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Renewable Fuels reFuels as necessary component for a GHG-neutral mobility

17. August 2022

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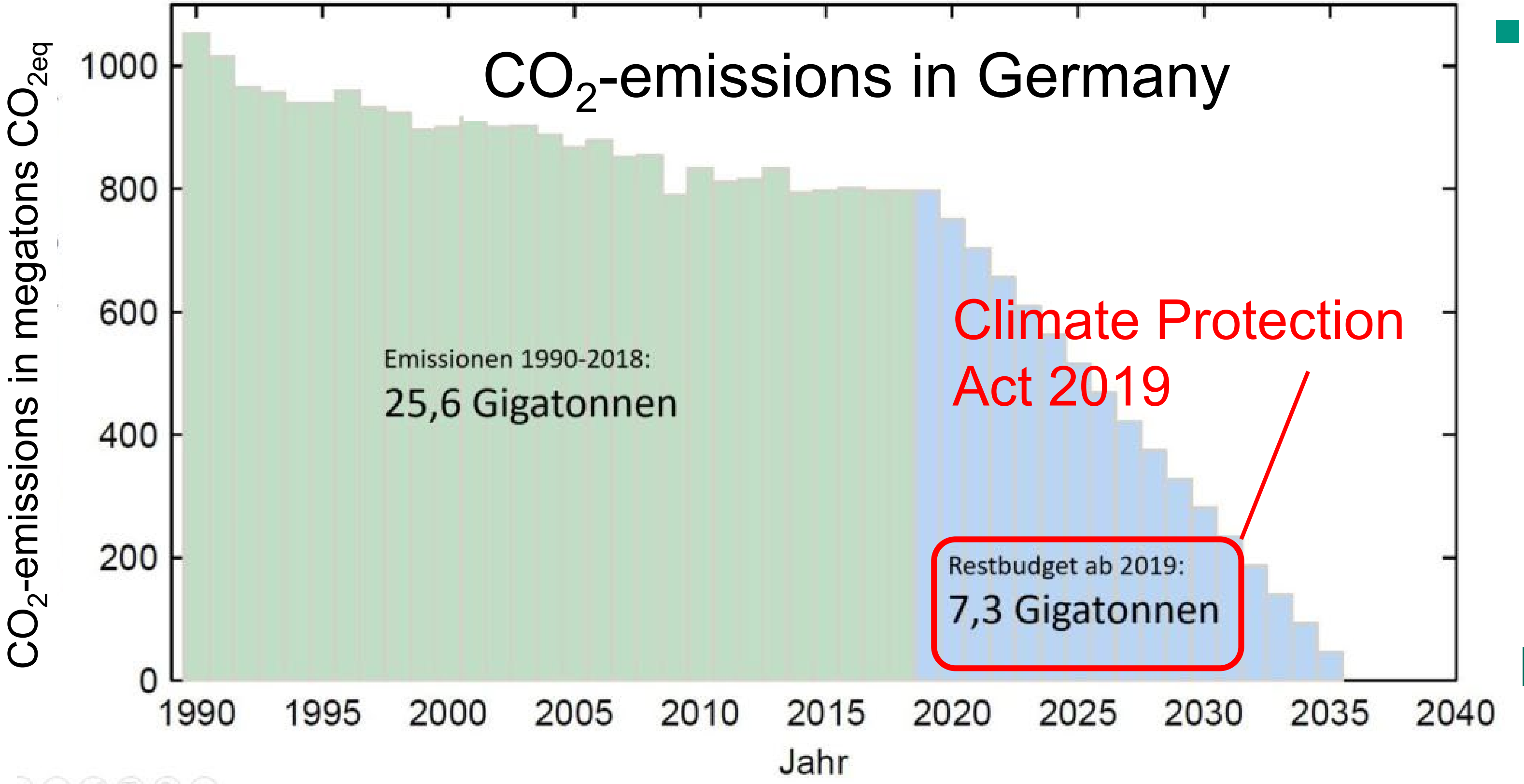
Motivation: Mobility Turnaround as Part of Fit for 55

CO_2 Accumulation limits Remaining budget

- Greenhouse gas residual budget



- 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

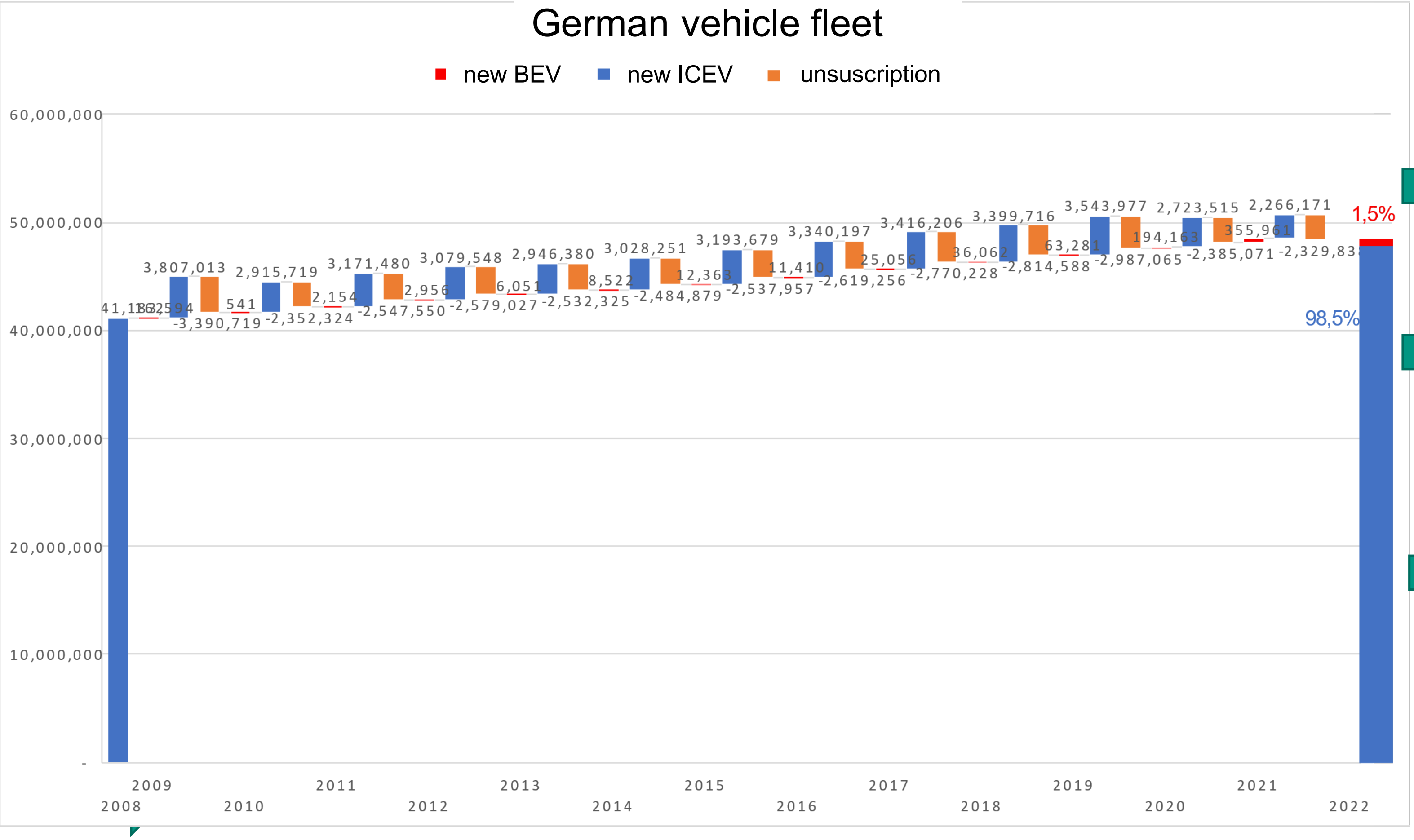
only changing the fleet does‘nt meet the targets!

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

reFuels as Element of Defossilisation Strategy

Realization of Mobility Turnaround

- Results by changing the fleet



50% CO_2-reduction TTW would need 50% BEV

10 Mio BEV/48 Mio cars=20%

15 Mio BEV/48 Mio cars=31%

24 Mio BEV/48 Mio cars=50%

23,3 Mio BEV in 8 years

2,9 Mio BEV / year =~90%

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reFuels as Element of Defossilisation Strategy

Clean Vehicle Directive

- Regulation targeting procurement of „clean Vehicles“ (SaubFahrzeugBeschG)
- Clean heavy-duty vehicle:

any truck or bus using one of the following alternative fuels:

- hydrogen,
- battery electric (including plug-in hybrids),
- natural gas (both CNG and LNG, I ncluding biomethane),
- liquid biofuels,
- synthetic and
- paraffinic fuels,
- LPG.

Fahrzeug-klasse	Definition „sauberes Fahrzeug“		Beschaffungsquoten 1. Referenzzeitraum, 02.08.2021 bis 31.12.2025	Beschaffungsquoten 2. Referenzzeitraum, 01.01.2026 bis 31.12.2030
Pkw	50 g CO_2/ km, 80% Luftschadstoffe (Prozentsatz der Emissionsgrenzwerte nach RDE)	ab 2026: 0 g CO_2/ km, k.A. zu Luftschadstoff-emissionen	38,5 %	
leichte Nfz (< 3,5 t zGM)	50 g CO_2/ km, 80% Luftschadstoffe (Prozentsatz der Emissionsgrenzwerte nach RDE)		38,5 %	
Lkw (> 3,5 t zGM)	Nutzung alternativer Kraftstoffe (lt. Art. 2 AFID bspw. Strom, Wasserstoff, Erdgas, synthetische Kraftstoffe**, Biokraftstoffe**)		10 %	15 %
Busse (> 5 t zGM)			45 % *	65 % *

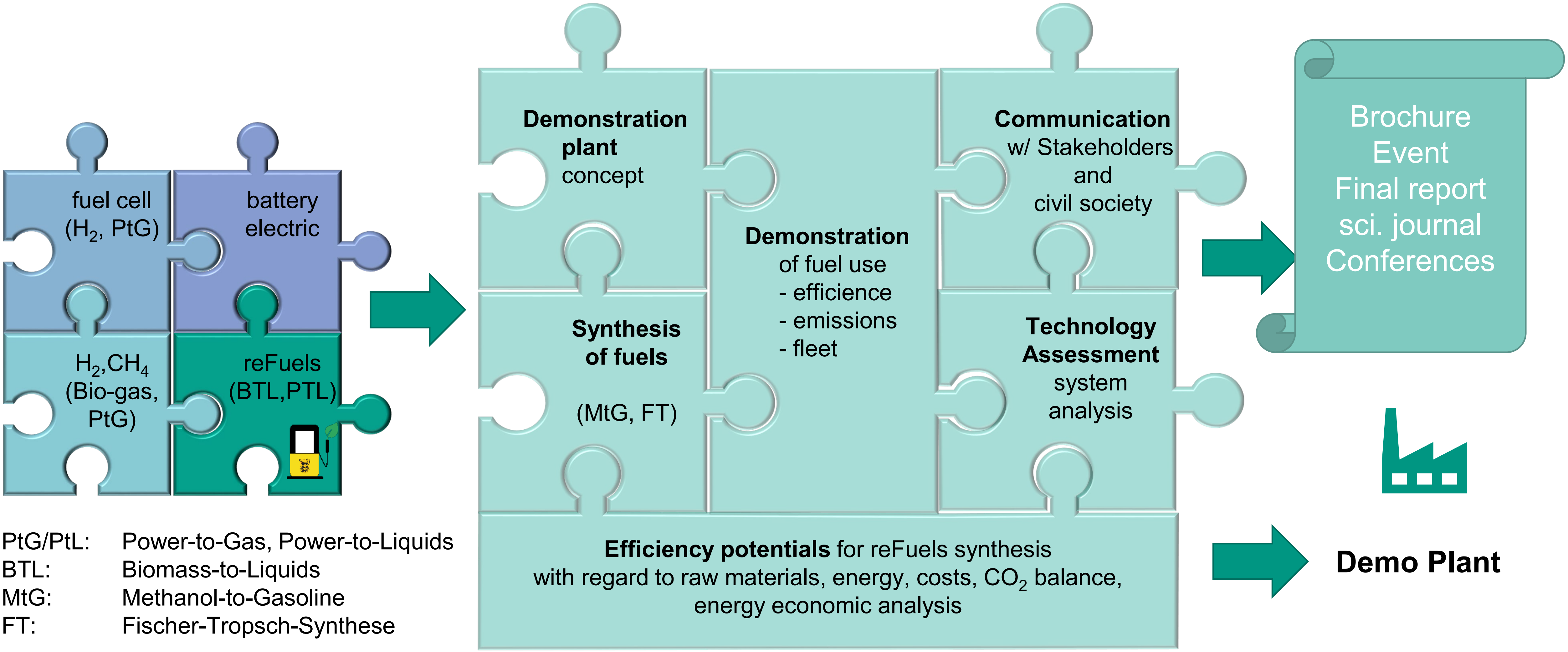
Quelle:https://www.bmvi.de/SharedDocs/DE/Artikel/G/clean-vehicles-directive.html

100% synthetic fuels as a fulfillment option

synthetic (free of palm oil) fuels are a fulfillment option for exeptional vehicles too and demonstrators in paralell

reFuels – rethinking Fuels

reFuels as a Building Block of CO_2-neutral Mobility



PtG/PtL:	Power-to-Gas, Power-to-Liquids
BTL:	Biomass-to-Liquids
MtG:	Methanol-to-Gasoline
FT:	Fischer-Tropsch-Synthese

The refuels project
Definition reFuels

reFuels comprise the group of fuels 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 regeneratively.

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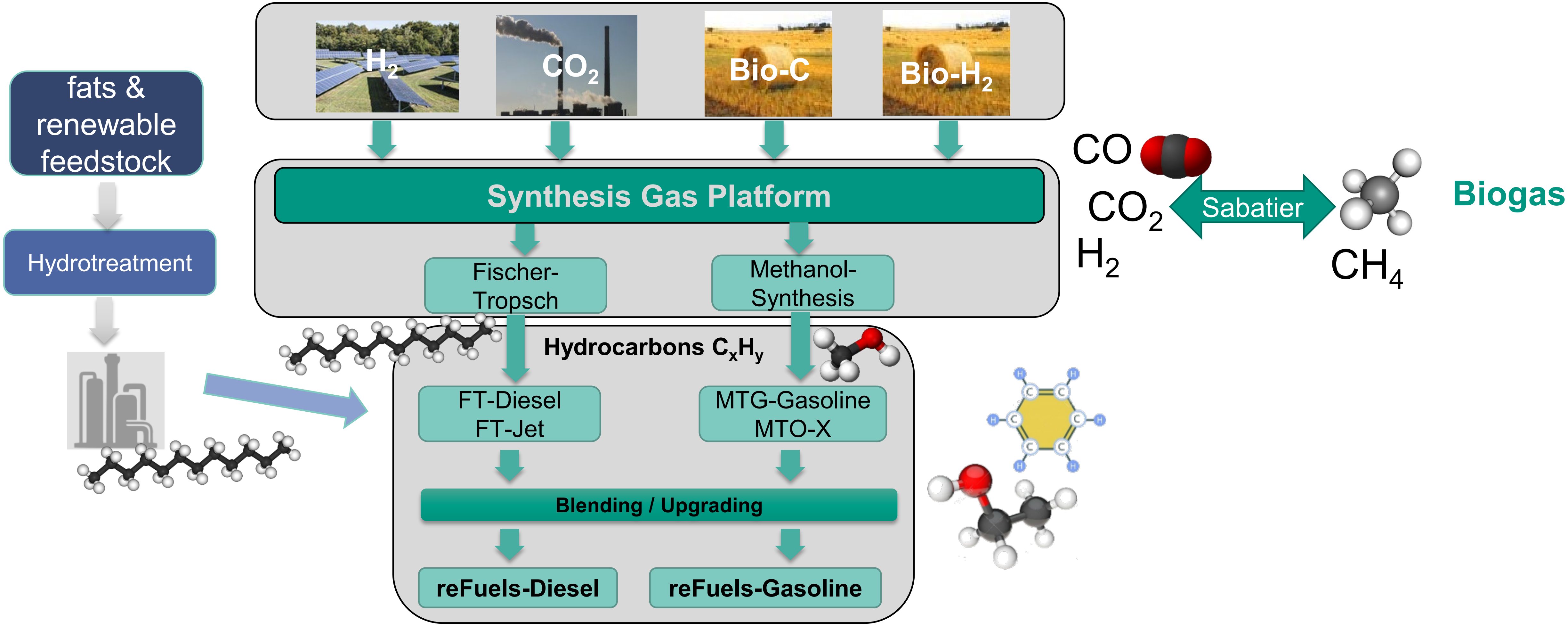
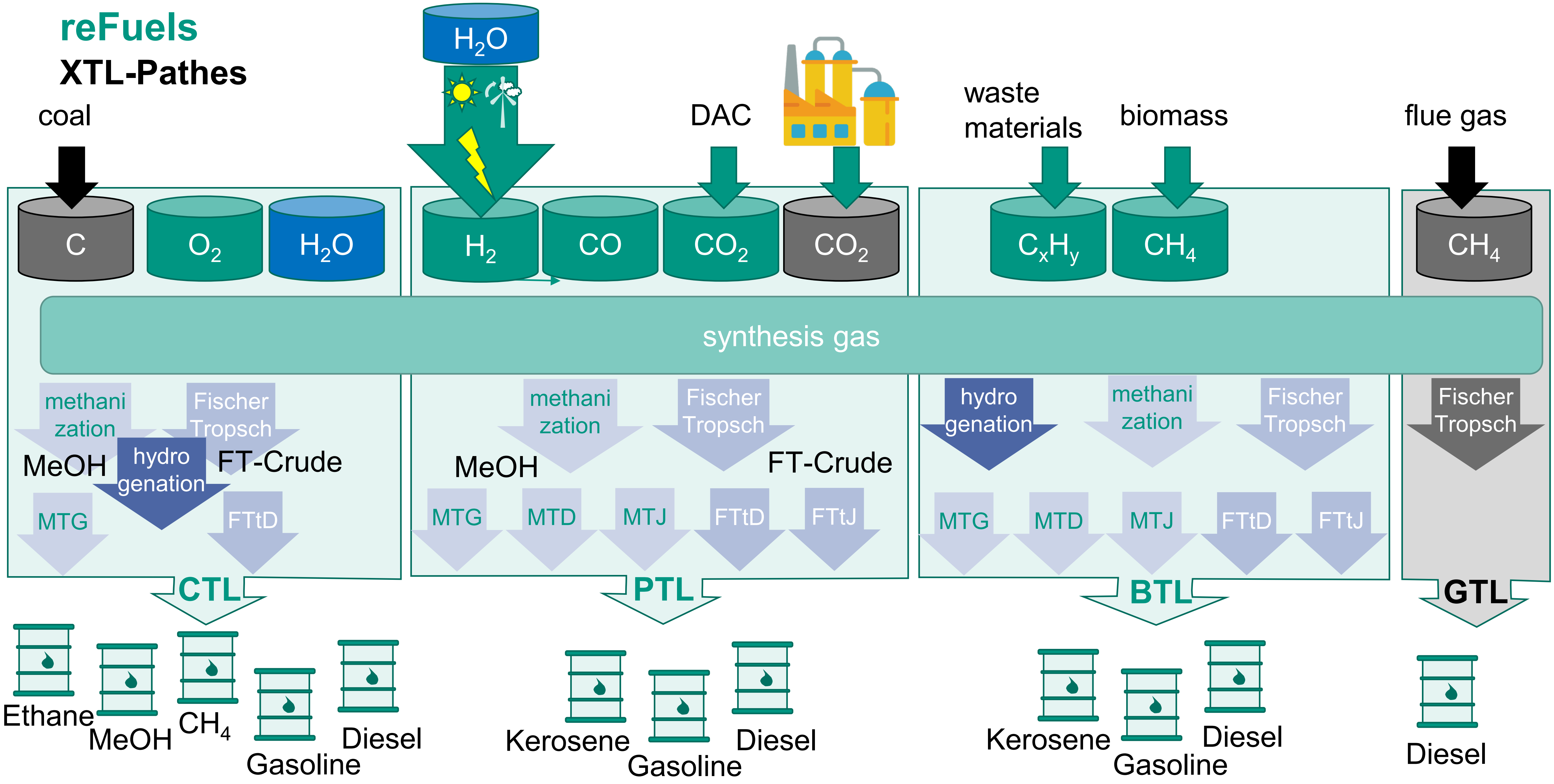
reFuels – rethinking Fuels

Synthesis Gas and Intermediates as Interfaces

- Exemplary synthesis pathways for reFuels



reFuels
XTL-Pathes



reFuels – rethinking Fuels

From fossile to synthetic fuels

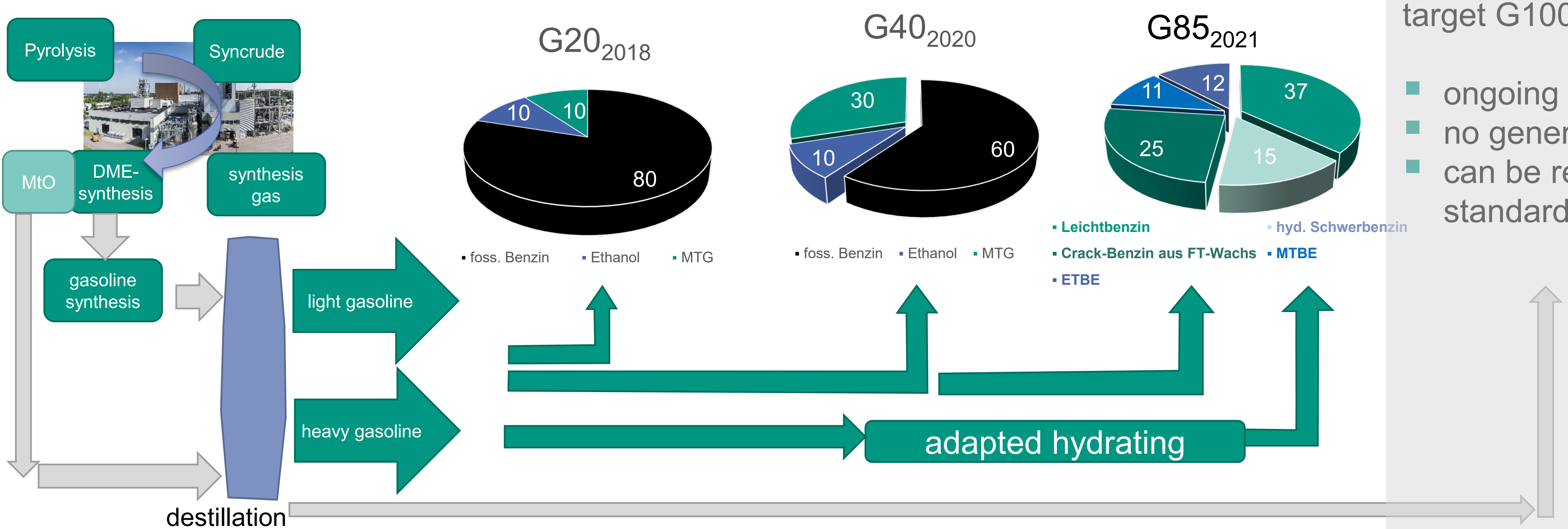
- **E-diesel and HVO have lower density than EN590 → EN15940 paraffinic diesel**
- **EN15940 paraffinic diesels are not listed in the 10th BImSchV, but are in CVD and rest of EU**
- **MtG - gasoline must be processed so that the aromatics content is in EN228**
- **MtG – post treatment of heavy gasoline fraction to fit in EN228**

Foto: Amadeus Bramsiepe, KIT

reFuels – rethinking Fuels

Gasoline Synthesis Strategy up to 100% regenerative Fuels in EN228

- Methanol-to Gasoline (MtG) – Blending of EN 228-fuels



target G100

- ongoing work
- no general problem
- can be realized with standard processes

- optimized yield
- high aromatic content

- red. light gasoline
- optimized aromatic content

- red. light gasoline
- hydrated heavy gasoline
- hydrated FT-wax
- ETBE + MTBE

- hydrated MtO-gasoline
- MtO-ETBE + MtO-MTBE

reFuels – rethinking Fuels

Test of the Fuels

- Tests of G40,G85 on engines @Ford, Porsche® Mahle MAHLE and KIT KIT Karlsruher Institut für Technologie

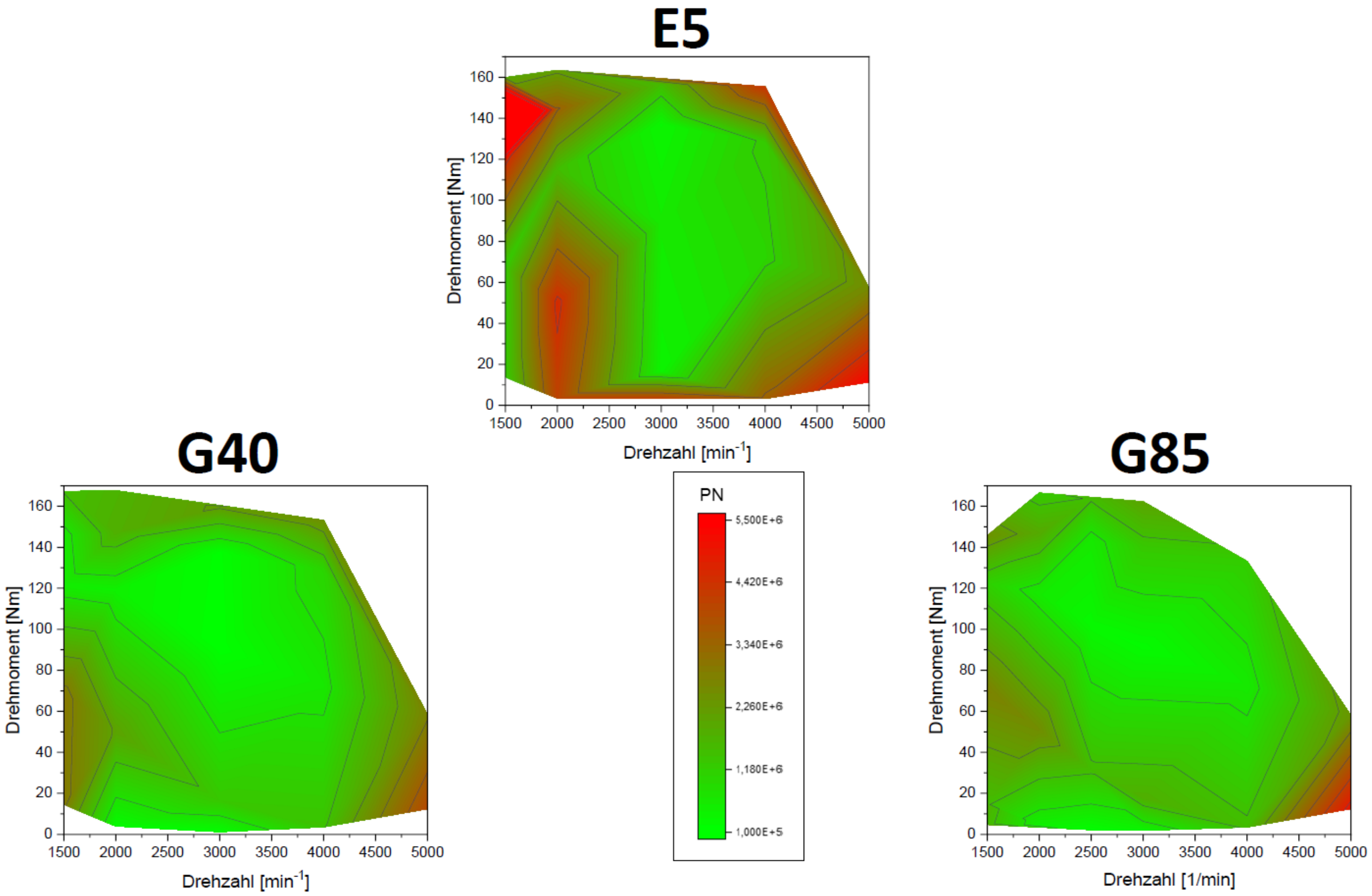
	research engine	full engine	vehicle
particles (PM und PN)	✓	✓	✓
CO	✓	✓	✓
HC	✓	✓	✓
NOx	✓	✓	✓
oil dilution		✓	✓
coldstart soot particles		✓	✓

No unexpected emissions, component- or oil-effects → 30% potential of CO_2- reduction

All ongoing Tests with G85 show comparable results → 75% potential of CO_2- reduction

Production Engine Tests using E5, G40 and G85

- Particulate Number different Blends



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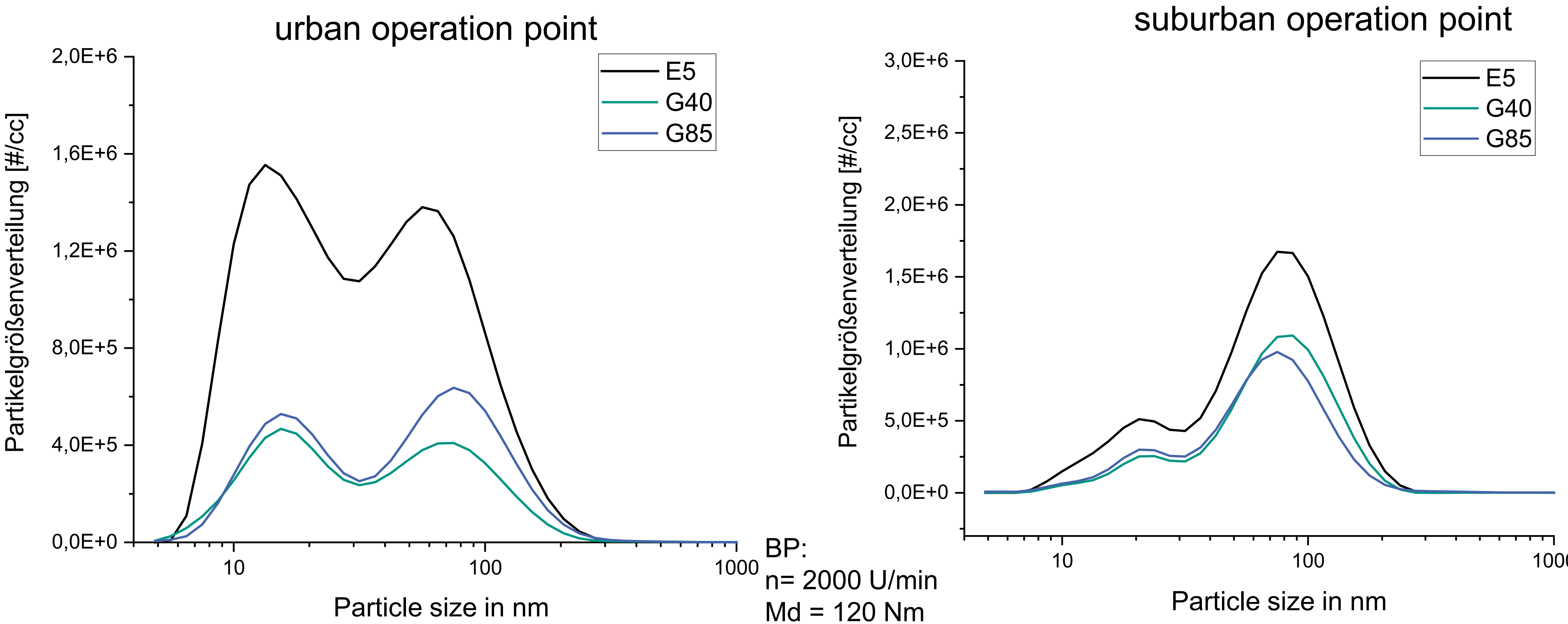
Production Engine Tests using E5, G40 and G85

- Particle Size distribution



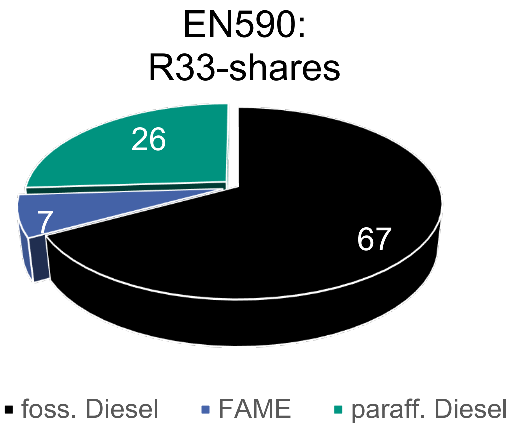
BP:
n= 2000 U/min
Md = 120 Nm

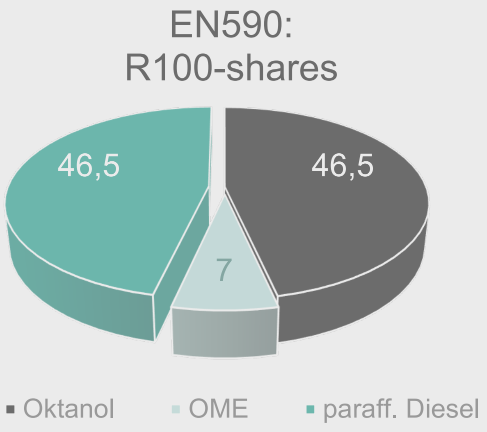
OP:
n= 4000 U/min
Md = 70 Nm

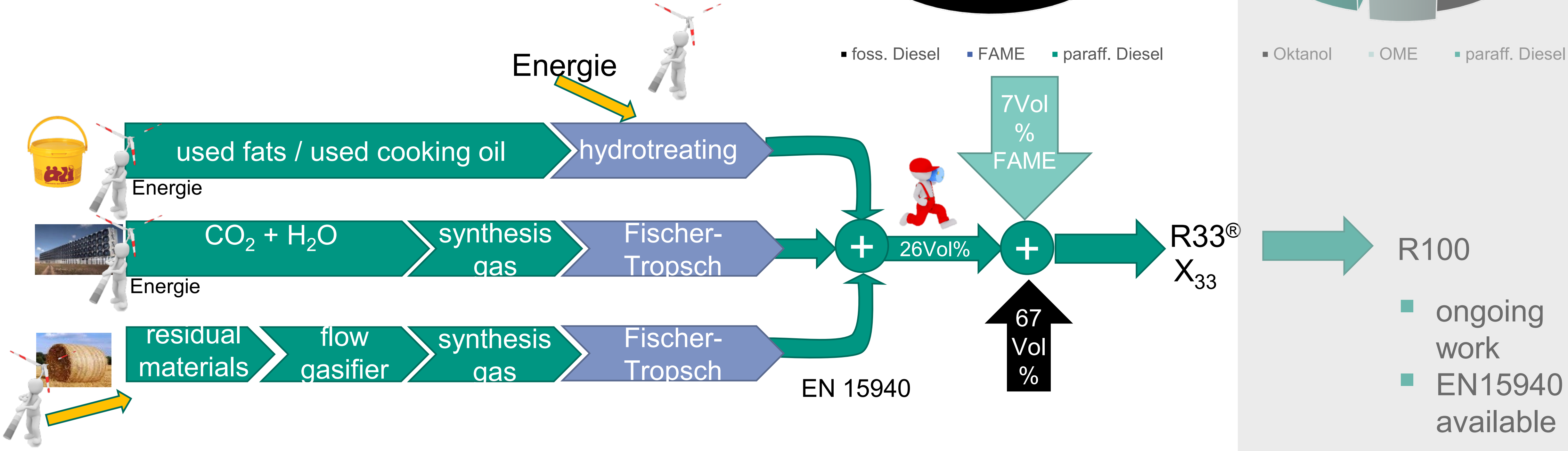
Trend toward lower particulate number and mass but room for improvement

reFuels – rethinking Fuels
reFuels in existing Fuel Norms

- **Diesel- fuel**







EN590-compliant blend - R33 available - R100 cold stability in progress

EN15940 - Approval for all commercial vehicle powertrains from approx. 2015, for the majority of passenger cars

reFuels – rethinking Fuels

Fleet testing C.A.R.E-Diesel as Example for EN15940-Diesel

- more than 900.000 km
- Ongoing testing of Truck pairs (B7 / HVO) for each track minimum up to 5 years
- Extension of fleet testing by short distance urban tracks
- Accompanying analysis of the engine oil after fixed intervals so far without negative findings

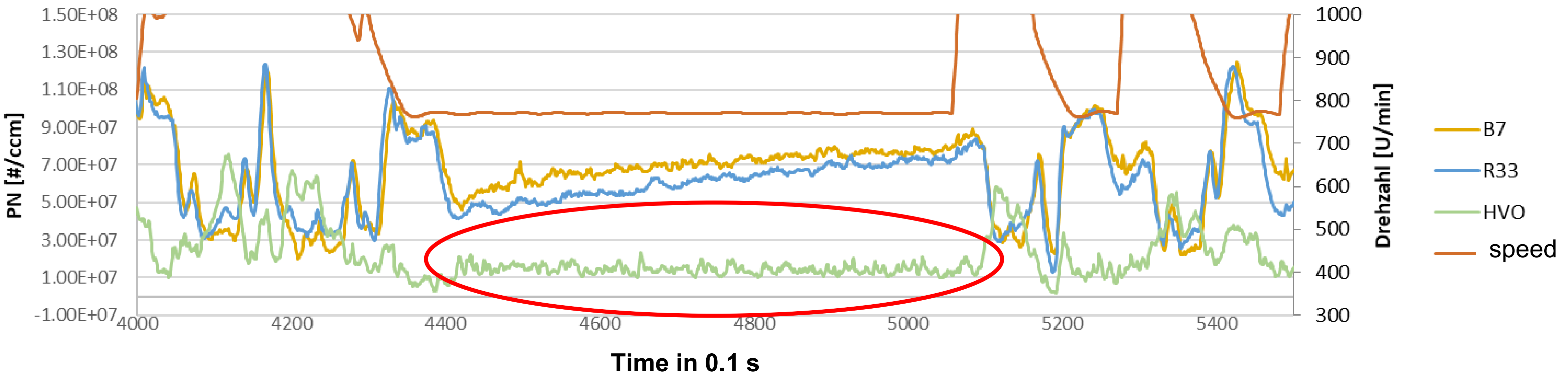
⇒ **Slight reduction in fuel consumption observed**

⇒ **Trend toward lower particulate emissions**

reFuels – rethinking Fuels
Diesel WLTC-cold start cycles

- **Experiments at -7°C**

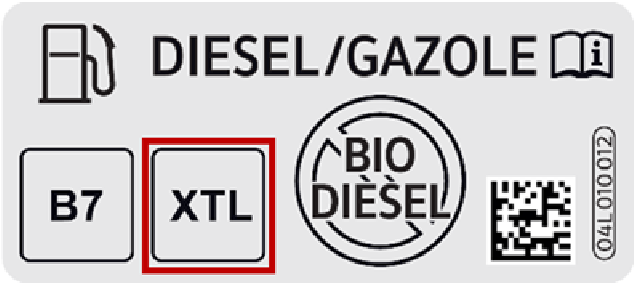
Particulate number in idle phase of WLTC



Paraffinic Diesel shows reduced particulate emissions in idle situations

reFuels – rethinking Fuels

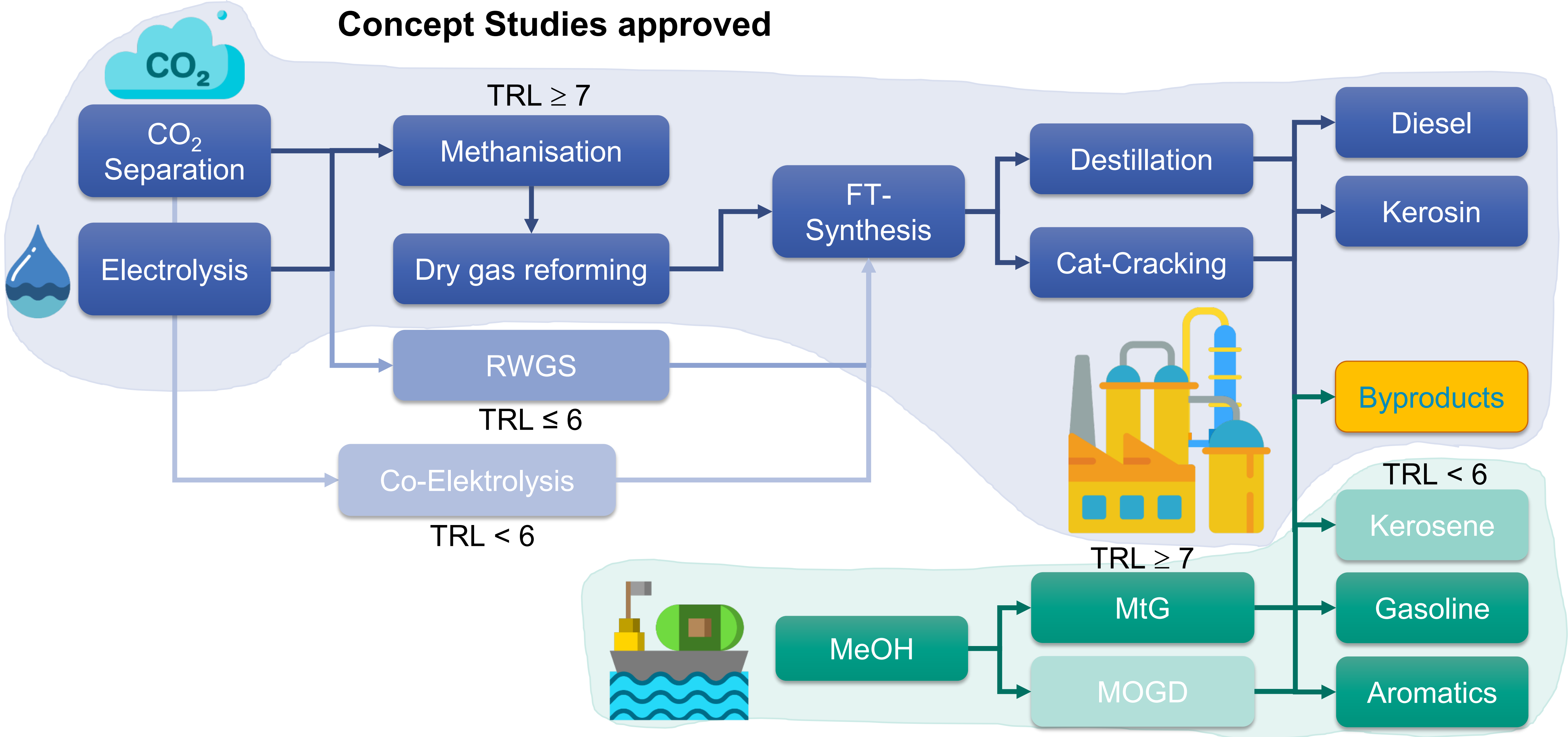
XtL – Approvals – EN15940



- ✓ Audi and Volkswagen - all current Diesels except a few top 6-cylinder engines
- ✓ BMW - all Diesels with XTL approval
- ✓ Daimler all passenger cars 4-cylinder volume applications passenger cars and VAN
- ✓ Ford - all Diesel VAN volume applications
- ✓ Commercial vehicles - no new vehicle known that does not have XTL approval
- ✓ Special vehicles are built by bodywork specialists on the basis of volume models

Material Flows and Modules Demo Facility to target „green refinery“

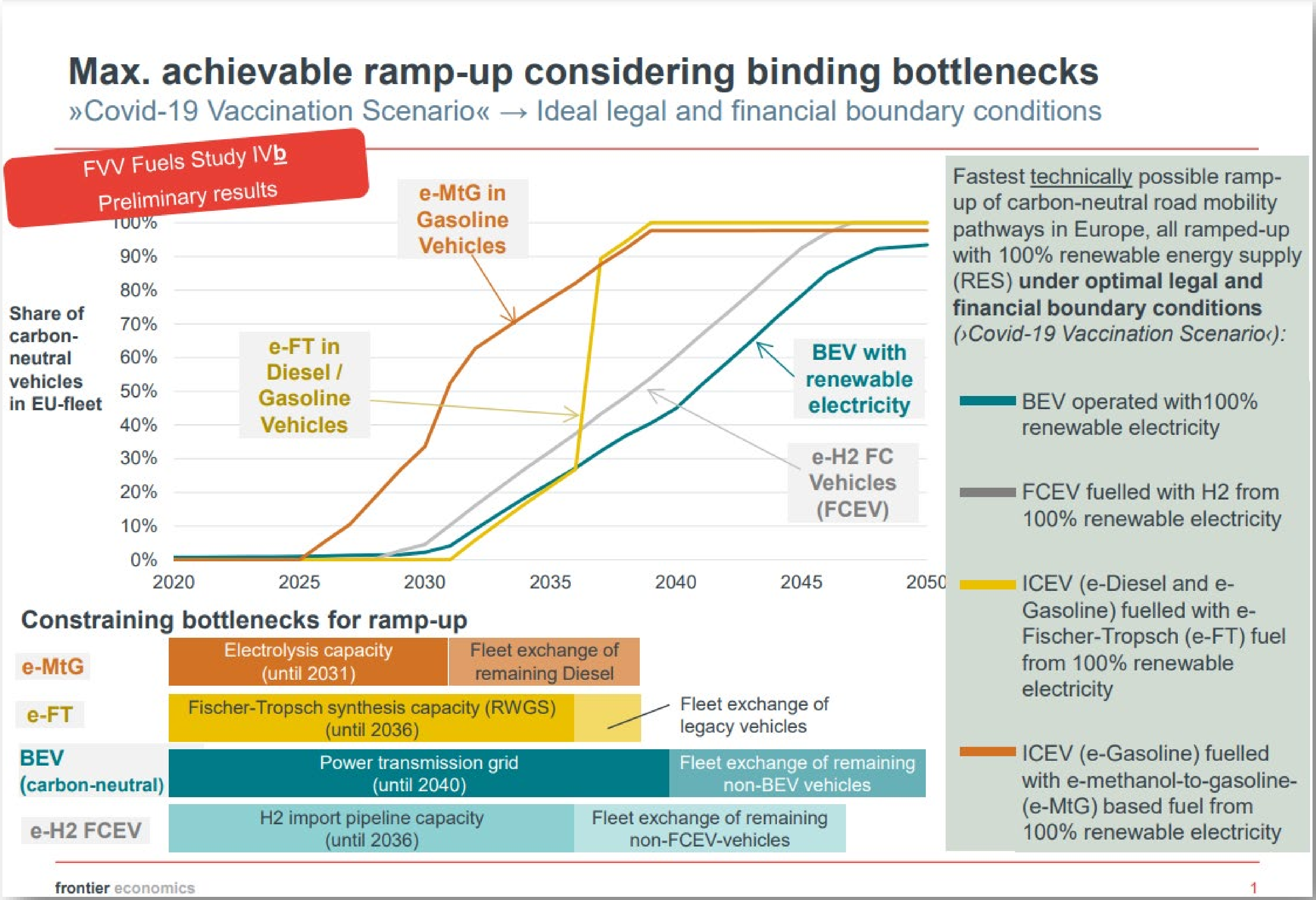
Concept Studies approved



reFuels – next steps

Scalability of fuel synthesis

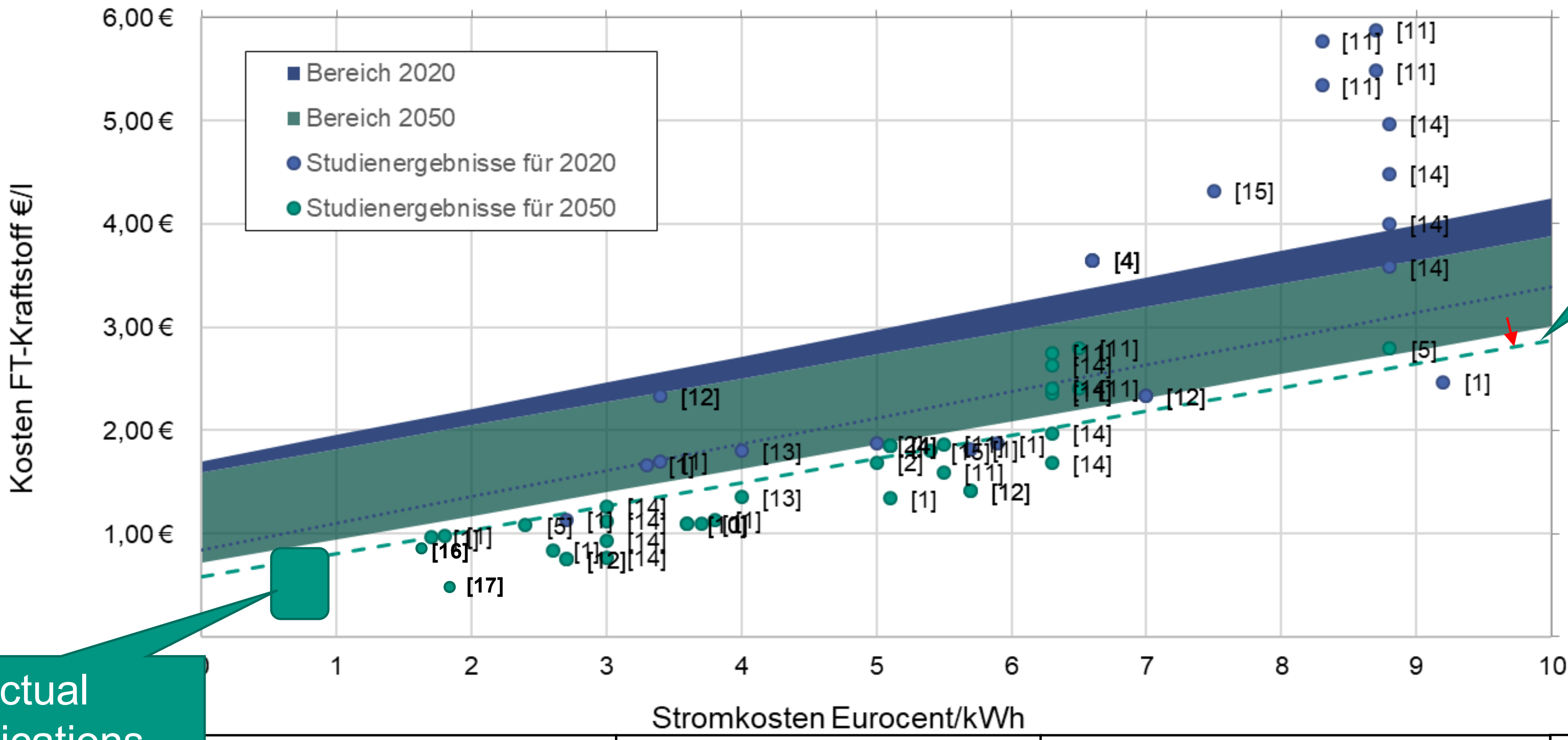
- Technology maturity needs scaling
- Scaling is only possible in stages not to change processes
- Time determined by planning, approval and construction



- FVV-Kraftstoffstudie IV Erscheint im Herbst 2022 und untersucht dem Rampup
- Randbedingungen unter https://www.fvv-net.de/medien/aktuelles/detail/wie-schnell-geht-nachhaltig/

reFuels – rethinking Fuels

Results volume cement plant FTS with other study results related to electricity costs



Cost reduction effects due to scaling effects for larger plants

actual publications

[1] Agora/Frontier Economics 2018	[6] UBA/Ifeu/Infras/LBST 2016	[11] FVV/LBST 2016	[16]:Agora/Frontier Economics 2018: PV im nahen Osten;Alkalisch PEM
[2] Leopoldina/Acatech 2017	[7] Öko-Institut/DLR/Ifeu/Infras 2016	[12] Prognos/Fraunhofer Umsicht/DBFZ 2018	[17]:Prognos/Fraunhofer Umsicht/2018: Import Nordafrika/mittl.Osten
[3] UBA 2019	[8] Enervis 2017	[13] BCG/Prognos 2018	
[4] UBA/Öko-Institut/KIT/Infras 2016	[9] Öko-Institut/Fraunhofer ISI 2015	[14] Dena/LBST 2017	
[5] FVV 2018	[10] Dena/EWI 2018	[15] EWI 2019	

Calculation on german electricity supply clarify the necessarity of international solutions

reFuels – rethinking Fuels

Factors influencing the business case of a reFuels demo plant

Elektrolysis / CCU / DAC → RWGS / synthesis gas-processing → Fischer-Tropsch / methanol-synthesis → hydrating isomerisation / methanol-to-Olefine / methanol-to-gasoline → Kerosene / Diesel / Gasoline

Political options for action

Technical influences

- Investment amount per target quantity
- Processes (efficiency)
- Process optimization
- Maintenance

Technically related additional costs

+ Δ-costs Invest/ target quantity 50.000 t/a- size
+ Δ-costs 1000.000t/a

Regulatoric influences RED II

+ creditability CO_2
  - DAC
  - CCU
+ requirements renewable electricity
  - Additionality
  - Simultaneity
  - Bottleneck avoidance
+ necessarity regenerative CH_4

– creditability BEHG
– creditability THG
– creditability fleet

→ **Δ-costs carbon sources**

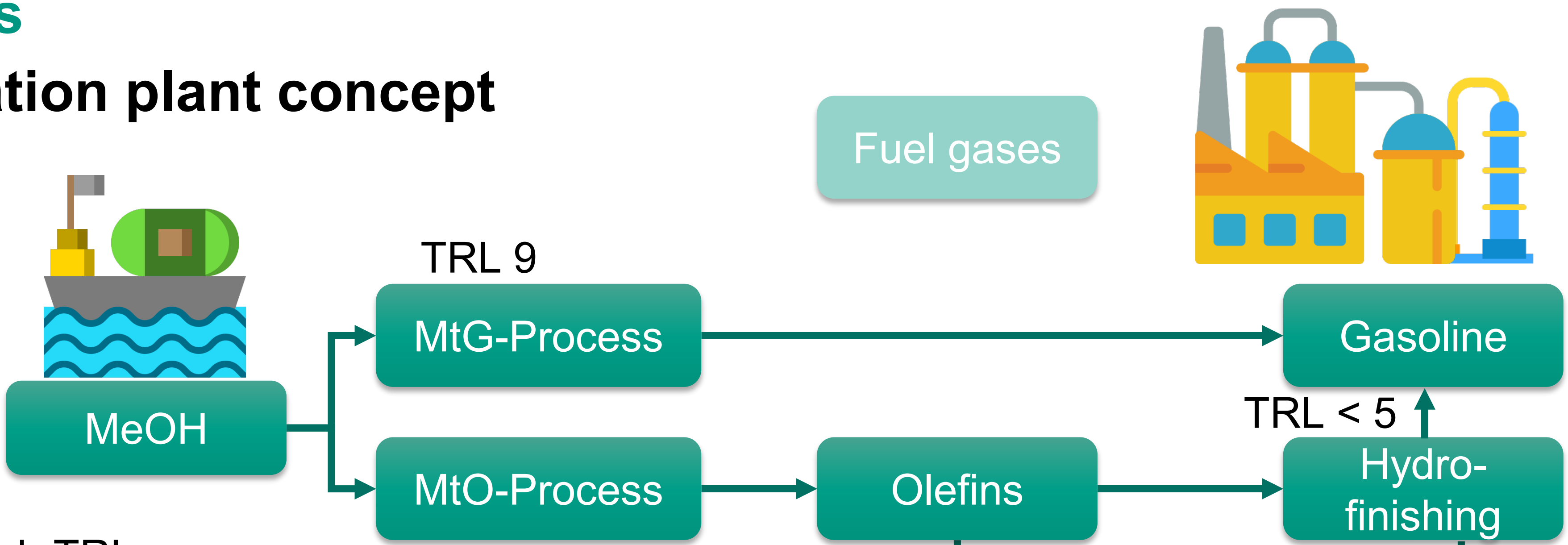
→ **Δ-costs electrical supply**

→ **Δ-costs regen. CH_4-supply**

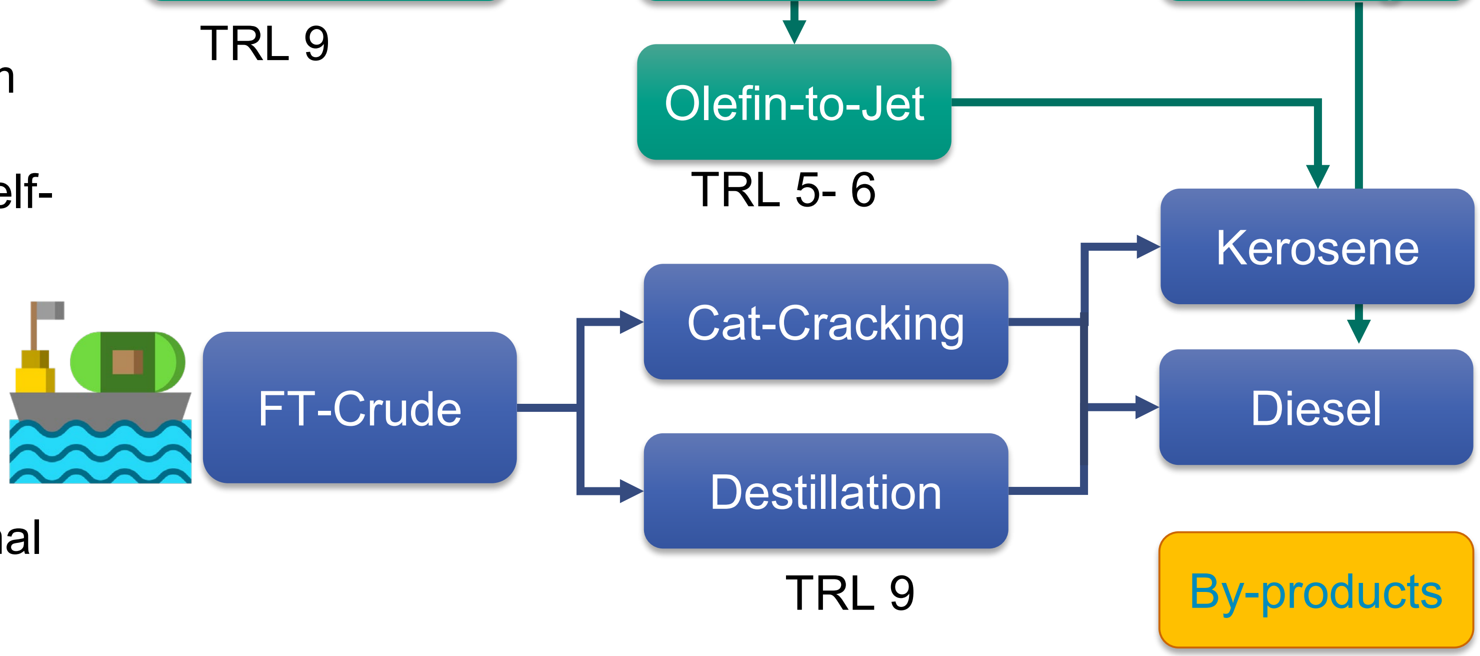
→ **Δ-income certificates**

reFuels – next steps

Modular demonstration plant concept



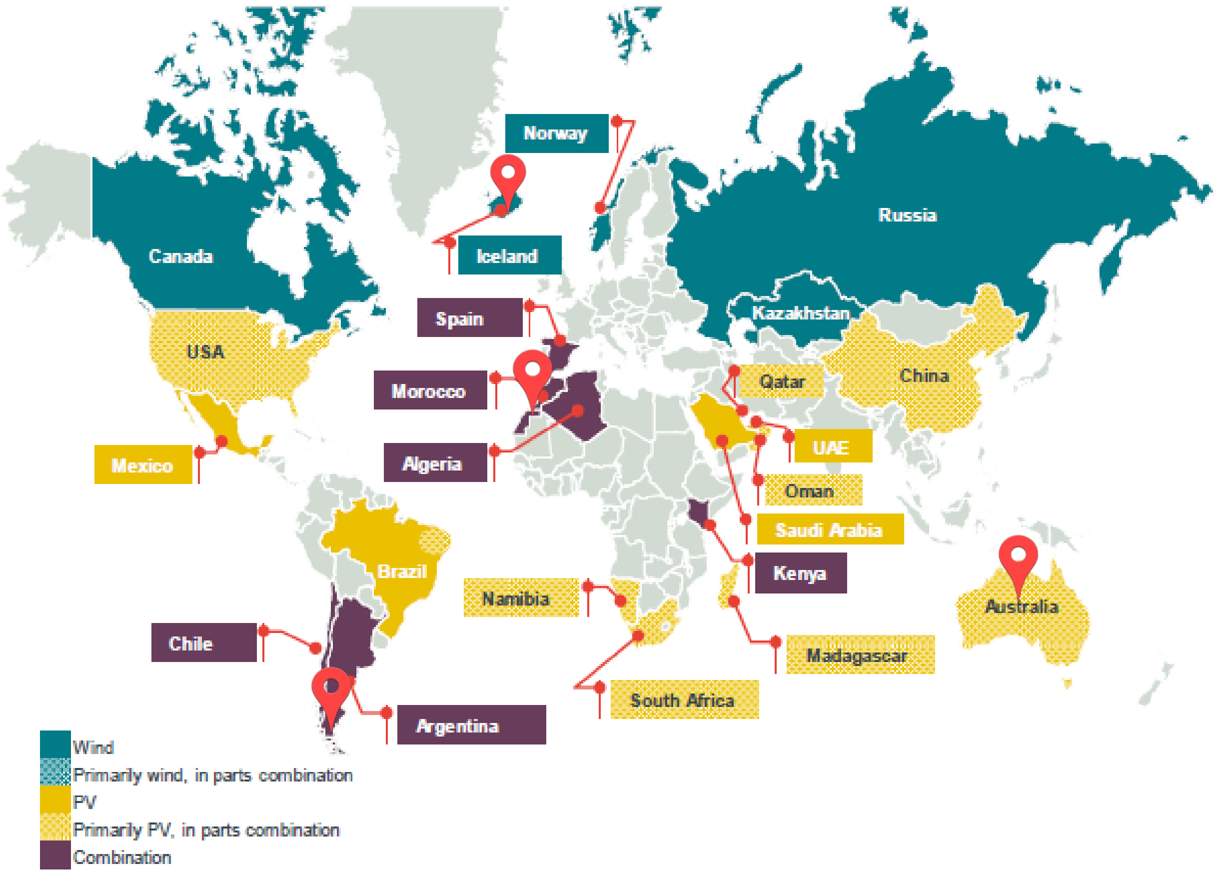
- FT route established with high TRL.
- Pending market availability FT-crude from sustainable feedstocks.
- Current regulatory framework prevents self-synthesis of green FT or green methanol i.e. in sounth of Germany.
- Methanol-based products economically favored
- Feedstock- and TRL-related shift in the sequence of the construction of the original planned process modules.



reFuels – rethinking Fuels

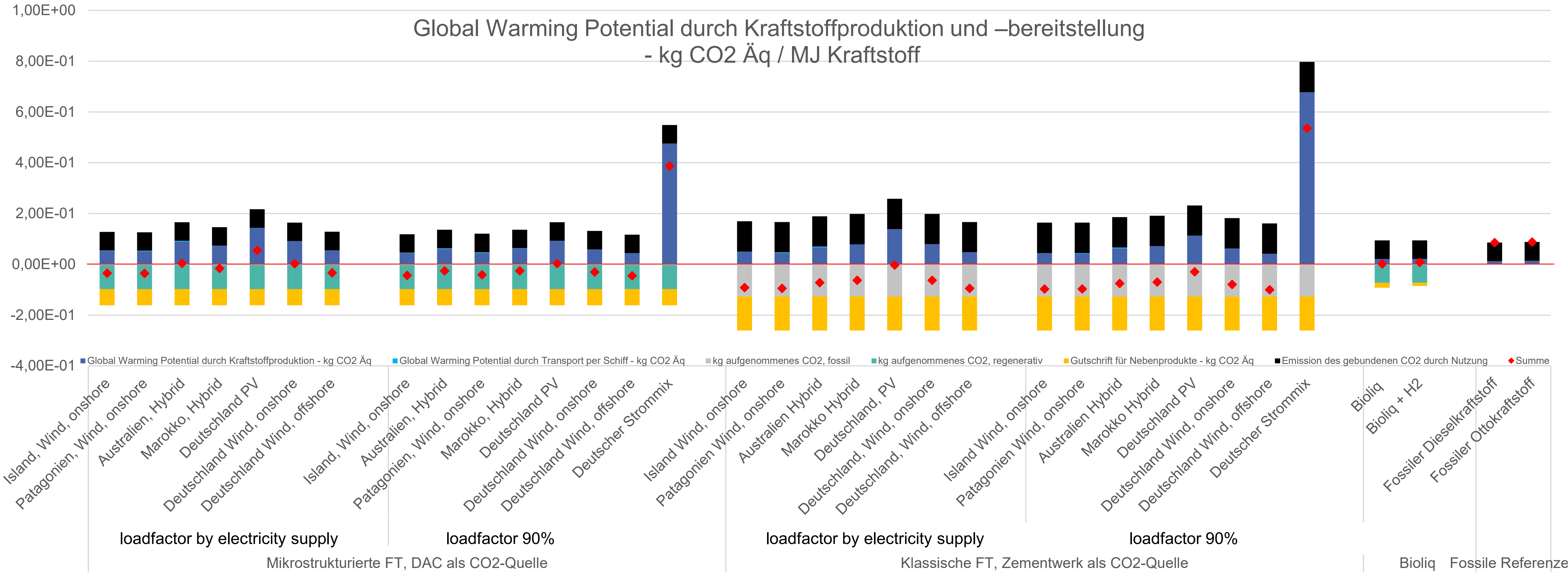
Fuel Synthesis Life Cyckle Assessment – international Approach

- Importszenarios incl. product transport by ship
- Energy use data by Pfenninger/Staffell (2016)
  - wind turbine: Enercon E112
  - PV-plant: 1-Axis-tracking
  - Marokko, Agadir
    - Hybrid PV-Wind, onshore
    - capacity factor Wind 17 %, Solar PV 30 %
  - Argentinien, Patagonia
    - wind, onshore
    - capacity factor Wind 56 %
  - Australien
    - Hybrid PV-wind, onshore
    - capacity factor Wind 30 %, Solar PV 30 %
  - Island
    - Wind onshore
    - capacity factor Wind 45 %



Source: Frontier economics, 2018

reFuels – rethinking Fuels
Fuel Synthesis Life Cycle Assessment – Global Warming Potential

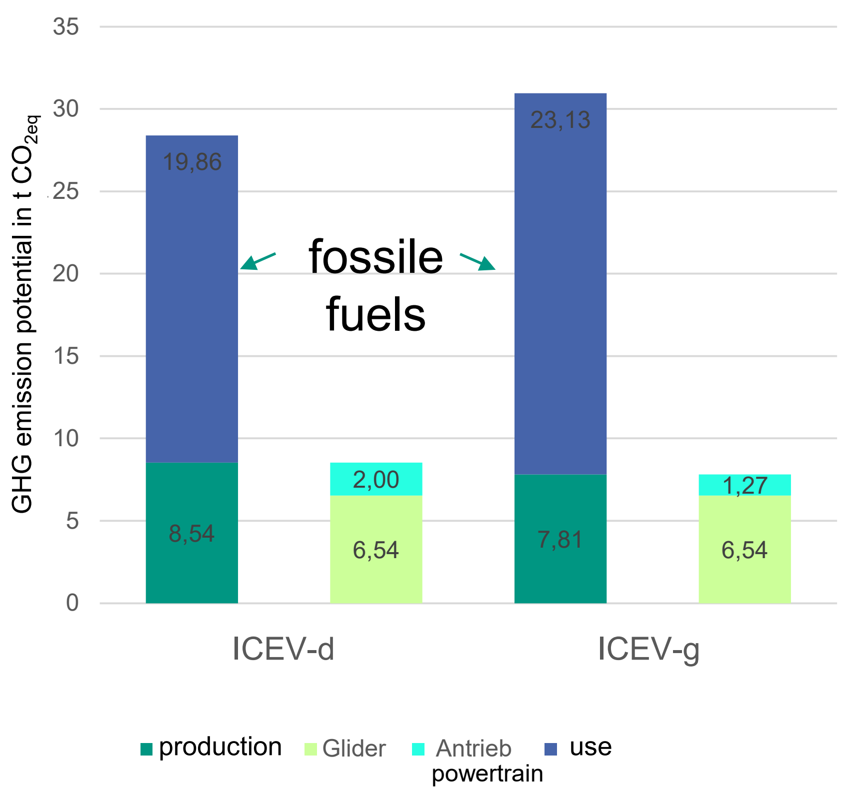


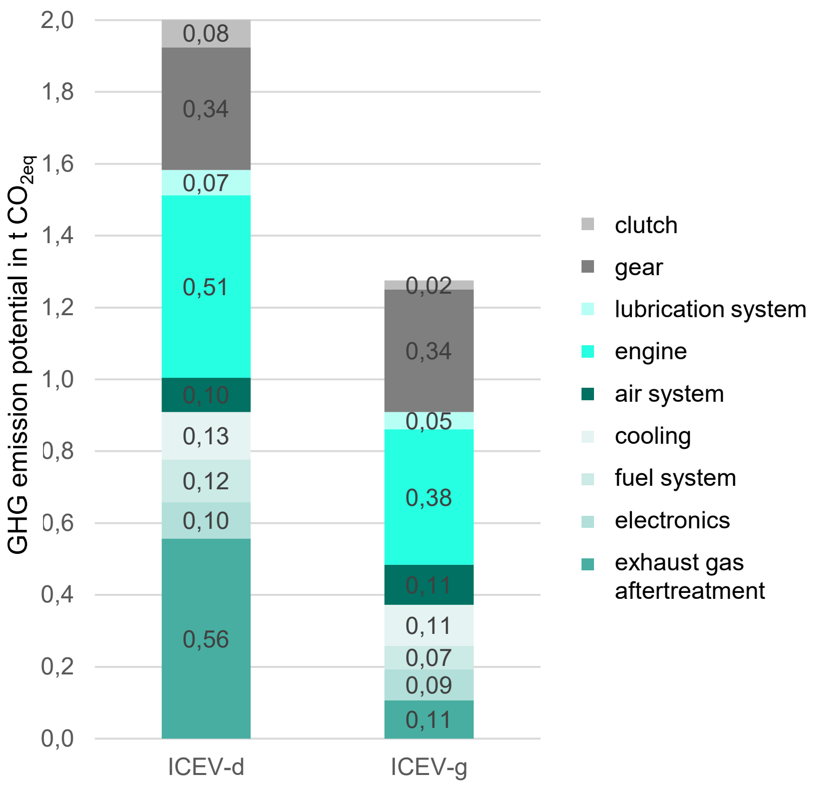
Fuel and intermediates (methanol, FT-crude) transportable in existing infrastructure

reFuels – rethinking Fuels

Vehicle LCA using fossile reFuels

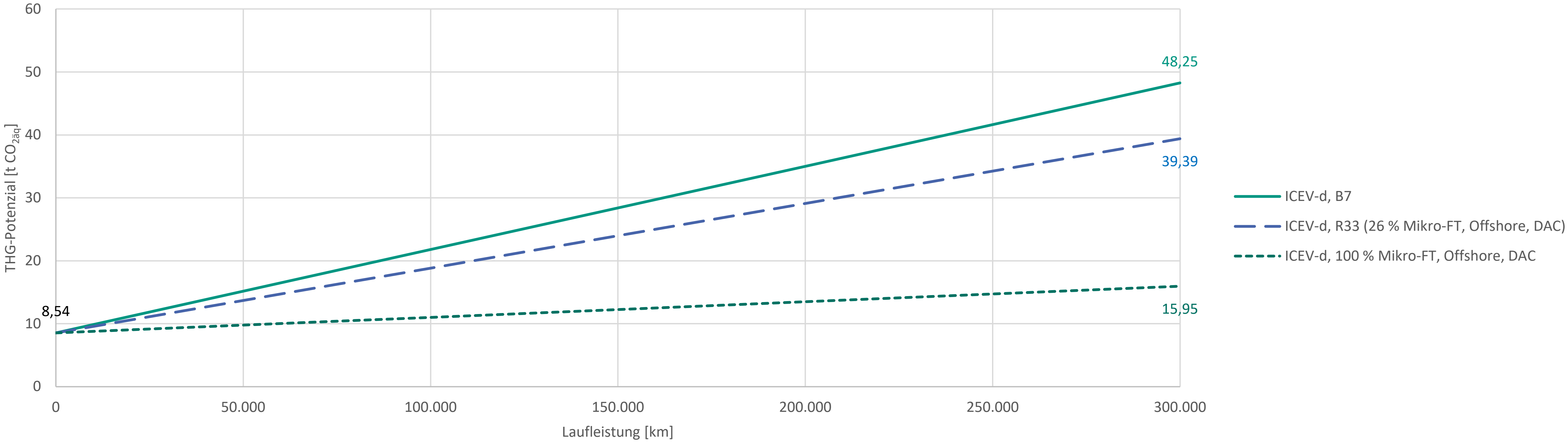
- Production and use-related emissions of a Diesel and a Gasoline vehicle (mid class 150.000 km)





reFuels – reFuels – rethinking Fuels
Vehicle LCA using reFuels as Diesel replacemenet

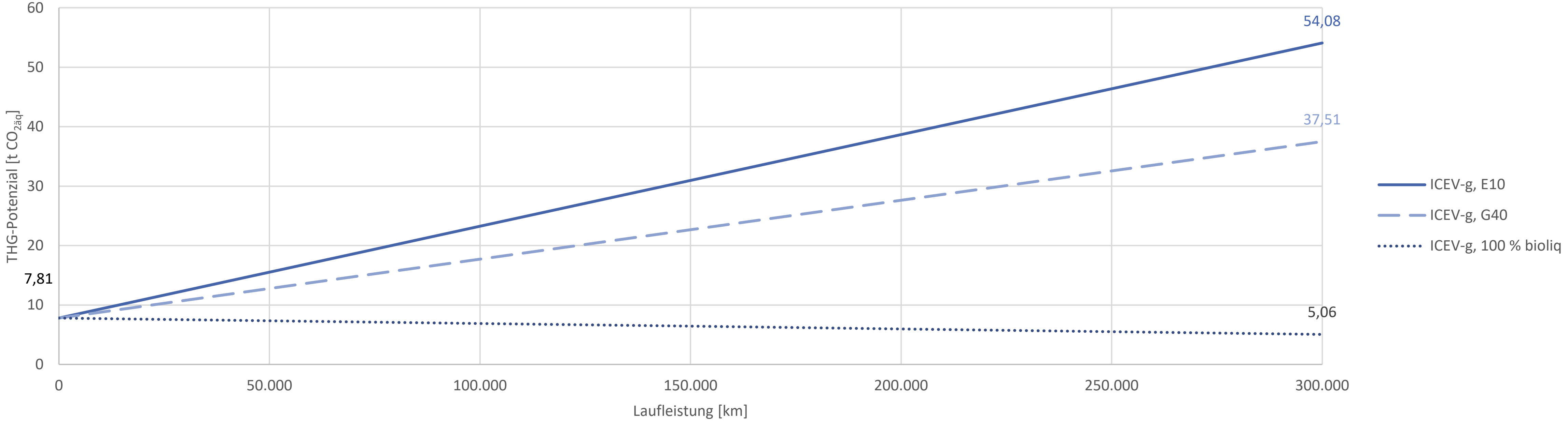
- Diesel fuel variation



- 26 vol% admixture (R33) limits CO_2 reduction potential to 22%
- E-fuel -diesel allows approx. 82% CO_2 reduction in the fleet (existing fleet and infrastructure)
- Neste states 90% for HVO (on balance sheet without palm oil)
- H_2 conversion of Diesel engine as a CO_2-neutral solution

reFuels – rethinking Fuels
Vehicle-LCA: reFuels as E10 gasoline replacement

- Gasoline Variation

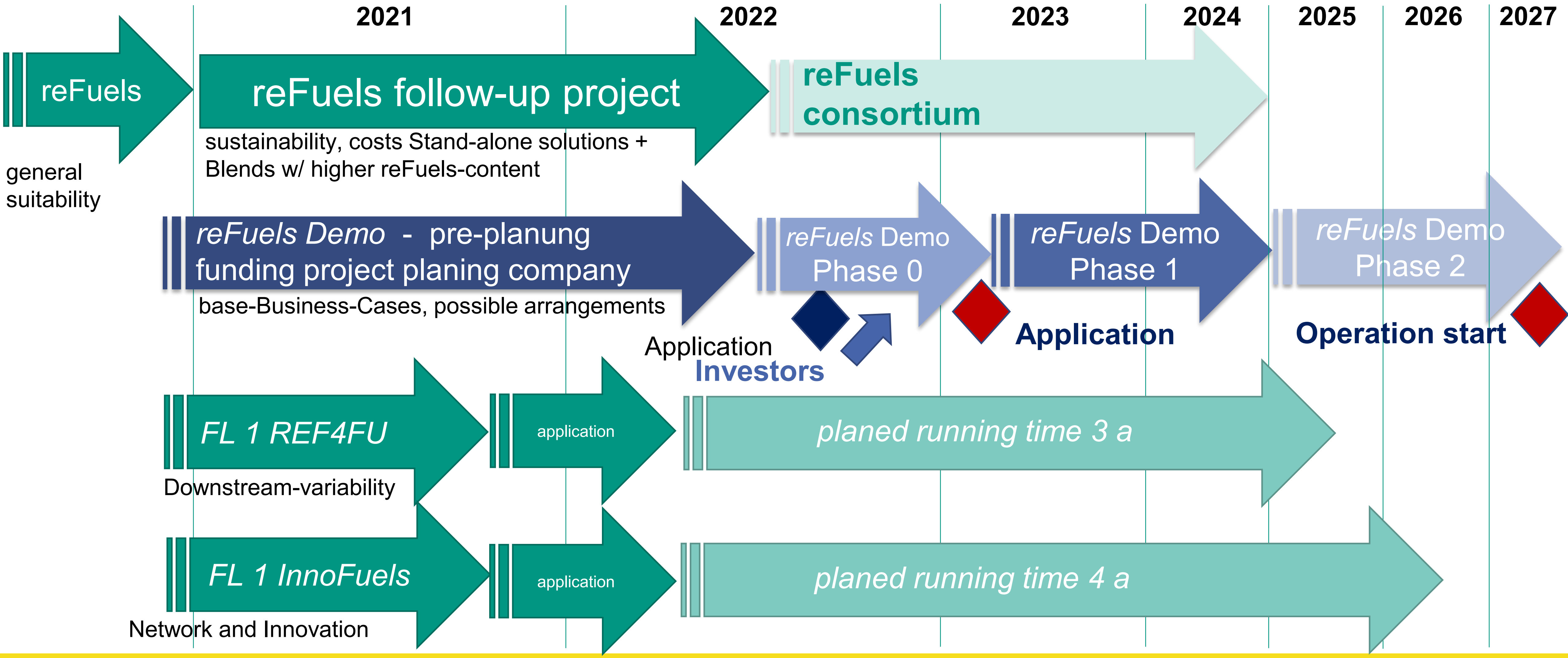


➡ MtG-gasoline by biogenic waste stores CO_2 from the air, is self-sufficient in terms of energy and supplies waste heat (□CO_2-negative within the system boundaries).

➡ EN 228 blend with 30% residual MtG gasoline achieves significant CO_2 reduction in use.

➡ EN 228-compatible G85 blend as a step towards CO_2 neutrality.

Beyond reFuels
Storylines



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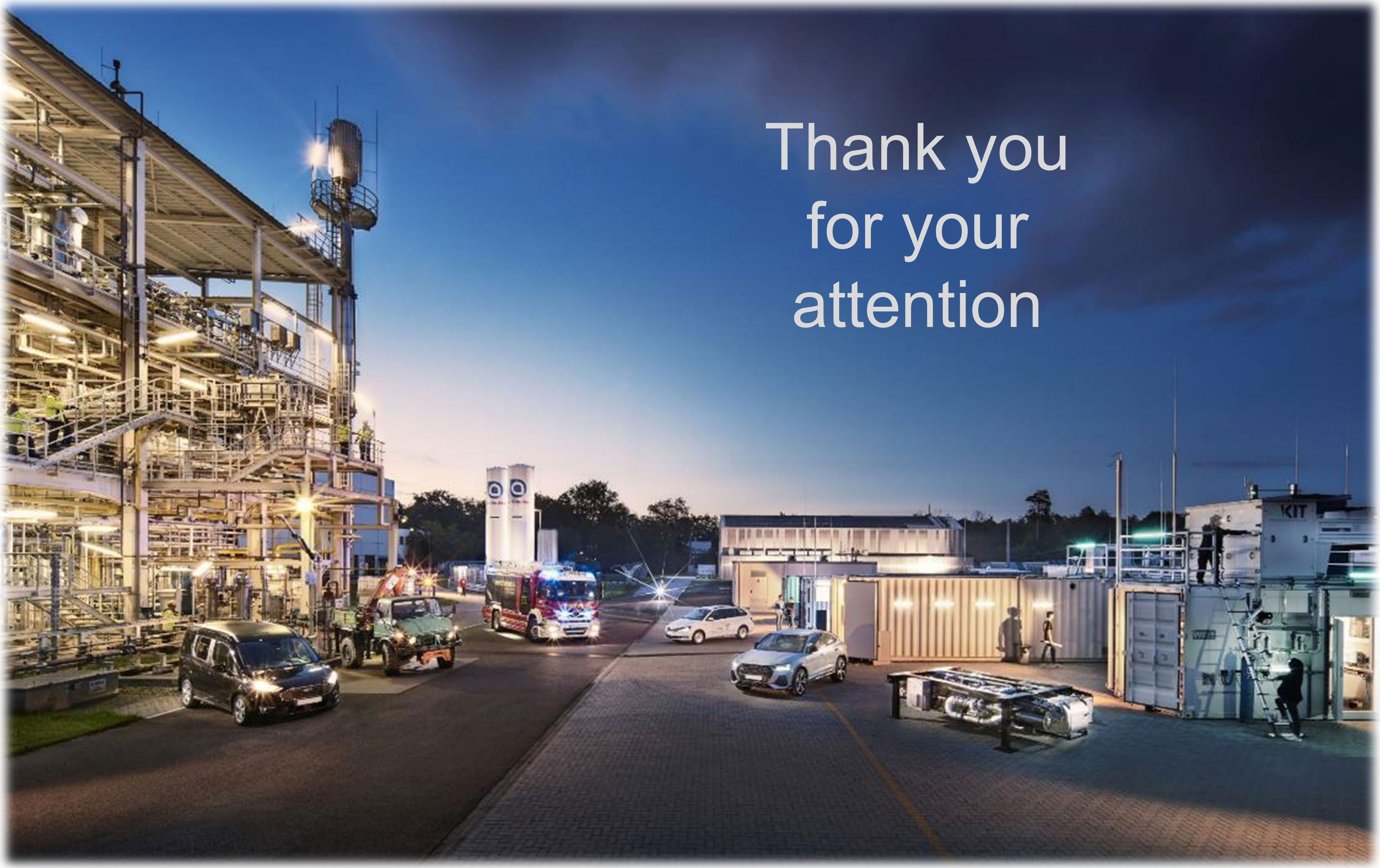
reFuels – rethinking Fuels

There are Facts - what are our Conclutions?

- Large existing fleet of ~250 Mio vehicles in EU
- Even ambitious targets of BEV share 15 Mio of 48 Mio vehicles in Germany are far away from 50% (EU mobility CO_2 reduction target)
- Vehicle fleet changes max. ~3%/year with ~5-8tCO_{2eq}/car plus battery efforts
- CO_2 ist accumulating in atmosmphere and our budget is limited
- We are importing crude oil, why not importing Methanol, FT-crude or pyrolysis oil?
- There is no additional CO_2 emission when enabling reFuels under renewable conditions
- Not the ICE is the CO_2-emittend it's the fuel
- reFuels are CO_2-negative, in user there are nearby CO_2-neutral
- reFuels will come on an international base – the only question is, weather we participate or not

→not considering reFuels as part of the CO2-reduction activities is an active environmental damage


Thank you
for your
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KIT