Synthetic renewable fuels potential, combustion and emissions

Dr.-Ing. Olaf Toedter
Motivation: Mobility Turnaround as Part of Fit for 55

CO₂ Accumulation limits remaining GHG budget

- GHG exchange processes are slow
- Releasing carbon from fossil sources adds CO₂ to the atmospheric system

400Gt CO₂eq budget in 2021

Separation by country and by segment

Motivation: Mobility Turnaround as Part of Fit for 55

CO₂ Accumulation limits remaining GHG budget

- Greenhouse gas “budget” is limited

- the German „Council of Environmental Issues“ states a residual budget for 2020 of
  - 4,2Gt CO₂eq to achieve Paris-goals (1,5°C @ 50%)
  - 6,6 Gt CO₂eq 1,75°C @ 50% identical to the targets from Climate Protection Act 2019 only changing the fleet doesn‘t meet the targets!

Motivation: Mobility Turnaround as Part of Fit for 55
Realization of mobility turnaround

- Results by changing the fleet as part of sector-specific targets

50% CO₂-reduction TTW would need
50% BEV

target of German government
15 Mio BEV/48 Mio cars=31%
24,3 Mio BEV/48,7 Mio cars=50%

1,1 Mio BEV @ 1.1.2023
23,2 Mio BEV in 7 years

3,3 Mio BEV / year
>100% of all new vehicles
Motivation: Mobility Turnaround as Part of Fit for 55
Does new Vehicle Registrations reflect the transition?

Vehicle Change in Germany using 10,000€ bonus

- Non-electrified ICE Vehicles
- Hybrid w/o Plug-In
- Plug-in-Hybrid
- Elektro (BEV)
- Fuel Cell

Graph showing vehicle change in Germany from 2016 to 2023, with categories for different types of vehicles.
Motivation: Mobility Turnaround as Part of Fit for 55
Does new Vehicle Registrations reflect the transition?

Fleet consumption challenge

new registrations BEV

Car manufacturers try their best to fulfill the regulation but overall GHG stays the same
Motivation: Mobility Turnaround as Part of Fit for 55
Is there enough room for new vehicle registrations?

Motorization Rate enables or limits fleet exchange speed

- Saturated markets don’t speed up fleet exchange
- Medium vehicle age in EU is 12 years and increasing
- Vehicle switch will not be fast enough for a to reduce GHG in time

[1]
Energy availability as decision factor for customers and professional users
Limiting the ramp up speed by limited raw materials

- Raw materials limit ramp up of BEV

No effect of any „mobility transition“ without „energy transition“

Beside of Steel and Aluminium IEA sees these materials as critical with regard to the energy transition
Motivation: Mobility Turnaround as Part of Fit for 55
Limiting the ramp up speed by limited raw materials

- Parallel transitions in energy, digitalisation and mobility ask for the same raw materials
Motivation: Mobility Turnaround as Part of Fit for 55
GHG neutral Mobility

■ Interim Balance:
• GHG residual Budgets asks for fast transitions
• Fleet Change is limited to ~6%/year
• Ramp up of Battery electric vehicle is limited by intensive use of raw materials
• Energy from renewable sources is the key and needs limited raw materials too

→ the greenhouse gas reduction through a fleet change has no chance of being fast enough!

→ Thinking from a higher-level System
a) Internal combustion engines are energy-conversion units
b) Not the engine is responsible for additional CO\textsubscript{2}-Emission but the use of fossil energy carrier
reFuels – potential synthesis pathes
Synthetic Fuels from a renewable Base

Organic residual and waste materials -> synthesis gas platform

- Hydrocarbons $C_xH_y$
  - Fischer-Tropsch
  - Methanol-synthesis

- Blending / Upgrading
  - reFuel-Diesel
  - reFuel-gasoline

Biogas
CH$_4$

CO
CO$_2$
H$_2$

Sabatier
cost-optimal allocation of Elektrolysis regarding RED II in 2030
Methanol-to Gasoline (MtG) – Blending of EN 228 fuels

- Optimization of production
- High aromatic content
- Red. light fraction
- Optimized aromatic content
- Red. light fraction
- Hydrated heavy fraction
- Hydrierated FT-wax
- ETBE + MTBE

Hydrierated MtO-gasoline
ETBE + MTBE from MtO

Target G100
Concept for gasoline fuels
reFuels – Fuel synthesis

Diesel fuels

- **Integrierted Synthesis-Container for fuel synthesis by Fischer-Tropsch from CO\textsubscript{2} and H\textsubscript{2}**
  - Integration of RWGS
  - Integration of the hydrogenation of the products
  - Integration of the separation of products
reFuels – Fuel synthesis
Refinery for Future REF4FU project

- Hydrogen
- FT-Green Crude
- MeOH

- Hydro-Cracking / -isomerisation
- Fractionation
- Naphtha
- Hydrotreatment
- Olefin-to-Jet
- Hydrofinishing
- Hydrofinishing
- Olefines
- Benzin
- Heavy Low
- Hydrotreatment
- Fractionation
- TRL 9
- TRL 5 - 6
- TRL < 5
- TRL 9

- Gasoline
- Kerosene
- Diesel
- Heavy Oil Diesel Fuel
- Chemical Intermediates

TRL
- TRL 9
- TRL 9
- TRL < 5
- TRL 5 - 6

Dr.-Ing. Olaf Toedter: Synthetic renewable fuels potential

Institut für Kolbenmaschinen
Prof. Dr. sc. techn. Thomas Koch
E-diesel and HVO have lower density than EN590 → EN15940 paraffinic diesel

EN15940 paraffinic Diesel will be implemented in German law (10. BImSchV)

Aromatic content of Methanol-to-gasoline fuel has to be aligned with Octane number
reFuels – testing
Large matrix of tested fuels

### Analysis of reFuels and their blends

<table>
<thead>
<tr>
<th>fuel</th>
<th>boiling [°C]</th>
<th>density [kg/m³]</th>
<th>ratio [% (V/V)]</th>
<th>RON</th>
</tr>
</thead>
<tbody>
<tr>
<td>E5</td>
<td>197,1</td>
<td>747,4</td>
<td>4,8 % Ethanol</td>
<td>95,0</td>
</tr>
<tr>
<td>G40</td>
<td>180,1</td>
<td>751,8</td>
<td>10 % E10 + 30 % bioliq® 2020 + 60% fossil gasoline</td>
<td>100,8</td>
</tr>
<tr>
<td>G85</td>
<td>173,7</td>
<td>762,9</td>
<td>85% regenerativ</td>
<td>95,2</td>
</tr>
<tr>
<td>bioliq®/10 2018</td>
<td>196,9</td>
<td>-</td>
<td>90 % E5 + 10 % bioliq® 2018</td>
<td>96,4</td>
</tr>
<tr>
<td>bioliq®/10 2019</td>
<td>197,1</td>
<td>-</td>
<td>90 % E5 + 10 % bioliq® 2019</td>
<td>96,0</td>
</tr>
<tr>
<td>bioliq®/30 2019</td>
<td>190,2</td>
<td>-</td>
<td>90 % E5 + 30 % bioliq® 2019</td>
<td>97,4</td>
</tr>
</tbody>
</table>

- Almost all fuels can be replaced by regenerative fuels in series production.
- No abnormalities in material compatibility.
- No conspicuity in raw emissions with optimized blends.
- No conspicuity in use.
- Secondary potential for emissions reduction.

<table>
<thead>
<tr>
<th>fuel</th>
<th>density [kg/m³]</th>
<th>ratio [% (V/V)]</th>
<th>Cetane number</th>
</tr>
</thead>
<tbody>
<tr>
<td>B0</td>
<td>833,1</td>
<td>100% fossil Diesel</td>
<td>53,5</td>
</tr>
<tr>
<td>B7</td>
<td>837,6</td>
<td>93% fossil Diesel + 7 % FAME</td>
<td>52,7</td>
</tr>
<tr>
<td>R33¹</td>
<td>821,0</td>
<td>7 % FAME + 26% BtL + 67% foss. Diesel B0</td>
<td>62,6</td>
</tr>
<tr>
<td>S33</td>
<td>821,0</td>
<td>7% FAME + 24% PtL + 69% foss. Diesel B0</td>
<td>59,9</td>
</tr>
<tr>
<td>R33²</td>
<td>821,9</td>
<td>7 % FAME + 26% BtL + 67% foss. Diesel B0</td>
<td>56,7</td>
</tr>
<tr>
<td>HVO</td>
<td>780,1</td>
<td>100% BtL</td>
<td>74,8</td>
</tr>
</tbody>
</table>
reFuels – testing
Wide spread of test vehicles and engines

- Positive analysis of reFuels and their blends in engines, vehicles and fleets

Test facility tests and in-system-conformity tests are necessary (RDE w/ PEMS)!
reFuels testing
HVO testing on aged train engines (cam-controlled injection systems)

- less particle mass but increased particle number → tends to produce more small particles
- comparable power even at cam – controlled injection systems
reFuels - testing
Tests with full cylinder engine on engine test facility

- WLTC results and RDE results are comparable
- Gaseous emissions with synthetic fuel - tends to be lower
- Evaporation curve as a major impact on particulate and gaseous emissions
reFuels - testing
Tests with full cylinder engine on engine test facility

- Reduced PN emissions with synthetic fuel - especially at cold conditions
- Particulate size distribution is comparable
**reFuels - testing**

Tests with full cylinder engine on engine test facility

- G40 & G85 show reduced particulate number with respect to E5 reference fuel

- Evaporation curve design by light synthetic fractiones helps to reduce particle emissions
- Aromatic content $\geq$ C9 as base point for particle formation
- Aromats necessary for Octane number
reFuels – testing
Fleet test C.A.R.E diesel as an example of EN15940 diesel

- Already covered over 1,000,000 km
- Parallel driving of B7 and HVO fueled trucks
- Short distance tours (inner city) and long distance tours
- Detailed engine oil analysis
  - Slightly reduced fuel consumption
  - Tends to lowe particulate emissions
reFuels – environmental balance
Life cycle assessment of vehicles

System Borders of life cycle assessment

Passenger Car

Production
- Wind
- Solar
- gas
- coal
- energy converter
- Infrastructure
- 150-180 Subsystems / components
- ecoinvent v3.8
- raw materials
- production processes
- Vehicle
- Powertrain
- Glider
- Masses

Use
- energy converter
- Infrastructure
- Fossil fuels / Power plant types
- Biofuels
- Fuel blend / Electricity mix
- energy consumption
- Emissions
- Maintenance

End-of-Life
- energy converter
- Infrastructure
- disposal
- recycling
reFuels – environmental balance
Life cycle assessment of vehicles

- emissions during the production and use of a diesel and a gasoline vehicle.

Neither vehicle production nor energy sources can be ignored.
Variation of the diesel fuel

- also as admixture (R33) a 22% CO₂ reduction in use
- app. 82% CO₂ reduction through e-fuel diesel in the fleet with electricity from offshore wind
- CO₂ reduction potential increases with availability of energy from regular sources → fav. locations
- Import of intermediates (Fischer-Tropsch crude and methanol) into existing refineries.
ReFuels – scaling production
International approaches for ReFuels production

- Import scenarios with transport of products by ship
  - Wind power: Enercon E112, weather data by Pfenninger und Staffell (2016)
  - PV: 1-axis-Tracking

- Marokko, Agadir
  - Hybrid PV-Wind, onshore
  - Capacity factor Wind 17 %, Solar PV 30 %

- Argentinia, Patagonia
  - Wind power, onshore
  - Capacity factor Wind 56 %

- Australien
  - Hybrid PV-Wind, onshore
  - Kapazitätsfaktor Wind 30 %, Solar PV 30 %

- Island
  - Windkraft, onshore
  - Kapazitätsfaktor Wind 45 %
Sensitivity Study of Life Cycle Assessment of reFuels

reFuels are CO$_2$-negative!

In combination with their usage the system can be CO$_2$-neutral

Environmental Potential of GHG-negative Fuels
**reFuels – the path to refineries**

**Modular Production Concept**

- **CO₂ Separation**
- **Electrolysis**
  - Methanization
  - Dry gas reforming
  - RWGS
- **Co-Electrolysis**
- **FT-Synthesis**
  - Destillation
  - Cat-Cracking
- **Co-Elektrolysis**
  - FT-crude

- **Diesel**
- **Kerosene**
- **By-products**
  - Methanol
  - MeOH
  - MOGD
  - MtG
  - Gasoline
  - Aromats

**TRL**
- TRL > 7
- TRL ≤ 6
- TRL < 6
Scalability of the Fuels Production

- Technology maturity needs scaling
- Scaling only works in steps
- Times determined by planning, approval and construction

Scaling of Synthesis Units is limited by Scaling Factor and Time

x ml/trial  | 1-100 l/a  | 1-1000 t/a  | 10,000 - 50,000 t/a  | > 500,000 t/a
Potential ramp up rate without fleet change is significant faster as shown in FVV Fuels Study IVb

Bottleneck effects are smaller than delay by changing the fleet
reFuels – scaling production
Fast Ramp-Up needs enough Energy

- Hot Spots for e-Fuels Production are globally distributed

Transportability of fuels allows use of the global favorable Sites
Example Chile shows potential in seasonability and continuity.
reFuels – scaling production

Fast Ramp-Up needs enough Energy

- Is there enough energy?

- “Reasonably Assured Recoverable Reserves“ of renewable Energy Resources compared to finite fossile Enerav Reserves

Efficiency is not the issue, transport and storage are the tasks

when regulatory constraints take physics into account, reFuels will come
We will not achieve Paris Climate Targets without the use of reFuels!

Thank you for your Attention
References