009</td>
<td>2030</td>
</tr>
<tr>
<td>proportion of bio-fuels</td>
<td>0-8 %</td>
<td>15 %</td>
</tr>
<tr>
<td>electricity – CO₂ emission</td>
<td>600 [g/kWh]</td>
<td>550 [g/kWh]</td>
</tr>
<tr>
<td>electricity – consumer price</td>
<td>0.18 [€/kWh]</td>
<td>0.35 [€/kWh]</td>
</tr>
<tr>
<td>hydrogen – source</td>
<td>natural gas</td>
<td>electrolysis</td>
</tr>
<tr>
<td>hydrogen – CO₂ emission</td>
<td>350 [g/kWh]</td>
<td>650 [g/kWh]</td>
</tr>
<tr>
<td>hydrogen – consumer price</td>
<td>0.13 [€/kWh]</td>
<td>0.35 [€/kWh]</td>
</tr>
<tr>
<td>CO₂ – new vehicle fleet target</td>
<td>---</td>
<td>113 [g/km]</td>
</tr>
<tr>
<td>CO₂ – penalty for exceeding</td>
<td>---</td>
<td>95 [€/(g/km)]</td>
</tr>
<tr>
<td>market share small / medium / large</td>
<td>25 / 55 / 20%</td>
<td>30 / 45 / 25%</td>
</tr>
</tbody>
</table>

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Scenario results: new vehicle fleet

Market shares of vehicle technologies ...

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Scenario results: new vehicle fleet and stock

- **CO₂**: new vehicle fleet [g/km]
  - **scenario 1**
  - **scenario 2**

- **CO₂**: vehicle stock [million t]
  - **scenario 1**
  - **scenario 2**
    - 2010: 19, 2015: 12, 2020: 8, 2025: 4, 2030: 2

Market shares of vehicle technologies …

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Scenario results: fuel and energy demand

Market shares of vehicle technologies …

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Market shares of vehicle technologies …

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Conclusion

- VECTOR21 allows analysis of complex scenarios of future market
- significant CO₂ reductions possible in both scenarios
- renewable energy critical when using electric vehicles
- costs tend to increase in both scenarios
- focus groups for model results: automotive manufacturers, fuel and energy suppliers, politics
- model expansion plans: regions, time horizon, pollutants

source: „Ein Jahrhundert Automobiltechnik Personenwagen“, VDI-Verlage Düsseldorf, 1986

Market shares of vehicle technologies …

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No reversal of trend for CO₂ yet

- emissions from pollutants decreasing, despite of increase in mileage
- for CO₂ emissions no clear reversal of trend observable to date

Market shares of vehicle technologies ...

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potential for cost reduction: reduction of platinum loading, increase of power density, mass production, economies of scale

significant influence on production costs: market price of platinum