Electricity-based fuels as a link between the electricity and transport sectors

Alexander Tremel, Siemens Corporate Technology

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Low cost renewable energy is a new opportunity for the decarbonization of the transportation sector

Challenge: decarbonization of transportation sector

GHG emissions in Europe

Transport
Energy
Industry

1990 = 100
125
100
75
50
1990 2000 2010

Climate protection plan of German government (Nov 2016)
GHG emission from transportation (Germany)

163 Mt CO₂-Eq.
1990

25 years

164 Mt CO₂-Eq.
2015

-40%

97
2030

15 years

Opportunity: low cost renewable electricity

Worldwide renewable power generation projects

Photovoltaics
Onshore wind
Offshore wind

Chile
published: 2017
price: €2,2 ct/kWh

Morocco
published: 2016
price: €2,7 ct/kWh

Germany
published: 2016
price: €4,4 ct/kWh

Further expected cost decline\(^1\) of solar PV by 59%, and onshore wind by 26%, all by 2025

Wind and solar PV become the cheapest ways of producing electricity in many countries during the 2020s and in most of the world in the 2030s (BNEF\(^2\))

...but local energy system integration as challenge & not always local electricity demand

\(^1\) IRENA (2016) – The Power to Change: solar and wind cost reduction potential to 2025
The decarbonization of long distance, heavy weight & marine transport and aviation requires CO₂ neutral fuels with high energy density

Challenge: the decarbonization of the transportation sector (23% of global greenhouse gas emissions)

Pathways for decarbonization

<table>
<thead>
<tr>
<th>Direct electric</th>
<th>Battery electric vehicles</th>
<th>Hybrid vehicles</th>
<th>Liquid fuels</th>
</tr>
</thead>
<tbody>
<tr>
<td>2%</td>
<td>46%</td>
<td>28%</td>
<td>12%</td>
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Global transportation energy, 2012¹

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CO₂ neutral fuels needed

Reasoning

▪ Electric cars are preferred for individual transport – but would require car users to adjust their expectations for travel distances and charging times.²

▪ Due to battery capacity limits (very high cost, additional weight - even in the long term), battery only vehicles are not a realistic option for the other transportation modes.²

▪ Liquid fuels will be the dominating source of transportation energy¹ (e.g. still a share of 88% in 2040).

▪ The European Commission³ already indicated that food-based biofuels have a limited role after 2020

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³ European Comission (2016) – A European Strategy for low-emission mobility
Electricity-based fuels have the lowest greenhouse gas emissions compared to other liquid fuel options

Life cycle greenhouse gas emissions of different fuel options

Overall process efficiency decreases when hydrogen is further converted in downstream synthesis plants.

Realistic process efficiency considering economic perspective

Simulation parameters:
- Electrolysis efficiency: 4.5 kWh/Nm³ (average during operation)
- H₂ loss: 1%
- Aux. power consumption: dependent on synthesis
- Synthesis efficiency: dependent on synthesis (thermodynamic limit as reference)

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Page 5 January 2018

Alexander Tremel, CT REE ENS
Methanol is liquid synthesis product with already good fit to existing infrastructure and relatively low cost

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### Multi-objective product evaluation based on quantitative and qualitative parameters (starting point: hydrogen)

#### Economics

<table>
<thead>
<tr>
<th>Production cost of synthetic product, value (conventional / green), plant CAPEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNG</td>
</tr>
<tr>
<td>Ammonia</td>
</tr>
<tr>
<td>DME</td>
</tr>
<tr>
<td>FT diesel</td>
</tr>
<tr>
<td>Methanol</td>
</tr>
</tbody>
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#### Technology

<table>
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<th>Technology fit to “Power-to-Fuel use case” (smaller scale, complexity, flexible, efficiency)</th>
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#### Acceptance

<table>
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<th>Evaluated by infrastructure fit, health and environment issues, energy density</th>
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1) Energy density for transport not an issue for SNG; Infrastructure 100% in place

### Summary: Methanol with highest score

- Evaluation based on green field plant without existing infrastructure (exception see footnote)
- Detailed evaluation is site and customer specific and may result in deviating outcome

#### Total score (0-10 points):

<table>
<thead>
<tr>
<th>Product</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNG</td>
<td>5.7</td>
</tr>
<tr>
<td>Ammonia</td>
<td>4.1</td>
</tr>
<tr>
<td>DME</td>
<td>5.6</td>
</tr>
<tr>
<td>FT diesel</td>
<td>6.4</td>
</tr>
<tr>
<td>Methanol</td>
<td>7.6</td>
</tr>
</tbody>
</table>

Power-to-Fuel plants as missing link for electricity-based fuels and the utilization of the existing liquid fuel infrastructure

Renewables (on-grid / off-grid)

200 MW wind farm
560 GWh_{el}

Power-to-Fuel Plant

Integrated plant

Electrolysis

Hydrogen storage

CO₂

Chemical synthesis

Fuel

280 GWh Green Fuel

Liquid fuel infrastructure

Air traffic

Airbus A320

8.7 mil. km air mileage
fleet with 6 planes

Road transport

Scania G410

85 mil. km road mileage
fleet with 2000 trucks

Private transport

520 mil. km road mileage
fleet with 50,000 cars
Electricity-based fuels can link energy systems worldwide with benefits for exporting and importing countries.

Regions with demand for energy import and with decarbonization targets:
- **LCOE**: ~5 ct/kWh
- **Efficiency**: ~50%
- **e-fuel**: ~10 ct/kWh + high CAPEX
- Local weather conditions
- Usage competition (e-mobility, Power-to-Heat)
- Land constraints
- Low plant capacity factor
- Rather smaller scale

Power-to-Fuel plant: Efficiency ~50%

Regions with very good weather conditions:
- **LCOE**: ~2 ct/kWh
- **Efficiency**: ~50%
- **e-fuel**: ~4 ct/kWh + lower CAPEX
- Good weather conditions
- No usage competition (e-mobility, Power-to-Heat)
- Land availability
- High plant capacity factor
- Large scale

Power-to-Fuel plants
South Australia with good wind and solar conditions as an example for Power-to-Fuel system layout and operation

Case Study: Power-to-Fuel plant in Australia in the next 5-10 years

Location for pre-feasibility study
- South Australia
- Good solar conditions: 1680 FLH
- Good wind conditions: 3500 FLH
- CO₂ capture from flue gas is assumed

Methodology for optimized plant layout and operation

<table>
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<tr>
<th>Weather data based on Meteonorm</th>
<th>Time resolved PV power generation</th>
<th>Time resolved energy &amp; mass balance of the process (transient)</th>
<th>Specific cost of all components as input</th>
<th>Cost optimal design of component sizes</th>
<th>Derivation of optimized plant operation</th>
<th>CAPEX &amp; OPEX calculation</th>
<th>Fuel production cost</th>
</tr>
</thead>
</table>

1 CO₂ cost of 50 EUR/t are assumed, in line with Rubin et al. (2015)
Lowest fuel production costs are enabled by curtailment, by intermittent plant operation, and relatively low capacity factors

Highest efficiency

- No curtailment
- Large hydrogen storage
- Continuous synthesis operation

Lowest production cost

- Curtailment
- Small hydrogen storage
- Flexible synthesis operation

Future techno-economic parameters, e.g.
- Renewables: 400 EUR/kW (PV), 900 EUR/kW (wind) | Electrolysis: 500 EUR/kW, 4.5 kWh/Nm³ | Hydrogen storage: 286 EUR/kg | Chemical synthesis: 450 EUR/kW HHV
- WACC: 7-8%; lifetime: 20-25 years

- 2 400 EUR/kW and 900 EUR/kW are ca. 50% lower than today’s lowest prices given by IRENA (2017)
- 3 Future parameters (2025/30) according to E4Tech (2013)
- 4 Kruck et al. (2015) HyUnder project
- 5 Tremel et al. (2015)
Local conditions in several places around the world will enable e-fuel production cost around 1 EUR/l gasoline equivalent in the next 5-10 years.

Power-to-Fuel plants around the world – optimized for future boundary conditions (2025/2030)

- Direct connection to solar photovoltaics, onshore wind and low cost hydropower enable the lowest e-fuel production cost.

Locations and energy source:

- Germany (Grid-connected),
- Morocco (Onshore wind),
- Chile (Offshore wind),
- Germany (Hydropower),
- CO2 from air
- Dubai (PV),
- South Australia (Wind & PV).

E-fuel production cost:

- Grid-connected plant and offshore wind with significantly higher cost.
- Many plants in the 0.9 to 1.1 EUR/l range.

Electricity-based fuels might be cost competitive to biofuels in the future, and could result in lower CO₂ reductions cost. Production costs and CO₂ reduction potential of electricity-based fuel.

Today’s European price level in summer 2017

* Murphy and Kendall, 2014
Electricity-based fuels could be a future important link between the electricity and transport sectors, but require regulatory support in front running countries.

**Summary and final remarks**

The decarbonization of long distance, heavy weight & marine transport and aviation requires CO₂ neutral fuels with high energy density.

The Power-to-Fuel technology can utilize low cost electricity (< 3 ct/kWh) at locations with good solar and wind conditions and can provide CO₂ neutral fuel that is compatible with today’s liquid fuel infrastructure.

Process and plant design is a challenge due to the fluctuating energy input. A high operational flexibility and low specific cost of electrolysis and chemical synthesis are the key to improve the overall plant economics.

Electricity based fuels might be cost competitive to biofuel in the future (50 MW+ scale), have a very low carbon footprint, and have the potential to result in lower CO₂ avoidance cost.

Since significantly higher costs in the market introduction phase are expected, larger scale demonstration plants and a suitable regulatory framework (e.g. blending quota) in front running countries are needed.
Thank you for your kind attention!

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