Comparative Analysis of Infrastructures
Hydrogen Fueling and Electric Charging of Vehicles

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IEK-3: Electrochemical Process Engineering

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MOTIVATION

Transport sector essential for reaching the ambitious climate protection goals

Electric drivetrains key elements of low carbon, clean and energy-efficient transport based on renewable energy

Fuel Cell Electric Vehicles (FCEV) and Battery Electric Vehicles (BEV) require new energy supply infrastructures

Research Question

What are the investments, costs, efficiencies and emissions for an infrastructure capable of supplying hundred thousand or several million vehicles with hydrogen or electricity?
APPROACH

Meta-analysis of existing infrastructure scenario studies

In depth scenario analysis of infrastructure designs, Case Study for Germany

Consistent scenario framework with different vehicle penetration

Spatially and temporally resolved models for generation, conversion, transport and distribution

Analysis of investment, costs, efficiencies and emissions

Number of electric vehicles in million: 0.1, 1, 3, 5, 10, 20

Market penetration scenario: Ramp up, Mass market

Renewable electricity and demand

Electricity generation and grid

Hydrogen Production

Electric Vehicle Penetration
STATUS QUO OF INFRASTRUCTURE

Hydrogen Fueling

• Approx. 2,500 FCEV in operation worldwide

• End of 2016, 213 public Hydrogen Fueling Station (HRS) in operation worldwide: Japan (44%), the USA (17%) and Germany (13%)

• Germany: HRS network reached 30 stations by mid June 2017. At present, 27 HRS are under construction or being planned in Germany, with a goal to build up to 400 HRS before 2023

• Pipeline systems for the transportation and distribution of hydrogen concentrated for the chemical uses of hydrogen

<table>
<thead>
<tr>
<th>Existing Hydrogen Pipelines (by 2017-05)</th>
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<tbody>
<tr>
<td>The USA</td>
</tr>
<tr>
<td>Europe</td>
</tr>
<tr>
<td>of which in Germany</td>
</tr>
<tr>
<td>Rest of world</td>
</tr>
<tr>
<td>World total</td>
</tr>
</tbody>
</table>

Sources: [9], [10], [14], [15]
STATUS QUO OF INFRASTRUCTURE

Electric Charging

• By the end 2016, the total BEV and PHEV vehicle stock came to about 2 million worldwide and was largely concentrated in China (32 %) followed by the United States (28 %) [16]

• Dynamic rollout of slow and fast charging worldwide

• Leading countries end of 2016 are China, the United States and the Netherlands

• For fast charging options (Modes 3 and 4) highest dynamic and absolute number in China

Sources: [16]
META ANALYSIS

Selection criteria of scenario studies

- **Focus on Germany** (broader context studies for EU, worldwide) and quantitative results; parameters: number of hydrogen fueling stations and charging points, cumulative investment for infrastructure set-up

- Total number of scanned literature sources: **79**

- Selected studies for meta analysis: **25** (12 hydrogen and 13 electric charging)

Lessons learned of the meta analysis

- **Mostly aggregated results** and, in many cases **without** provision of **techno-economic assumptions**

- **Lack of** information in literature of important **infrastructure parameters**, e.g., hydrogen pipeline length, number of trucks for hydrogen transport => no meta-analysis possible

- Regarding **electric charging** studies: **lack of** studies concerning high xEV **penetration scenarios**, **investment** for infrastructure build-up, **demand for fast-charging and impacts on the distribution grid**
META ANALYSIS

Hydrogen Infrastructure – Vehicle Specific Cumulative Investment

- Cumulative investment differs significantly due to different assumptions e.g. consideration of power plant investment or number of fueling stations
- Specific cumulative investment per FCEV in the range of €2,000 to 4,000 per FCEV
- Expected decreasing specific investment per FCEV with increasing FCEV stock (due to learning curve and economy of scale) is not observed

*Including investment for power plants for upstream electricity production

McKinsey – EU&CH&NO, IEA - worldwide
META ANALYSIS

Electric Charging Infrastructure – Vehicle Specific Cumulative Investment

According to specific cumulative infrastructure investment per BEV is approx. € 500 per BEV stable for small BEV stocks.

Highest specific investment per BEV occur in the 30 million BEV scenario by Grube et al. => investment for additional grid reinforcements considered and high number of charging points (on-street and additional fast charging).
HYDROGEN SUPPLY PATHWAYS
NUMBER OF BEV AND CHARGING POINTS

- Number of overnight chargers (Mode 1 & 2) increases with BEV number but with decreasing ratio:
  - 1 by 1 in the first two scenarios (all BEV have an overnight charging option)
  - 1 by 2 in the last scenario (only 58% of all BEV have an overnight charging option)
- The ratio of BEV per Mode 4 charger increase due to decreasing charging frequency caused by higher driving range (battery capacity)
<table>
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<tr>
<th></th>
<th>Ramp up</th>
<th>Mass market</th>
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<tbody>
<tr>
<td></td>
<td>0.1 million</td>
<td>3 million</td>
</tr>
<tr>
<td>cable length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>transformer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>slow chargers</td>
<td>1,800 km</td>
<td>28,000 km</td>
</tr>
<tr>
<td></td>
<td>6,100</td>
<td>55,000</td>
</tr>
<tr>
<td>fast chargers</td>
<td>100,000 @ 3.7 kW</td>
<td>2.8 million</td>
</tr>
<tr>
<td></td>
<td>6,000 @ 150 kW</td>
<td>81,000</td>
</tr>
<tr>
<td>storage capacity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>electrolysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 TWh</td>
<td>5 TWh</td>
</tr>
<tr>
<td></td>
<td>3 GW</td>
<td>10 GW</td>
</tr>
<tr>
<td>truck trailer</td>
<td>42</td>
<td>730</td>
</tr>
<tr>
<td>pipeline</td>
<td>12,000 km</td>
<td>12,000 km</td>
</tr>
<tr>
<td>fueling</td>
<td>400</td>
<td>1,500</td>
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TOTAL CUMULATIVE INVESTMENT

Hydrogen Infrastructure

cumulative Investment [billion €]

Production | Storage and Distribution | Fueling

GH2 Trailer | GH2 Pipeline | Pipe/Trailer | LH2 Trailer | GH2 Trailer | GH2 Pipeline | Pipe/Trailer | LH2 Trailer

0.5 | 5.5 | 4.2 | 0.6 | 1.9 | 8.4 | 6.1 | 2.5

0.1 million FCEV | 1 million FCEV | 20 million FCEV

44.1 | 46.3 | 40.0 | 43.9
TOTAL AND SPECIFIC INVESTMENT

Charging Infrastructure

- Total investment (in million €)
- Invest per BEV (in €)

Charts showing the distribution of investment across different BEV levels:
- 0.1 million BEV: 311 million €, 3,112 € per BEV
- 1 million BEV: 2,834 million €, 2,834 € per BEV
- 20 million BEV: 50,538 million €, 2,527 € per BEV

Pie charts showing the specific investment:
- Home.M1+M2: 36% (33% of 20%)
- Street.M1+M2: 28% (20% of 4%)
- Pblc.M3: 36% (9% of 6%)
- City.M4: 20% (6% of 9%)
- Mtwy.M4: 25% (5% of 9%)
- EMS: 23% (8% of 23%)
- Transformers: 20% (4% of 20%)
- Cables: 8% (2% of 8%)

Institute of Electrochemical Process Engineering IEK-3
Hydrogen more expensive during the transition period to renewable electricity-based generation

High market penetration: battery charging needs more investment than hydrogen fueling

For both infrastructures investment low compared to other infrastructures

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<th>Infrastructure Roll-Out</th>
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<table>
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<th>Investment [€ billion]</th>
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<tr>
<td>Renewable electricity generation scenario</td>
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<tr>
<td>Electric grid enhancement plan 2030</td>
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<tr>
<td>Federal transport infrastructure plan 2030</td>
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<tr>
<td>Hydrogen fueling infrastructure</td>
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<tr>
<td>Electric charging infrastructure</td>
</tr>
</tbody>
</table>
For small vehicle fleets, i.e. 0.1 million cars, BEV fuel costs are significantly lower compared to FCEVs.

Increase for hydrogen between 1 and 3 million cars results of switching to exclusive utilization of renewable energy for hydrogen production via electrolysis.

Mobility costs per kilometer are roughly same in the high market penetration scenario at 4.5 €ct/km for electric charging and 4.6 €ct/km => the lower efficiency of the hydrogen pathway is offset by lower surplus electricity costs.
CO₂ EMISSIONS & ELECTRICITY DEMAND

- **Efficiency** of charging infrastructure is **higher**, but **limited in flexibility** and use of surplus electricity.
- Fueling infrastructure for **hydrogen** with **inherent seasonal storage** option.
- **Low** specific CO₂ **emissions** for **both options** in high penetration scenarios with advantage for hydrogen, well below the EU emission target after 2020: 95 gCO₂/km.
CONCLUSIONS

• Hydrogen and controlled charging key to integration of renewable electricity in transportation

• Complementary development of both infrastructures maximize energy efficiency, optimize the use of renewable energy and minimize CO₂ emissions

• Hydrogen infrastructure roll-out for transportation sector enables further large-scale applications in other sectors

NEED FOR FURTHER RESEARCH

• Integrated analysis of infrastructures and energy systems to identify win-win situations

• Modeling of BEV charging require in depth analysis: high uncertainties regarding number of chargers, siting and impact of fast charging on electric distribution grid

• Analyze the impact of new mobility and vehicle ownership concepts as well as autonomous driving on future transport supply concepts
Full Report Available:

http://hdl.handle.net/2128/16709

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REFERENCES


