Karlsruher Institut für Technologie

IFKM

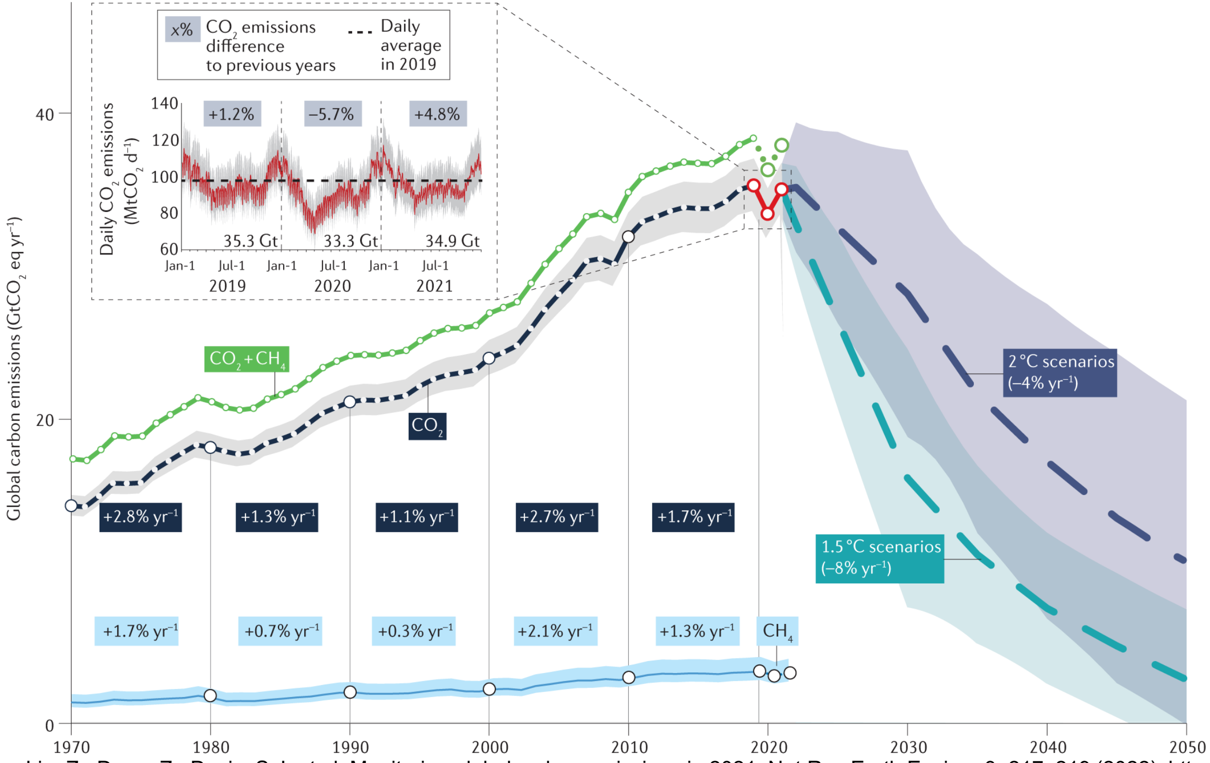
Synthetic renewable fuels potential, combustion and emissions

Dr.-Ing. Olaf Toedter

Motivation: Mobility Turnaround as Part of Fit for 55

CO_2 Accumulation limits remaining GHG budget

Karlsruher Institut für Technologie



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

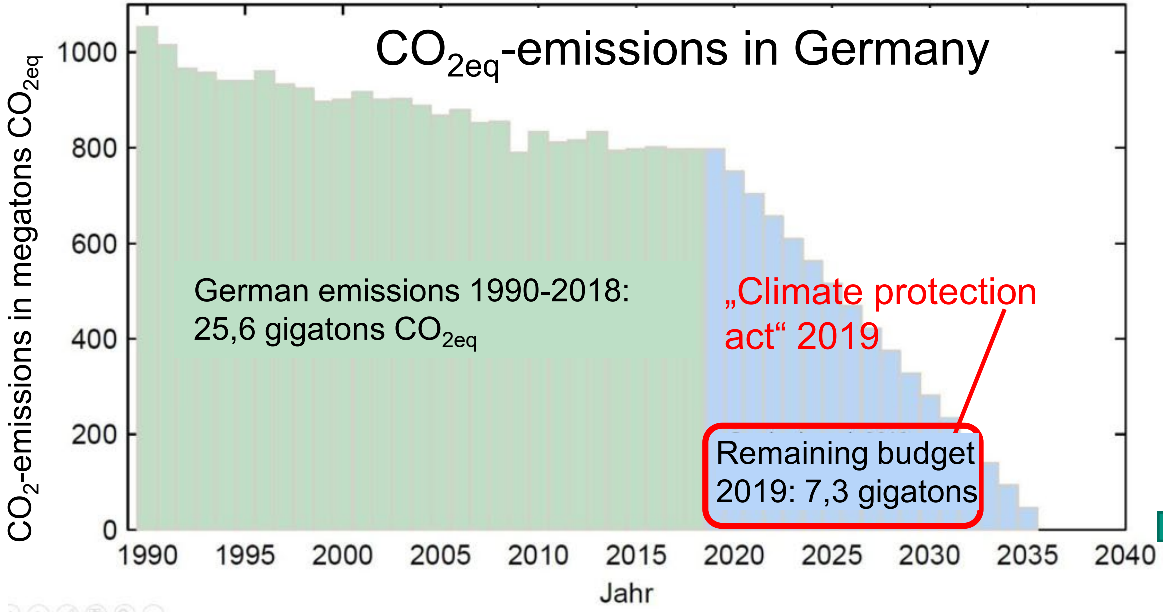
➡ 400Gt CO_{2eq} budget in 2021

Separation by country and by segment

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

CO_2 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 $CO_{2äq}$ to achieve Paris-goals (1,5°C @ 50%)
  - 6,6 Gt $CO_{2äq}$ 1,75°C @ 50% identical to the targets from Klimate Protection Act 2019

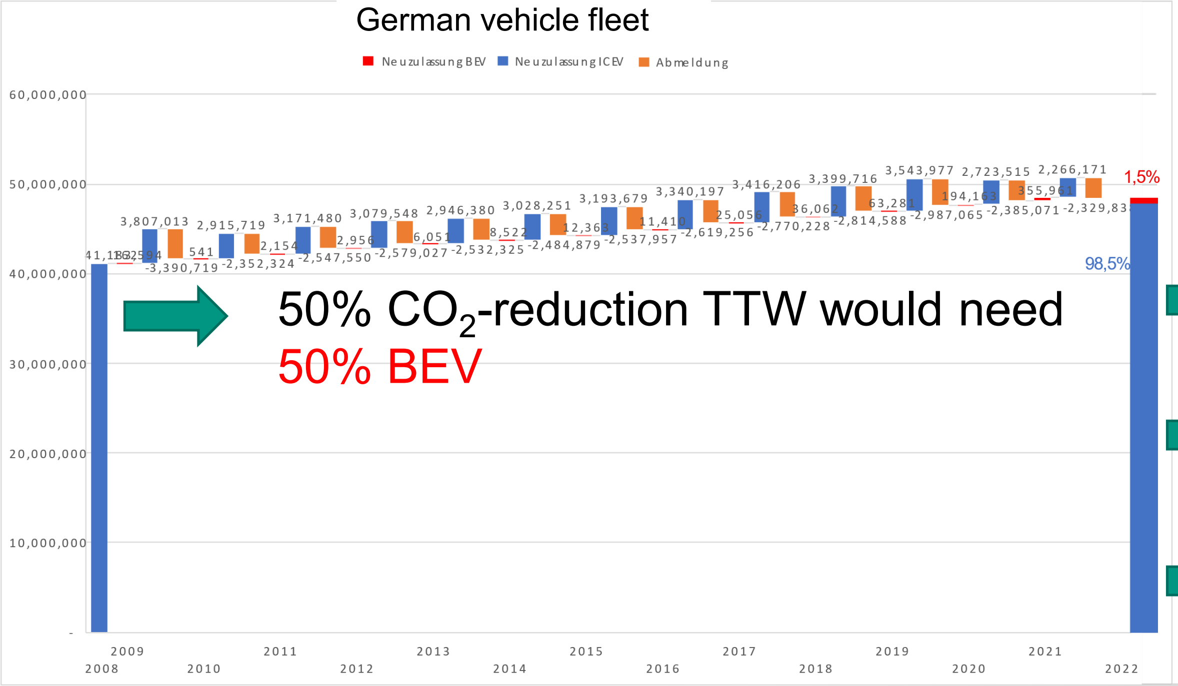
→ **only changing the fleet does'nt meet the targets!**

Rahmstorf, S, 2019, Spectrum.de SciLogs https://scilogs.spektrum.de/klimalounge/wie-viel-co2-kann-deutschland-noch-ausstossen/

Motivation: Mobility Turnaround as Part of Fit for 55

Realization of mobility turnaround

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



2%

2023

50% CO_2-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

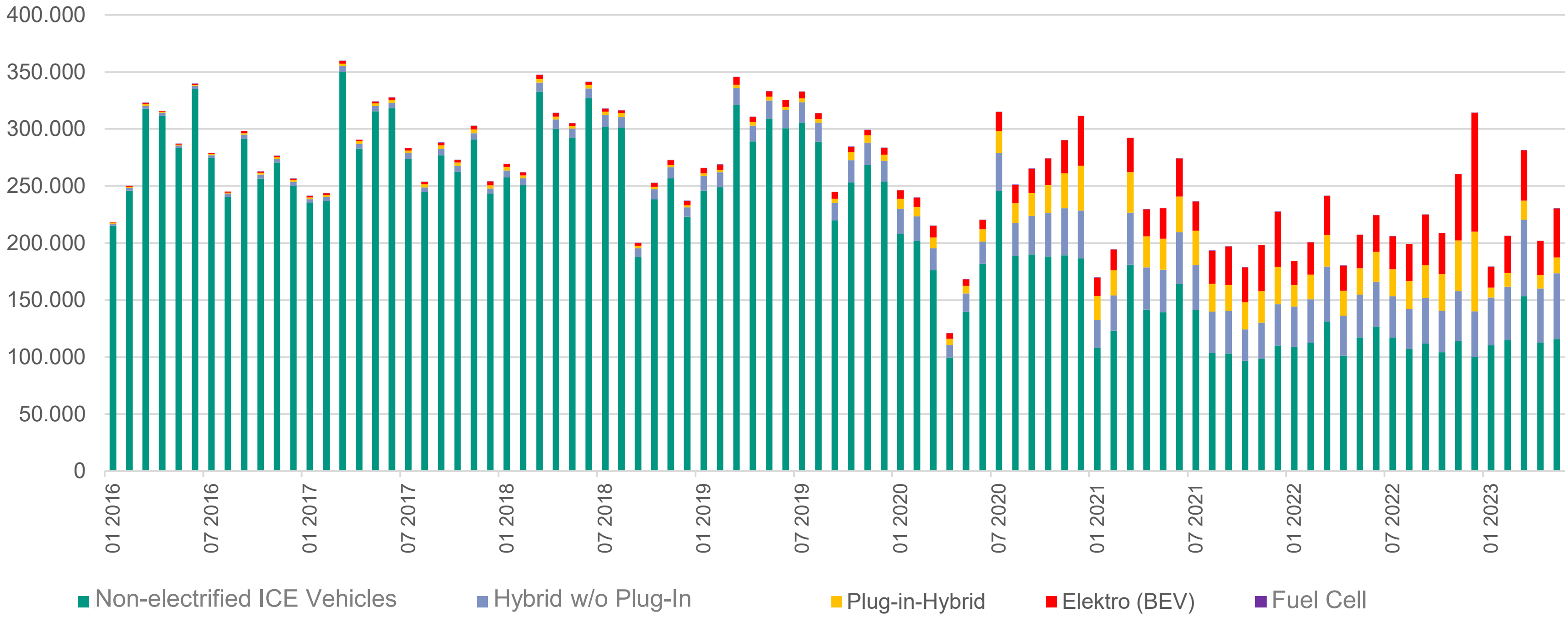
3,3 Mio BEV / year
>100% of all new vehicles

Institut für Kolbenmaschinen
Prof. Dr. sc. techn. Thomas Koch

Motivation: Mobility Turnaround as Part of Fit for 55
Does new Vehicle Registrations reflect the transition?

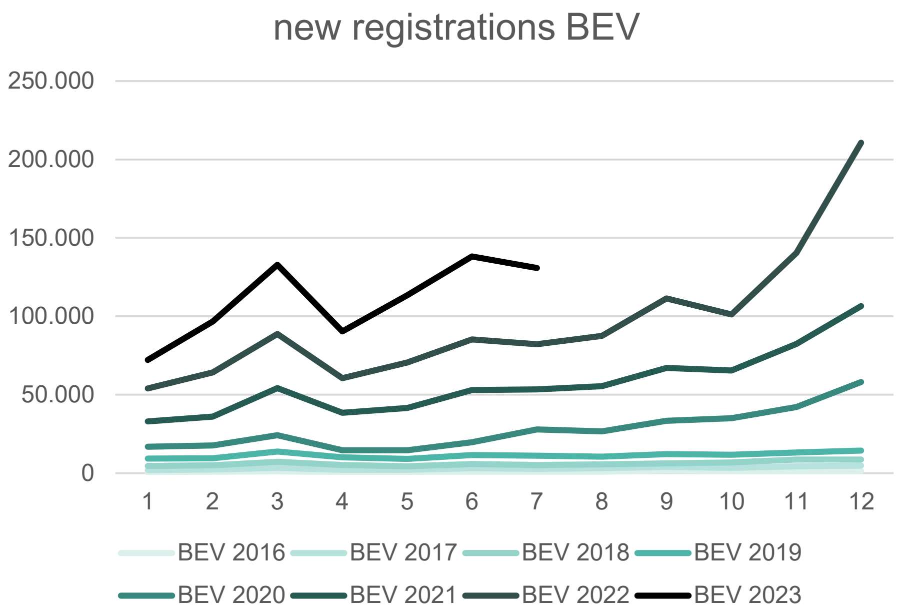
Karlsruher Institut für Technologie

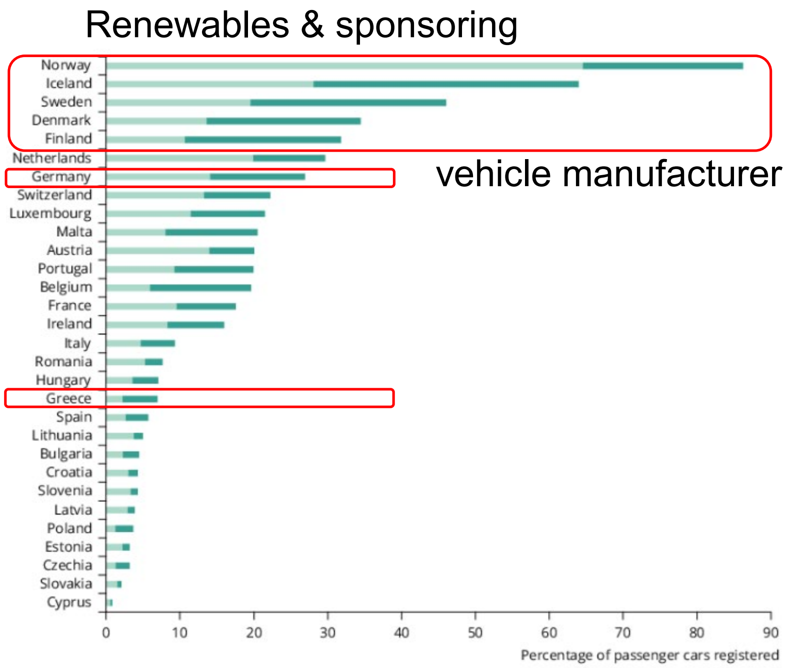
- Vehicle Change in Germany using 10.000€ bonus



Motivation: Mobility Turnaround as Part of Fit for 55
Does new Vehicle Registrations reflect the transition?

- Fleet consumption challenge



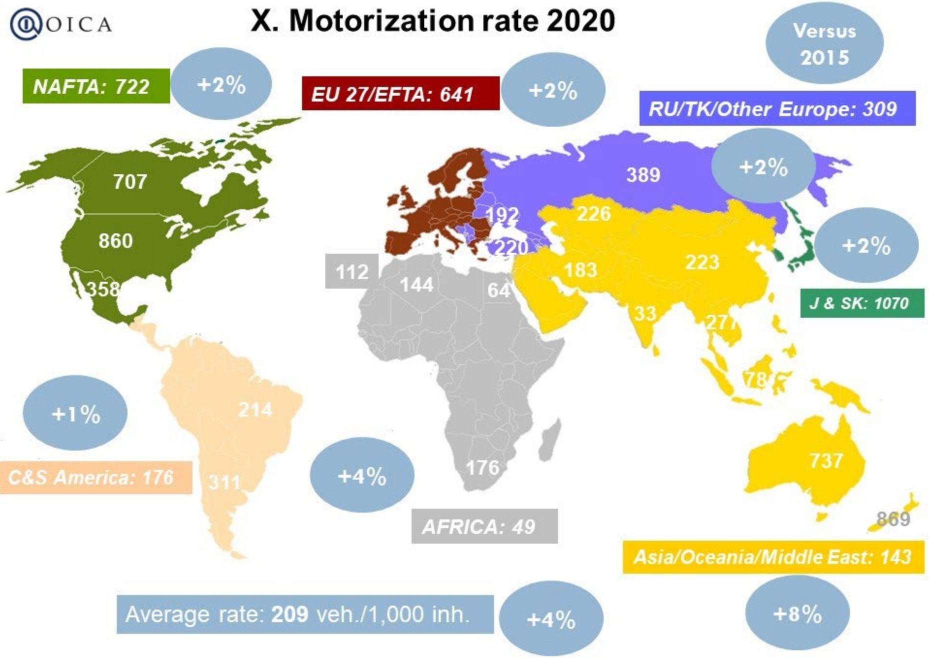


→ Car manufacturers try their best to fullfill the regulation but overall GHG stays the same

Institut für Kolbenmaschinen
Prof. Dr. sc. techn. Thomas Koch

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



[1]

→ Saturated markets don‘t speed up fleet exchange

→ Medium vehicle age in EU is 12 years and increasing

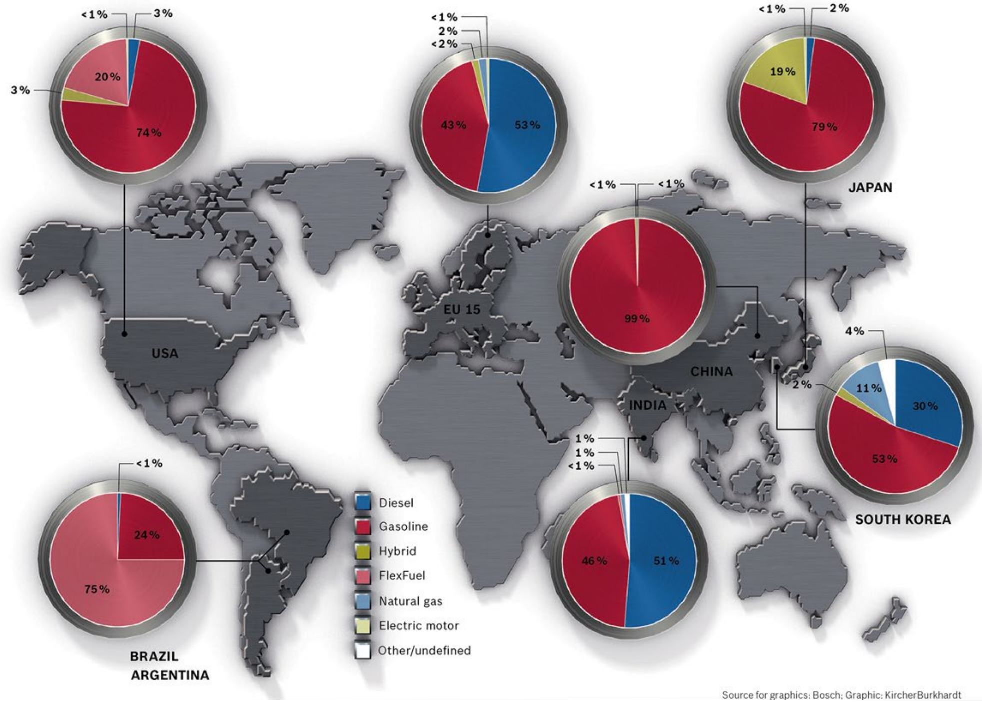
→ Vehicle switch will not be fast enough for a to reduce GHG in time

Institut für Kolbenmaschinen
Prof. Dr. sc. techn. Thomas Koch

World map of mobility energy supply

Available Energy Supply influences powertrain choice

- Energy availability as decision factor for customers and professional users

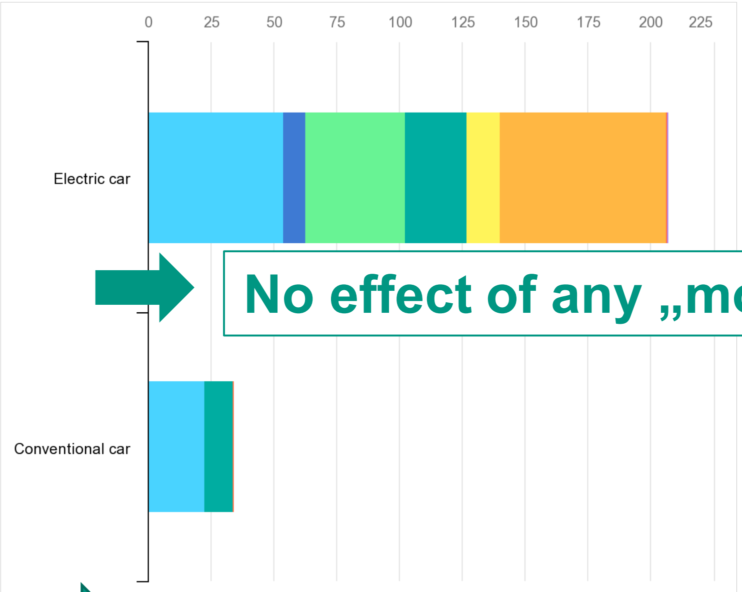


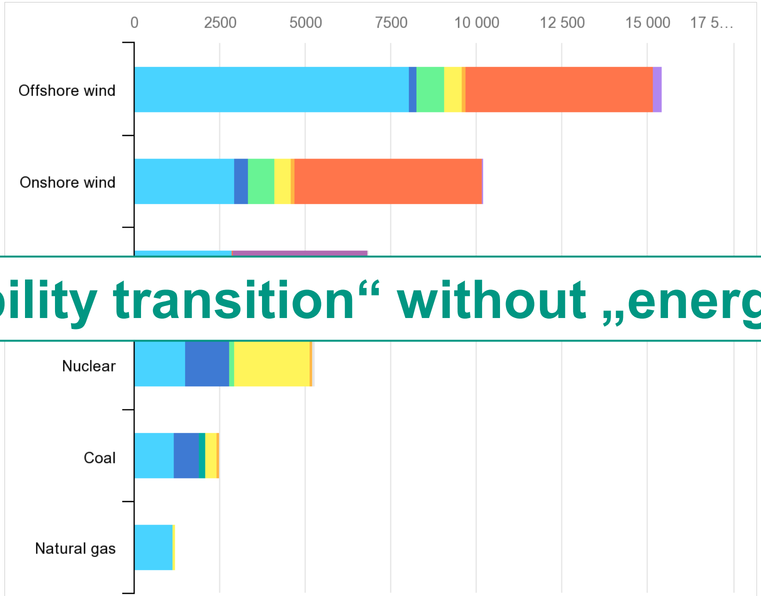
[2]

Institut für Kolbenmaschinen
Prof. Dr. sc. techn. Thomas Koch

Limiting the ramp up speed by limited raw materials

- Raw materials limit ramp up of BEV





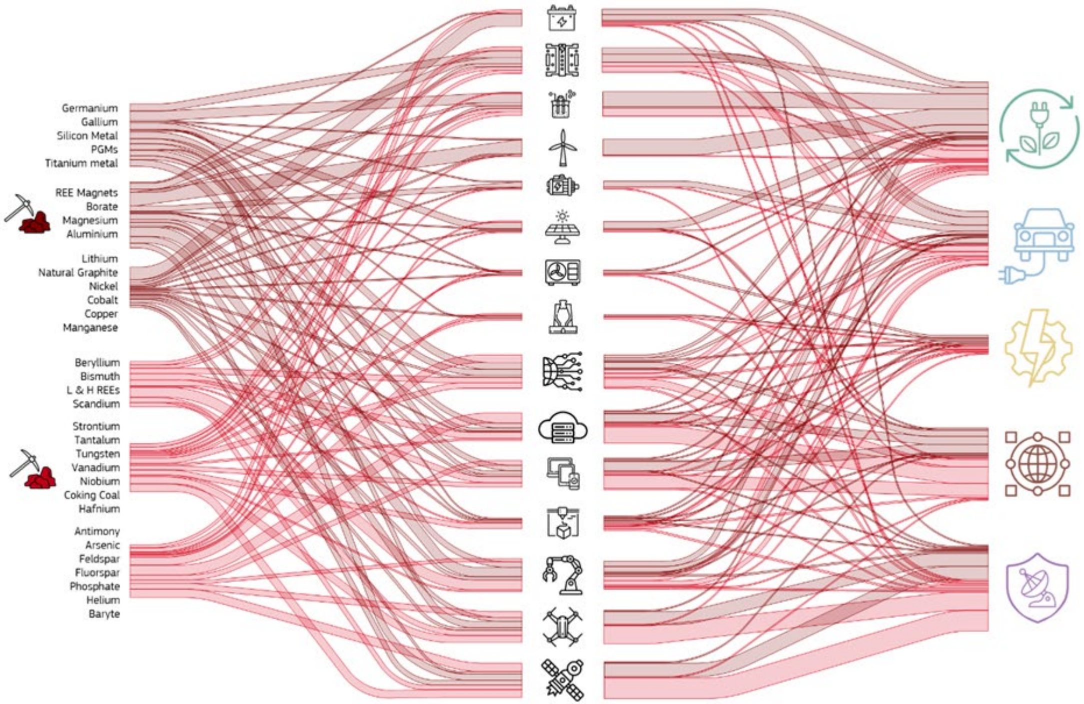
No effect of any „mobility transition“ without „energy transition“

Beside of Steel and Aluminium IEA sees these materials as critical with regard to the energy transition

Institut für Kolbenmaschinen
Prof. Dr. sc. techn. Thomas Koch

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



[3]

Motivation: Mobility Turnaround as Part of Fit for 55
GHG neutral Mobility

Karlsruher Institut für Technologie

Interim Balance:

- GHG residual Budgets asks for fast transitions
- Fleet Change ist 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 !

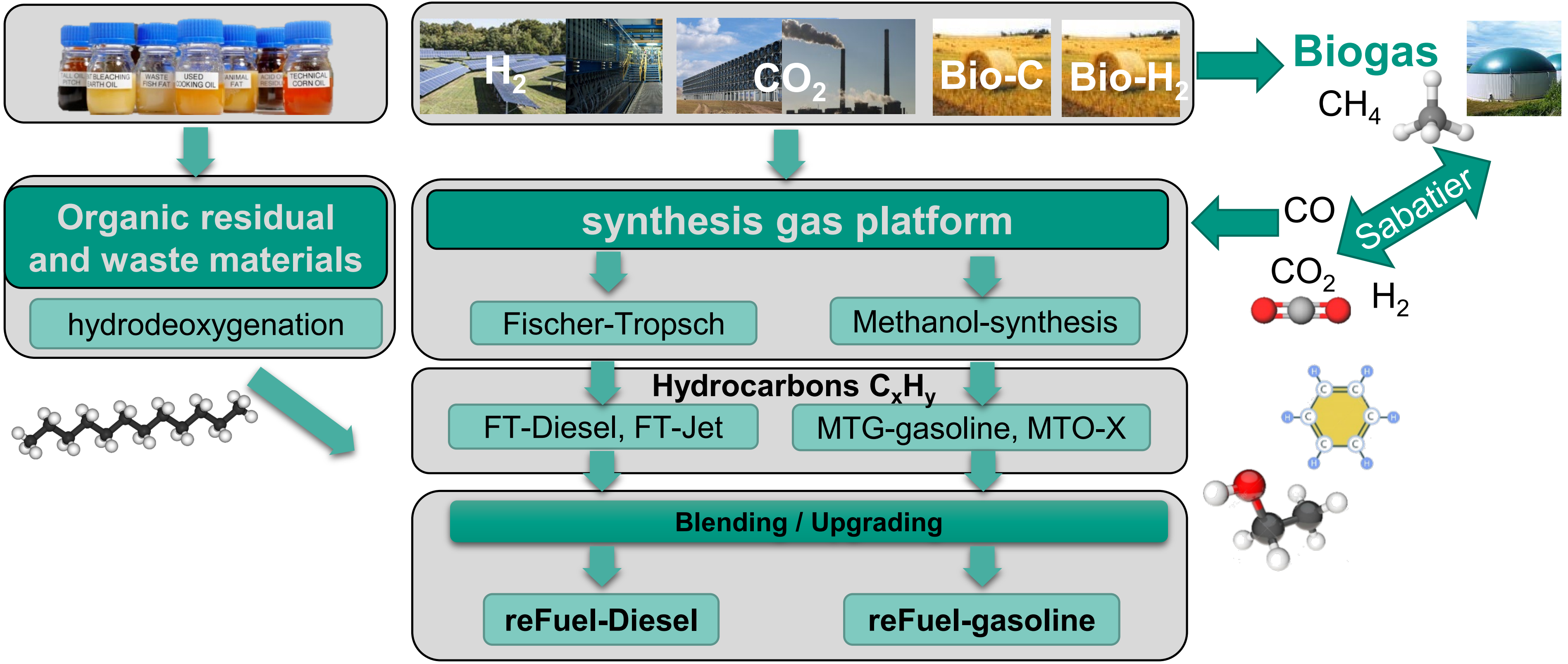
➔Thinking fom a higher-level System

a) **Internal combustion engines are energy-conversion units**

b) **Not the engine is responsible for additional CO_2-Emission but the use of fossile energy carrier**

reFuels – potential synthesis pathes
Synthetic Fuels from a renewable Base

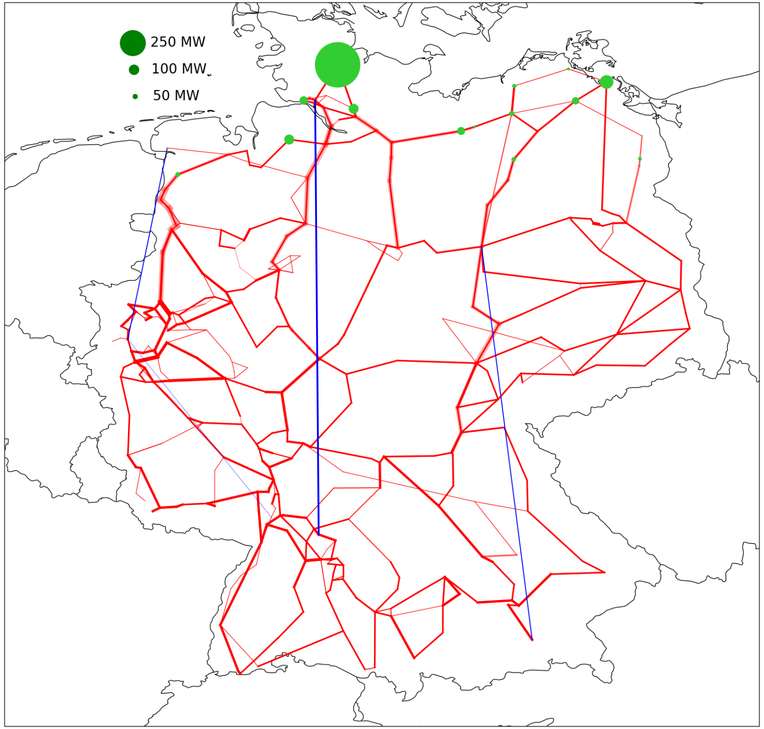
Karlsruher Institut für Technologie

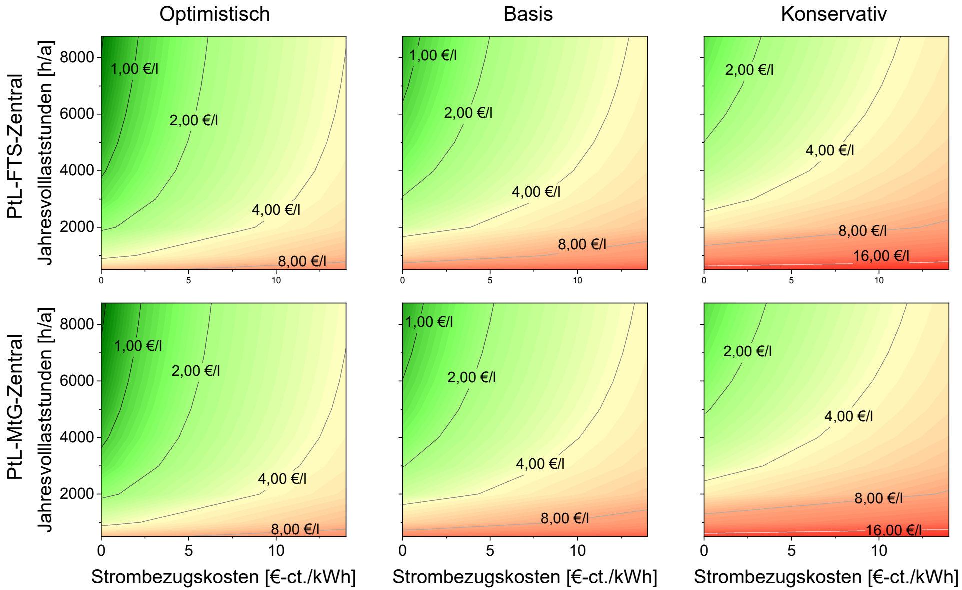


reFuels – fuels production

Production costs

- cost-optimal allocation of Elektrolysis regarding RED II in 2030





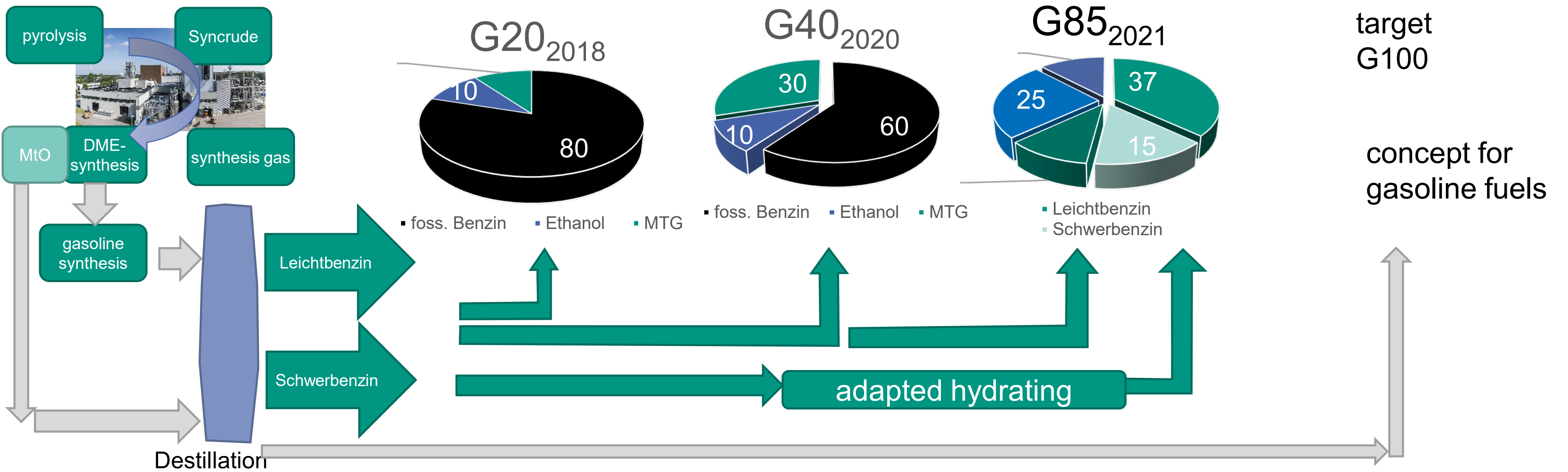
Institut für Kolbenmaschinen
Prof. Dr. sc. techn. Thomas Koch

reFuels – fuels production

Gasoline fuels

Karlsruher Institut für Technologie

- 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

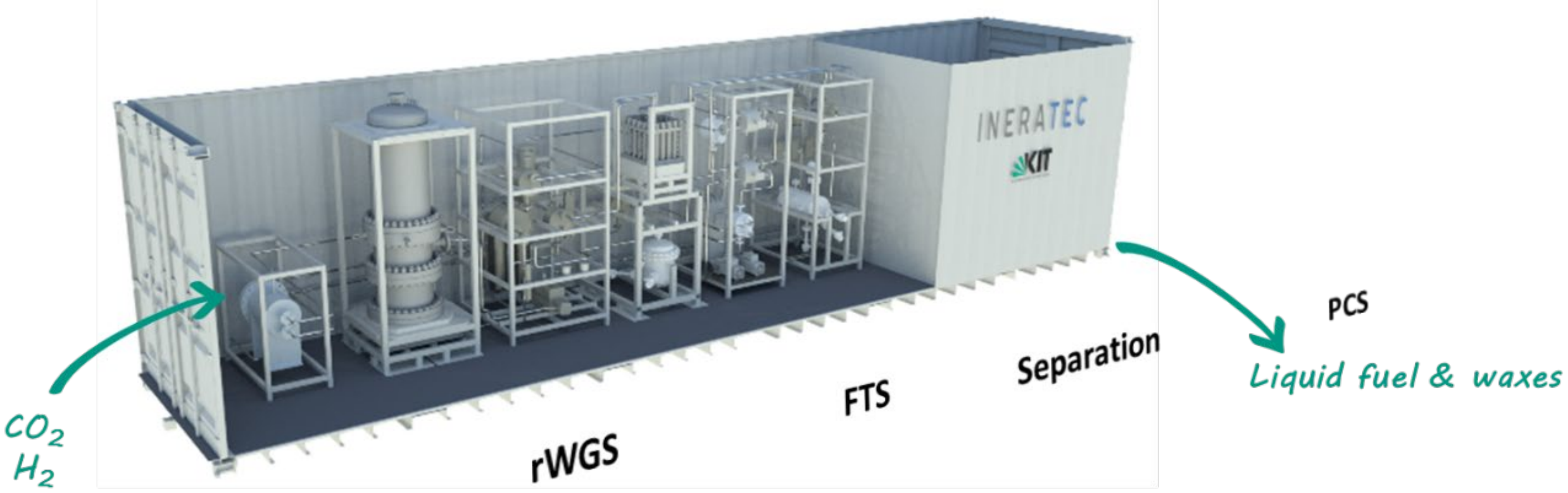
- hydrierated MtO-gasoline
- ETBE + MTBE from MtO

Institut für Kolbenmaschinen
Prof. Dr. sc. techn. Thomas Koch

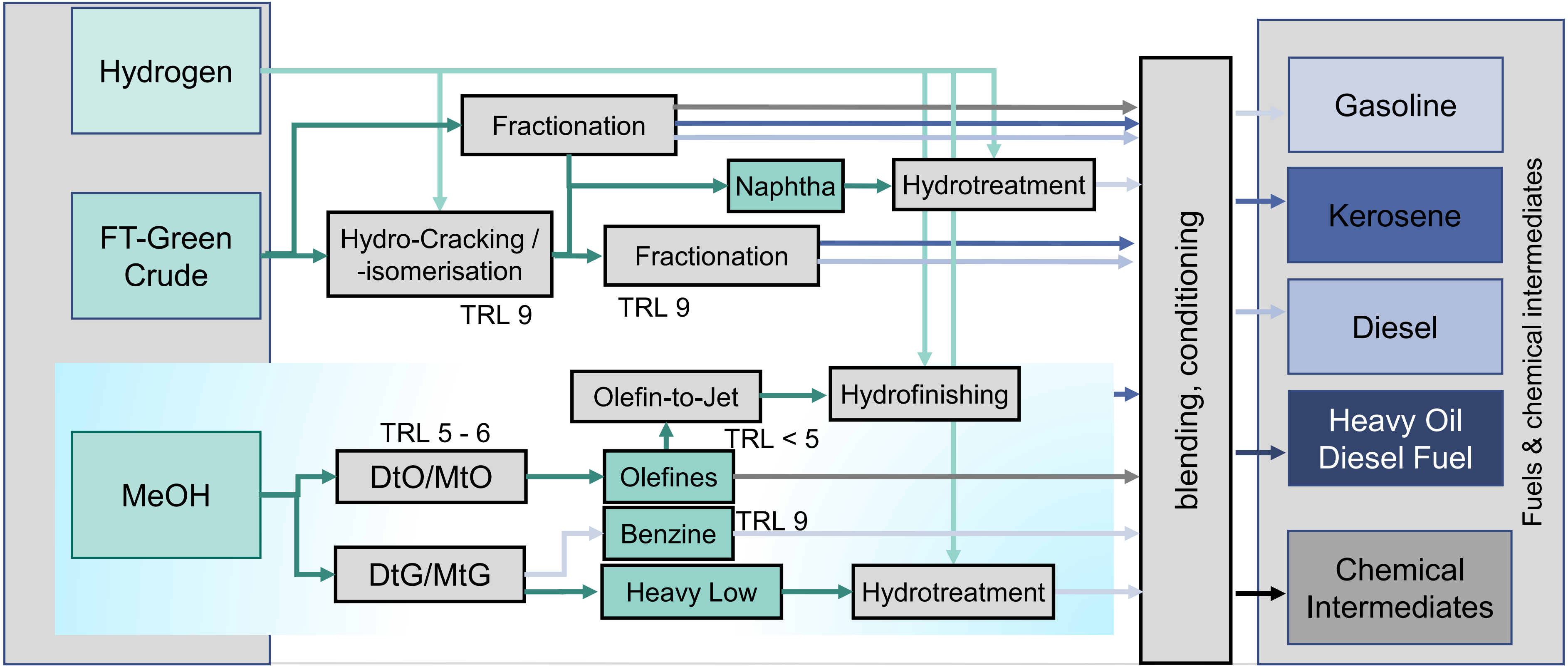
reFuels – Fuel synthesis

Diesel fuels

- *Integrierted Synthesis-Container for fuel synthesis by Fischer-Tropsch from CO_2 and H_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



Institut für Kolbenmaschinen
Prof. Dr. sc. techn. Thomas Koch

reFuels – testing
Nerby transparent fuels

- **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**

Foto: Amadeus Bramsiepe, KIT

reFuels – testing

Large matrix of tested fuels

Karlsruher Institut für Technologie

- Analysis of reFuels and their blends

fuel	boiling [°C]	density [kg/m³]	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

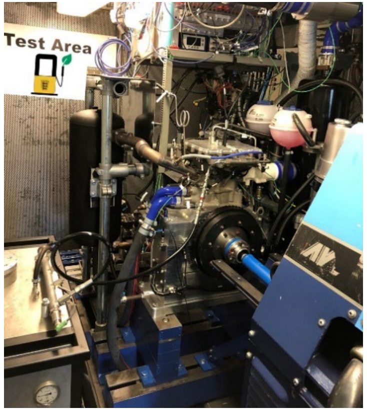
fuel	density [kg/m³]	ratio [%(V/V)]	Cetane number
B0	833,1	100% fossil Diesel	53,5
B7	837,6	93% fossil Diesel + 7 % FAME	52,7
R33[1]	821,0	7 % FAME + 26% BtL + 67% foss. Diesel B0	62,6
S33	821,0	7% FAME + 24% PtL + 69% foss. Diesel B0	59,9
R33[2]	821,9	7 % FAME + 26% BtL + 67% foss. Diesel B0	56,7
HVO	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

reFuels – testing
Wide spread iof test vehicles and engines

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





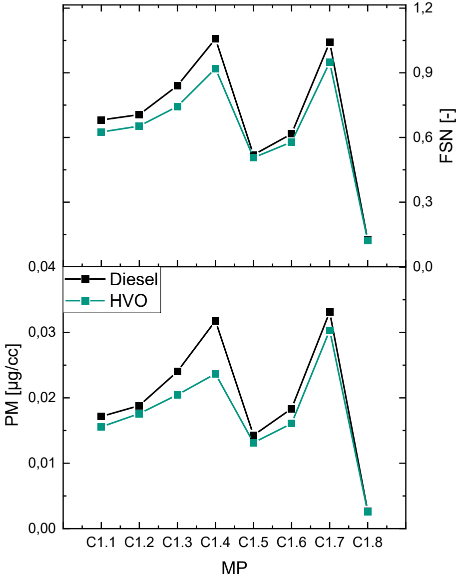
➡ Test facility tests and in-system-conformity tests are necessary (RDE w/ PEMS)!

reFuels testing

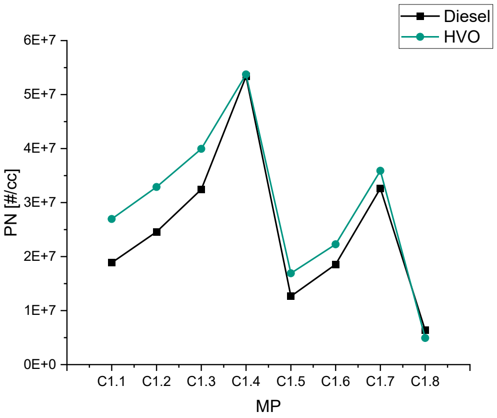
HVO testing on aged train engines (cam-controlled injection systems)

Karlsruher Institut für Technologie

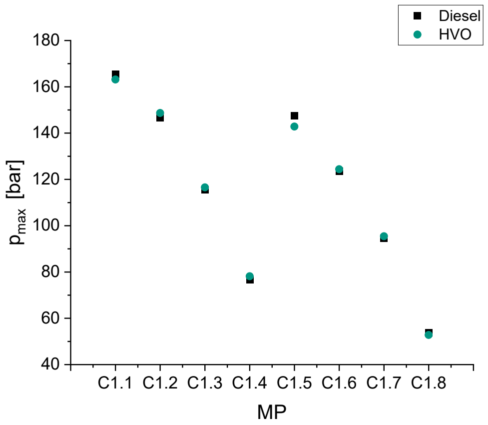
particle mass



particle number



peak pressure

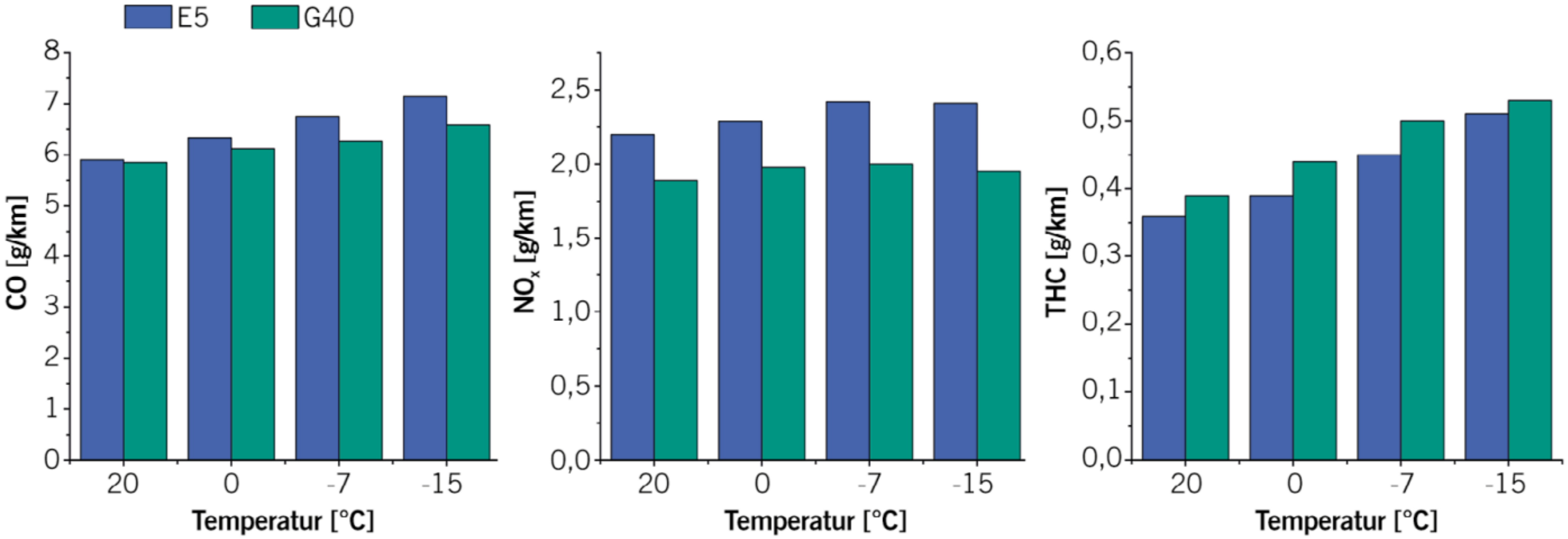


- less particle mass but increased particle number → tends to prduce more small particles
- comparable power even at cam – controlled injection systems

Institut für Kolbenmaschinen
Prof. Dr. sc. techn. Thomas Koch

reFuels - testing

Tests with full cylinder enginge on engine test facility

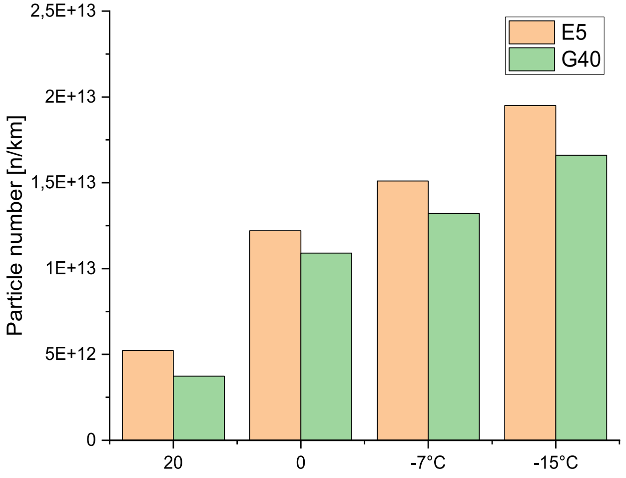


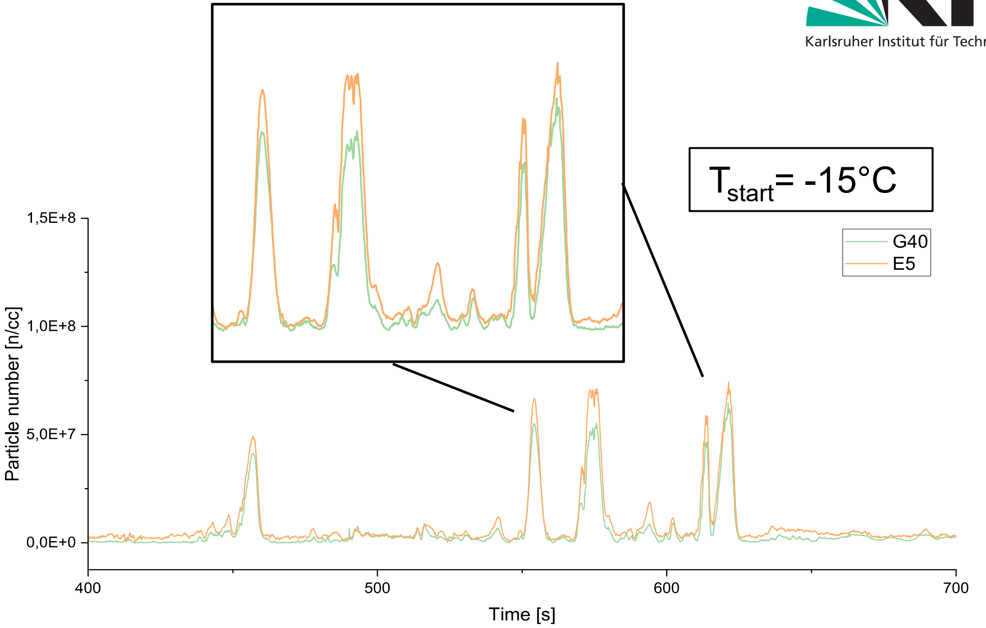
- WLTC results and RDE results are comparable
- Gaseous emissions with synthetic fuel - tends to be lower
- Evapuration curve as a major impact on particulate and gaseous emissions

Institut für Kolbenmaschinen
Prof. Dr. sc. techn. Thomas Koch

reFuels - testing

Tests with full cylinder enginge on engine test facility



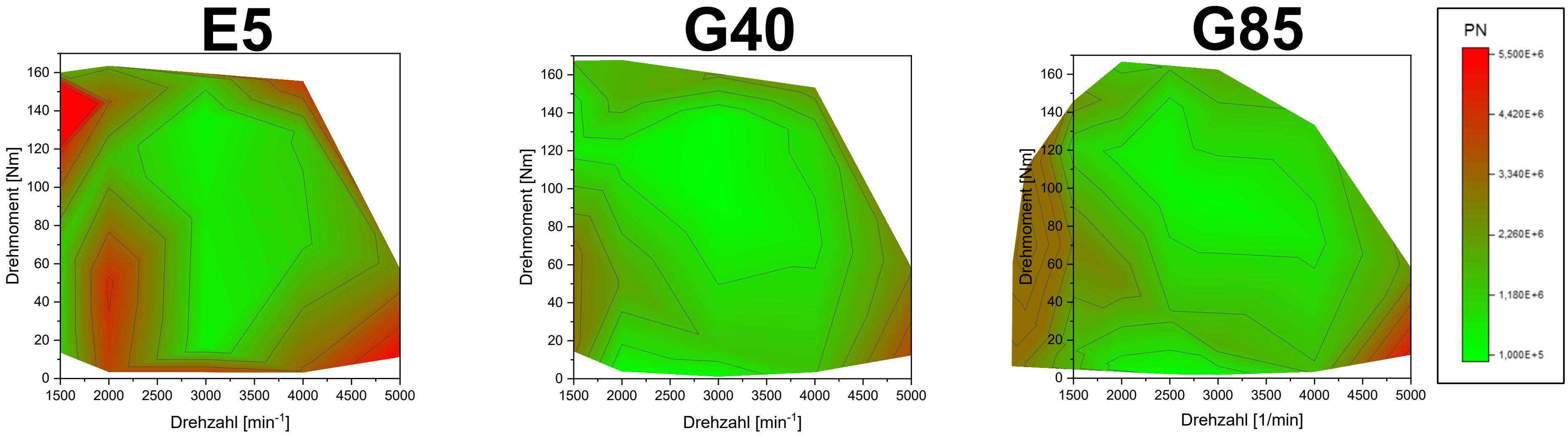


- Reduced PN emissions with synthetic fuel - especially at cold conditions
- Particulate size distribution is comparable

reFuels - testing

Tests with full cylinder enginge on engine test facility

- 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

Institut für Kolbenmaschinen
Prof. Dr. sc. techn. Thomas Koch

reFuels – testing

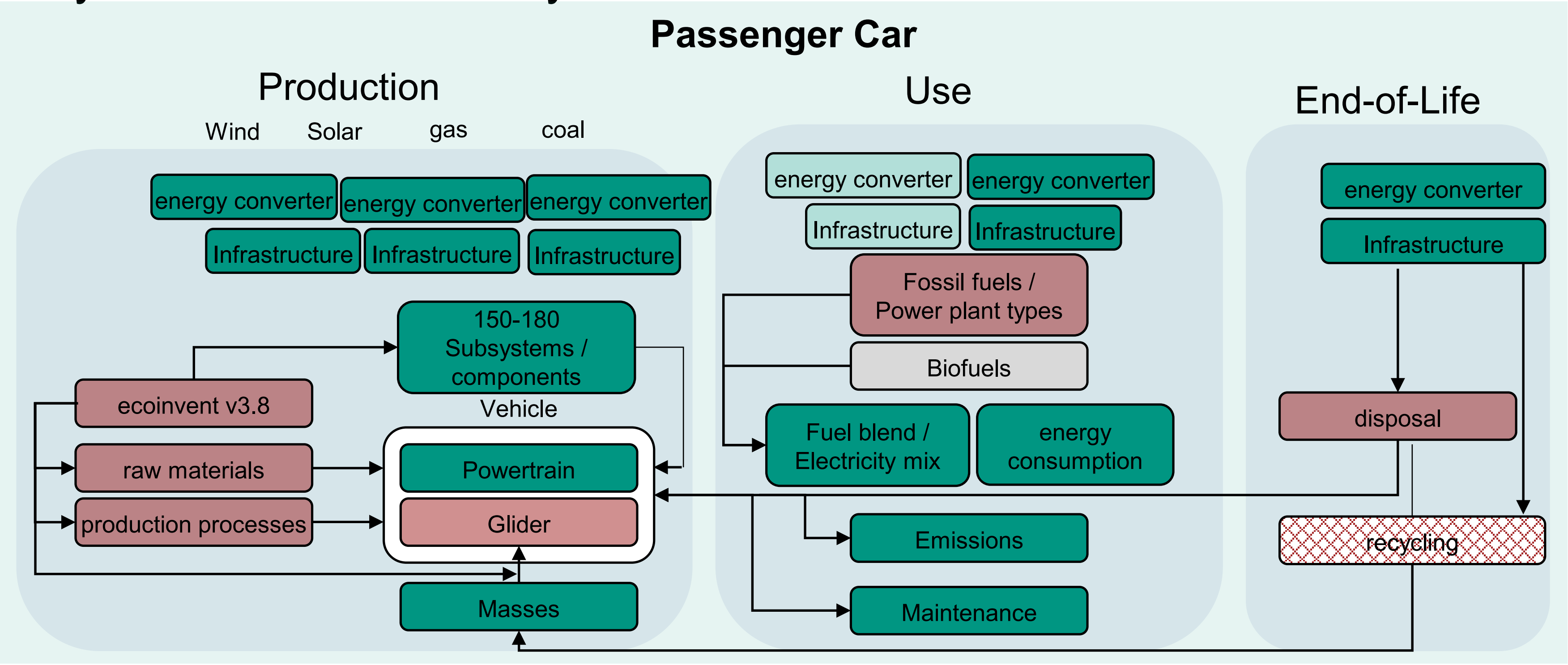
Fleet test C.A.R.E diesel as an example of EN15940 diesel

- 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

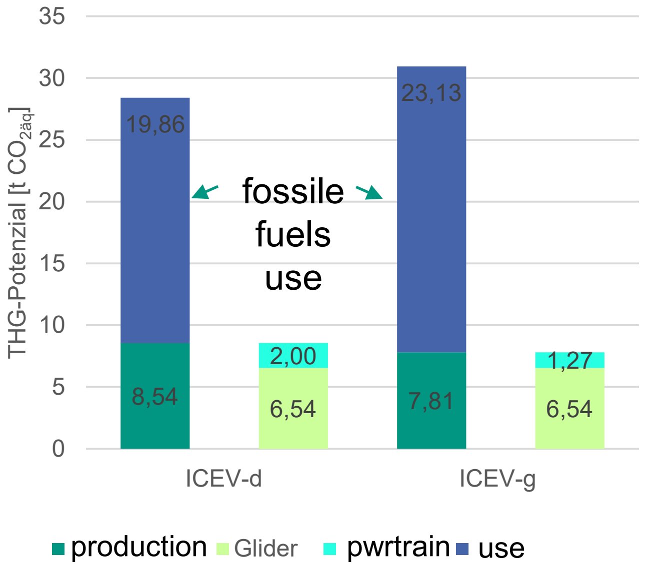
- System Borders of life cycle assesment

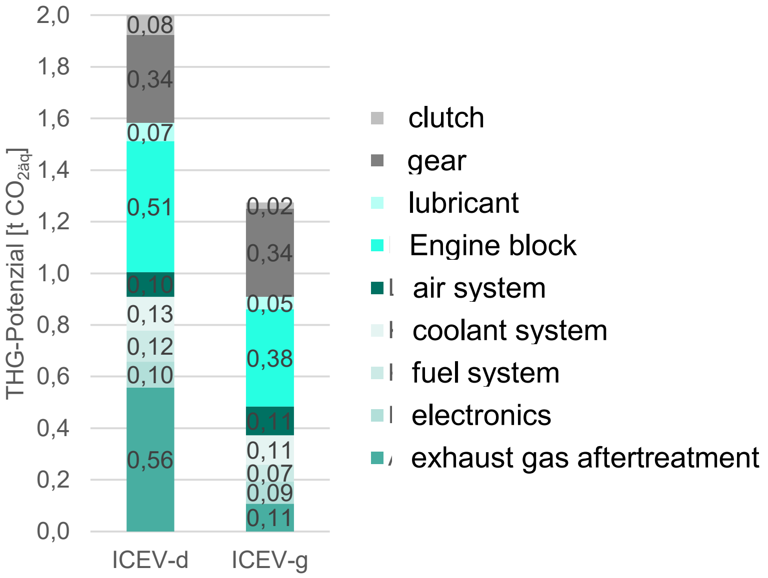


reFuels – environmental balance

Life cycle assessment of vehicles

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



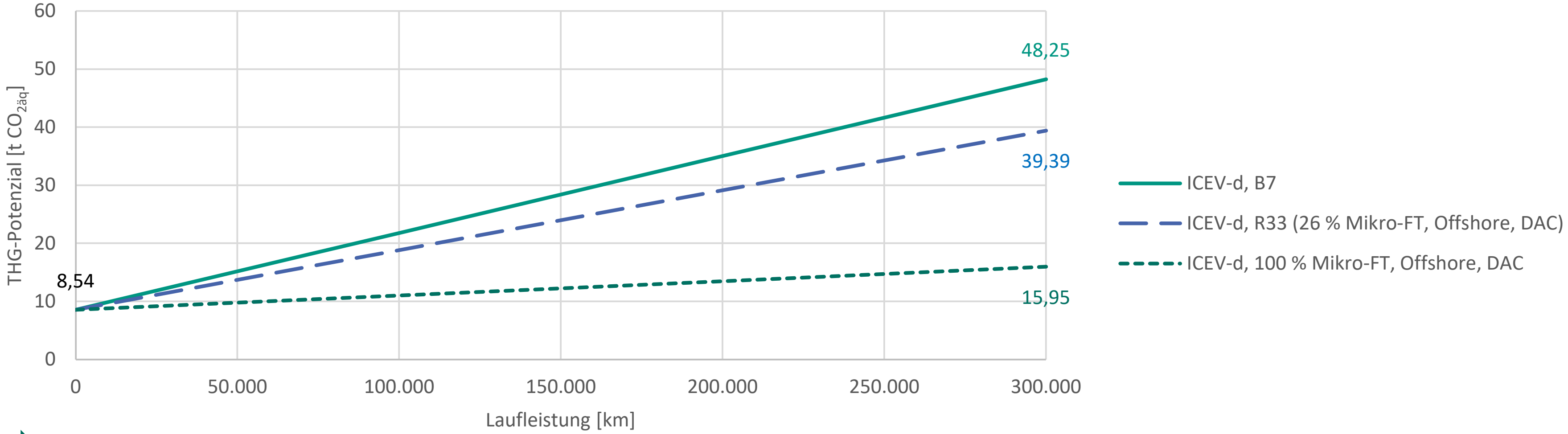


➡ Neither vehicle production nor energy sources can be ignored

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

Karlsruher Institut für Technologie

- 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.

reFuels – scaling production

international approaches for reFuels production

Karlsruher Institut für Technologie

- 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 %

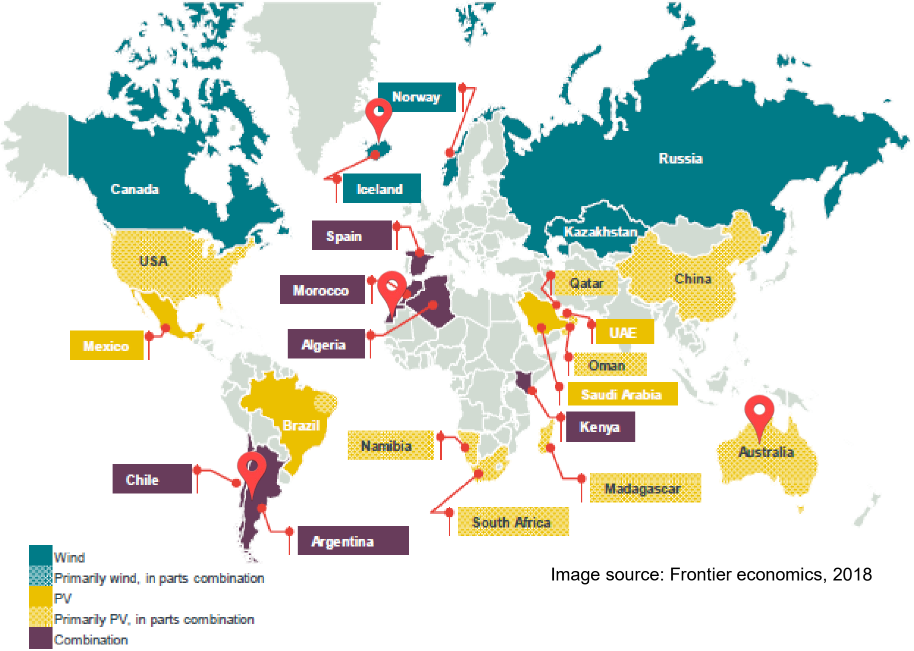


Image source: Frontier economics, 2018

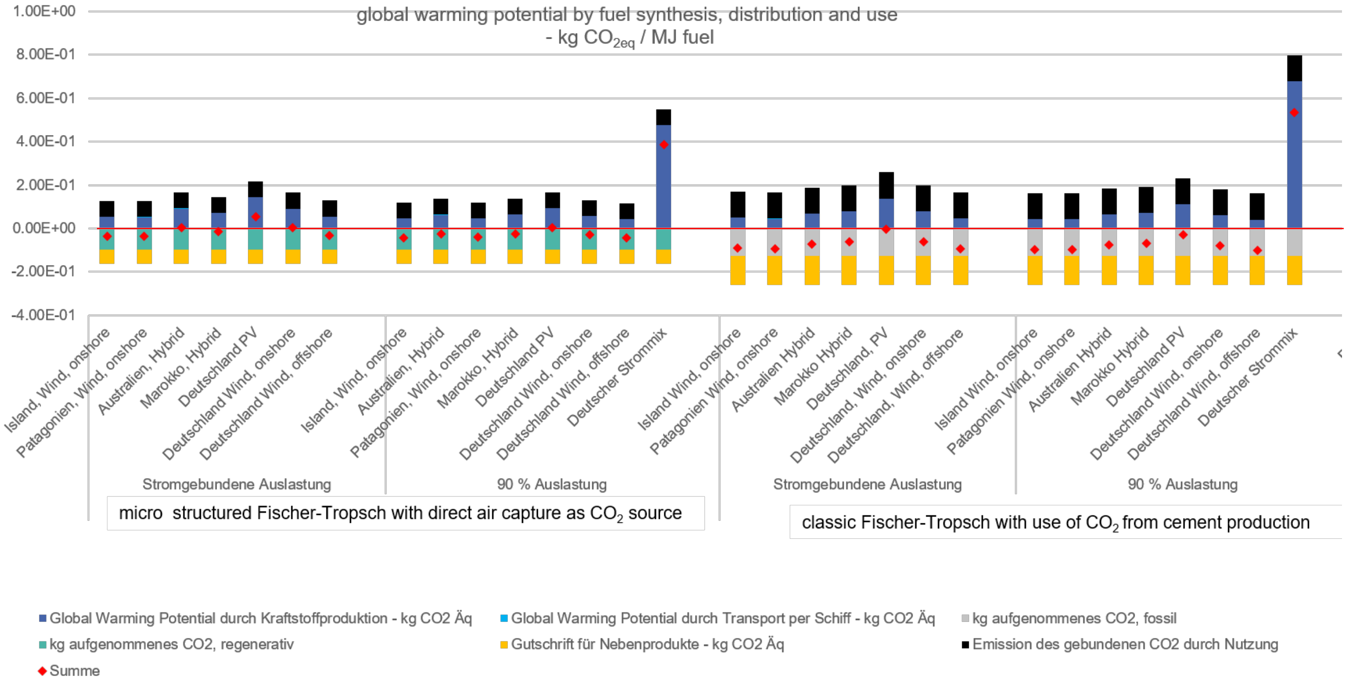
Institut für Kolbenmaschinen
Prof. Dr. sc. techn. Thomas Koch

reFuels – environmental analysis

Environmental Potential of GHG-negative Fuels

Karlsruher Institut für Technologie

Sensitivity Study of Life Cycle Assessment of reFuels

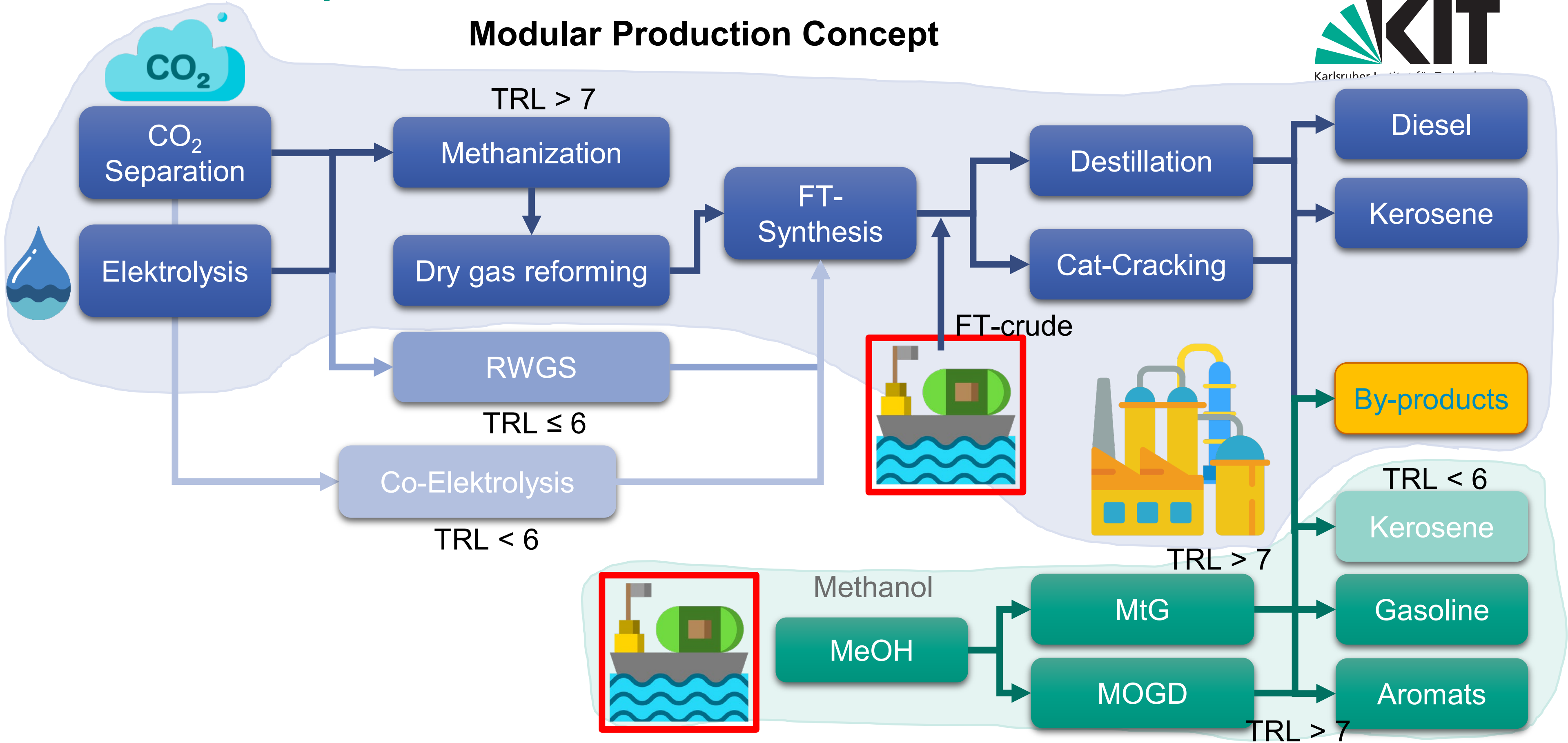


reFuels are **CO_2-negative**! In combination with their usage the system can be CO_2-neutral

Institut für Kolbenmaschinen
Prof. Dr. sc. techn. Thomas Koch
IFKM

reFuels – the path to refineries

Modular Production Concept



Institut für Kolbenmaschinen
Prof. Dr. sc. techn. Thomas Koch

Scalability of the Fuels Production

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

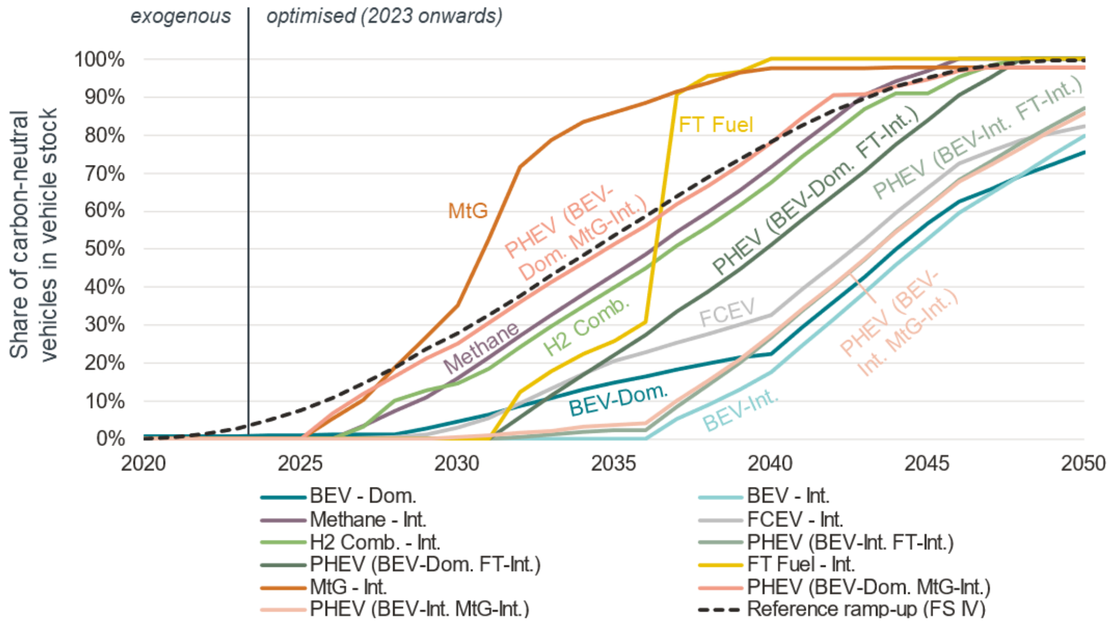
x ml/trial 1-100 l/a1- 1.000 t/a 10.000 - 50.000 t/a > 500.00 t/a

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

reFuels – scaling production

Achievable Scalability of the Fuels Production

- 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

[4]

Institut für Kolbenmaschinen
Prof. Dr. sc. techn. Thomas Koch

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

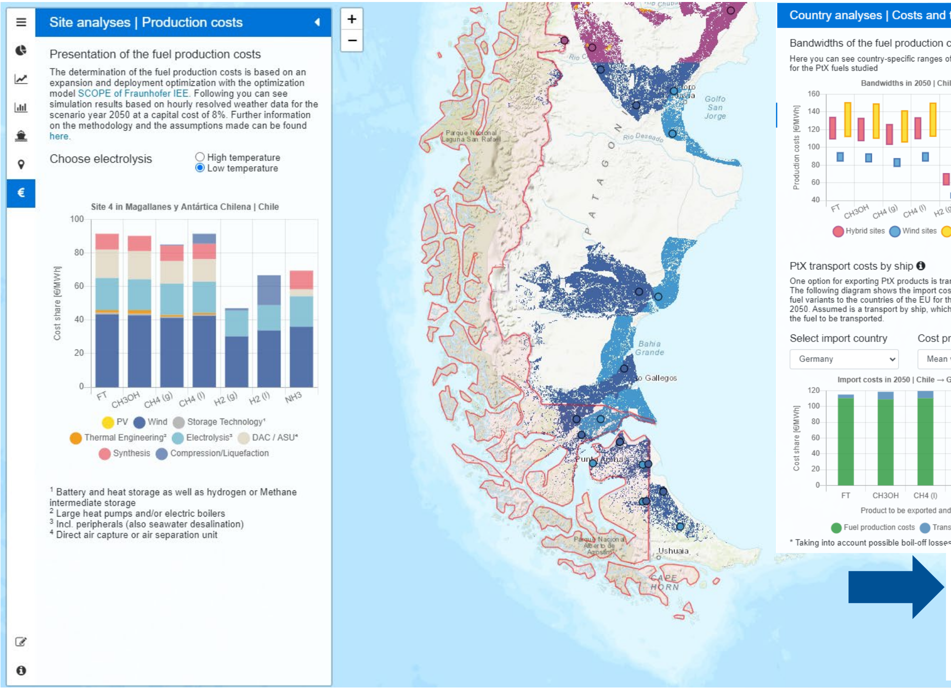
[5]

Institut für Kolbenmaschinen
Prof. Dr. sc. techn. Thomas Koch

Favorable Energy Sites drops Costs and push the Ramp-up

Karlsruher Institut für Technologie

- Example Chile shows potential in saisonability and continouity



Production Costs between 0,8 and 1,5 € are realistic today

Additional Cost Reduction as Result of ongoing Developments are expected

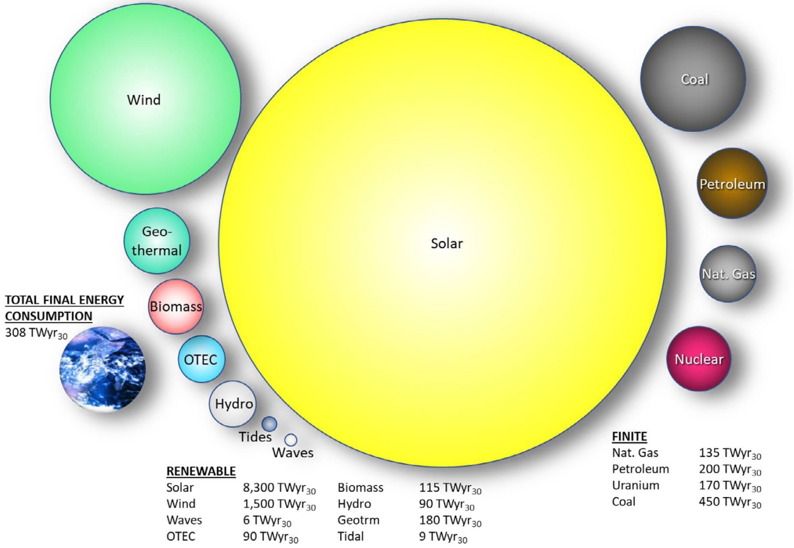
Institut für Kolbenmaschinen
Prof. Dr. sc. techn. Thomas Koch

IFKM

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 Energy Reserves



[6]

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

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

We will not achive Paris Climate Targets without the use of reFuels!

Thank you for your Attention

References

[1] OICA International Organization of Motor Vehicle Manufacturers, Motorization rate , https://www.oica.net/category/vehicles-in-use/

[2] Weltkarte der Auto-Antriebe: So fahren Europa, Amerika und Asien, https://ecomento.de/2014/11/11/weltkarte-auto-antriebe/

[3] IEA, 2022, The Role of Critical Minerals in Clean Energy Transitions, Executive Summary, https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary

[4] Ulrich Kramer, David Bothe et.al, Future Fuels: FVV Fuels Study IVb

[5] Global PtX Atlas, https://maps.iee.fraunhofer.de/ptx-atlas/ , last checked June 22 2023

[6] Mark Perez, Richard Perez, Update 2022 – A fundamental look at supply side energy reserves for the planet; Solar Energy Advances Vol 2, 2022, Elsevier