**Key Assumptions**

- **Chapter 1 (Potential):** e-Fuels are a necessity to reach long term goals decarbonization goals as set during COP 21.

- **Chapter 2 (Technology):** The e-Fuels technology is ready for deployment and requires almost no adaptation of infrastructure.

- **Chapter 3 (Costs):** e-Fuels can already be economically competitive with renewable fuel solutions (=bio-parity). Fossil parity is expected by 2050 latest.
Market Potential
e-Fuel: A Necessity for Transport to Tackle Climate Change

To achieve CO\textsubscript{2} reduction targets, fossil fuels need to be phased out

Hard-to-electrify sector will make up 50\% or 5,000 PJ in 2050

>300 GW of e-Fuels needed in 2050 (>10 GW/a from now)

Calculation based on dena/LBST „E-Fuels - The potential of electricity based fuels for low emission transport in the EU“, 2017
Achievable air mileage for an A320neo per ha of land

- **Zero cost** for infrastructure

- **8x more efficient use of land area** compared to biological alternatives

- **85% reduction in CO$_2$ emissions** compared to fossil fuel

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**Source:** German Federal Environment Agency - *Power-to-Liquids, September 2016*  
e-Fuel as Enabler for Renewable Energy Build Up

+ North-East Norway could cover >20% of EU transport sector power demand
+ On-site transformation to e-Fuel allow for transport and storage
+ Increases potential

*Values refer to On-Shore Wind Power Potential Source: NVE
Technology
e-Fuels: Two Main Conversion Pathways Available

**Fischer-Tropsch Pathway**
- e-Diesel
- e-Gasoline
- e-Jetfuel
- e-Waxes

**Methanol Pathway**
- e-Methanol
- e-Jetfuel
- e-OME

Carbon Capturing
Renewable Electricity

\( \text{CO}_2 \text{ from unavoidable sources} \)
Technology Comparison: Fischer-Tropsch Pathway

**CONVENTIONAL PROCESS**

1. \( H_2O \rightarrow \) Reverse Water-Gas Shift Reactor
2. \( \rightarrow CO+H_2 \rightarrow \) Fischer-Tropsch Synthesis Reactor
3. Achievable Efficiency* of 43% - 48%

*lower heating value of the fuel (620 kJ/kmol) compared to the electrical energy input

**ADVANCED PROCESS**

1. \( \rightarrow CO_2 \rightarrow \) Fischer-Tropsch Synthesis Reactor
2. Increased Efficiency* by +15% Points
3. Reduced CAPEX
4. 25% more Output

\( CO+H_2 \rightarrow e-Fuels \rightarrow \) Fischer-Tropsch Synthesis Reactor

10.09.2018
Technology Comparison: Methanol Conversion

CONVENTIONAL PROCESS

- Methanol Synthesis Reactor

Achievable Efficiency* of 43 % - 48 %

ADVANCED PROCESS

- Methanol Synthesis Reactor

Heat Recovery

✓ Reduced Catalyst Usage

✓ 20% more Output

Increased Efficiency* by +10 % Points

*lower heating value of the fuel (620 kJ/kmol) compared to the electrical energy input
Europe - Global leader in PtL development

Global Leader in CO₂ capture from air (TRL 6-7)
Climeworks, Switzerland / Germany

Global Leader in e-Methanol (TRL 8-9)
Carbon Recycling International, Iceland

Global Leader in green hydrogen generation (TRL 7-8)
Hydrogenics, Belgium / McPhy, France / ITM, UK

Global Leader in e-Crude via Fischer-Tropsch (TRL 6-7)
Sunfire and Ineratec, Germany

*TRL level based on sunfire assessment
Cost Comparisons
Cost Projections in Recent Studies

Long-term e-Fuel production costs for “sweet spots” (Fischer-Tropsch)

<table>
<thead>
<tr>
<th></th>
<th>year</th>
<th>PtL cost [€/MWh]</th>
<th>electricity [ct/kWh]</th>
<th>full load hours</th>
<th>efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBST&lt;sup&gt;1&lt;/sup&gt;</td>
<td>2016</td>
<td>~ 160</td>
<td>5,5</td>
<td>6.500</td>
<td>~ 45 %</td>
</tr>
<tr>
<td>UBA&lt;sup&gt;2&lt;/sup&gt;</td>
<td>2016</td>
<td>~ 140</td>
<td>4,0</td>
<td>3.750</td>
<td>~ 47 %</td>
</tr>
<tr>
<td>LUT&lt;sup&gt;3&lt;/sup&gt;</td>
<td>2016</td>
<td>~ 86</td>
<td>1,94</td>
<td>6.840</td>
<td>~ 57 %</td>
</tr>
<tr>
<td>Dena/LBST&lt;sup&gt;4&lt;/sup&gt;</td>
<td>2017</td>
<td>~ 100</td>
<td>3,4</td>
<td>6.840</td>
<td>~ 48 %</td>
</tr>
<tr>
<td>IWES&lt;sup&gt;5&lt;/sup&gt;</td>
<td>2017</td>
<td>~ 115</td>
<td>3,8</td>
<td>6.292</td>
<td>~ 48 %</td>
</tr>
</tbody>
</table>

1) Ludwig Bölkow Systemtechnik, Renewables in Transport 2050, 2016
2) UBA, Erarbeitung einer fachlichen Strategie zur Energieversorgung des Verkehrs bis zum Jahr 2050 (72/2016), 72/2016
4) Ludwig Bölkow Systemtechnik and Deutsche Energie-Agentur, E-Fuels – The potential of electricity based fuels for low emission transport in the EU, 2017
5) Fraunhofer IWES, “Mittl- und langfristige Potenziale von PTL- und H₂-Importen aus internationalen EE-Vorzugsregionen”, 2017

Spread of cost projections: 85 – 160 €/MWh

+ Studies converge for assumptions
+ Key driver for costs is the price of electricity and operation hours
+ Sunfire agrees with electricity costs, but sees lower full load hours and higher efficiencies
Cost Projections in Recent Studies

Cost of synthetic methane and liquid fuels in cent\textperthousand per kilowatt hour final product (without network charges and distribution cost)

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Agora Energiewende / Agora Verkehrswende, The Future Cost of Electricity-Based Synthetic Fuels, 2018
Cost Projections in Recent Studies

Production price range between 100-120 €/MWh (0.9-1.1 €/l) expected

Summary
Key Messages

- **Technology is ready** for deployment
- **Less sunk investment** through re-use of existing refining system and fuel infrastructure
- **Immediate CO₂-reduction** potential via blend in existing vehicle fleet
- **No-regret measure** to use e-Fuels in passenger mobility first, as long-term mandatory for aviation, navigation, heavy duty and chemical industry
- **Economically competitive** with renewable fuel solutions and long-term competitiveness with today’s fossil gasoline prices
- **Sufficient renewable power and CO₂ supply** in Europe available
THANK YOU!

ENERGY EVERYWHERE

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Backup

Details on the Fischer-Tropsch Pathway
Conversion: Three different Electrolysis Types (simplified)

**PEM electrolysis**

- Hydrogen membrane
- Efficiency: 50-60%\textsubscript{LHV} or 5-6 kWh/Nm\textsuperscript{3}
- Low temperature (<100\textdegree C)
- Flexible operation from part load to full load (0%-300%)

**Alkaline electrolysis**

- Hydroxide membrane
- Efficiency: 50-60%\textsubscript{LHV} or 5-6 kWh/Nm\textsuperscript{3}
- Low temperature (<100\textdegree C)
- Mature technology

**High-temperature (steam) electrolysis**

- Oxygen membrane
- Efficiency: 82%\textsubscript{LHV} or 3.7 kWh/Nm\textsuperscript{3}
- High temperature (850\textdegree C)
- Ability to electrolyse CO\textsubscript{2}
- Less mature, most promising economics
Fischer-Tropsch Pathway:  
Conventional Water-Electrolysis + RWGS + Synthesis

All values refer to energy conversion necessary for the production of 1 kmol of \(-\text{C}_x\text{H}_y\)- hydrocarbons

\[ \text{RWGS} + 41 \text{ kJ} \]
\[ \text{Water-Electrolysis} + 858 \text{ kJ} \]
\[ \text{Syngas} \]
\[ \text{LHV of fuel} + 619 \text{ kJ/kmol} \]

\[ \eta_{\text{max, theor}} = 69 \% \]

lower heating value of the fuel (620 kJ/kmol) compared to the electrical energy without any parasitic losses

\[ \eta_{\text{max, real}} = 43 - 48 \% \quad \text{BENCHMARK} \]
Fischer-Tropsch Pathway: Step 1 Improvement: Seam-Electrolysis + RWGS + Synthesis

Renewable electricity → RWGS + 41 kJ → CO₂ + H₂ → Syngas → Heat Recovery → - 147 kJ → e-Crude CₓHᵧ

SOEC steam-electrolysis achieves higher efficiency as waste heat can be used.

η_{max, theor} = 81 % calculated as before

η_{max, real} = benchmark + 10 % points parasitic loss for pressurization of H₂ is included

All values refer to energy conversion necessary for the production of 1 kmol of -CₓHᵧ- hydrocarbons

RWGS: Reverse-Water-Gas-Shift-Reaction
Fischer-Tropsch Pathway:
Step 2 Improvement: Co-Electrolysis + Synthesis

η_{max, theor} = 81 %
calculated as before

\eta_{max, real} = \text{benchmark} + 15 \% \text{ points}
parasitic loss for pressurization of H\_2 is included

Higher efficiency due to process integration and shift from catalytic to electro-chemical conversion

All values refer to energy conversion necessary for the production of 1 kmol of -C\text{x}H\text{y}- hydrocarbons

RWGS: Reverse-Water-Gas-Shift-Reaction
Sunfire Company

Impressions and Overview
Sunfire - Executive Summary

+ Leading provider of electrolyzers and fuel cells based on Solid Oxide Technology

+ Serving the emerging gigawatt markets for renewable gases and fuels (e-Fuels, e-Gas, e-Hydrogen)

+ Providing solutions for a variety of fuel cell market segments from micro to mini CHP

+ Delivering game-changer products through highest process efficiency and lowest equipment costs
Company Facts

Knowhow
- ~ 100 Employees
- Skills in Ceramics, Stack + System Production, Engineering, Synthesis Processes, etc.

Patents
- 46 patent families (e.g. »process patent sunfire« WO/2008/014854)

Recognition
- Cleantech 100 Company 2014/2015/2017/2018 (only fuel cell + electrolysis company)
- Fast Company Most Innovative Company of 2016 (with Tesla and Toyota)
- German Gas Industry’s 2016 Innovation & Climate Protection Award
- Kanthal Award 2017 for solutions in Sustainability, Quality of Life and Energy Efficiency

Revenues
- Multi-million Euro Revenues in Global Markets since 2011

Investors

[Image of logos: ELECTRANOVA CAPITAL, idinvest PARTNERS, INVIEIN CAPITAL, KFW, Total]
Impression

Sunfire Headquarter in Dresden

e-Fuels plant

Stack production

Test facilities
System Integrators and Customers Worldwide since 2011

Global industry leader in solid oxide technology
- Hundreds of systems installed
- Longest operation in customer applications
- Largest SOC electrolysis installer of the world