Chancen und Potenziale alternativer Kraftstoffe
Results from the FVV scenario study «Renewables in Transport 2050»

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LBST · Ludwig-Bölkow-Systemtechnik GmbH · Munich · Germany
- Independent expert for sustainable energy and mobility for over 30 years
- Bridging technology, markets, and policy
- Renewable energies, fuels, infrastructure
- Technology-based strategy consulting, System and technology studies, Sustainability assessment
- Global and long term perspective
- Rigorous system approach – thinking outside the box
- Serving international clients in industry, finance, politics, and NGOs

Latest projects:
- FVV Renewables in Transport 2050
- BMVI German Mobility & Fuels Strategy (MKS)
- JRC/EUCAR/CONCAWE (JEC) Well-to-Tank Analyses

Agenda

1. Motivation and approach

2. Scenarios

3. Results
   - Greenhouse gas emissions
   - Energy demand
   - Costs

4. Conclusions
Study motivation

- Greenhouse gas reduction targets of 80-95% by 2050 will require substantial contributions from the transport sector
- 100% renewables in transport by 2050 – pie in the sky?
  \( \rightarrow \) 2 archetype scenarios + 1 mix scenario
- What are the consequences in terms of energy and costs?
- What are determinants for future use of internal combustion engines?
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## Two distinct transportation demand scenarios (HIGH, LOW)

<table>
<thead>
<tr>
<th>Transportation demand scenario</th>
<th>Sector</th>
<th>Change from 2010 to 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>DE</strong></td>
</tr>
<tr>
<td>HIGH</td>
<td>Passenger</td>
<td>+30%</td>
</tr>
<tr>
<td></td>
<td>Freight</td>
<td>+60%</td>
</tr>
<tr>
<td>LOW</td>
<td>Passenger</td>
<td>-25%</td>
</tr>
<tr>
<td></td>
<td>Freight</td>
<td>+20%</td>
</tr>
</tbody>
</table>

**Sources:**
- DE-HIGH: Verkehrsprognose 2030, extrapolated to 2050, DE-LOW: eMobil 2050, scenario „Regional“
- EU: AEA (2012), EU Transport GHG – Routes to 2050 II
Renewable share in the fuels (per MJ fuel)

Target scenario – gradual shift from today to 100% renewable PtX by 2050

- Gasoline/kerosene/diesel
- Methanol
- Methane
- Hydrogen

PtL · Power-to-Liquids
PtX · Power-to-Anything

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Definition of three distinct fuel/powertrain scenarios

- **PTL** | Conservative scenario based on well established fuels/powertrains/infrastructures, incl. ICE mild hybrids with power-to-liquids dominating all transportation modes

- **FVV** | A mix of currently discussed options, comprising ambitious ICE development progress, incl. ICE hybrids, REEV, BEV, FCEV

- **eMob** | Derived from the study “eMobil 2050” [Öko-Institut 2015], with a dominance of electrified drivetrains
Fuel/powertrain scenario | Example: FVV | Cars

<table>
<thead>
<tr>
<th>Year</th>
<th>ICE-Gasoline</th>
<th>ICE-Diesel</th>
<th>ICE-Methane</th>
<th>Hybrid-Gasoline</th>
<th>Hybrid-Diesel</th>
<th>Hybrid-Methane</th>
<th>REEV-Gasoline</th>
<th>REEV-Diesel</th>
<th>REEV-Methane</th>
<th>BEV</th>
<th>FCEV</th>
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<tr>
<td>2010</td>
<td>42</td>
<td>57</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2020</td>
<td>18</td>
<td>18</td>
<td>5</td>
<td>25</td>
<td>20</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>4</td>
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<td>2030</td>
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<td>30</td>
<td>25</td>
<td>5</td>
<td>15</td>
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<td>2040</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>16</td>
<td>11</td>
<td>2</td>
<td>25</td>
<td>20</td>
<td>0</td>
<td>16</td>
<td>9</td>
</tr>
<tr>
<td>2050</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>40</td>
<td>30</td>
<td>0</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

% new registrations

Car ICE-Gasoline
Car ICE-Diesel
Car ICE-Methane
Car Hybrid-Gasoline
Car Hybrid-Diesel
Car Hybrid-Methane
Car REEV-Gasoline
Car REEV-Diesel
Car REEV-Methane
Car BEV
Car FCEV
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Greenhouse gas emissions (example FVV scenario)
Recall: Fuel target scenario => 100 % renewable by 2050

Climate impacts from high-altitude emissions (aviation) not included
Final fuel demand, electricity demand
- Relative importance of trucks, ships and aviation increases
- Ships and aviation predominantly international destinations
Transportation demand is the key driver for energy use across all scenarios.

- Truck freight and aviation push transportation demand in the HIGH scenarios.
- Total electricity demand in 2050 is a factor 3 to 4.5 of today’s electricity demand.
- Most scenarios could be feasible with domestic renewable electricity production.
Cumulated investments energy transition in transportation
Cumulated investments until 2050 | Methodology

- The cumulated investments consist of the following elements:
  - Renewable power plants
  - PtX production plants
  - Infrastructure for fuel transport & distribution

- Investments for end-of-life replacements are included in the cost model with a PtX plant lifetime of 25 years.

- Learning curves for electrolysers assumed, i.e. the 1\textsuperscript{st} PtX production plant is more expensive than the n\textsuperscript{th} one.

- BEV home-charging assumed for passenger cars.

- Vehicle costs not included.
Cumulated investments fuel supply until 2050 | EU

For comparison 2014 in EU:

- Gross domestic product (GDP) = 13920 billion €/a
- Fossil oil spendings = ~290 billion €/a
- >364 GW renewable power (150 GW hydro, 121 GW wind onshore, 8 GW wind offshore, 85 GW PV)
Fuel costs
Fuel costs – EU – 2015 (well-to-tank)

- Methane, hydrogen
- Gasoline/kerosene/diesel
- CNG from NG
- LNG from NG
- CGH2 via SMR (onsite)
- EE-PtL methanol route
- EE-PtL FT route
- EE-PtL SOEC methanol route
- EE-PtL SOEC FT route
- EE-CH4 (CNG)
- EE-CH4 (LNG)
- EE-CH4 (CNG) SOEC
- EE-CH4 (LNG) SOEC
- EE-CGH2 (onsite)
- Electricity (0.4 kV)

- LNG shipping
- H2 storage (incl. compressor)
- NG costs (excl. transport)
- CO2 provision
- CH4 storage
- CH4 liquefaction (onsite)
- Electricity costs
- Methanation/synthesis
- Distribution via truck
- H2 production
- NG grid
- Distribution via truck
- Filling station

- Fuel costs (without taxes) \[\text{\euro}/\text{Dru} \] 

- Methane, hydrogen
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- Electricity costs
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- Distribution via truck
- H2 production
- NG grid
- Distribution via truck
- Filling station

- 13.4 ct/kWh electricity costs (incl. transport)
- 4000 h/a equivalent full load period
- CO2 from air
- 60 US$/bbl fossil liquids (today)
- 0 \text{\euro}/t CO2

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Fuel costs – EU – 2050 (well-to-tank)

- 8.0 ct/kWh electricity costs (incl. transport)
- 4000 h/a equivalent full load period
- CO₂ from air
- 100 US$/bbl fossil liquids (IEA)
- 0 €/t C0₂
### Fuel costs – PtL Import vs. PtG EU – 2050 (well-to-tank)

#### FOSSIL IMPORT
- PtL import from North Africa
  - Electricity from SOT with heat storage (5.5 ct/kWh @ 6500 h/a)
  - CO₂ from air via TSA

#### RENEWABLE IMPORT
- PtG (H₂, CH₄) in Germany
  - Renewable electricity mix (8.2 ct/kWh @ 4000 h/a)
  - CO₂ from air via TSA

#### RENEWABLE DE
- Potentially cost-effective

<table>
<thead>
<tr>
<th>Fuel costs [without taxes] [€/l (Diesel-equiv.)]</th>
<th>Gasoline/kerosene/diesel</th>
<th>Methane</th>
<th>H₂</th>
<th>Electricity (0.4 kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.61</td>
<td>0.51</td>
<td>0.41</td>
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<tr>
<td>1.58</td>
<td>1.76</td>
<td>1.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.60</td>
<td>1.59</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.05</td>
<td>2.09</td>
<td></td>
<td></td>
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</tbody>
</table>

**Notes:**
- LNG shipping
- H₂ storage (incl. compressor)
- CH₄ storage
- Reference
- NG costs (excl. transport)
- CO₂ provision
- Methanation/synthesis
- Transport to EU, Distribution via truck
- Filling station

#### IEA Data
- 100 US$/bbl fossil liquids
- 0 €/t CO₂
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Conclusions from the FVV Future Fuel study (EU) in a nutshell

- Transportation demand development (pkm, tkm) is strongest driver for fuel/electricity demand.
- All scenarios but PTL+HIGH could technically be satisfied with domestic renewable electricity in the EU.
- Depending on the scenario, total electricity demand in 2050 is a factor 3 to 4.5 of the electricity demand today.
- PtX fuel costs could half between 2015 and 2050; PtL imports ~20% lower in cost. ➔ Further cost reductions are subject to project-specific business cases.
- PtX costs are dominated by electricity costs, which strongly depends on the fuel choice (H₂, CH₄, PTL) and associated plant efficiencies.
- Fuel distribution infrastructure costs are negligible compared to the upstream investments required for any of the scenarios analysed.
- Cumulated investments for Energiewende (energy transition) in the transportation sector seem manageable for any of the scenarios analysed.
- Transport must get more electric, with regard to the fuel and the propulsion system.
Literature

P. Schmidt, W. Zittel, W. Weindorf, T. Raksha (LBST)

Renewables in Transport 2050 – Empowering a sustainable mobility future with zero emission fuels from renewable electricity – Europe and Germany

Research Association for Combustion Engines e.V. (ed.)

FVV-Report 1086 / 2016

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Spotlight on short-term, no-regret option

Renewable power-to-hydrogen for use in oil refineries
Substituting natural gas with renewable power-to-H₂

**Crude oil refinery**

- **Oil**
- **NG**
- **Hydrogen**
- **Fuel**

**Power-to-H₂**

- **Electrolysis**

**NG** (Natural Gas) is replaced by renewable power, which is converted into hydrogen through electrolysis. The hydrogen then replaces the oil in the crude oil refinery, allowing for the substitution of natural gas with renewable energy sources.
Refinery GHG emission reduction (gate-to-gate)
France and Germany

<table>
<thead>
<tr>
<th>GHG mitigation of refinery emissions</th>
<th>France</th>
<th>Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.33 Mt CO$_{2\text{eq}}$/a</td>
<td>1.50 Mt CO$_{2\text{eq}}$/a</td>
</tr>
<tr>
<td>14.1 %$_{\text{gate-to-gate}}$</td>
<td>7.2 %$_{\text{gate-to-gate}}$</td>
<td></td>
</tr>
<tr>
<td>331 €/t CO$_{2\text{eq}}$</td>
<td>339 €/t CO$_{2\text{eq}}$</td>
<td></td>
</tr>
</tbody>
</table>

→ Economic option for German refineries against 470 €/t CO$_{2\text{eq}}$ penalty

To give an impression about the quantities, this is equivalent to annual GHG emission in the order of 650,000 C segment cars in France and Germany each.

<table>
<thead>
<tr>
<th></th>
<th>France</th>
<th>Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline car @ 7.0l/100km</td>
<td>575,000</td>
<td>648,000</td>
</tr>
<tr>
<td>Diesel car @ 5.5l/100km</td>
<td>658,000</td>
<td>740,000</td>
</tr>
</tbody>
</table>

→ Tangible action for refinery corporate social responsibility (CSR)
Vanhoudt, W., Barth, F. (Hinicio), Schmidt, P., Weindorf, W. (LBST), et al.: Power-to-gas – Short term and long term opportunities to leverage synergies between the electricity and transport sectors through power-to-hydrogen; Brussels/Munich, 19 February 2016

Application A: Hydrogen from power-to-gas for use in refineries

Application B: Semi-centralised power-to-hydrogen business cases

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http://www.fondation-tuck.fr/jcms/r_16975/fr/hinicio-lbst
Acknowledgement

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