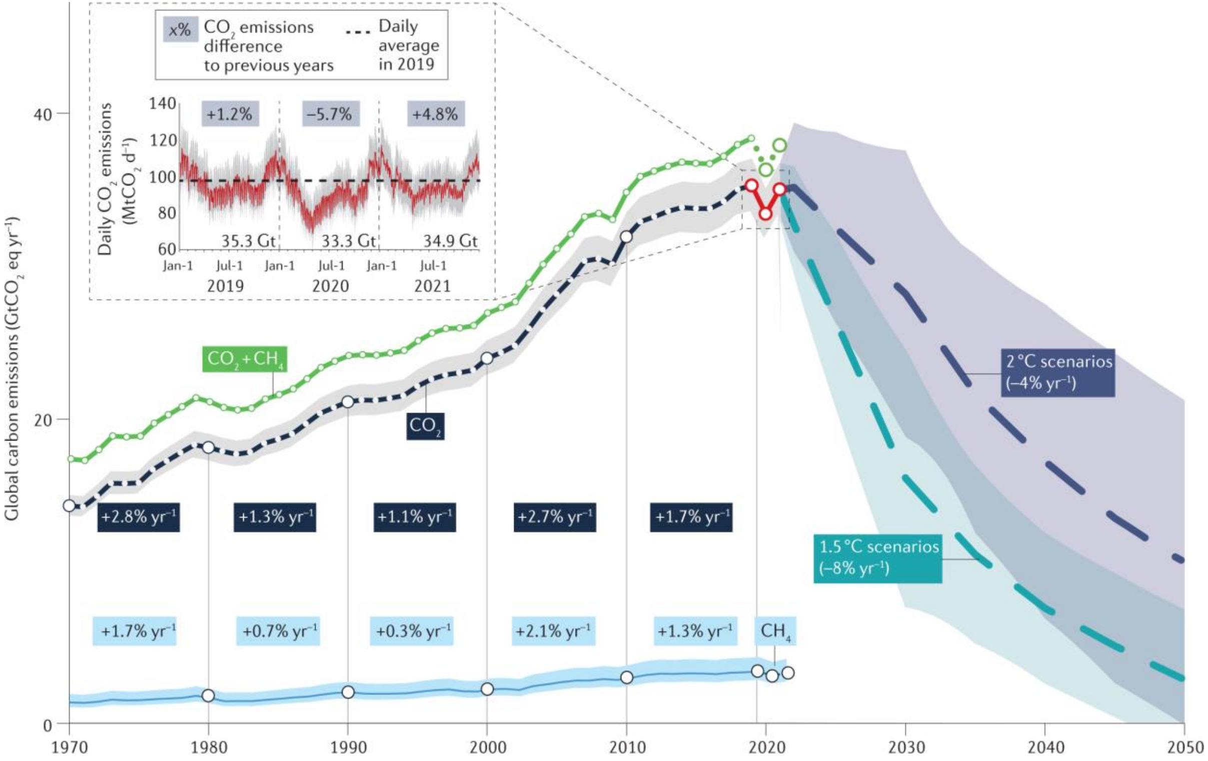
reFuels as necessary Element to achieve Paris Targets are ready

ECO-MOBILITY 2023

Dr.-Ing. Olaf Toedter


CO_2 Accumulation limits remaining GHG budget



Liu, Z., Deng, Z., Davis, S.J. et al. Monitoring global carbon emissions in 2021. Nat Rev Earth Environ 3, 217–219 (2022). https://doi.org/10.1038/s43017-022-00285-w

- GHG exchange processes are slow
- Releasing carbon from fossile sources adds CO_2 to the atmospheric system

→ 400Gt CO_{2eq} budget in 2021

Separation by country and by segment

reFuels as Part of Mobility Transition

Does new Vehicle Registrations reflect the transition?

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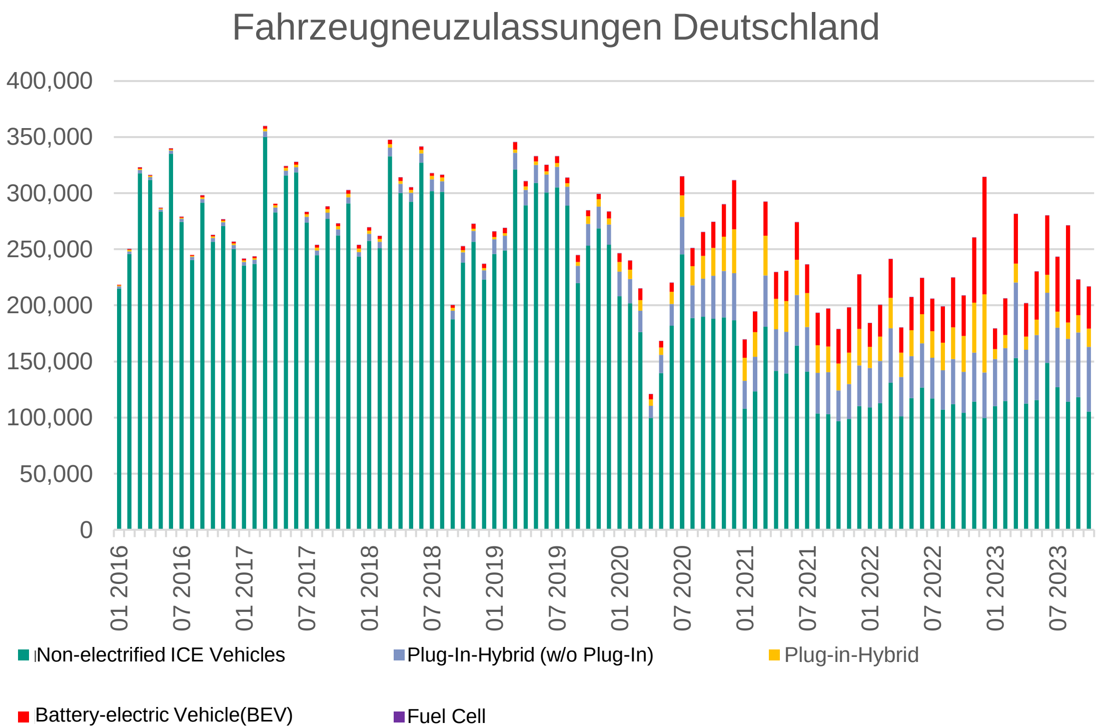
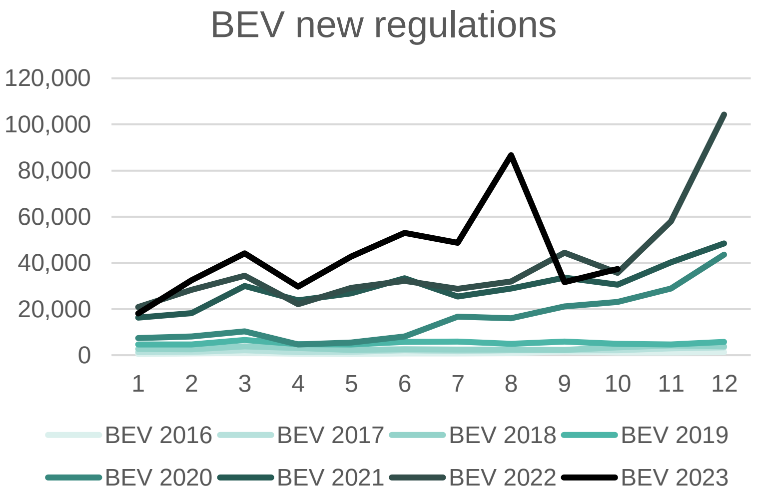
- New Vehicle Registrations in Germany





Data Source: KBA Germany

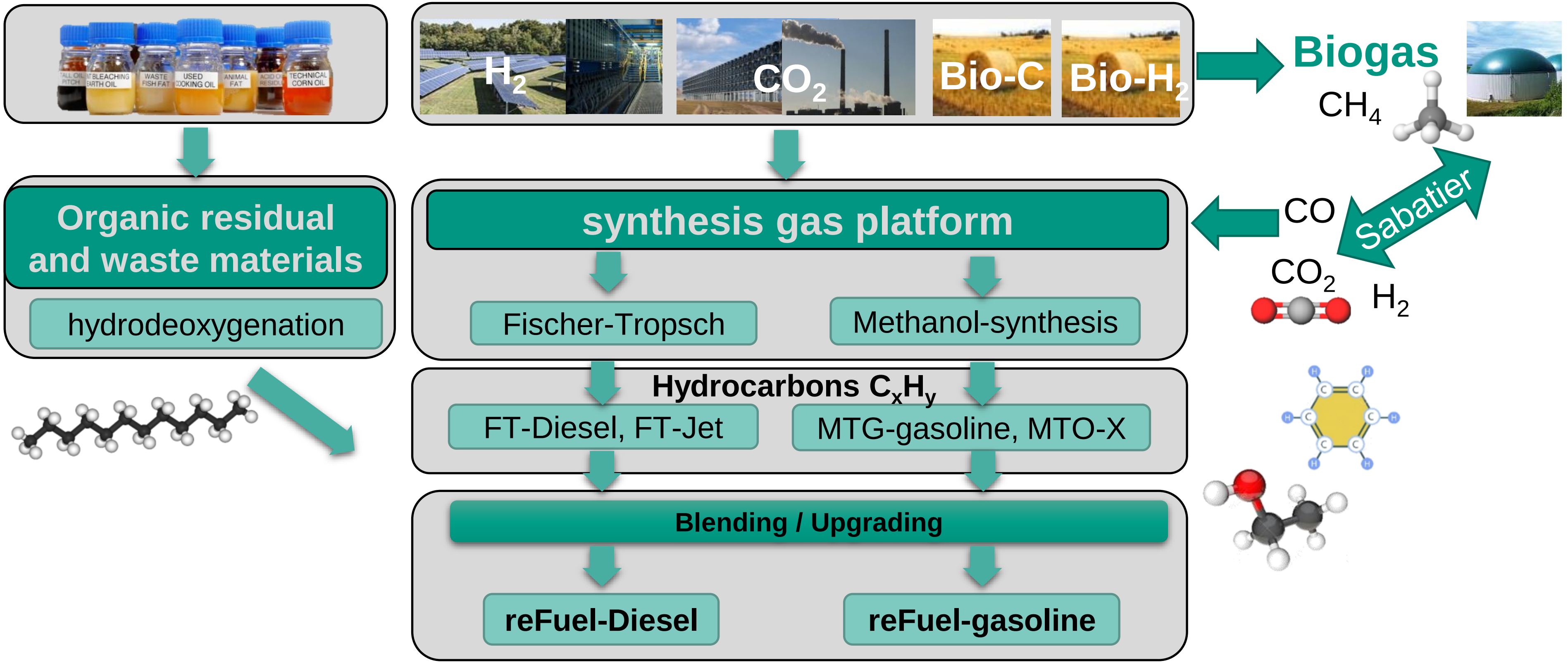
Hybrid w/o Plug-In

reFuels

Definition reFuels

reFuels comprise the group of fuels that are produced on the basis of non-fossil carbon and CO_2 sources, including advanced 2nd and 3rd generation biofuels, including in particular those hydrocarbons for whose production regeneratively produced hydrogen is used. reFuels are therefore the sum of all eFuels and biofuels and must be produced from renewable sources.

reFuels – potential synthesis pathes
Synthetic Fuels from a renewable Base



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reFuels – rethinking Fuels

From fossile to synthetic fuels

Foto: Amadeus Bramsiepe, KIT

- **E-diesel and HVO have lower density than EN590 → EN15940 paraffinic diesel**
- **MtG - gasoline must be processed so that the aromatics content is in EN228**
- **MtG – post treatment of heavy gasoline fraction to fit in EN228**

reFuels – testing

Large matrix of tested fuels

- Analysis of reFuels and their blends

fuel	boiling [°C]	density [kg/m^3]	ratio [%(V/V)]	RON
E5	197,1	747,4	4,8 % Ethanol	95,0
G40	180,1	751,8	10 % EtOH + 30 % bioliq® 2020 +60% fossil gasoline	100,8
G85	173,7	762,9	85% regenerativ	95,2
bioliq®/10 2018	196,9	-	90 % E5 + 10 % bioliq® 2018	96,4
bioliq®/10 2019	197,1	-	90 % E5 + 10 % bioliq® 2019	96,0
bioliq®/30 2019	190,2	-	90 % E5 + 30 % bioliq® 2019	97,4

fuel	density [kg/m^3]	ratio [%(V/V)]	Cetane number
B0	833,1	100% fossil Diesel	53,5
B7	837,6	93% fossil Diesel + 7 % FAME	52,7
R33[1]	821,0	7 % FAME + 26% BtL + 67% foss. Diesel B0	62,6
S33	821,0	7% FAME + 24% PtL + 69% foss. Diesel B0	59,9
R33[2]	821,9	7 % FAME + 26% BtL + 67% foss. Diesel B0	56,7
HVO	780,1	100% BtL	74,8

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

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reFuels – testing

Wide spread iof test vehicles and engines

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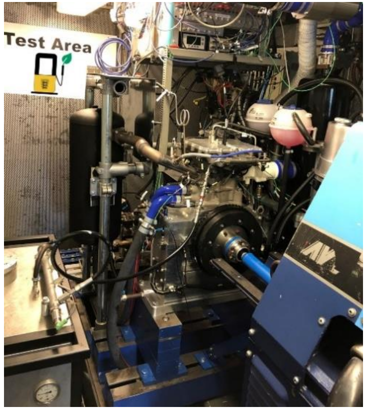
- Positive analysis of reFuels and their blends in engines, vehicles and fleets



➡ 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)

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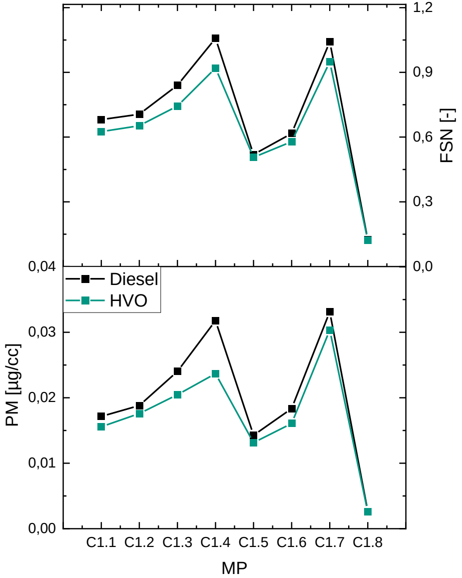
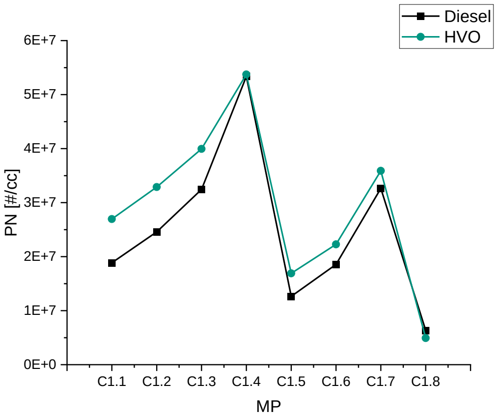
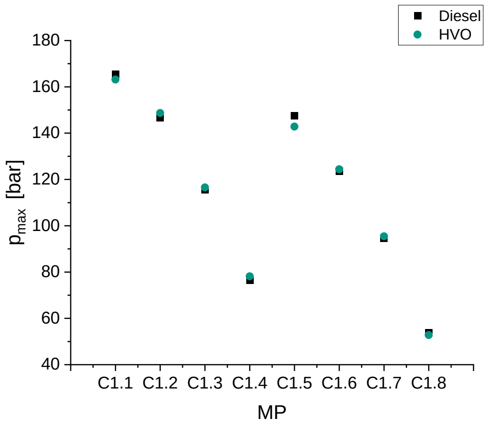
particle mass



particle number



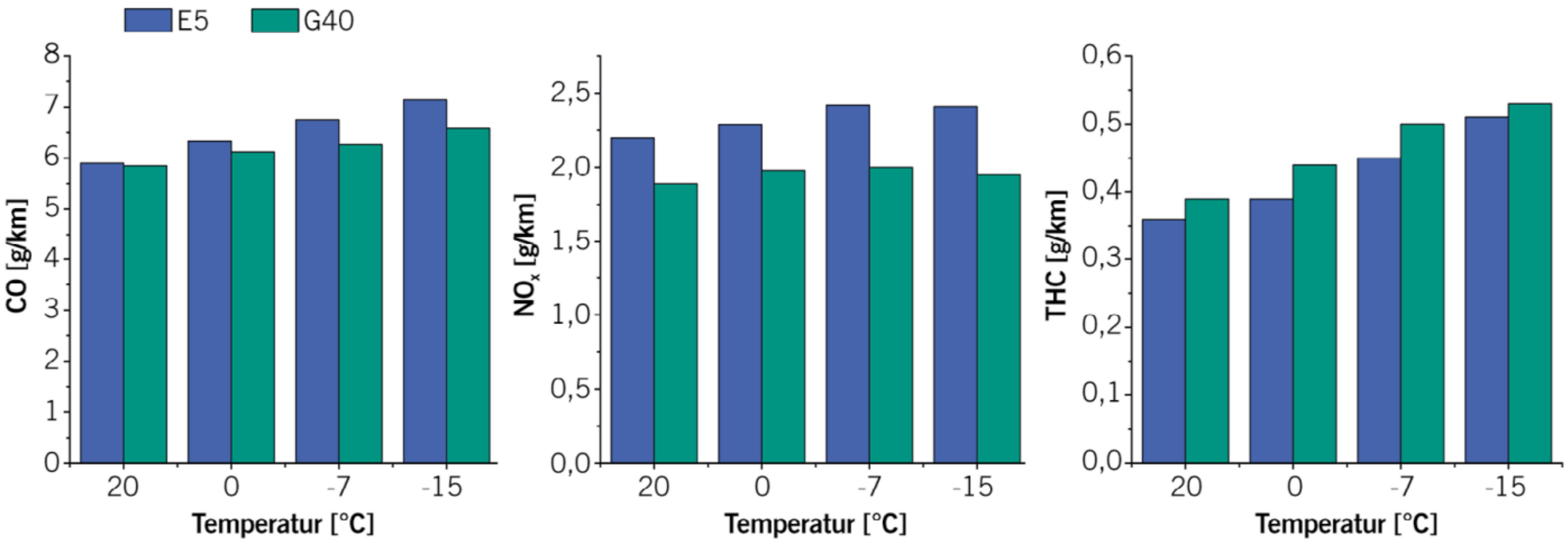
peak pressure



- less particle mass but increased particle number → tends to prduce more small particles
- comparable power even at cam – controlled injection systems

reFuels - testing

Tests with full cylinder enginge on engine test facility



- WLTC results and RDE results are comparable
- Gaseous emissions with synthetic fuel - tends to be lower
- Evapuration curve as a major impact on particulate and gaseous emissions

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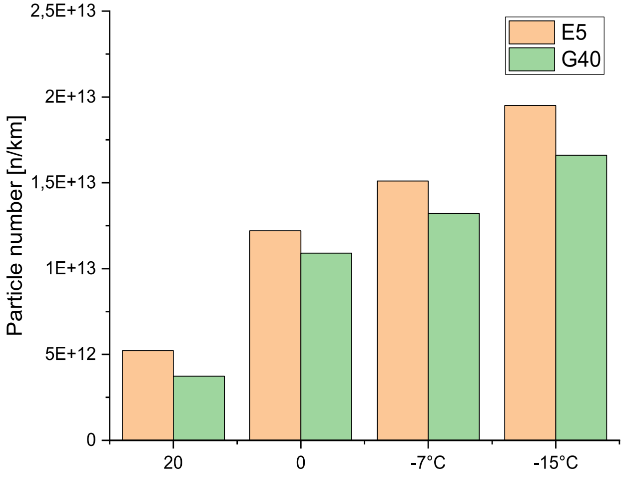
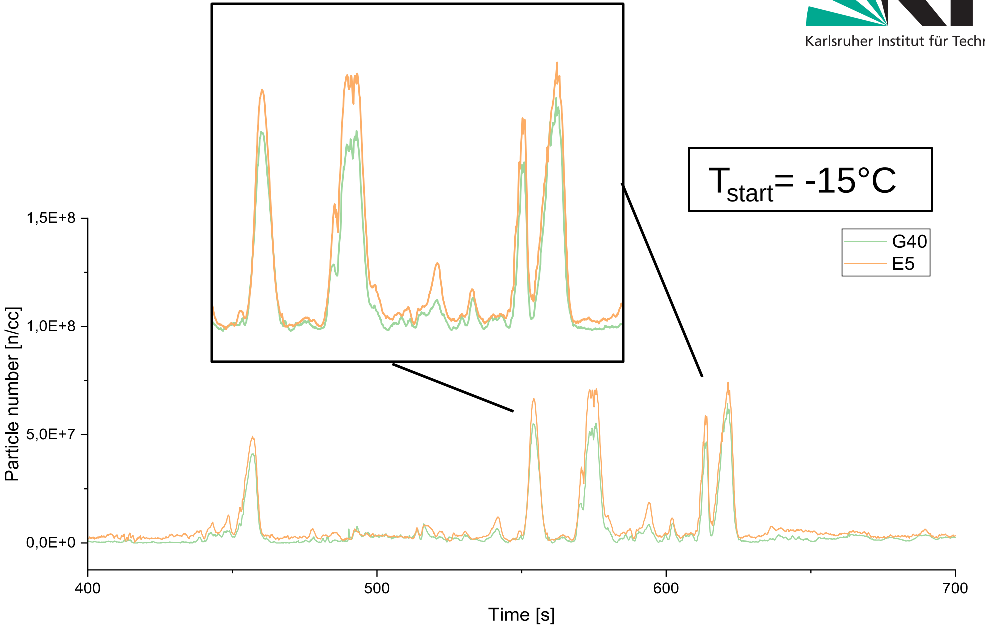
reFuels - testing

Tests with full cylinder enginge on engine test facility





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

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reFuels - testing

Tests with full cylinder enginge on engine test facility

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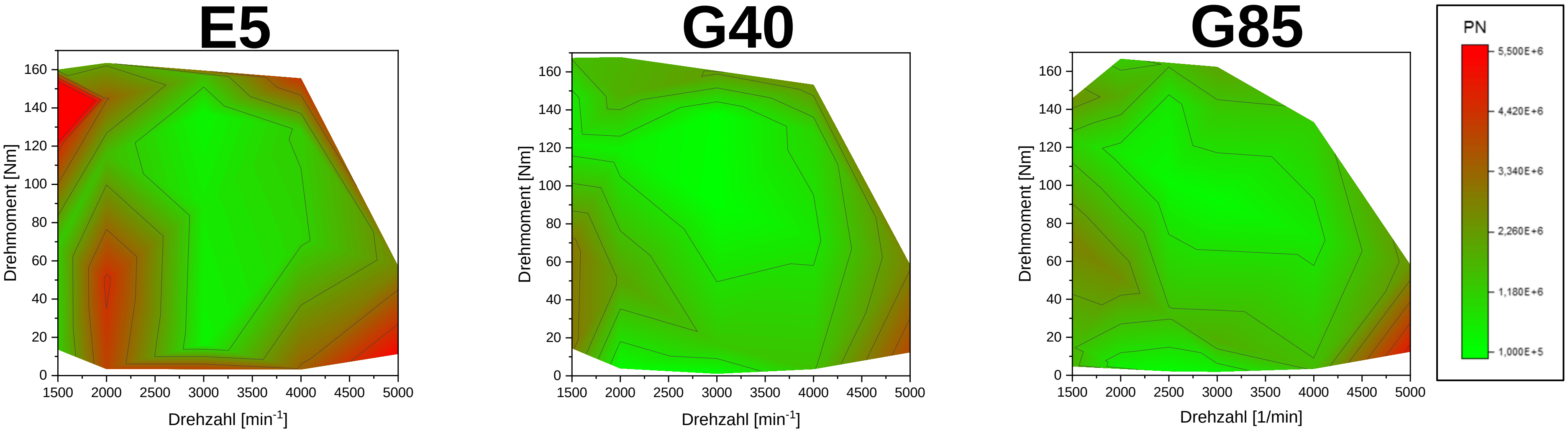
- G40 & G85 show reduced particulate number with respect to E5 reference fuel



- Evapuration curve design by light synthetic fractiones helps to reduce particle emissions
- Aromatic content >= C9 as base point for particle formation
- Aromats necessary for Octane number

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reFuels – testing

Fleet test HVO 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

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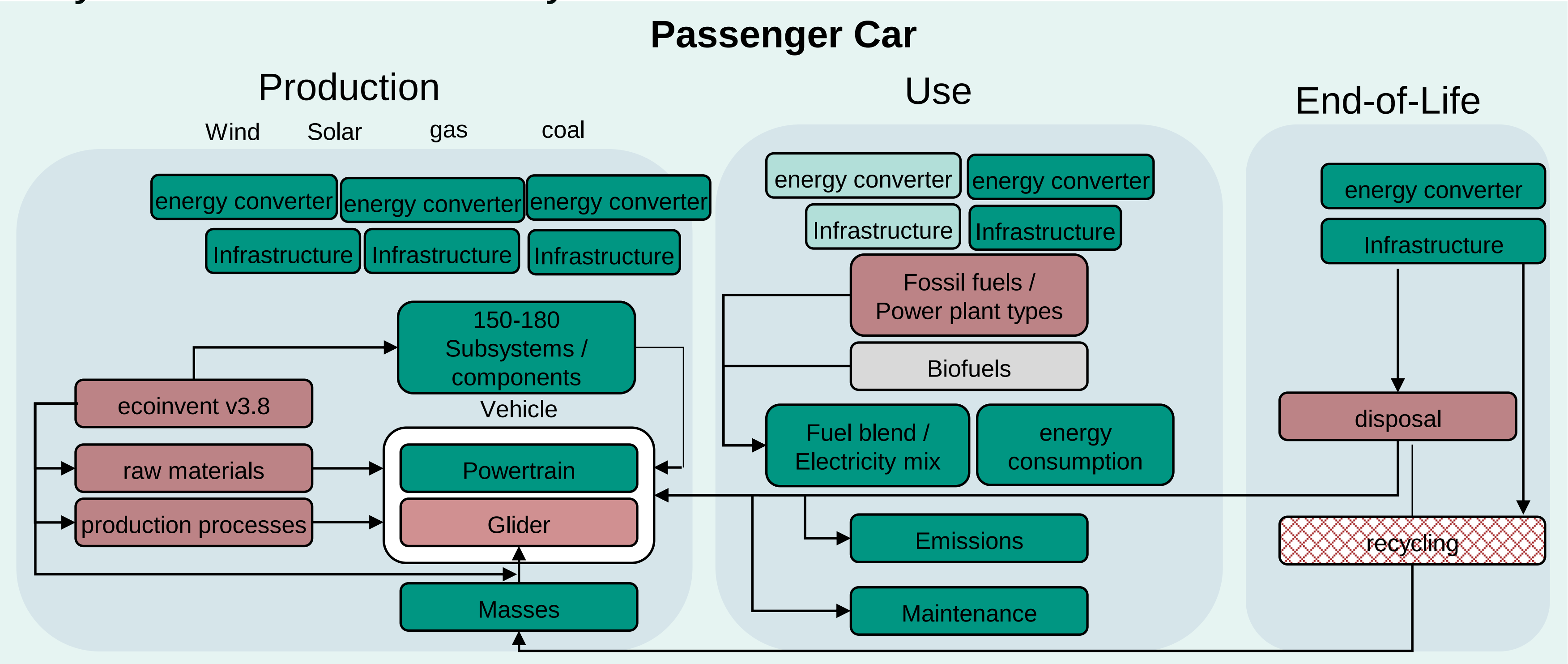
reFuels – environmental balance

Life cycle assessment of vehicles

- System Borders of life cycle assesment



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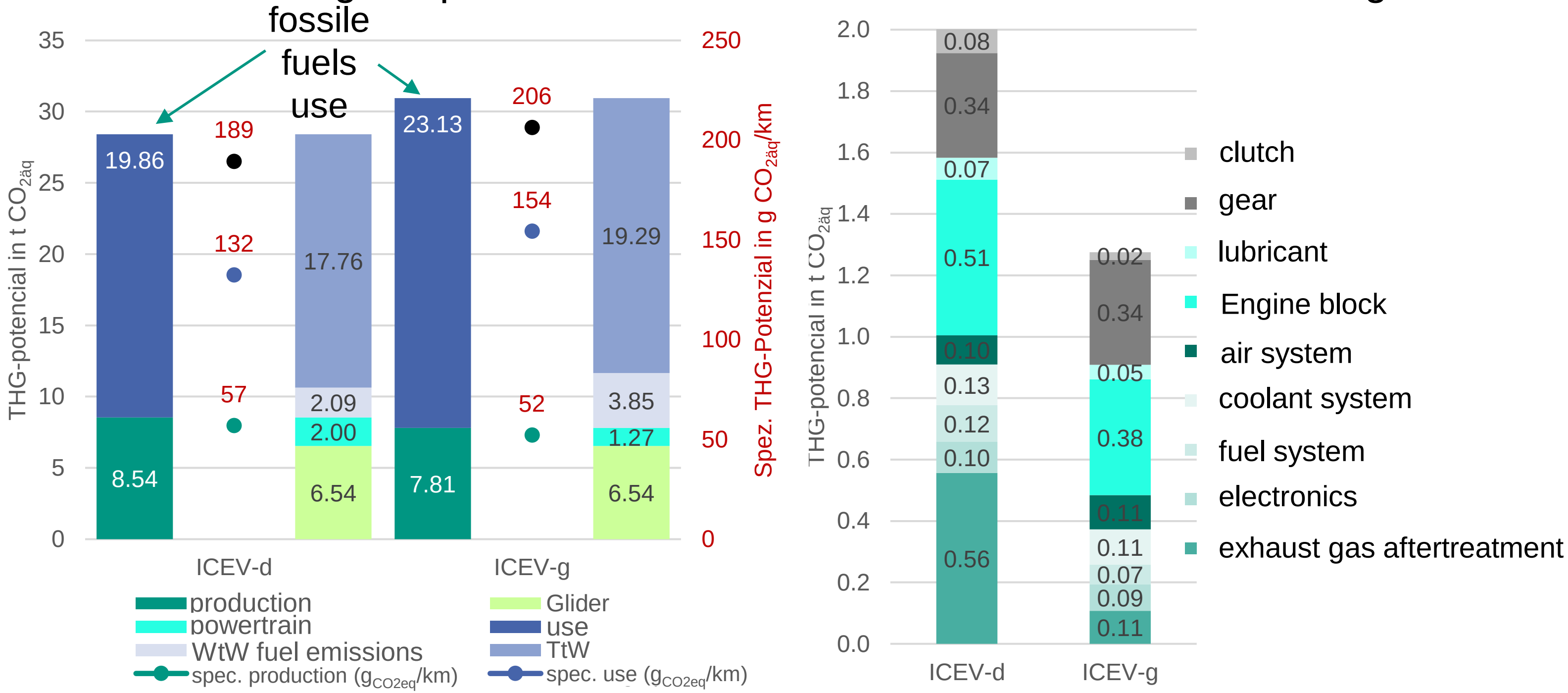
reFuels – environmental balance

Life cycle assessment of vehicles

- emissions during the production and 150.000 km use of a diesel and a gasoline vehicle.



➡ Neither vehicle production nor energy sources can be ignored

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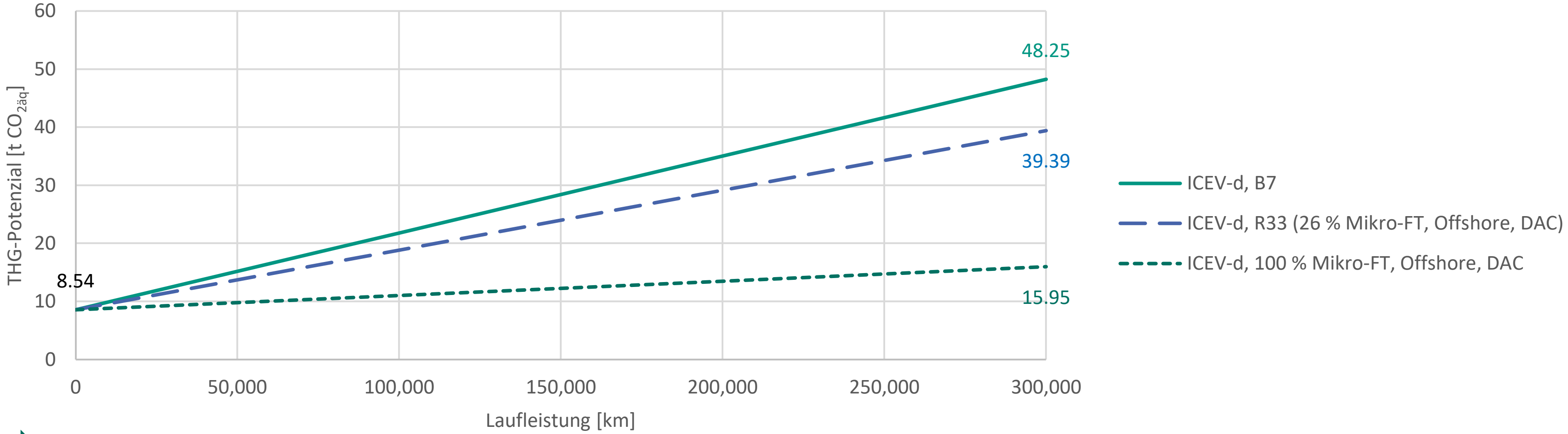
reFuels – environmental balance
LCA of vehicles using Diesel fuel and reFuels

- Variation of the diesel fuel



- also as admixture (R33) a 22% CO_2 reduction in use
- app. 82 % CO_2 reduction through e-fuel diesel in the fleet with electricity from offshore wind
- CO_2 reduction potential increases with availability of energy from regular sources → fav. locations
- Import of intermediates (Fischer-Tropsch crude and methanol) into existing refineries.

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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 %

Image source: Frontier economics, 2018

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reFuels – environmental analysis

Environmental Potential of GHG-negative Fuels

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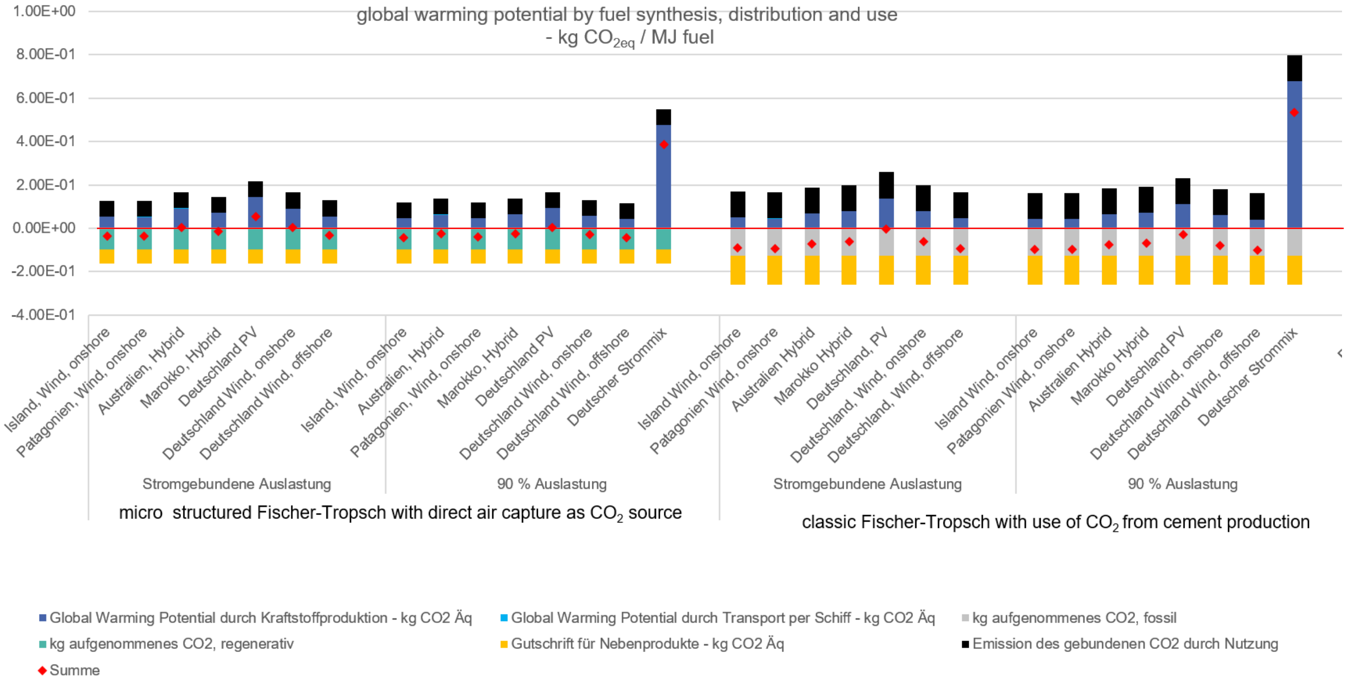
- Sensitivity Study of Life Cycle Assessment of reFuels



reFuels are **CO_2-negative**!
In combination with their usage the system can be CO_2-neutral

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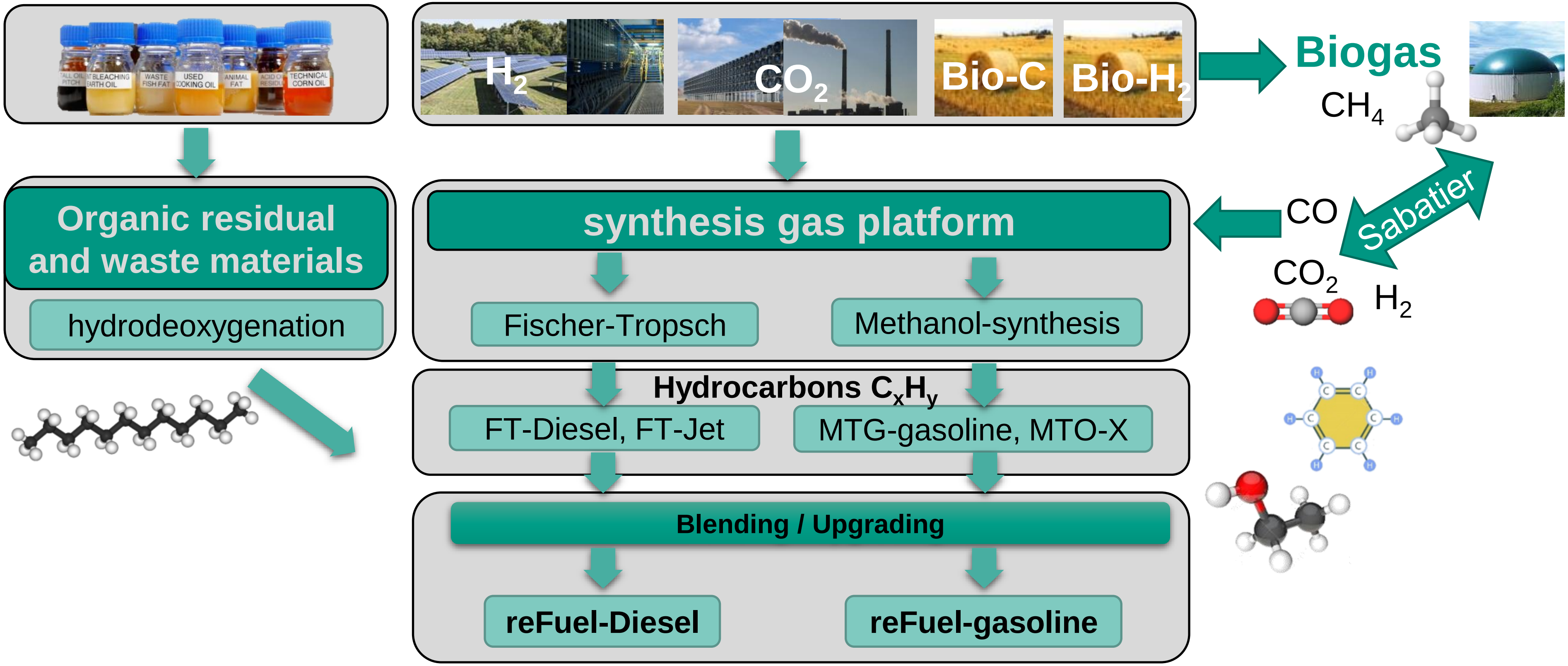
reFuels – potential synthesis pathes

Synthetic Fuels from a renewable Base



reFuels ramp-up

Significat production ramp-up - world-wide stronger development as in EU

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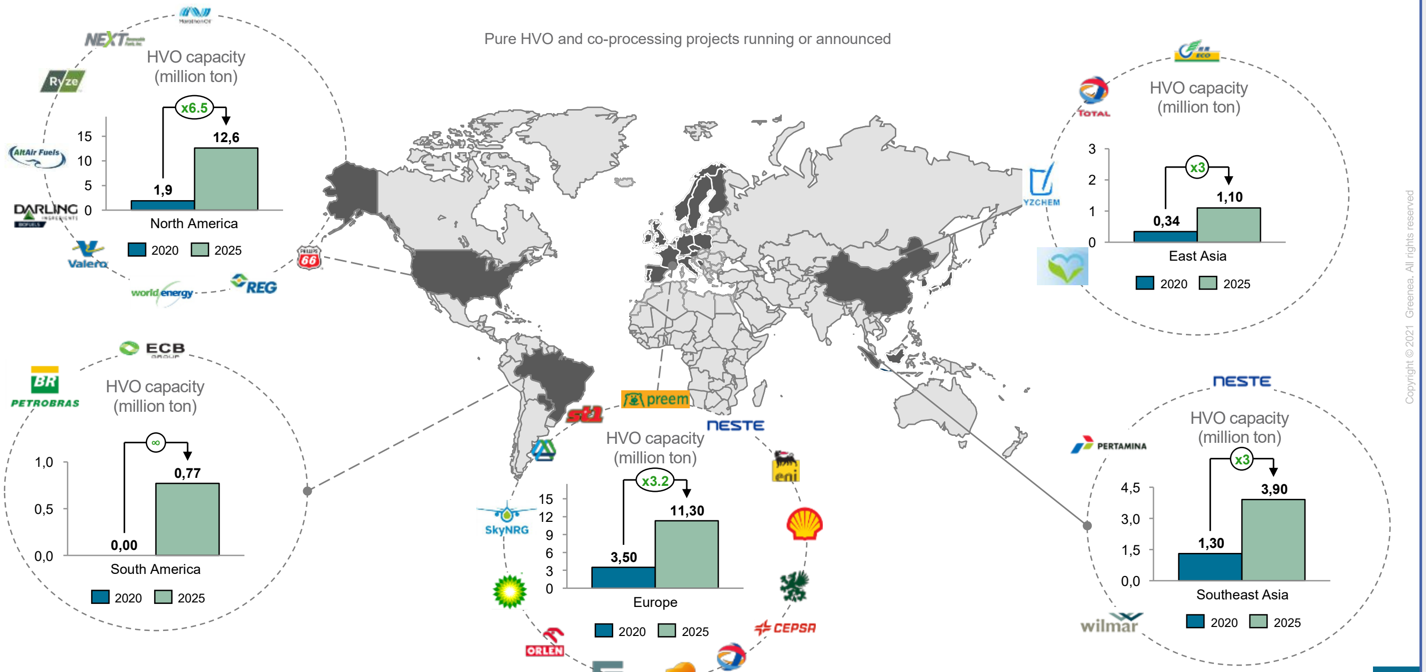
Everywhere in the world, new HVO[1] projects are projected to significantly increase by 2025, triple in the EU, six-fold in the US, and three-fold in Asia compared to 2020



Source: Greenea Analysis
Note: 1. Includes all type of HVO for road transport projects: pure and co-processing projects

3

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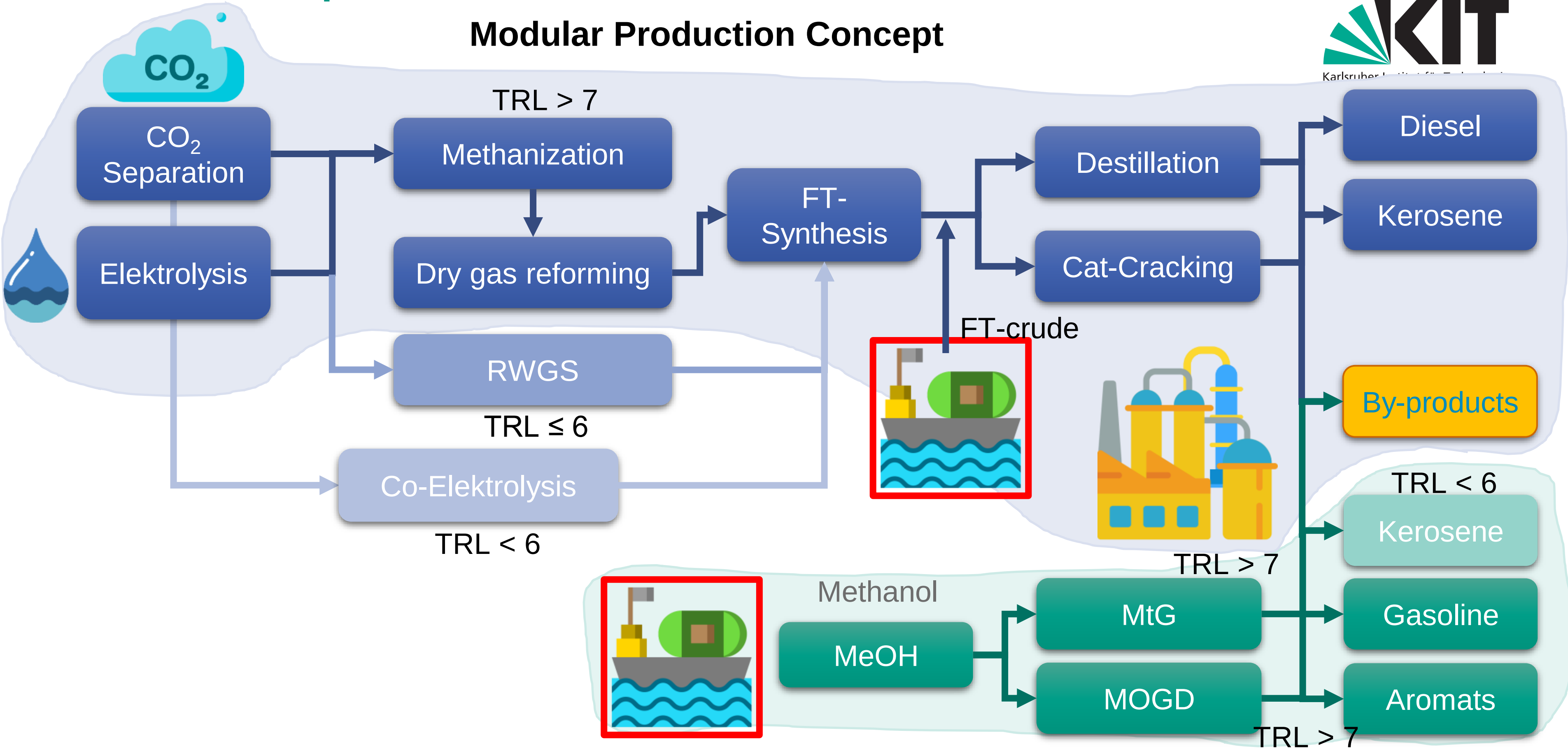
reFuels – the path to refineries



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Scalability of the Fuels Production

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

x ml/trial 1-100 l/a 1- 1.000 t/a 10.000 - 50.000 t/a > 500.00 t/a

→ Scaling of Synthesis Units is limited by Scaling Factor and Time

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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

[5]

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reFuels – scaling production
Fast Ramp-Up needs enough Energy

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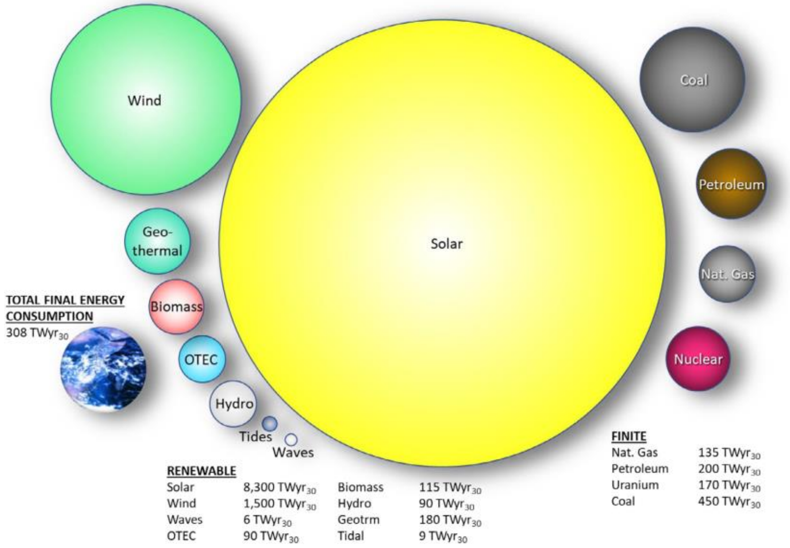
- Is there enough energy?
- „*Reasonably Assured Recoverable Reserves*“ of renewable Energy Resources compared to finite fossile Energy Reserves

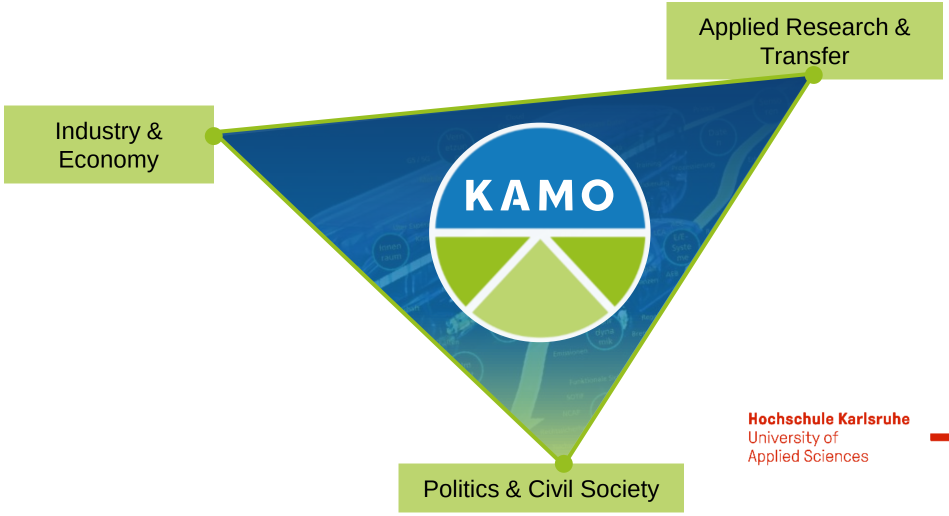


[6]

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

➡ when regulatory constraints take physics into account, reFuels will come

KAMO: Karlsruhe Mobility



KAMO is the well-established collaboration between the institutions for **mobility and logistic research**, **development & education** in Karlsruhe, Germany.

Central contact point for industry, politics and society.


We will not achive Paris Climate Targets without the use of reFuels!
But they are ready!!!
Thank you for your Attention
KIT