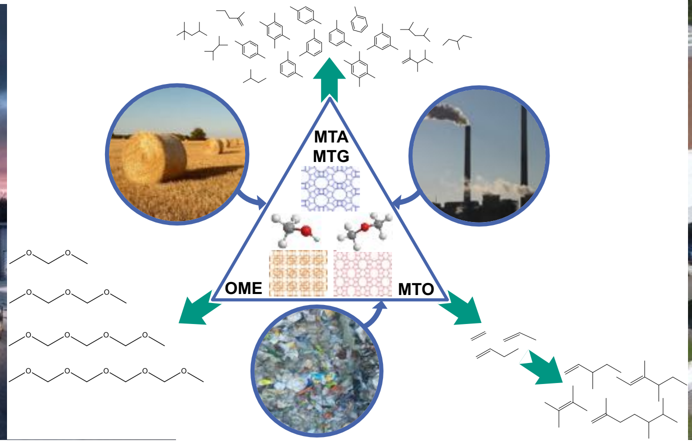
Karlsruhe Institute of Technology

# Systemwissen für die Energiewende: Das Energy Lab ~~2.~~0

**Jörg Sauer**




IKFT develops catalysts and process technologies of catalytic processes for the production of chemical energy carriers based on renewable energy and alternative raw materials. Research spans from the understanding of the processes at the molecular level to the pilot plant stage.

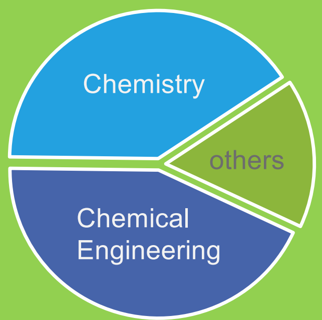
**465**
Publications since 2017 (peer-reviewed)

**64**
of which in 2023



# IKFT at a Glance

**131**
Staff members




**41**
PhD students with

**20**
being international

**6**
Scientific departments

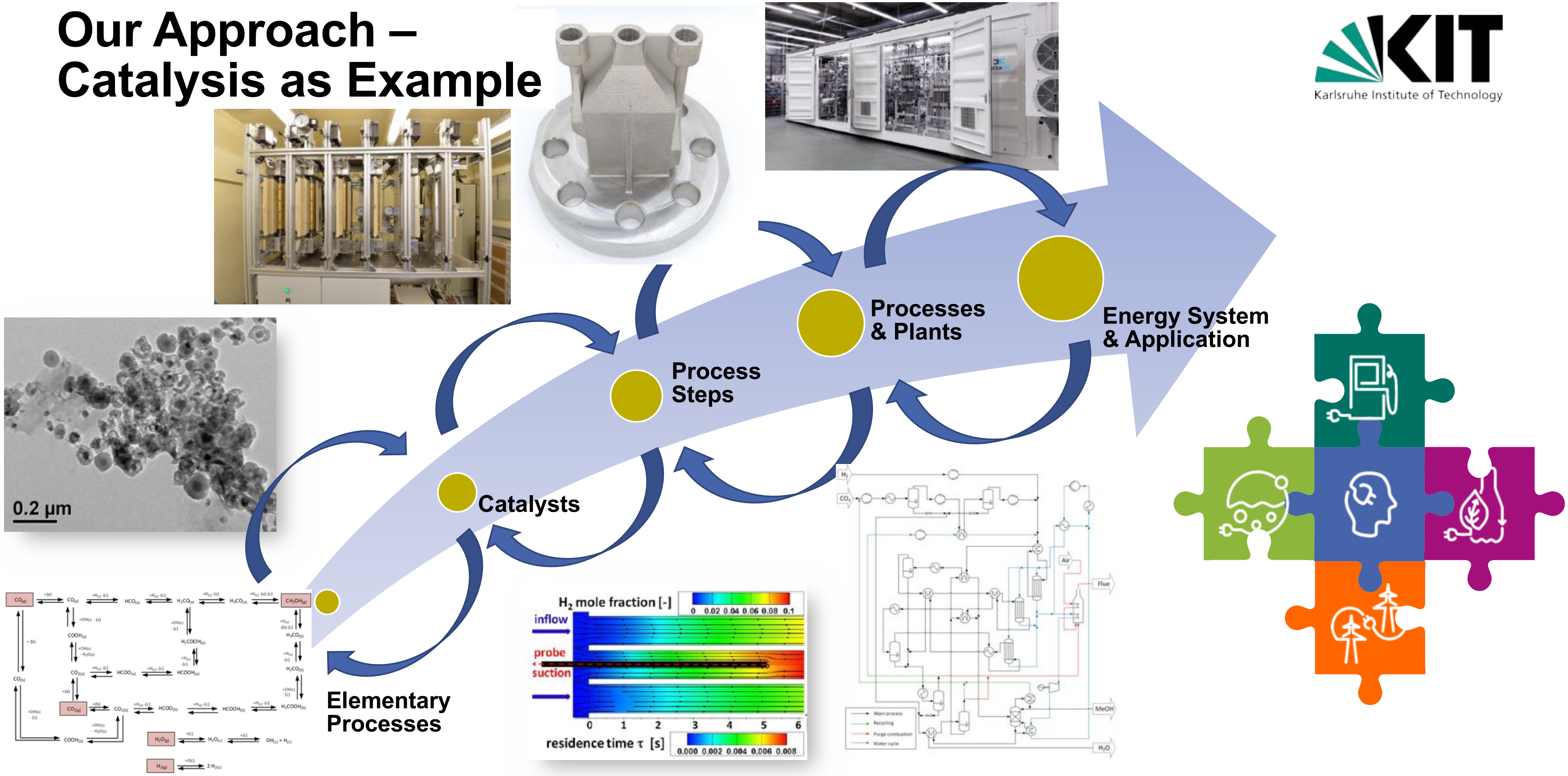
**7**
Professors

**5.037.852 €**
R&D Budget (2021, without personnel)

**47,04 %**
of which third-party funded

Experimental research and technological development are complemented by computational catalysis and *operando* techniques to provide a fundamental understanding of catalytic systems under realistic conditions.

# Our Approach – Catalysis as Example

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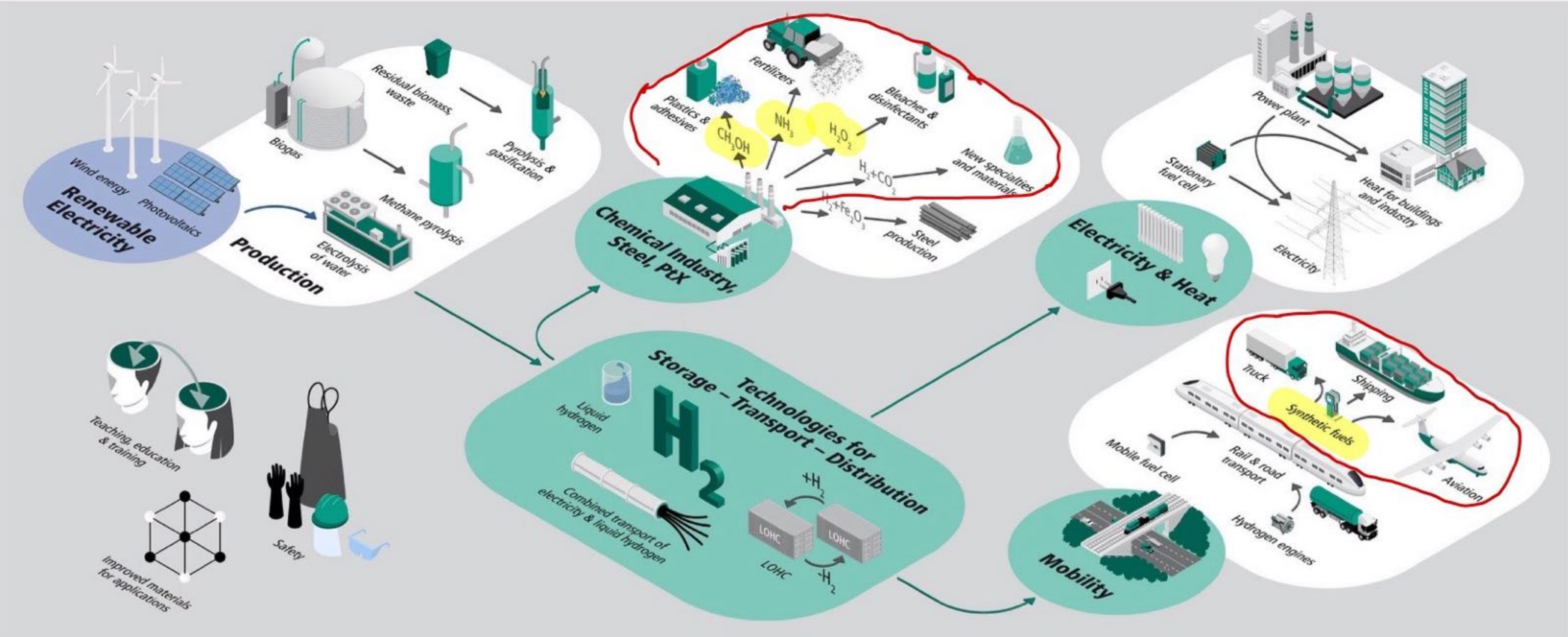
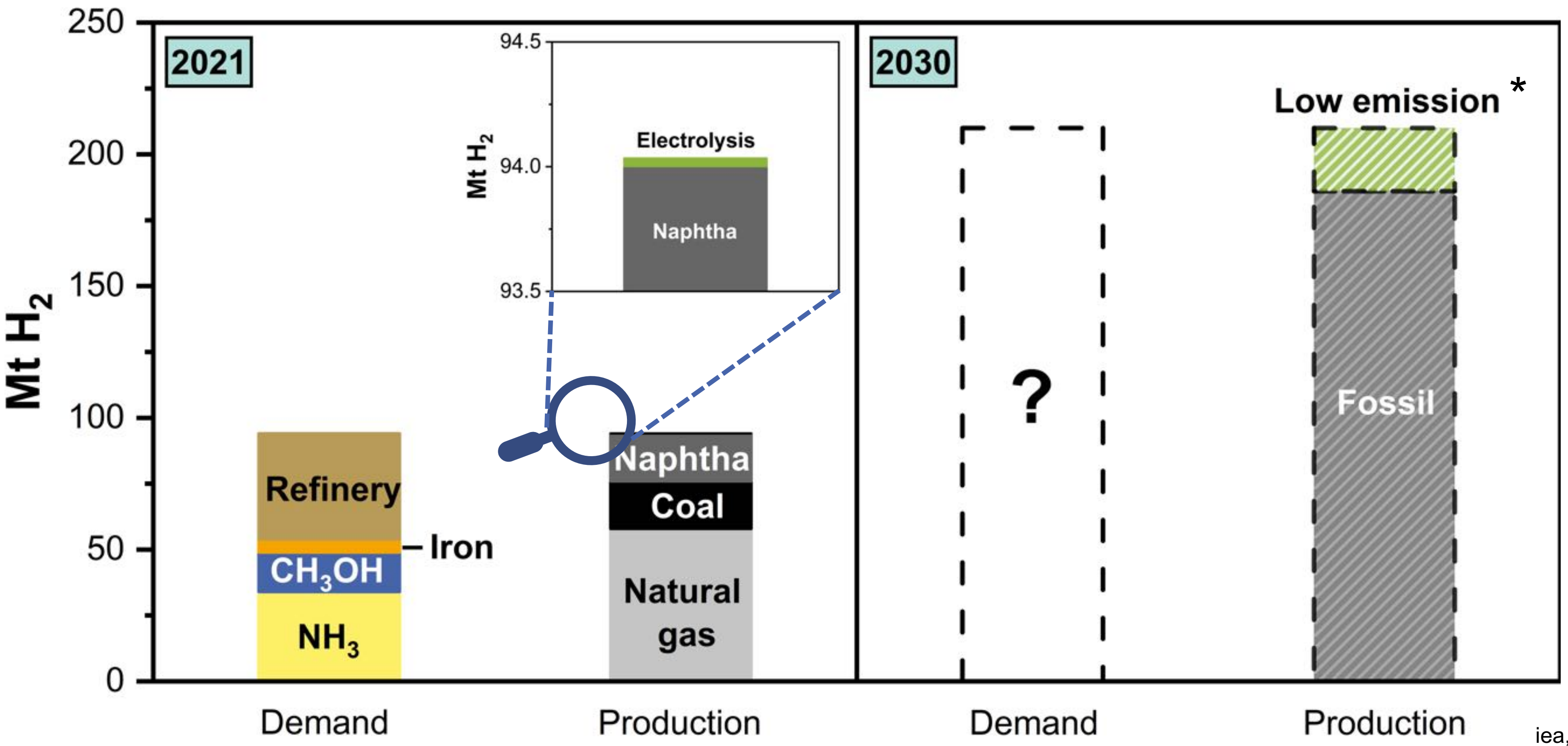
# KIT Research in the Field of Hydrogen Production and Use



# Hydrogen: Today and Tomorrow

* **Low emission hydrogen:**

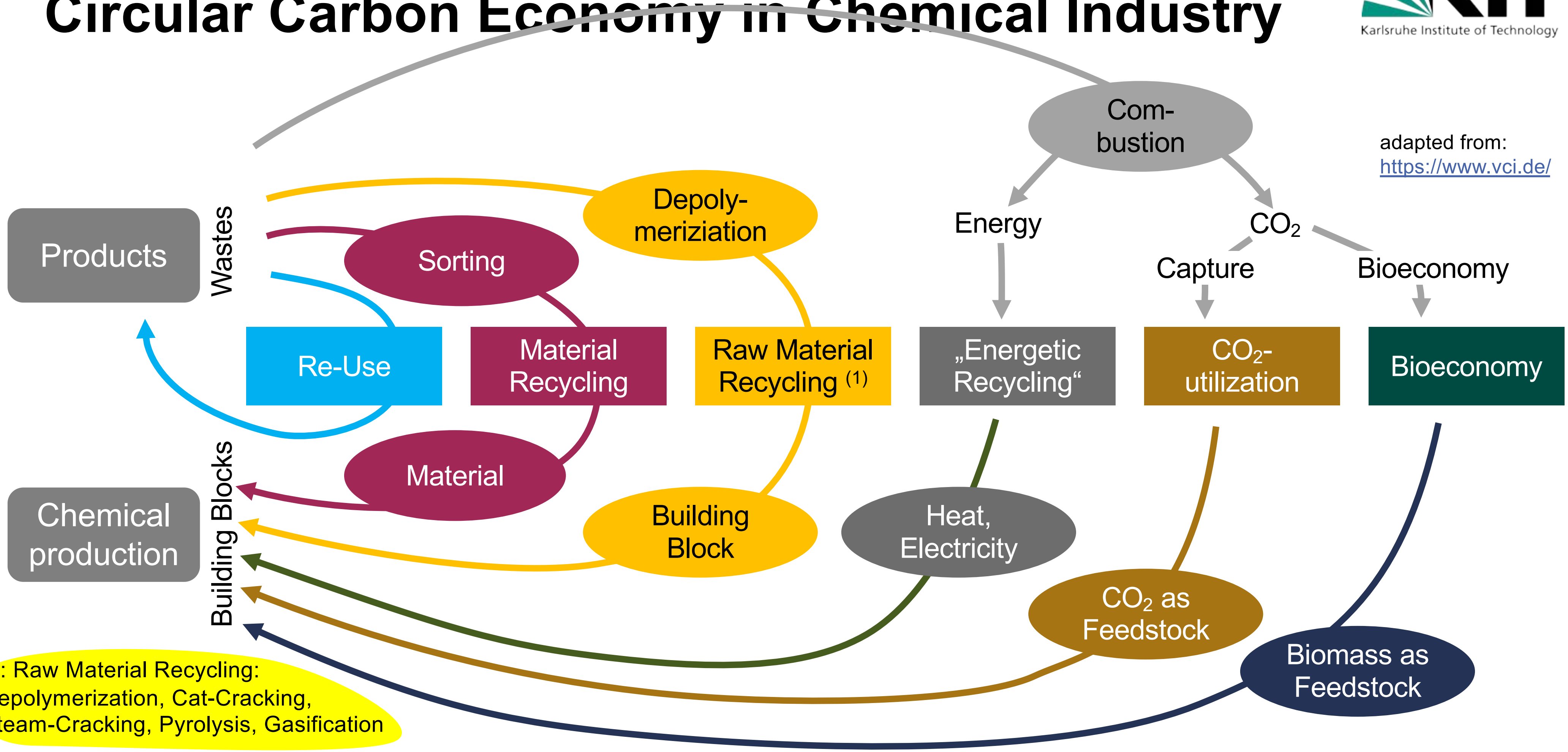
- From natural gas with CCSU
- From electrolysis




iea, *Global Hydrogen Review,* **2021**
iea, *Global Hydrogen Review,* **2022**

# Circular Carbon Economy in Chemical Industry

adapted from: https://www.vci.de/




(1): Raw Material Recycling: Depolymerization, Cat-Cracking, Steam-Cracking, Pyrolysis, Gasification

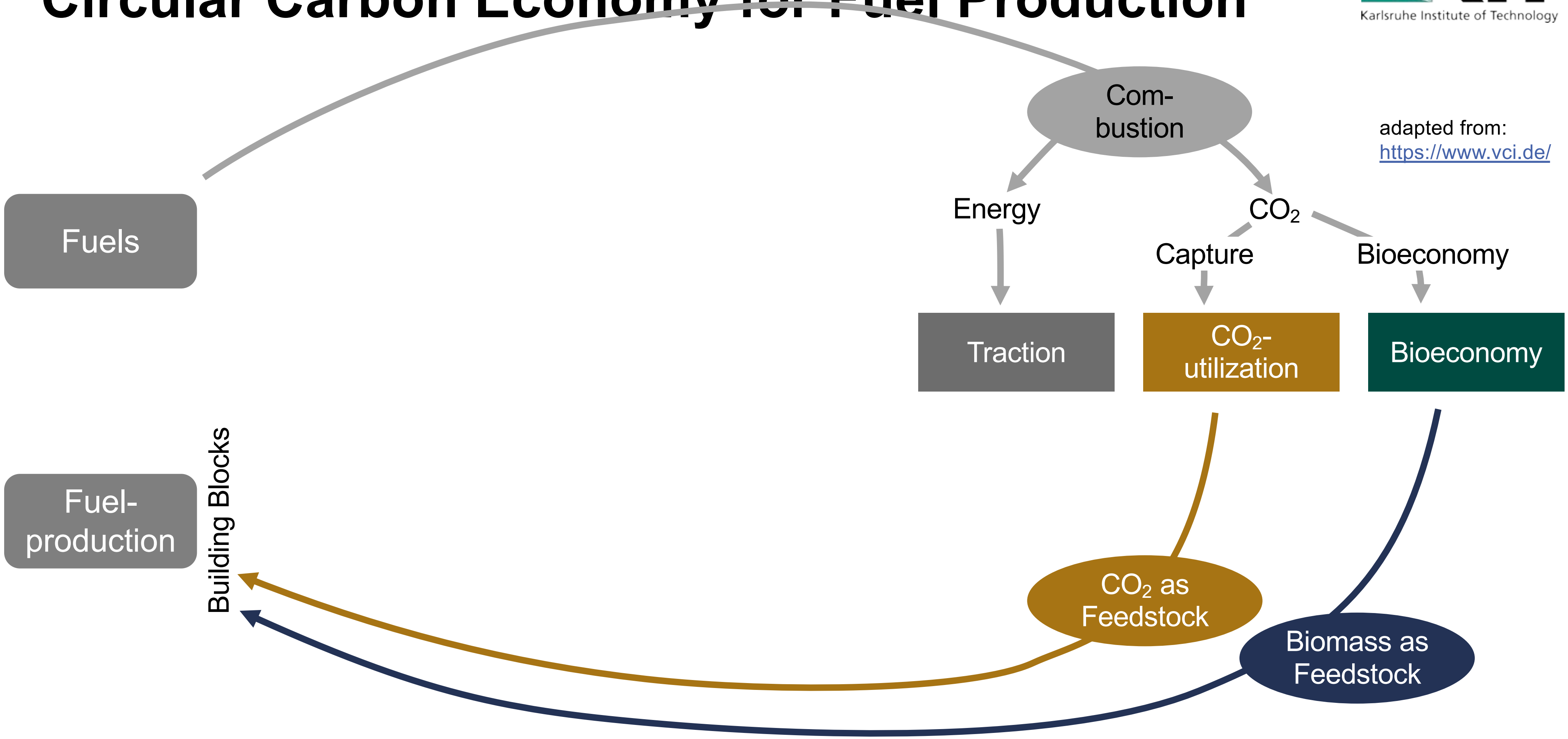
# The Scenarios of Chemistry4Climate

- **Target: "Climate Neutrality" of the German Chemistry until 2045**
- **Scenario 1:**
  - ⇒ Focus on maximum direct use of electricity
- **Scenario 2:**
  - ⇒ Focus on hydrogen and PtX fuels and raw materials
- **Szenario 3:**
  - ⇒ Focus on secondary raw materials (plastic waste and biomass)

| Parameter [Einheit] | Szenario 1 | Szenario 2 | Szenario 3 | Anmerkung |
|---|---|---|---|---|
| Strombedarf [TWh] | 464 | 508 | 325 | In Szenario 2 am höchsten wegen hohem $H_2$-Bedarf inkl. Strombedarf für Wasserstoff |
| Wasserstoffbedarf [TWh] | 214 | 283 | 148 | $H_2$-Bedarf für Fischer-Tropsch-Naphtha und Brennstoff in Szenario 2 besonders hoch |
| $CO_2$-Bedarf [kt] | 44.051 | 51.977 | 21.310 | Fischer-Tropsch-Naphtha-Route (Szenario 2) hat den höchsten $CO_2$-Bedarf |
| Biomassebedarf [kt Trockenmasse] | 2.700 für Spezialchemie | | 26.576 für Grundstoff, 2.700 für Spezialchemie | Nutzung zusätzlicher Biomasse und Einsatz in Grundstoffchemie nur in Szenario 3; dann max. verfügbares Potenzial ausgeschöpft |
| Kunststoffabfallbedarf [kt] | 3.160 für Mech. Recycling | | 3.160 für Mech. Recycling, 2.228 für Chem. Recycling | Chemisches Recycling und Einsatz in Grundstoffchemie nur in Szenario 3; dann max. verfügbares Potenzial ausgeschöpft |
| Fischer-Tropsch-Naphtha-Bedarf [kt] | - | 15.334 | 6.134 | |
| Bio-Naphtha-Bedarf [kt] | - | - | 5.691 | Nur in Szenario 3 |
| Methanolbedarf [kt] | 30.558 | - | - | Nur in Szenario 1 für MTO/MTA zu Olefinen und Aromaten |
| Nomin. Investitionen [Mio. €] | 40.296 | 40.623 | 25.676 | In Szenario 1 und 2 wegen Investitionen in Elektrolyseure am höchsten |

Source: Verband der Chemischen Industrie e. V. (VCI) vertreten durch Jörg Rothermel Verein Deutscher Ingenieure e. V. (VDI) vertreten durch Ljuba Woppowa, 2023. Retrieved 2023-10-14

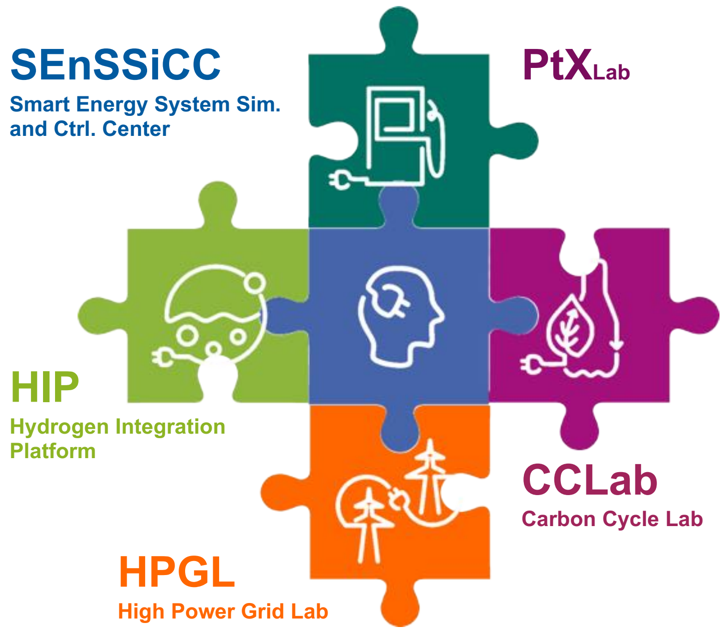
# Circular Carbon Economy for Fuel Production




adapted from:
https://www.vci.de/

# Interplay and synergies of Energy Lab elements

- Integrated energy concept: production, transport, storage and use
  - ⇒ Power – $H_2$ – heat – $CH_4$ – fuels – chemicals
  - ⇒ Carbon-supply from polymer wastes – biomass residues – $CO_2$
  - ⇒ Multi-modal energy networks
- Simulation, control, IT-security based on “real-life data” and units in operation
- Implementation of ”net-negative-technologies”



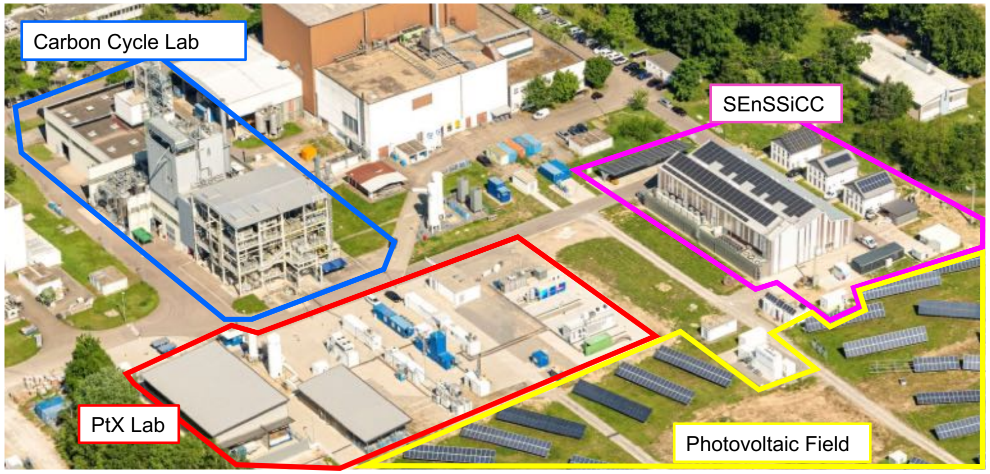
# Scientific potential of the Energy Lab

Individual units produce important contribution in their respective fields in research and application

Vision: flexible “plug-and-play platform” for coupled flows of energy - material - information

- Enablers:
  - ⇒ Development of a joint operations team
  - ⇒ Modularization of sub-units
  - ⇒ Standardization of tools and interfaces
  - ⇒ Interlinking with basic research

**Agile response to highly dynamic challenges, exceptional and social boundary conditions**




HPGL – High Power Grid Lab

HIP – Hydrogen Integration Platform

ESHL - Energy Smart Home Lab

# Interplay of elements – systemic approach
# What is the added value of the new infrastructure?



Creating systemic synergies through common research questions, common concepts, common operations and common transfer!

## Joint research challenges

- How can sub-systems be optimally operated jointly?
- How do "stationary processes" operate optimally with processes coupled to fluctuating energy supply?
- …

## Joint concepts

- Testing methods and key enabling technologies under realistic conditions covering all relevant energy sectors complemented by user behavior/acceptance feedback

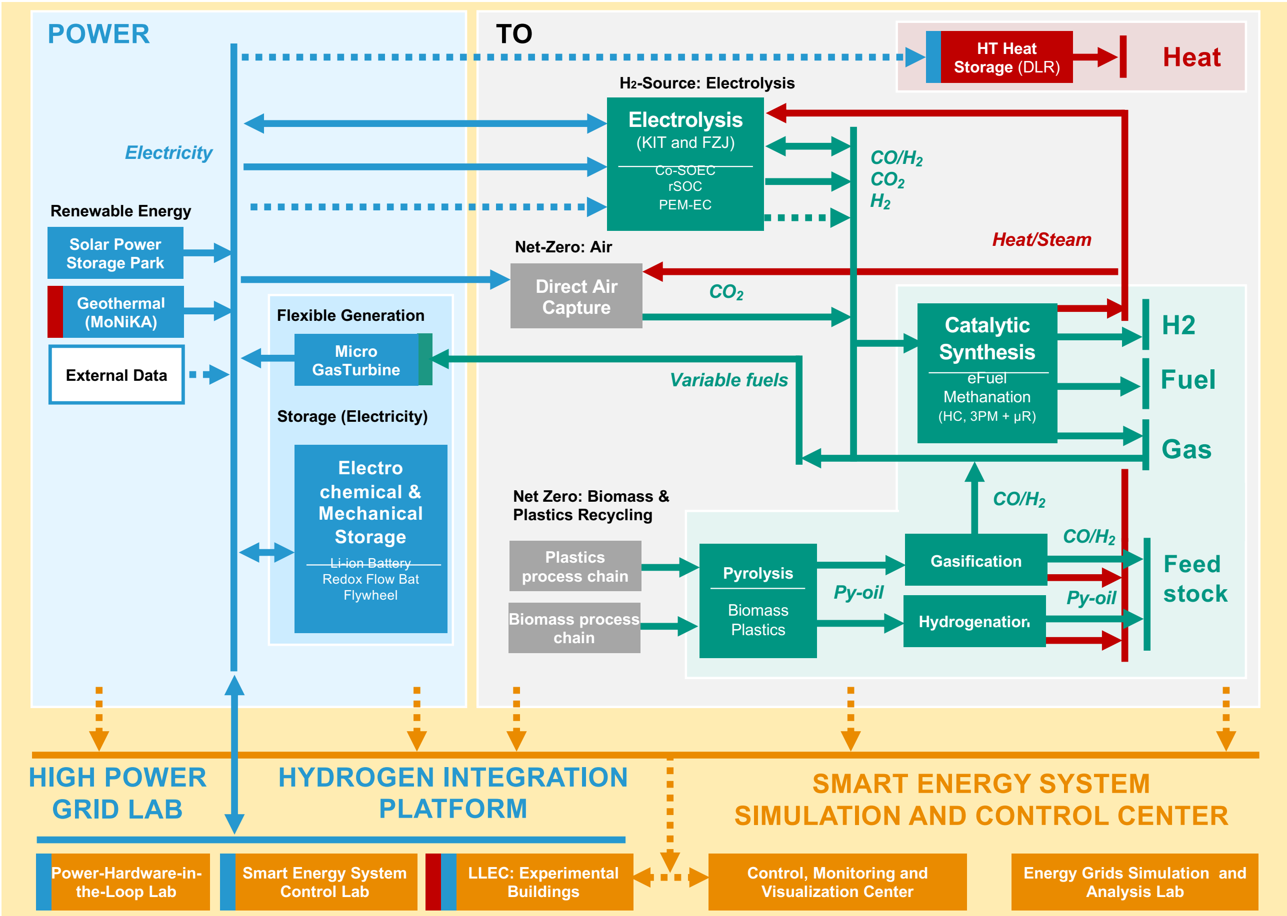
## Joint operations

- Jointly operated sub-systems
- Linking of expertise
- Trained personnel for common operation in test campaigns

## Joint transfer and public relations

- Industrial user lab
- Joint approach towards society, industry, politics
- Link to graduate school ENZo accessing innovative young researchers and ideas

# Interplay and synergies of Energy Lab elements



# Positioning of Energy Lab in the Competitive Environment

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## Competitors


## Energy Lab

- Unique setup with energy-systems-modelling, grid-technologies, power-to-X, carbon-supply
- Development, control and experimental testing of new technologies in realistic grid conditions
- High power (>1MVA, >1.5kV) and large-scale simulation (>1000 nodes) testing capability for energy technologies
- Representation and comparison of all important options for chemical energy carriers
- ”Carbon Supply” test field for an integrated energy system integrating ”net-negative-technologies”

# Smart Energy System Simulation and Control Center – SEnSSiCC

In Operation, part of Energy Lab 2.0

SEnSSiCC provides the foundation to design the future energy grids from conception to their implementation in order to ensure safe and secure operations.

- SEnSSiCC enables to setup a wide range of topologically variable microgrid experiments using real power system components.
- A real microgrid is connect to a digital replica of a real power grid, simulated in real-time, to form a hardware-in-the-loop setup, providing to researchers an automated and user-oriented research framework.
- SEnSSiCC aims to model, control and validate technologies for future energy systems in an experimental setting.
- Our research infrastructure enables testing of complex energy technologies, while reducing the time needed for development and commercialization.

# PtX Lab

In Operation, part of Energy Lab 2.0

- PtX Lab is a flexible infrastructure for investigation of Power-to-X technologies integrated in the whole process chain in relevant scale in a modular format.
- It is used for validation of new technologies at TRL 5-6, for studies on transient operation, and for providing data for validation of energy system models with PtX as a component in the grid.
- PtX Lab includes the production of synthetic natural gas, hydrocarbon fuels and methanol using $CO_2$ from point sources (storage tank) or ambient air and syngas from waste biomass or plastics waste; a power-to ammonia plant is in construction
- PEM and SOEC electrolyzers are available for hydrogen production as well as drying, deoxygenation and compression and a storage tank
- Application tests of hydrocarbon fuels are done together with relevant industry

# Carbon Cycle Lab


- **National research platform** with global visibility for **scale-up**, **demonstration** and **transfer** to application of **key enabling technologies** to close the anthropogenic carbon cycle based on complex feedstocks
- The Carbon Cycle Lab enables the **closure of the process chains**, the **full validation of closed cycles** (modeling, simulation, and evaluation), and **transfer oriented cross-discipline research partnerships**. Its advance in TRL, interlinkage of elements and its **focus on real waste** makes it globally unique.

In Operation, building on the bioliq concept

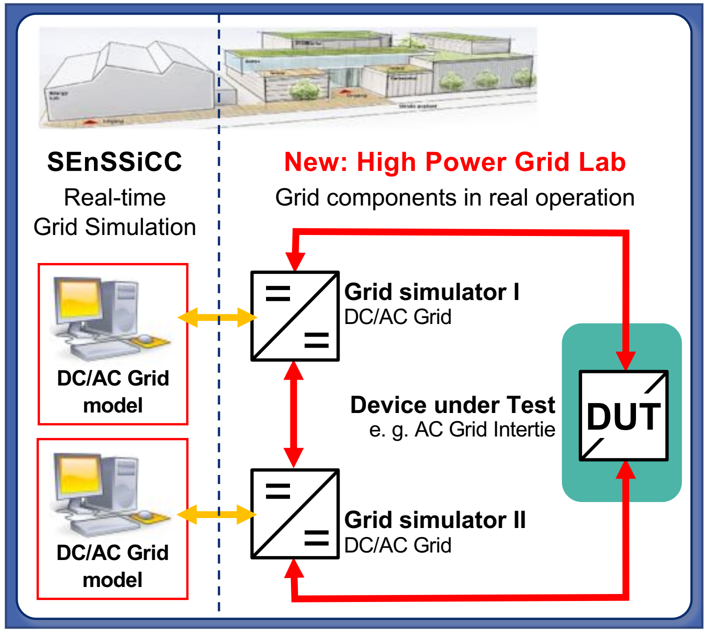
# Hydrogen Platform – HIP


[adobestock]

The HIP is aiming to connect the chemical energy world (hydrogen as an energy vector) to the electrical energy world (power engineering). The research will leverage the synergies extending into both worlds e.g. the for-free cooling by liquid hydrogen $LH_2$ with the need for heat removal by conventional electric power equipment. This will not only be studied by stand-alone components, but the newly developed devices benefiting from the efficiency increase by the combination of $LH_2$ and electric energy will be integrated into other parts of the Energy Lab – e.g. the $LH_2$-fueld powertrain will be connected to SEnSSiCC and the HPGL to simulate the full mission profiles of selected vehicles (trucks, trains, ships, aircrafts).

Planned

# High Power Grid Lab – HPGL

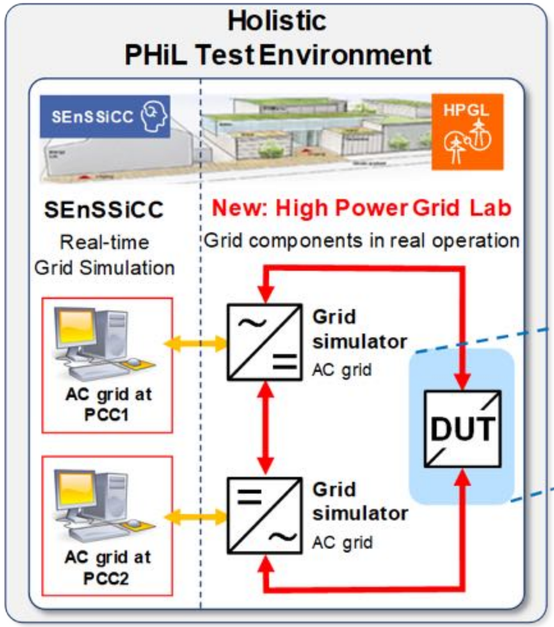


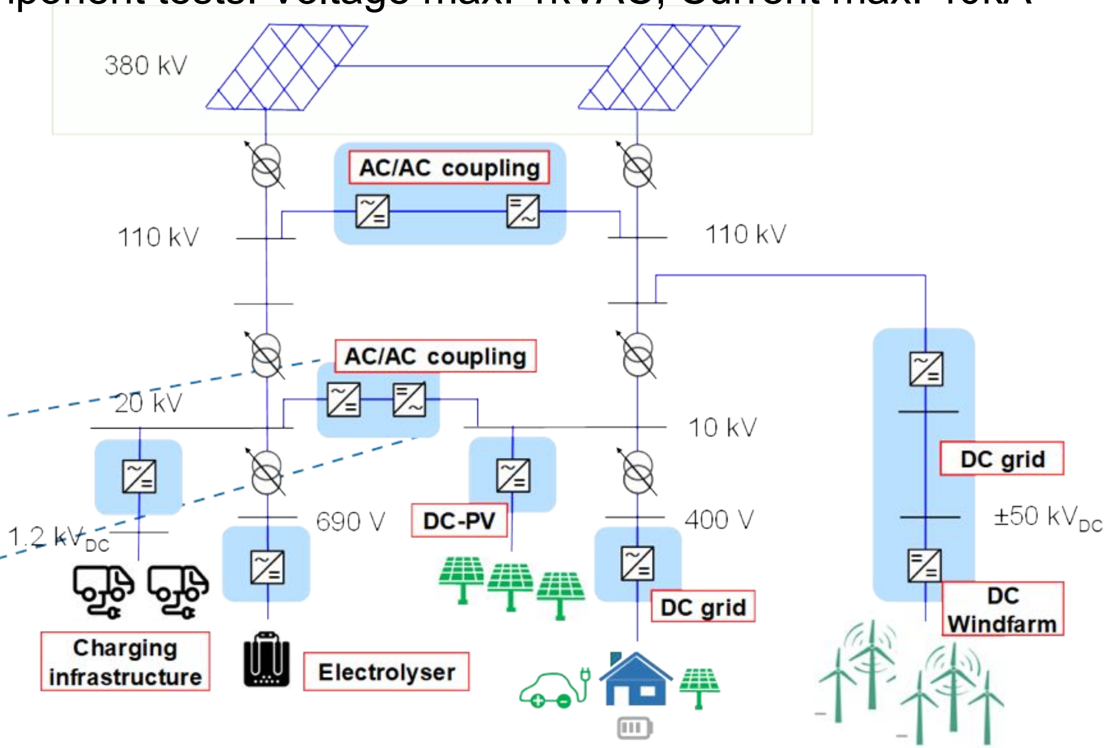

Application submitted

The High Power Grid Lab (HPGL) will be a high-performance laboratory for the control and operation of electrical power systems and testing of new grid components in the multi-MW range. As a research and test infrastructure that is unique in Europe, the HPGL combines the real-time simulation and control of the electrical grid with the examination of grid equipment in real operation conditions to create a holistic Power Hardware-in-the-Loop (PHiL) test environment and ideally complements the Smart Energy System Simulation and Control Center (SEnSSiCC) in the Energy Lab 2.0. Along with multi-purpose test laboratories, the heart of the HPGL are converter-based grid simulators (approx. 25 MVA, 20 kV), which allow at least two regulated DC or AC grids to be emulated.

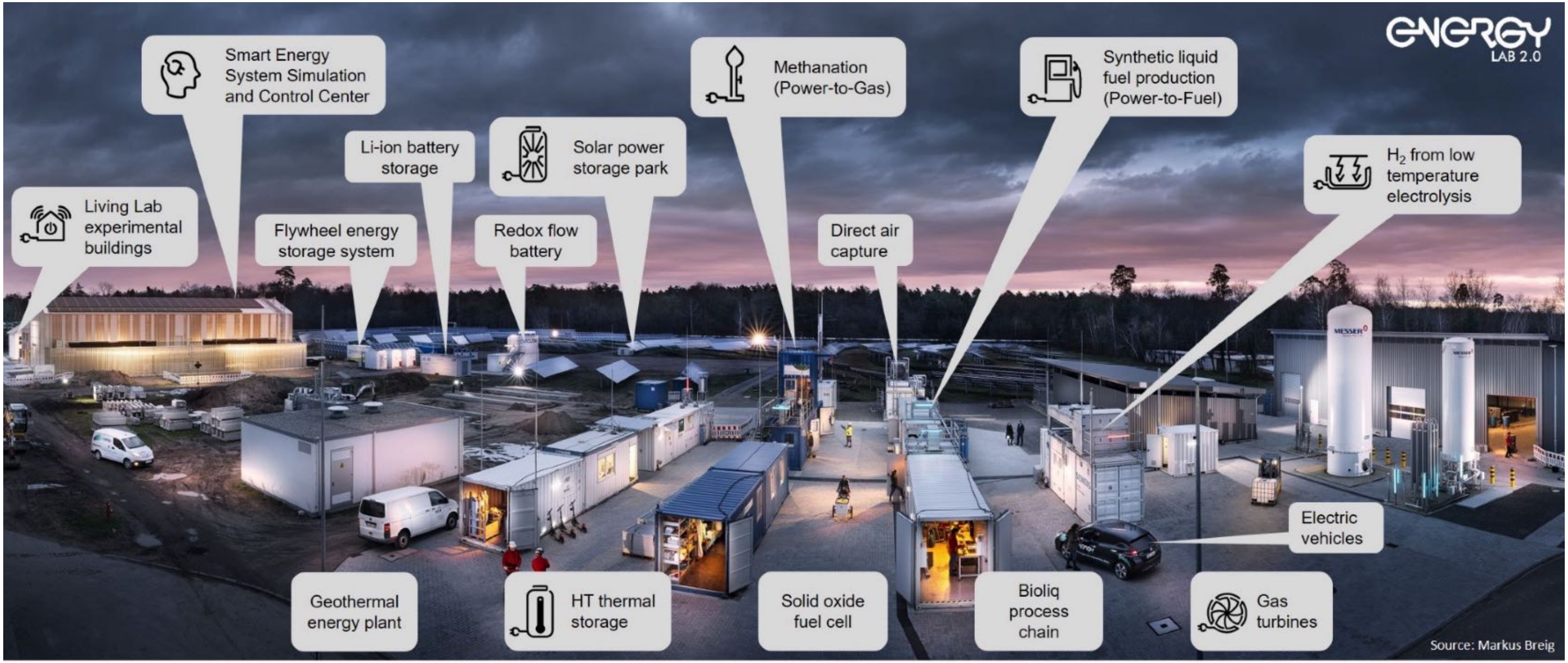
# High Power Grid Lab – HPGL

- **Power Hardware-in-the-Loop emulators**: Voltage max. 20 kVAC, Power 20..40 MW
- **Variable high current test system** for component tests: Voltage max. 1kVAC, Current max. 40kA



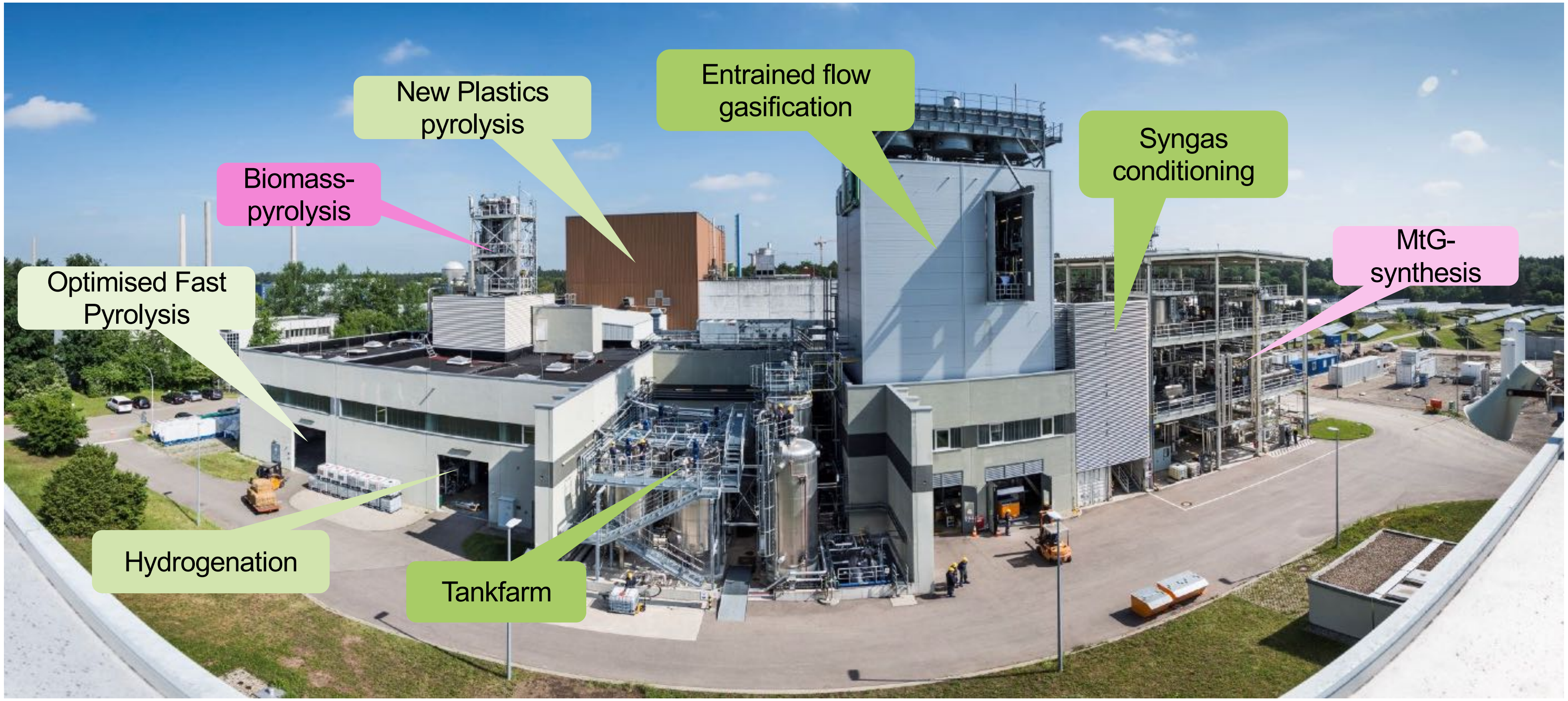



# Power-to-X - Lab



# Carbon Cycle Lab Pilot Plants & Process Chains

An element of KIT´s Energy Lab




operational

procurement

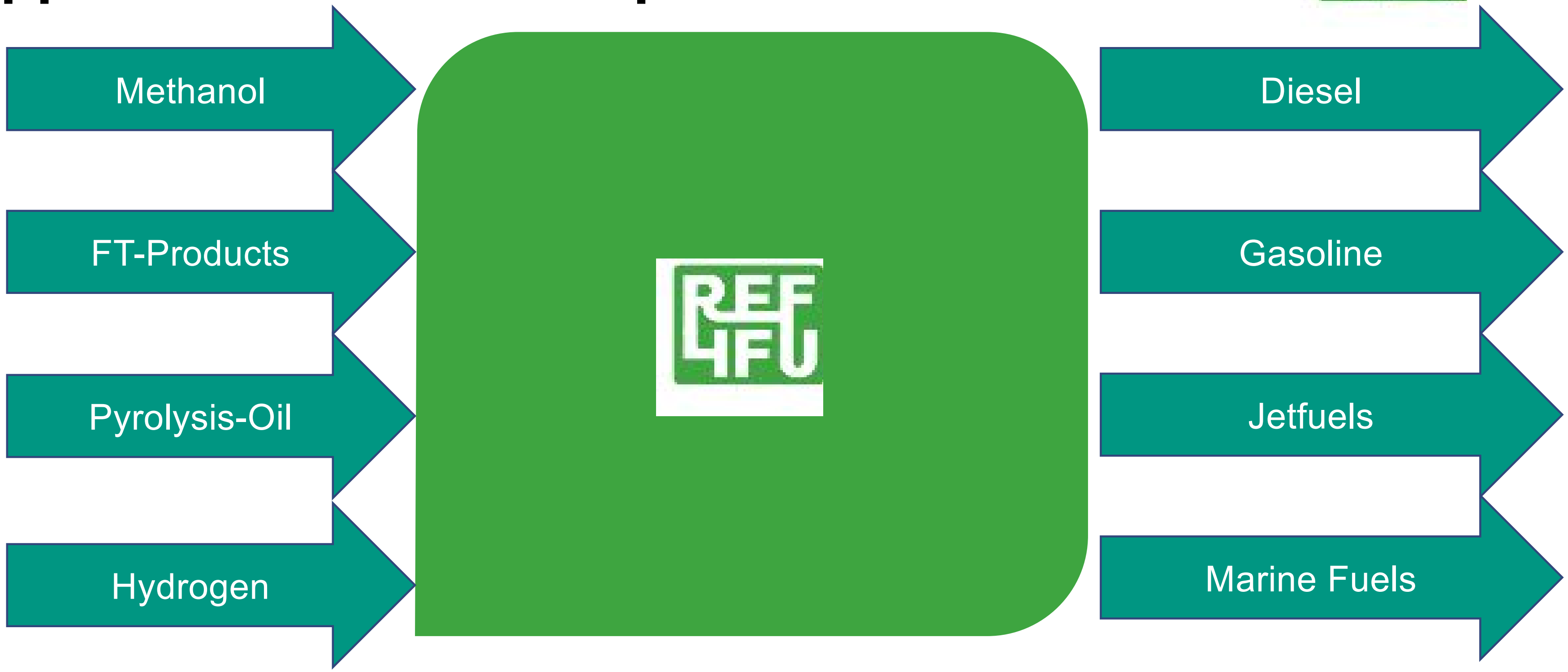
planning

decommission

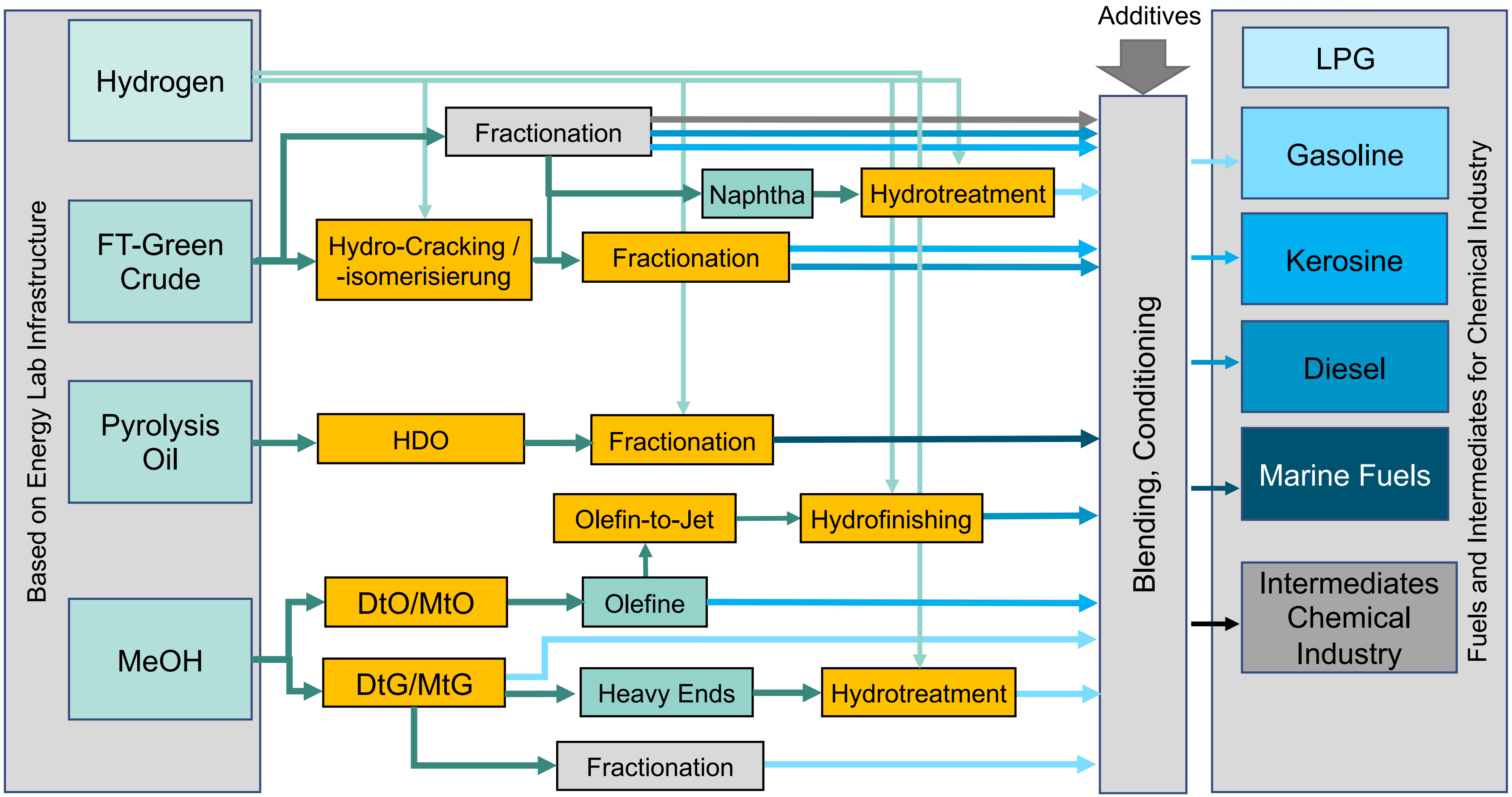
mothballed

Closure of process chains, technology scale-up, transfer, integrated energy, teaching & training

# Linking Energy Carriers with Applications from Transportation Sector

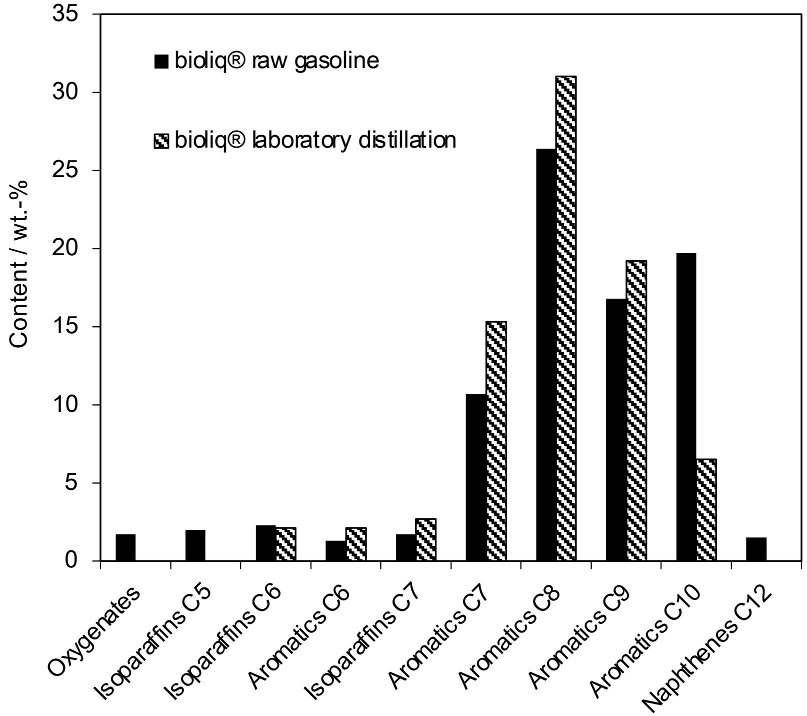


# Value Chains in REF4FU



# Gasoline from MTG- and DTG-processes
## Benjamin Niethammer

- Example: Gasoline from the DTG unit of the bioliq® process at KIT (MFI zeolite catalyst)
  - Product spectrum dominated by aromatics
  - High share of heavy gasoline
  - Work-up necessary
  - Distillation to remove high-boiling aromatics
  - Blending with conventional gasoline
  - Blends with 10% bioliq® gasoline within EN228 specification
  - Further improvement of fuel quality by chemical treatment

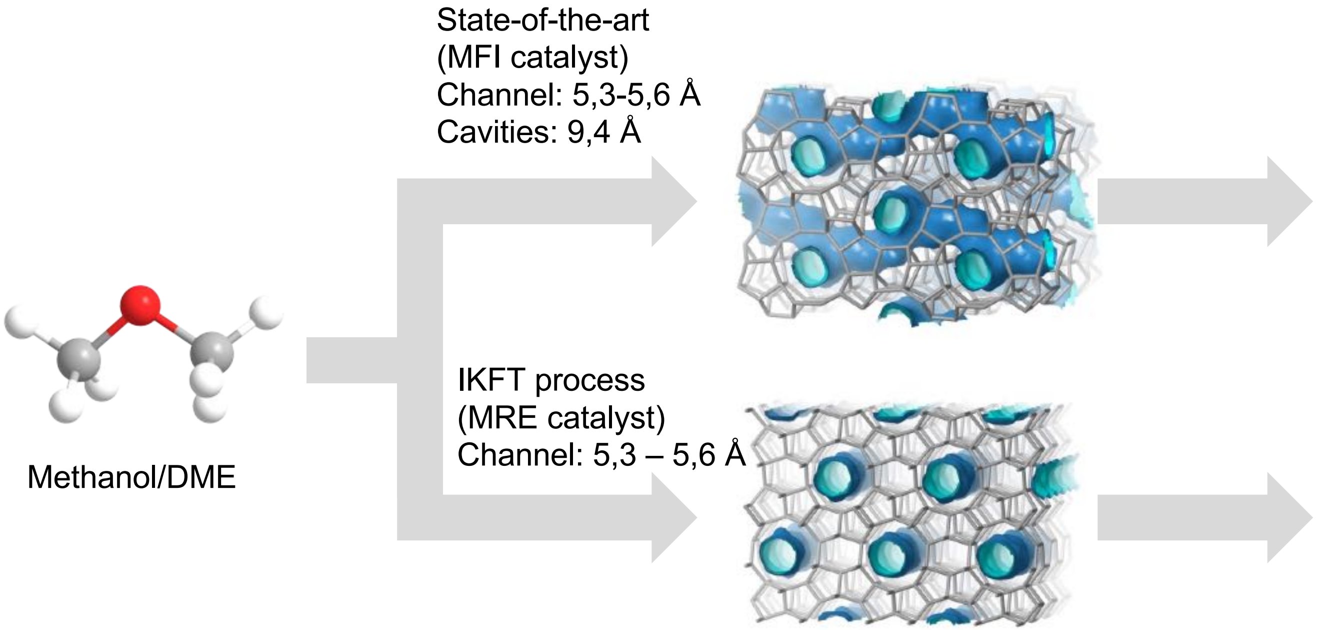


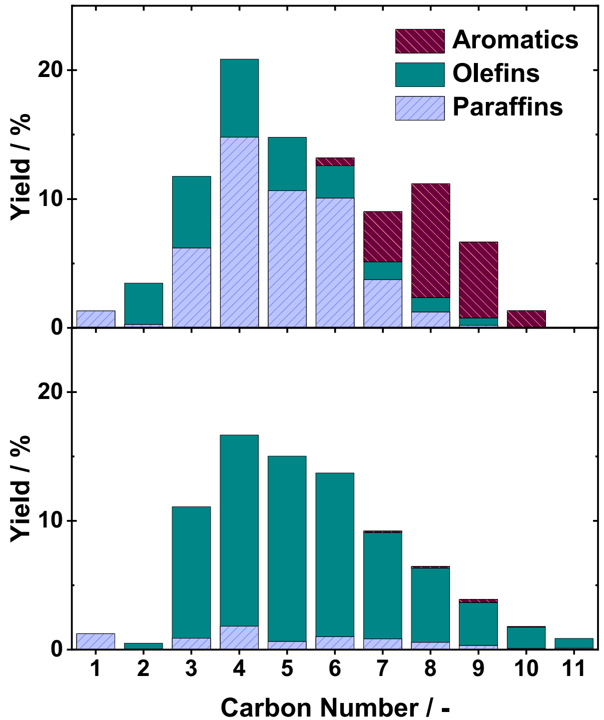


T. Michler, N. Wippermann, O. Toedter, B. Niethammer, T. Otto, U. Arnold, S. Pitter, T. Koch, J. Sauer, Gasoline from the bioliq® process: Production, characterization and performance, *Fuel Process. Technol.* **2020**, *206*, 106476.
DOI: 10.1016/j.fuproc.2020.106476

T. Michler, N. Wippermann, O. T. Michler, B. Niethammer, C. Fuchs, O. Toedter, U. Arnold, T. Koch, J. Sauer, Further Development of Gasoline from the bioliq® Process with Focus on Particulate and Hydrocarbon Emissions, *Fuels* **2022**, *4*, 205-220.
DOI: 10.3390/fuels4020013

# New concept for the conversion of methanol/DME to $C_{2-11}$ olefins




High yield of $C_{2-11}$ olefins compared to conventional MtX processes

B. Niethammer, U. Arnold, J. Sauer, *Appl. Catal., A* **2023**, *651*, 119021. DOI: 10.1016/j.apcata.2023.119021

## Modified DtO process and downstream olefin conversion
## Constantin Fuchs

Gasoline, kerosene, diesel fuel

**Option 3**
**(Co-)Oligomerization of $C_2$-$C_4$ olefins + hydrogenation**

**Option 1**
**Hydrogenation of $C_5$-$C_{11}$ olefins**

DME → **DtO process** → $C_2$-$C_{11}$ olefins → Gasoline

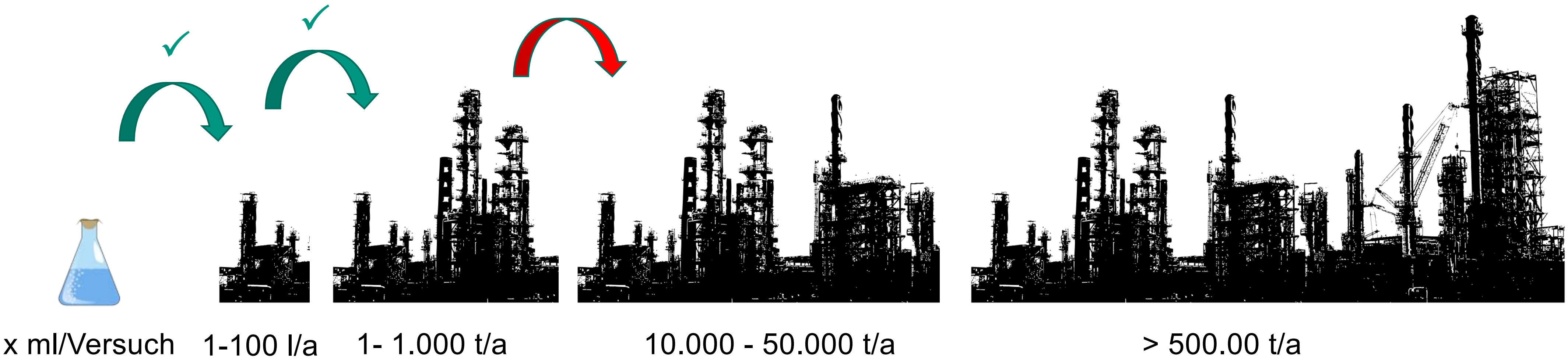
**Option 2**
**Dimerization of $C_5$-$C_{11}$ olefins + hydrogenation**

Higher olefins → Kerosene

# reFuels – Kraftstoffe neu denken

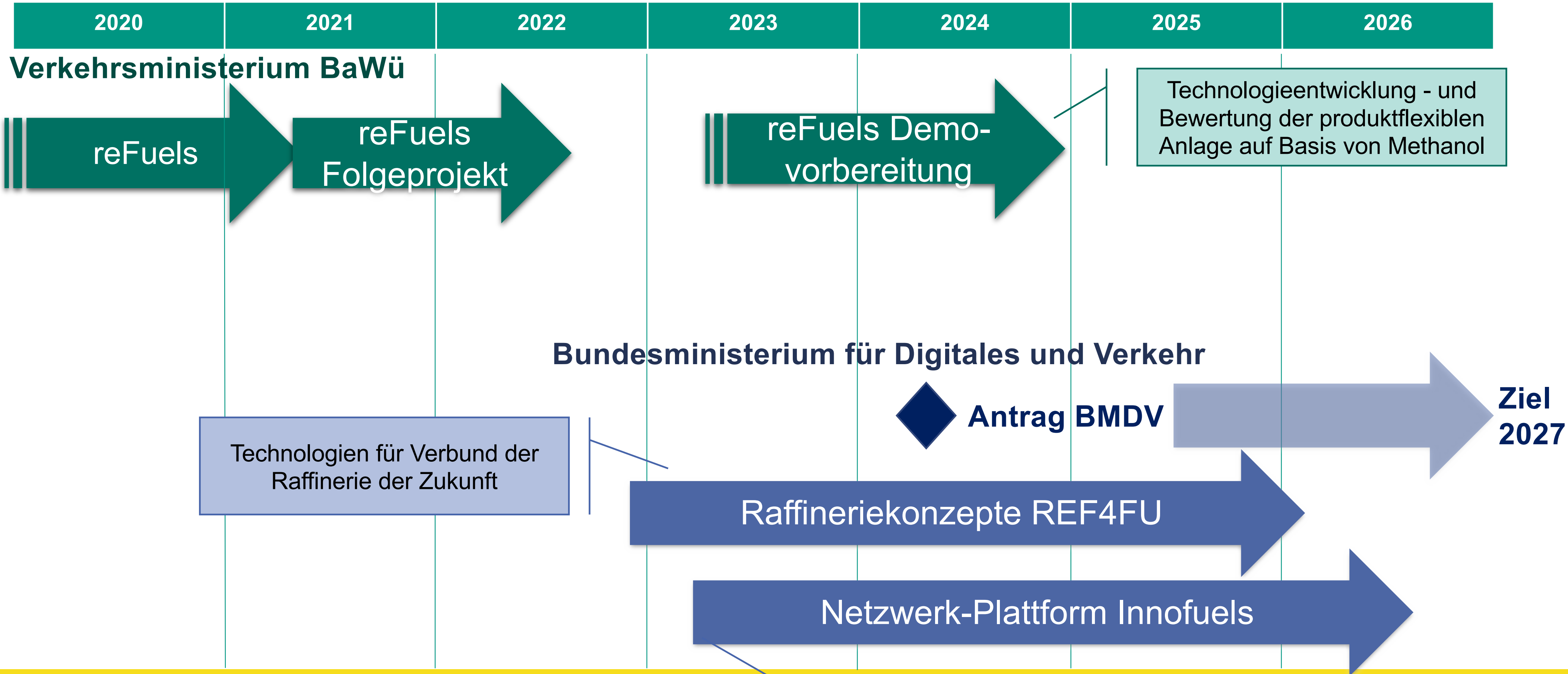
## Skalierbarkeit der Kraftstoffe

- Technologie-Reife braucht Skalierung
- Skalierung geht nur in Stufen
- Zeiten durch Planung , Genehmigung und Bau bestimmt



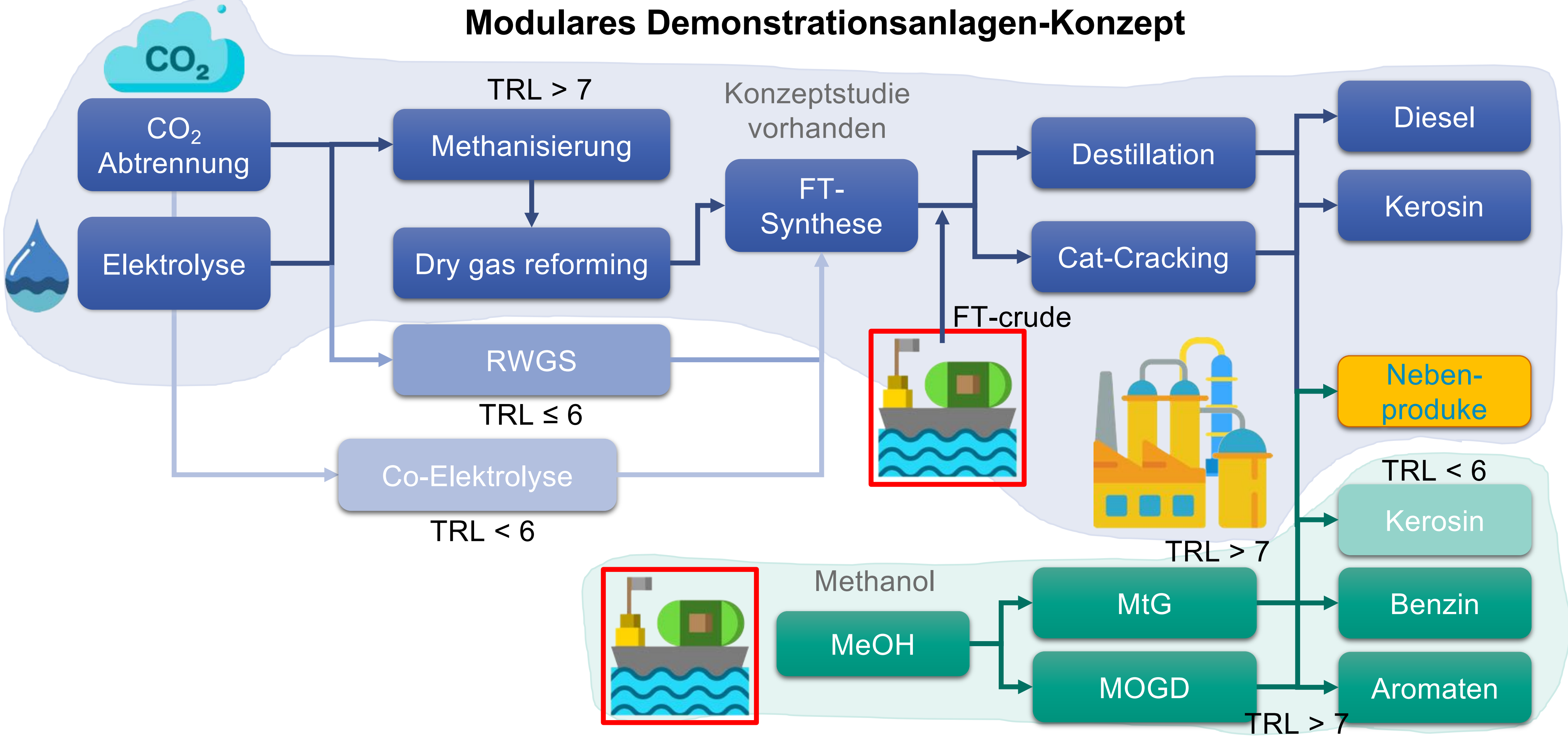
## reFuels – Kraftstoffe neu denken

### Strategische Vorhaben zu reFuels am KIT



# reFuels – Kraftstoffe neu denken

## Modulares Demonstrationsanlagen-Konzept



## Summary & Outlook

- KIT established the Energy Lab to perform integrated research for the production, transport, storage and use of energy carriers, with the target to establish a:

⇨flexible “plug-and-play platform” for coupled flows of energy - material - information

- For the sectors ”Chemical Industry” and “Long Haul Transportation” a combination of circular economy, import of energy carriers, biomass use and sector coupling may be a way to ”climate neutrality”

- Incorporating the scale-up from TRL 4 to 5(6) into academic research opens up interesting new research topics

# Acknowledgements

**HELMHOLTZ Energy** Research Programme MTET

Karlsruhe Institute of Technology

**Bundesministerium für Wirtschaft und Klimaschutz/ Projektträger Jülich**

3D-PROCESS - Disruptive reactor concepts through additive manufacturing: From digital design to industrial implementation

**Strategiedialog Automobilwirtschaft BW und Ministerium für Verkehr BW**

reFuels – Rethinking fuels

**Bundesministerium für Digitales und Verkehr / Fachagentur Nachwachsende Rohstoffe**

Renewable Fuels from green refineries of the future

**Bundesministerium für Bildung und Forschung / Projektträger Jülich**

Kopernikus Project Power-to-X

# Thank you for the attention