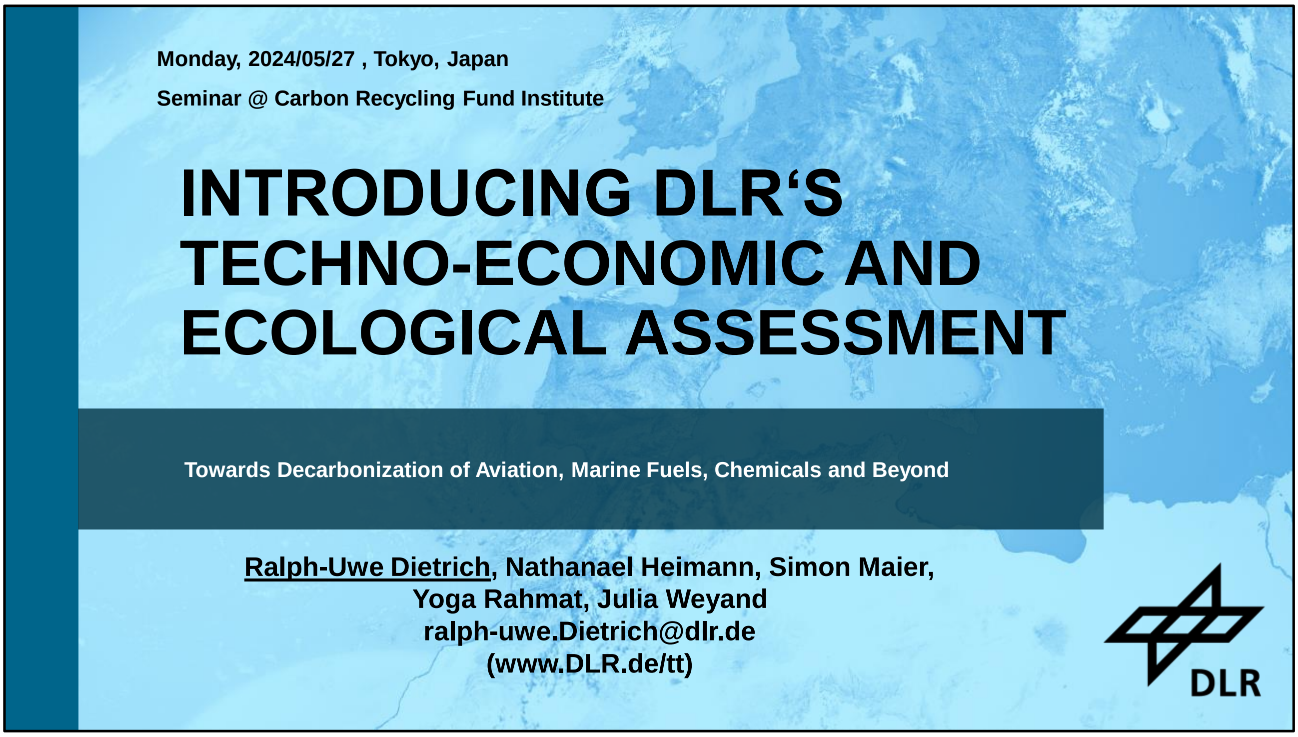


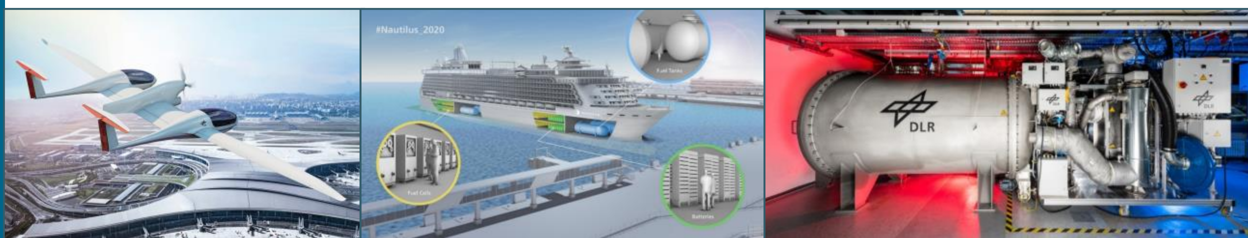
Invited by Carbon Recycling Fund Institute, Tokyo, Japan

Presentation of DLR‘s capabilities regarding
techno-economic and ecological assessment of

- Sustainable aviation fuels (SAF)
- Decarbonization examples for transport, chemicals, power

AGENDA
- Introducing DLR Dep. Energy System Integration (TT-ESI) and Techno-Economic Assessment (TEA)
- Motivation and Approach
- Assessment Insight
- Assessment results
- Partner search

Department of Energy System Integration (ESI)



Our Mission

Develop fuel cell powertrains and integrated electrolysis systems for sustainable fuels
Reduce carbon intensity of hard-to-abate transport in general (aviation in particular)

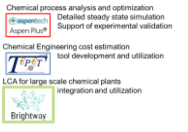
INTRODUCING DLR-TT-ESI

DLR Dep. Energy System Integration (TT-ESI) develops:

- Fuel cell powertrains and integrated electrolysis systems for sustainable fuels
- In order to reduce carbon intensity of hard-to-abate transport in general (aviation in particular).

DLR

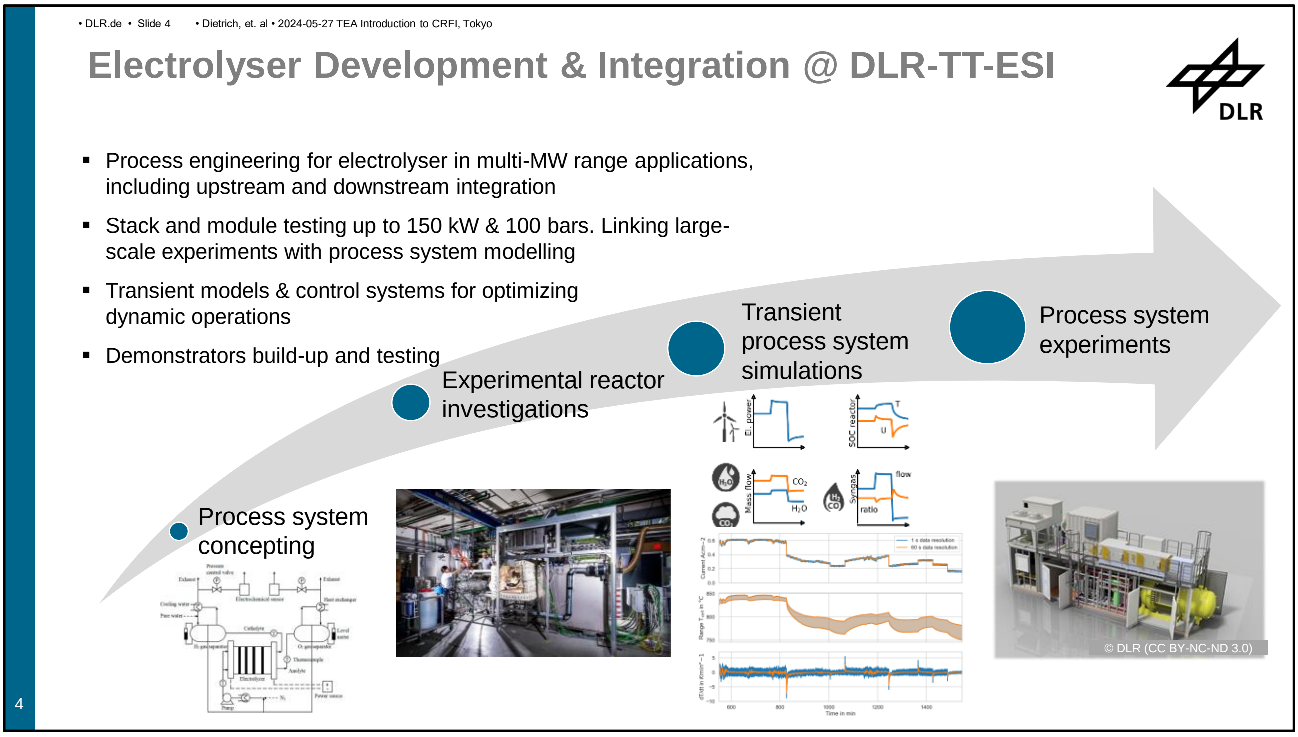
DLR-TT-ESI
Asif Ansar
Assistant(s) – Claudia Förster-Lauff, Volkan Dogrul

Hamburg	Stuttgart			
GSY C. Gentner	**FES** C. Bänsch	**NTE** S. Razmjooei	**HTE** M. Heddrich	**TEA** R.-U. Dietrich
				
Modelled systems & critical qualification	**Scale-up powertrain for aerospace**	**Low Temperature Electrolysis Systems**	**Solid Oxide Cell Systems**	**Techno economic & ecological analysis**
• Modelled system of integrated powertrains • New FC powertrain concepts & critical components • Freeze start-Up, optimization / degradation for fuel cell & -hybrid systems	• Scalable FC powertrain for aircrafts • Scalable qualified batteries for satellites • Integration and flying platforms	• Modelled MW systems & relevant tests • High pressure high temperature electrolysis systems • Integrated electrolysis systems with RES	• Pressurizes SOC system development and testing • Development & up-scaling of SOC powertrains, & electrolysis • Integrated and hybrid SOC systems with RES, and downstream processes	• Energy storage concept for stationary use • Design and integration of technical/holistic energy generation, storage & refueling systems

3

DLR Dep. Energy System Integration (TT-ESI) is led by Dr. Asif Ansar, containing groups for

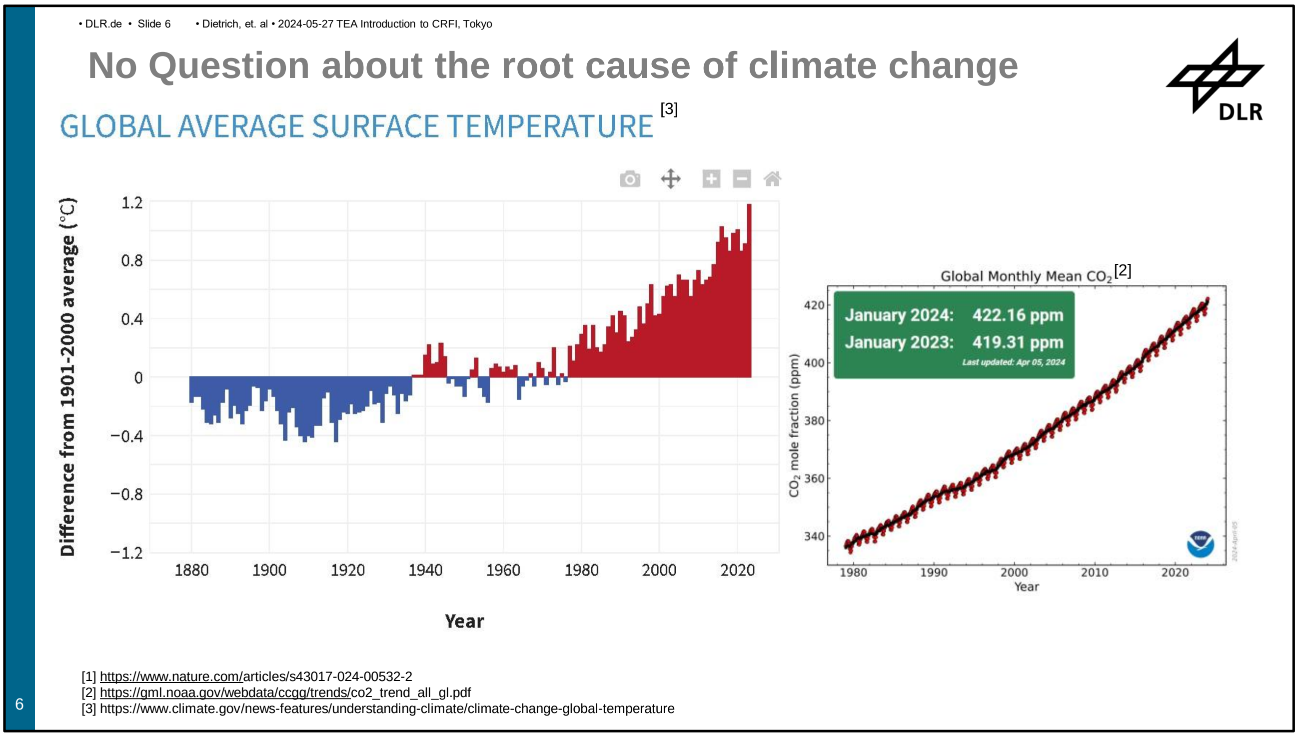
- Fuel cell powertrain development for aircraft applications (GSY, HH)
- Large scale fuel cell powertrain demonstration and scale up (FES)
- Low temp. electrolyzer development and implementation (NTE)
- High temp. electrolyzer and fuel cells development and implementation (HTE)
- Techno-economic and ecological assessment



- One example of ESI‘s approach is the electrolyser development and integration: from system concepting and testing individual stacks and modules to large scale systems and integration
- Research and Development of Solid Oxide Cell (SOC) systems
  - Process engineering for bringing electrolysis (EC) and fuel cell (FC) systems into the multi MW range applications
  - Linking large experiments with process system modelling
  - From concept KPIs to operation strategies
- SOEC-System in construction
  - Customized, transportable 40 feet sea container
  - 10 kW_{el} power input for electrolyzer
  - 90 electrolyte supported cells with 30 per stack
  - 8 to 25 bar operation pressure
  - Direct coupling to a Fischer-Tropsch synthesis unit
  - Offshore experiments to be performed in 2025

The following slides will address:

- Why is a rigorous assessment of decarbonisation concepts necessary?
- What should be discovered?
- How to compare different technologies?
- What accuracy is required? How to achieve sufficient confidence?



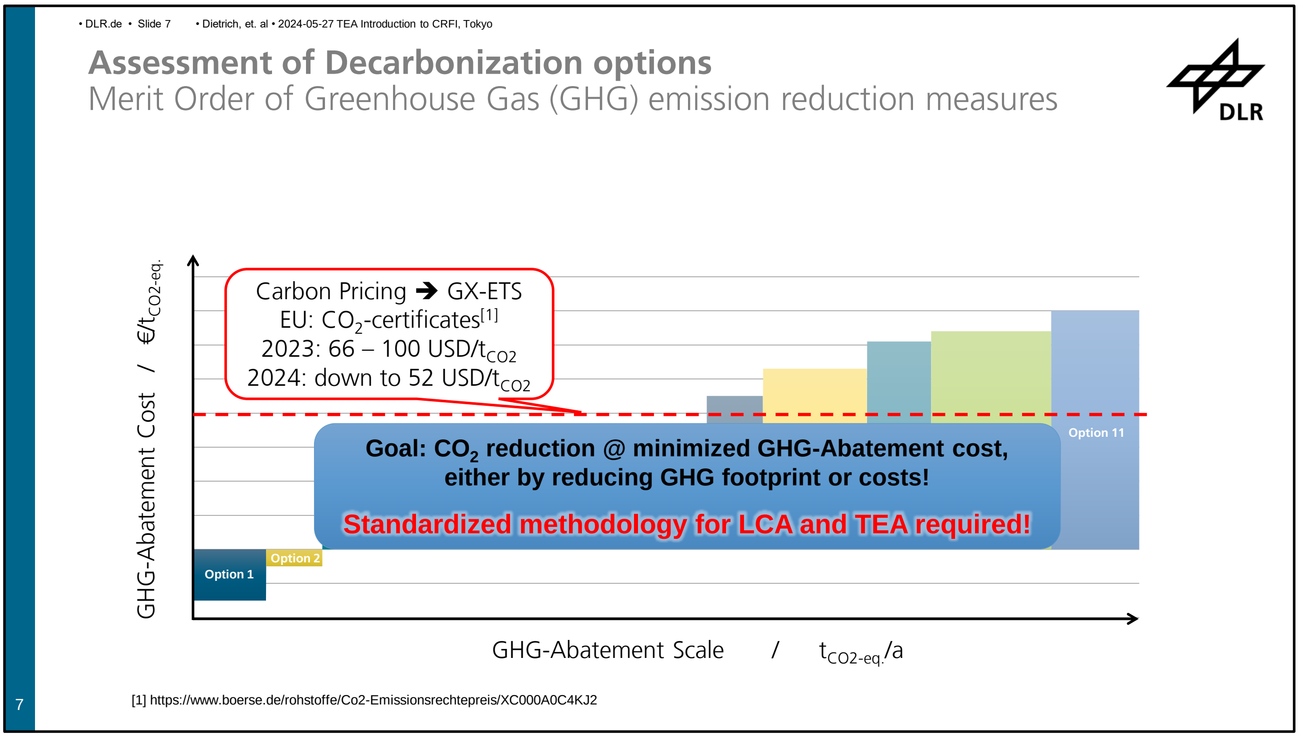
Temperature data show: climate change is undeniable

- No question about climate change root cause
  ➔ anthropogenic greenhouse gas emissions
  Power / industry / ground transportation / residential / aviation+shipping GHG emission contribution: 13.7 / 10.4 / 6.7 / 3.3 / 1.3 Gt_{CO2} in 2023!
- Global Carbon budget until 1.5 degree exceeded by 2031[2]
- Immediate action required – no time to wait
  IEA[1]: “Ramping up renewables, improving energy efficiency, cutting methane emissions and increasing electrification with technologies available today deliver more than 80% of the emissions reductions needed by 2030. ”

Meaningful action under growing pressure? ➔ reasonable decision making required

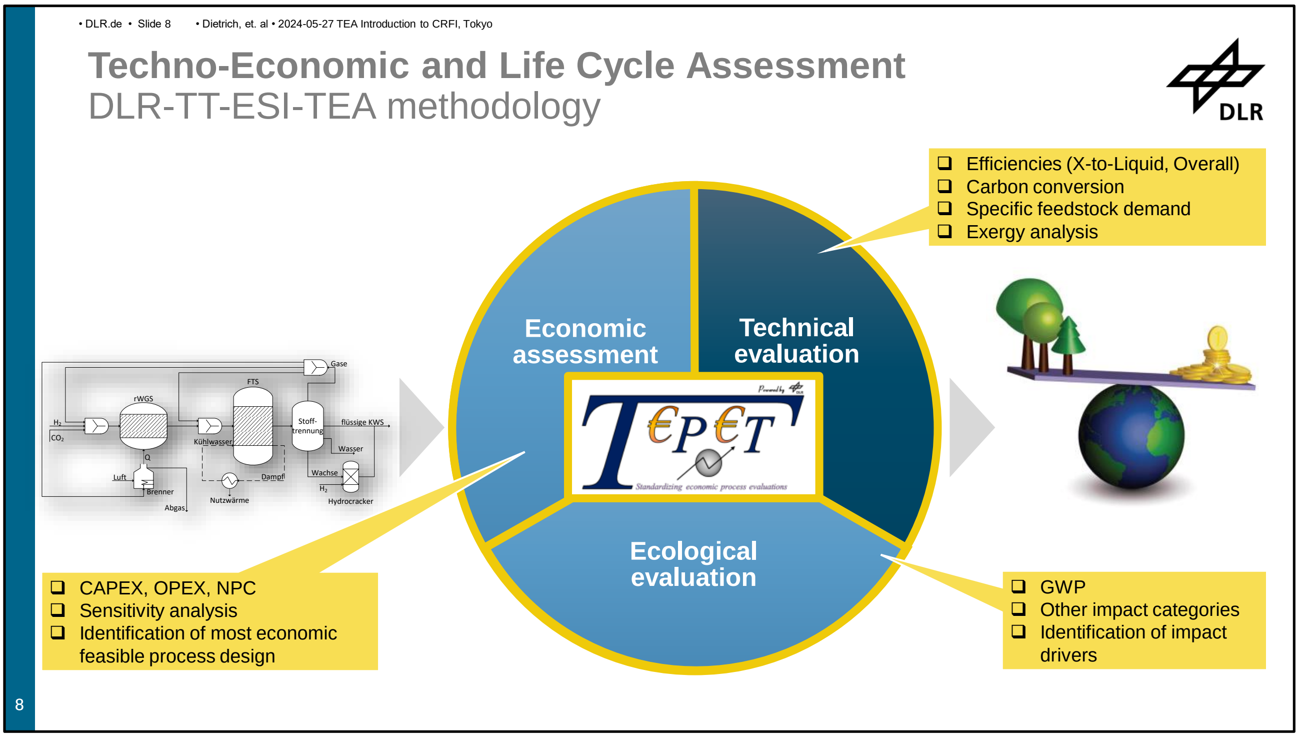
[1] https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-

reach
[2] https://globalcarbonbudget.org/carbonbudget/



- GHG emission reduction efforts to be assessed
  - Bring global CO_2 emissions from 35.8 Gt in 2023[1] to Net-Zero in 2050
    - 2023 emissions depleted 13.3% of the remaining post-2020 budget to avoid 1.5 °C (300 Gt CO_2), remaining 143 Gt CO_2 potentially exhausted within 3.6 years.
  - Introduce multiple measures on all sectors, all regions
    - Understand the scale of each measure
    - Understand the impact of each measure
- Provide transparent and standardized assessment of each measures scale/impact
  - Support policy makers for efficient regulation
  - Support technology development to improve climate change mitigation

[1] Liu, Z., Deng, Z., Davis, S.J. et al. Global carbon emissions in 2023. Nat Rev Earth Environ 5, 253–254 (2024). https://doi.org/10.1038/s43017-024-00532-2

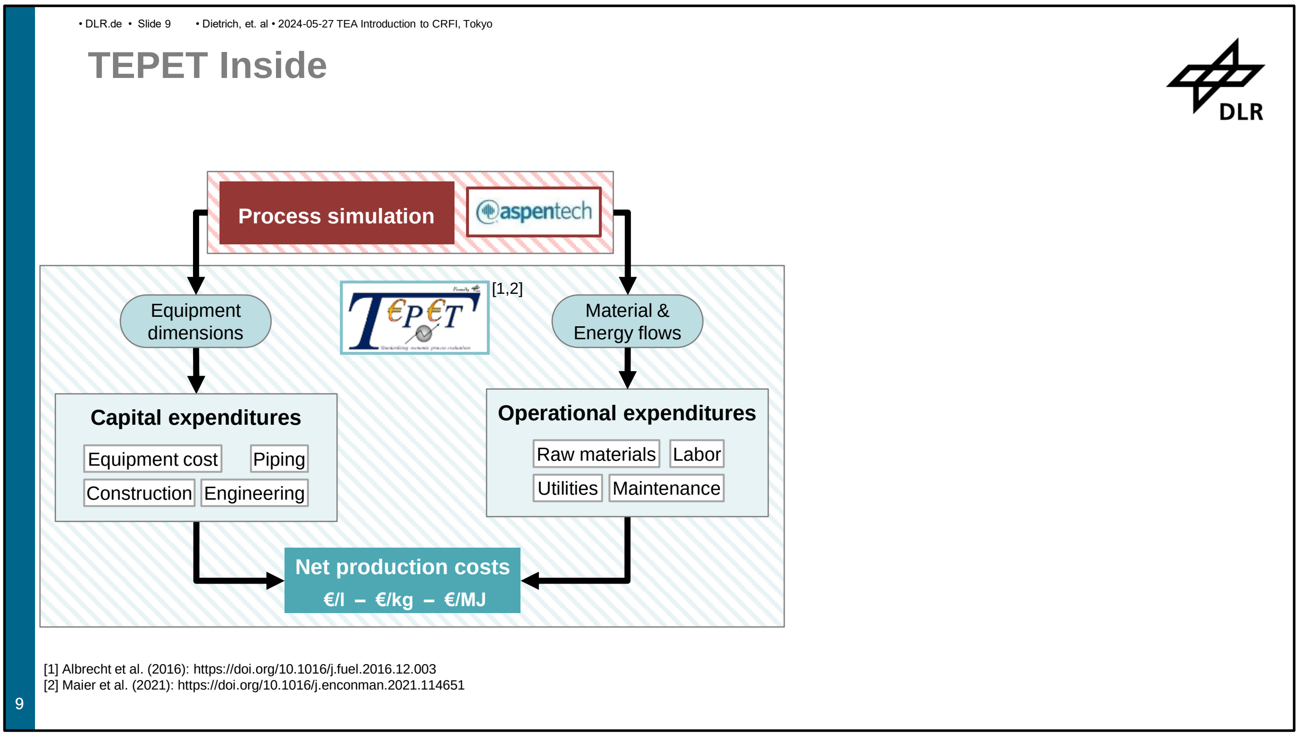


Standardized Techno-Economic and Life Cycle Assessment @ DLR provides reliable knowledge about multiple decarbonization measures in sectors like power generation, basic industry and transport.

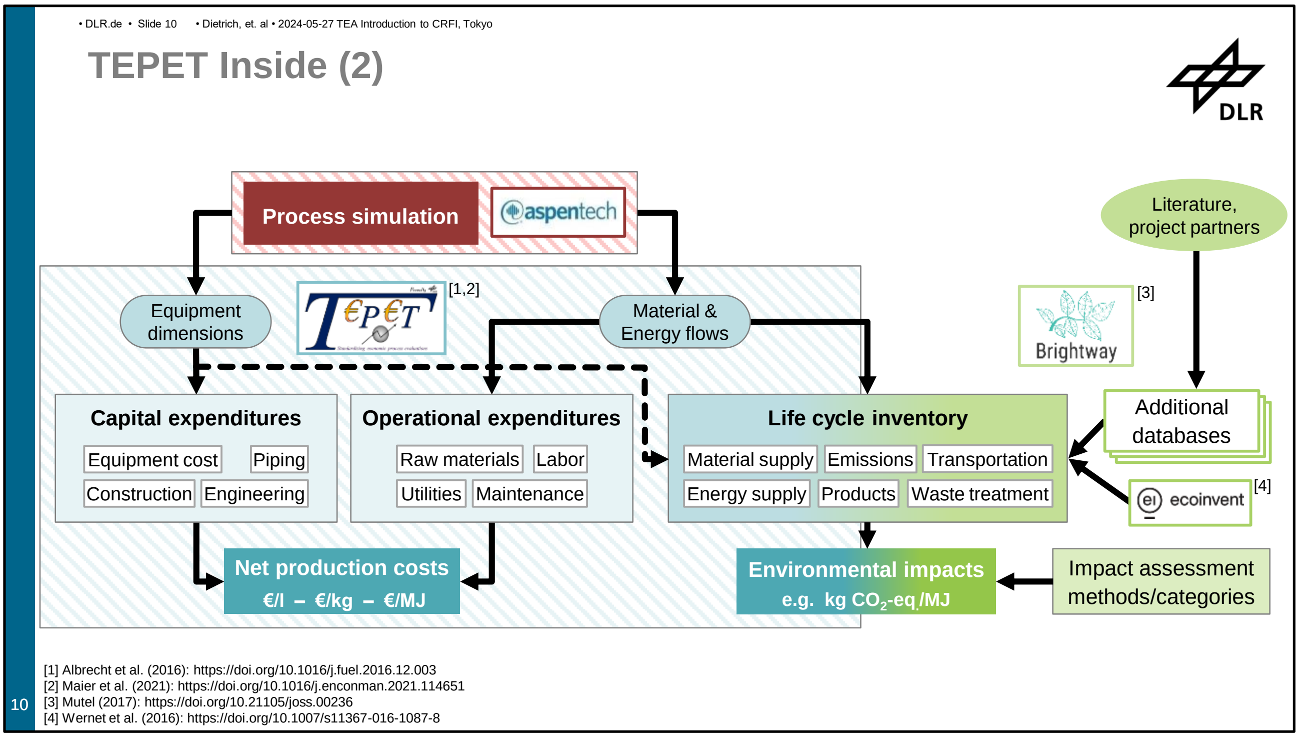
- Technical assessment includes rigorous process simulation of experimentally validated units and processes
- Economic assessment follows standard chemical engineering cost estimation rules and procedures
- Ecological assessment quantifies each environmental impact compared to fossil alternative

The ”Techno Economic Process Evaluation Tool” (TEPET)

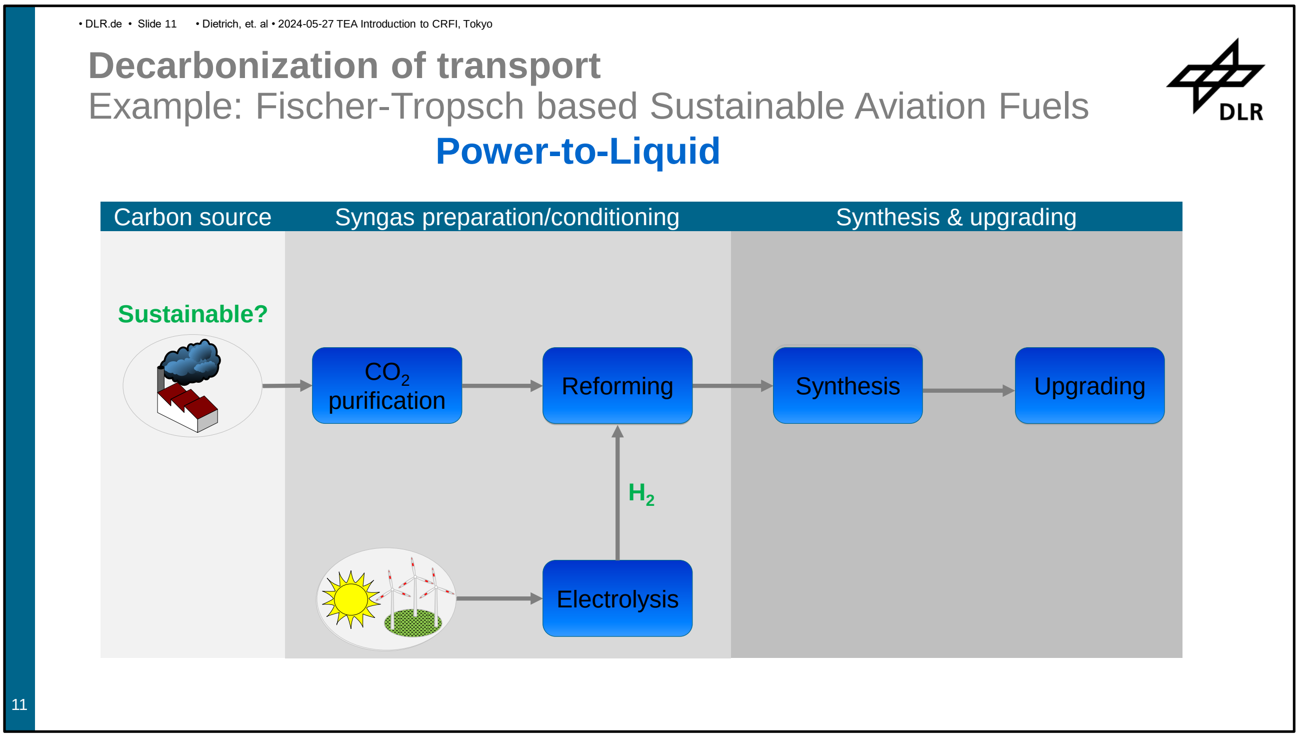
- Was adapted from best-practice chemical engineering methodology
- Meets AACE class 3-4 methodology, with a predicted accuracy of +/- 30 %
- Uses year specific annual CEPCI Index
- Includes an automated interface for simulation control, seamless integration of data flows, exergy analysis, heating networks, …
- LCA conforms to ISO 14040 and 14044 using current ecoinvent database
- Most recent LCA knowledge is adapted
- Allows sensitivity studies for each process parameter and boundary condistion
- Can be extended using learning curves, economy of scale, …



- TEPET uses rigorous process simulation results
    - Stream data provide material and energy flows
    - Equipment data provide cost and performance
- CAPEX derives from connecting equipment dimensions with generalized equipment cost data
- OPEX derives from connecting stream data with material cost data
- Net production cost derive from CAPEX and OPEX

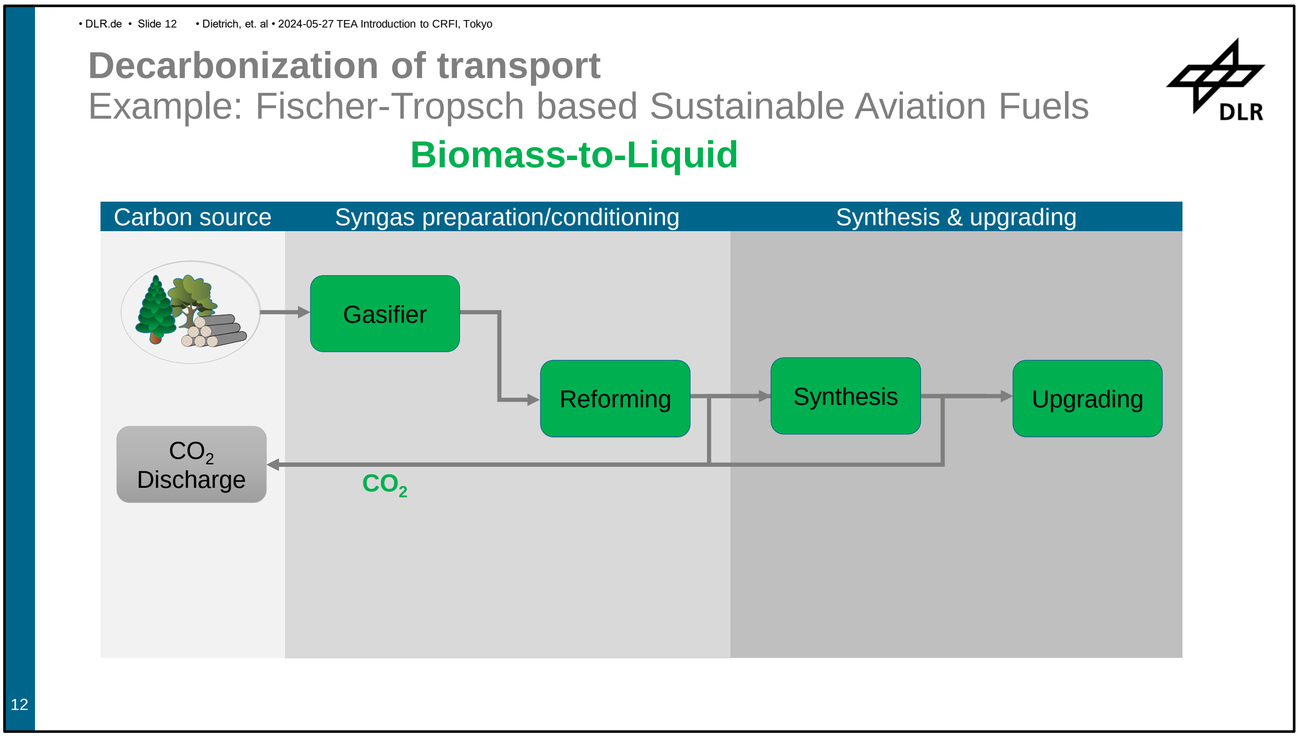


- Life Cycle Inventory (LCI) derives from connecting equipment dimensions and stream data with life cycle inventory datasets of commercial database, partially extended with external information
- Life Cycle Impact Assessment (LCIA) performed with Brightway2 (open source software) for each environmental impact category



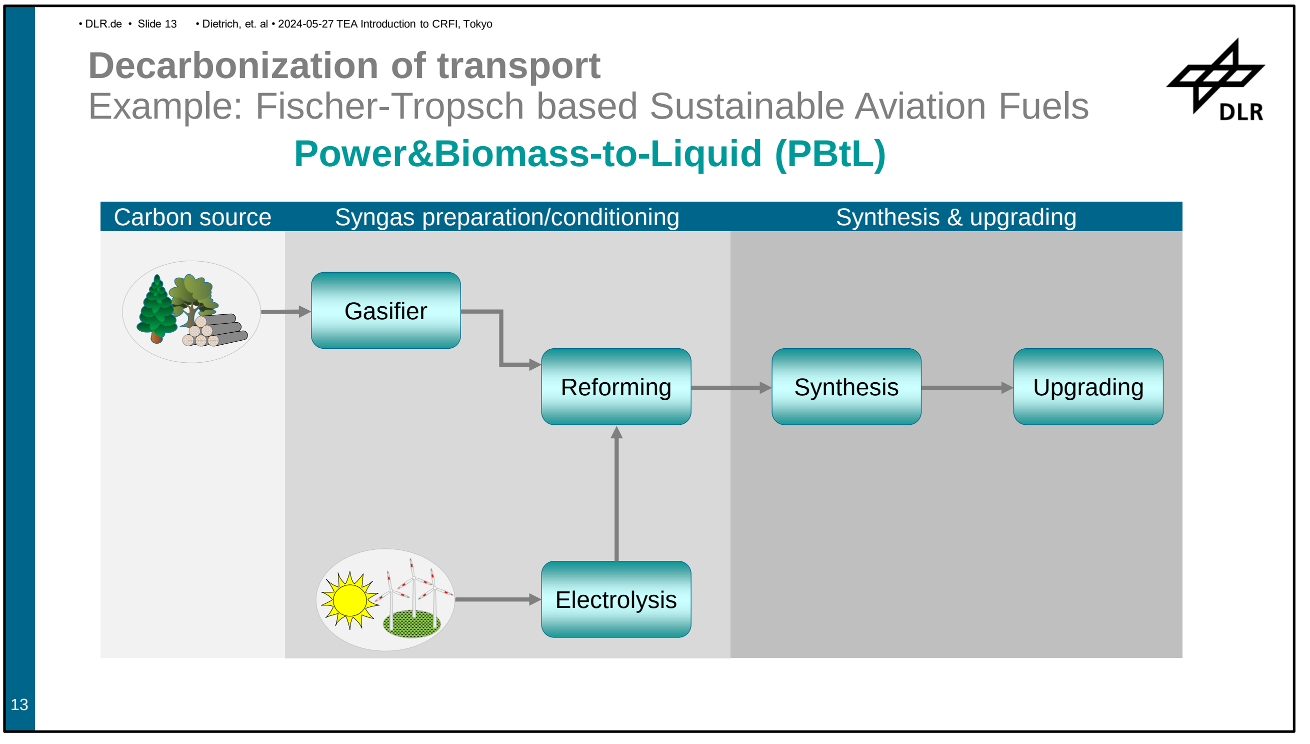
A first example to search for the production of sustainable aviation fuels (SAF) is the Power-to-Liquid process (PtL)

- CO_2 can be derived from industrial sources like cement factories or from direct air capture (DAC)
- Hydrogen is produced by water electrolysis, the power should be from renewable sources like wind or PV
- In a reverse water-gas-shift reaction CO_2 is converted with hydrogen to CO, H_2O is an unavoidable by-product
- The Fischer-Tropsch synthesis is a well-known reaction converting synthesis gas ($CO+H_2$) into liquid hydrocarbons, that will later be upgraded into aviation fuels



SAF can be produced via biomass gasification in a Biomass-to-Liquid process (BtL)

- Biomass can be converted into synthesis gas ($CO+H_2$) at high temperatures using oxygen and/or steam
- In a water-gas shift reaction CO is converted into CO_2, in order to achieve the right syngas composition
- In the following reformer, tars and methane are converted into CO, CO_2 and H_2, increasing the syngas amount and the right syngas composition for the synthesis
- The Fischer-Tropsch synthesis converts synthesis gas ($CO+H_2$) into liquid hydrocarbons, that will later be upgraded into aviation fuels



A third option to produce SAF is the Power&Biomass-to-Liquid process (PBtL)

- Biomass is converted into synthesis gas ($CO+H_2$) at high temperatures using oxygen and/or steam
- Hydrogen is produced by water electrolysis, the power should be from renewable sources like wind or PV
- In the syngas reformer hydrogen is added in order to achieve the right syngas composition
- The Fischer-Tropsch synthesis converts synthesis gas ($CO+H_2$) into liquid hydrocarbons, that will later be upgraded into aviation fuels

• DLR.de • Slide 14 • Dietrich, et. al • 2024-05-27 TEA Introduction to CRFI, Tokyo

Fischer-Tropsch based hydrocarbons
Stochiometric preference

DLR

Power-to-Liquid $\Delta H^0_{F,byproduct} = -484\ kJ \rightarrow -484 \frac{kJ}{(CH_2)}$

$$CO_2 + 3\ H_2 \rightarrow -CH_2- + 2\ H_2O$$

Biomass-to-Liquid $\Delta H^0_{F,byproduct} = -394\ kJ \rightarrow -131 \frac{kJ}{(CH_2)}$

$$2\ C_2H_3O^* \rightarrow 3\ -CH_2- + CO_2$$

Power&Biomass-to-Liquid $\Delta H^0_{F,byproduct} = -484\ kJ \rightarrow -121 \frac{kJ}{(CH_2)}$

$$2\ C_2H_3O^* + 6\ H_2 \rightarrow 4\ -CH_2- + 2\ H_2O$$

Palm oil-to-HEFA $\Delta H^0_{F,byproduct} = -484\ kJ \rightarrow -30 \frac{kJ}{(CH_2)}$

Crop-based

$$C_{16}H_{32}O_2^{**} + 2\ H_2 \rightarrow 16\ -CH_2- + 2\ H_2O$$

* Woody biomass elemental mass composition: $C_{52.1}H_{6.1}O_{38.5}X_{2.9}$

** Example: palmitic acid elemental molar composition: $C_{16}H_{32}O_2$

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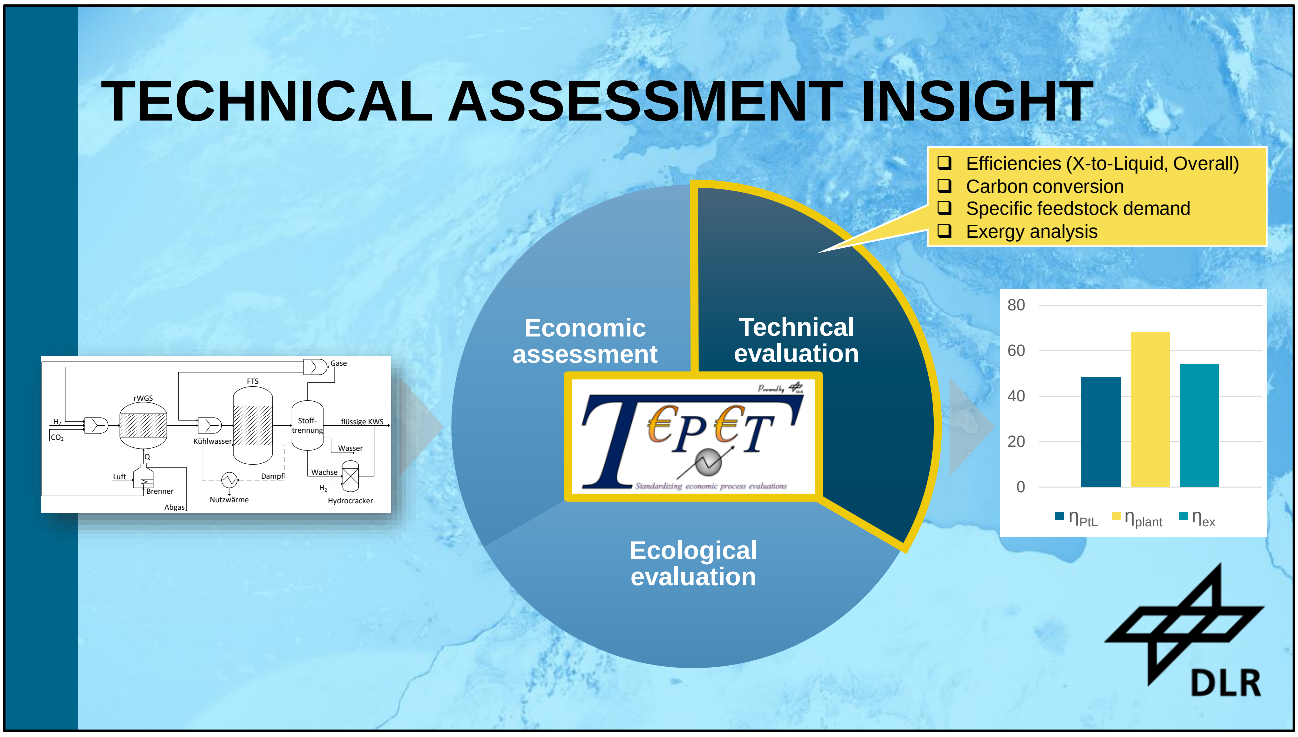
- Regarding the goal of terminating CO_2 emissions from aviation : 1.0 Gt in 2019[1]
- Simplified comparison of stochiometric heat losses
  - PtL penalty: H_2O production
  - BtL penalty: CO_2 production
  - PBtL penalty: reduced H_2O production
  - HEFA penalty: least H_2O production for deoxygenation and chain partition – consider feedstock limitation

[1] https://ourworldindata.org/global-aviation-emissions



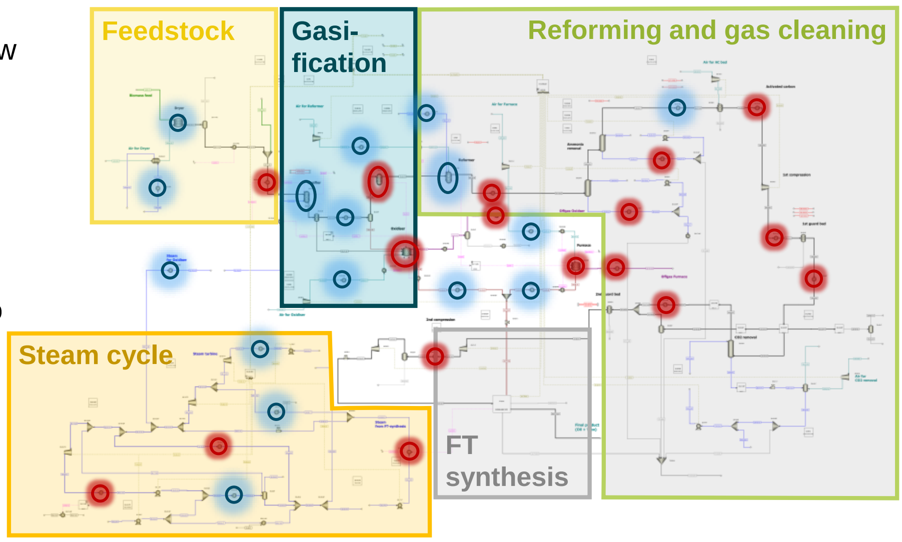
Technical assessment starts with rigorous process simulation

- Ensuring correct representation of the process
- Optimal by-product and heat integration
- Result: carbon / hydrogen / energy efficiency
- Exergetic analysis

COMSYN project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727476.

Fischer-Tropsch based biofuels
Rigorous technical assessment

- Validated process flow diagram
  - Component list
  - VLE method
  - Reaction kinetic, unit performance
  - Optimal heat integration
  - Realistic press. drop
- Additional process ideas
  - e.g. Steam cycle integration



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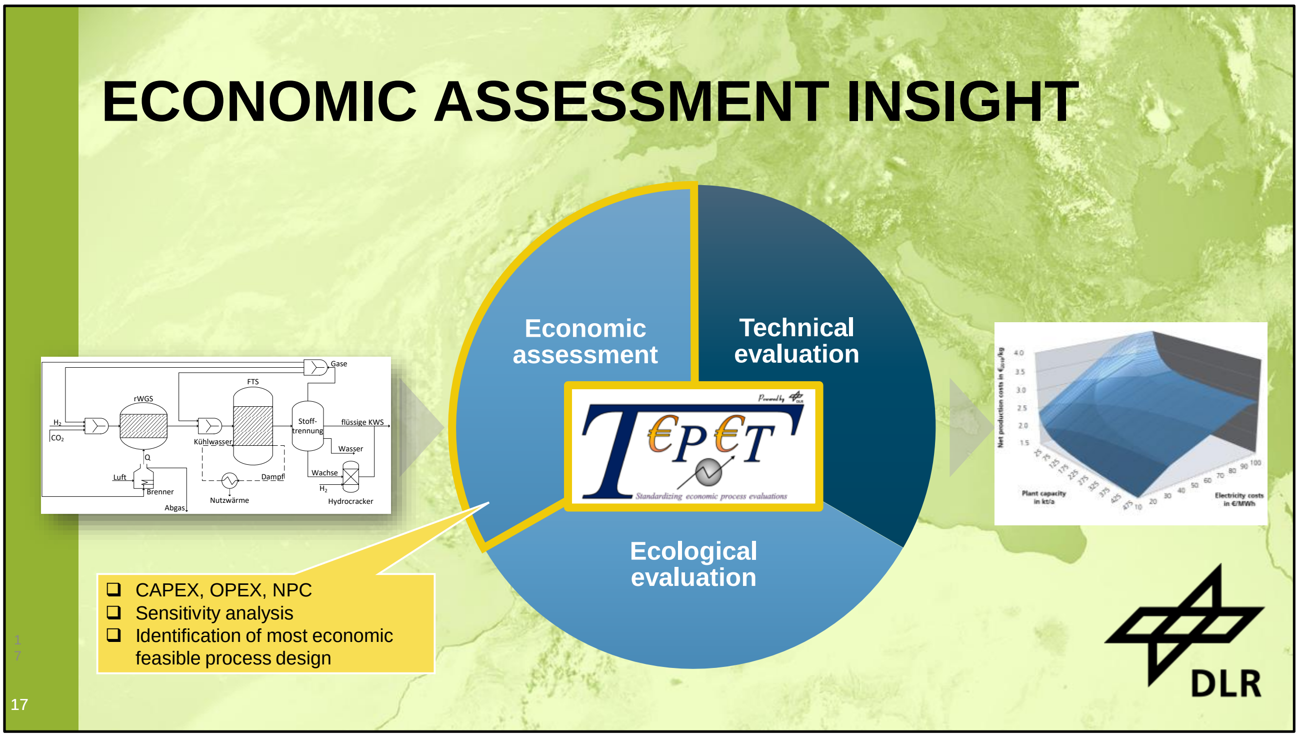
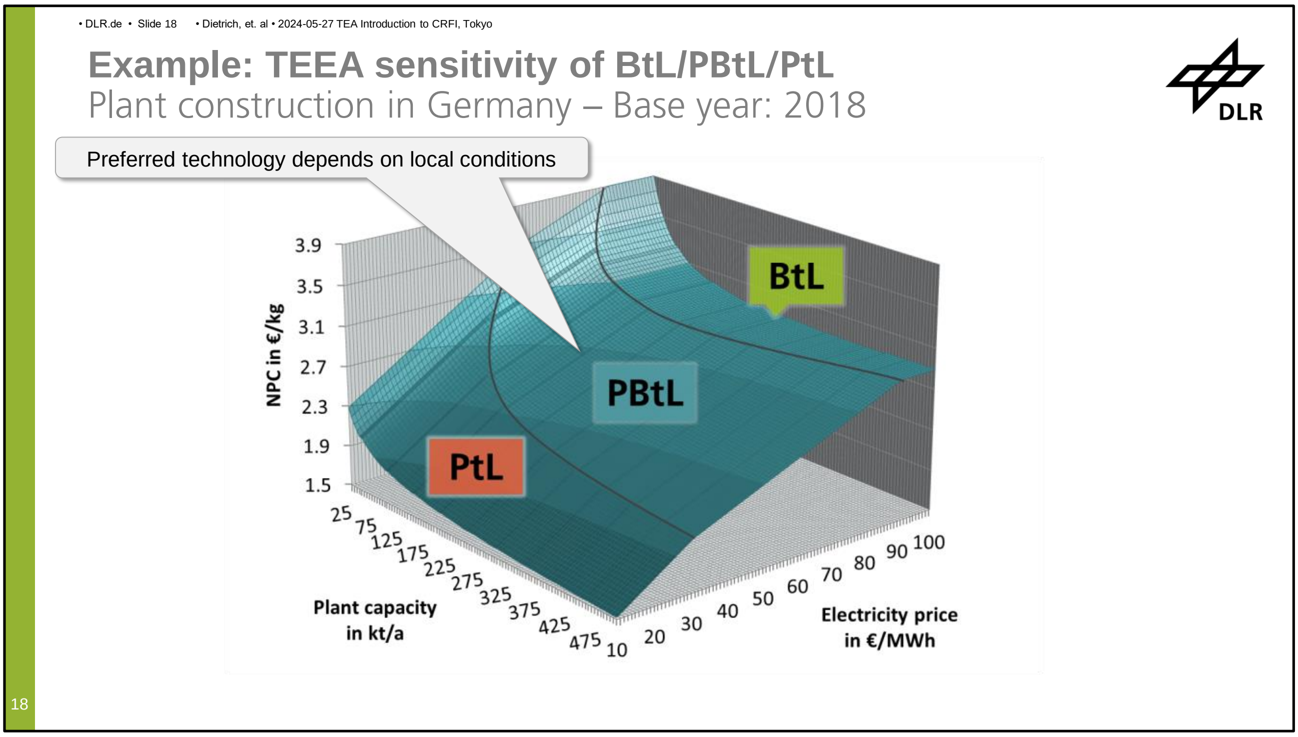
- Rigorous process simulation provides complete mass and energy balance
  - Trace material and energy flow through a complex value chain, across various plants/sectors/industries
  - Optimal heat integration via TEPET
  - Determine yields, efficiency, losses
- Example: biofuels production from woody biomass and straw gasification, reforming and gas cleaning, Fischer-Tropsch synthesis (COMSYN EU project)
- Steam cycle can utilize waste heat for power generation



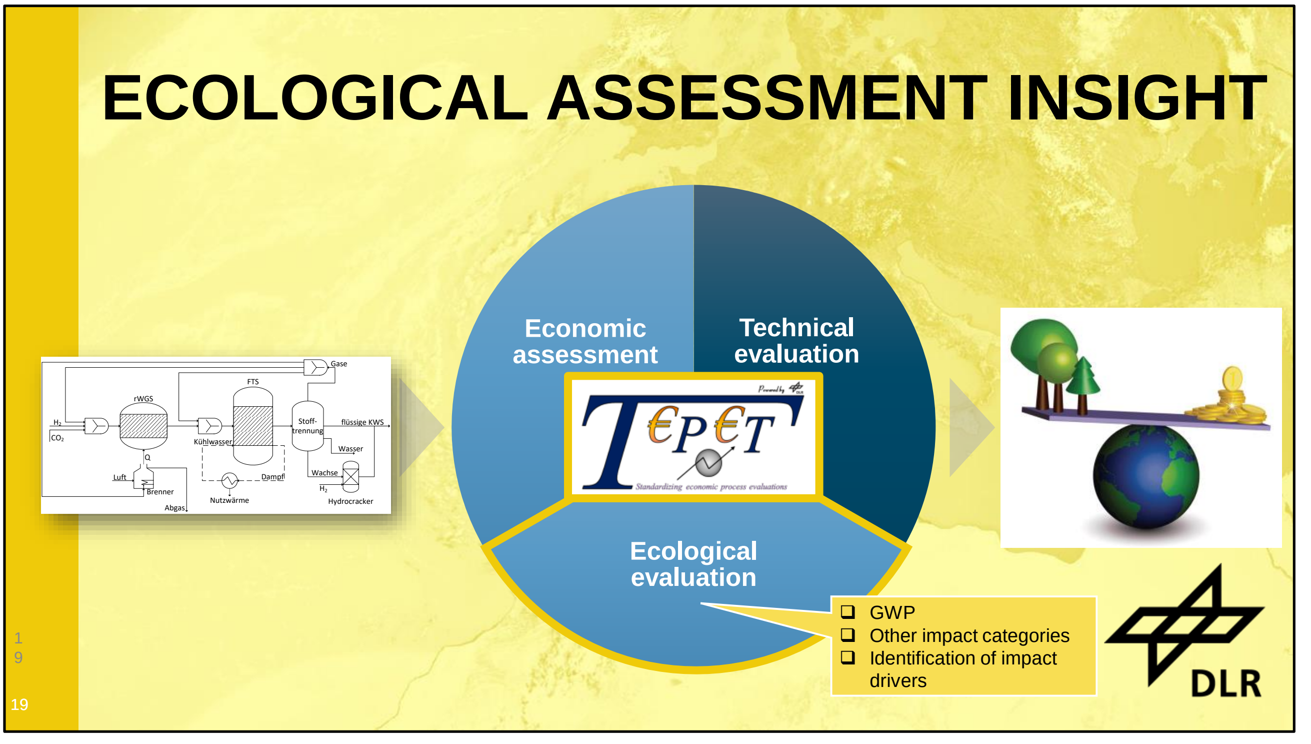
- Standard chemical engineering cost estimation
  - Fixed capital investment (FCI) costs consist of equipment costs (EC) and further capital requirements in the construction phase.
  - Database consisting of cost functions for main chemical process equipment as well as for fuel synthesis equipment included in TEPET based on data from scientific reference literature
  - Chemical Engineering Plant Cost Index (CEPCI) to account for inflation and temporal cost variations of equipment
  - Results: CAPEX, OPEX, Net Production Cost
- Sensitivity of each process parameter on production costs
- Search for cost improvements, potential operation sweet spots
  - Comparing different process designs

  ➔ Identifying the ideal process configuration at given boundary conditions
- Accuracy of chemical process cost estimation is expected to be ±30% according to class three/four of the classification system of AACE (Association for the Advancement of Cost Engineering) [1]

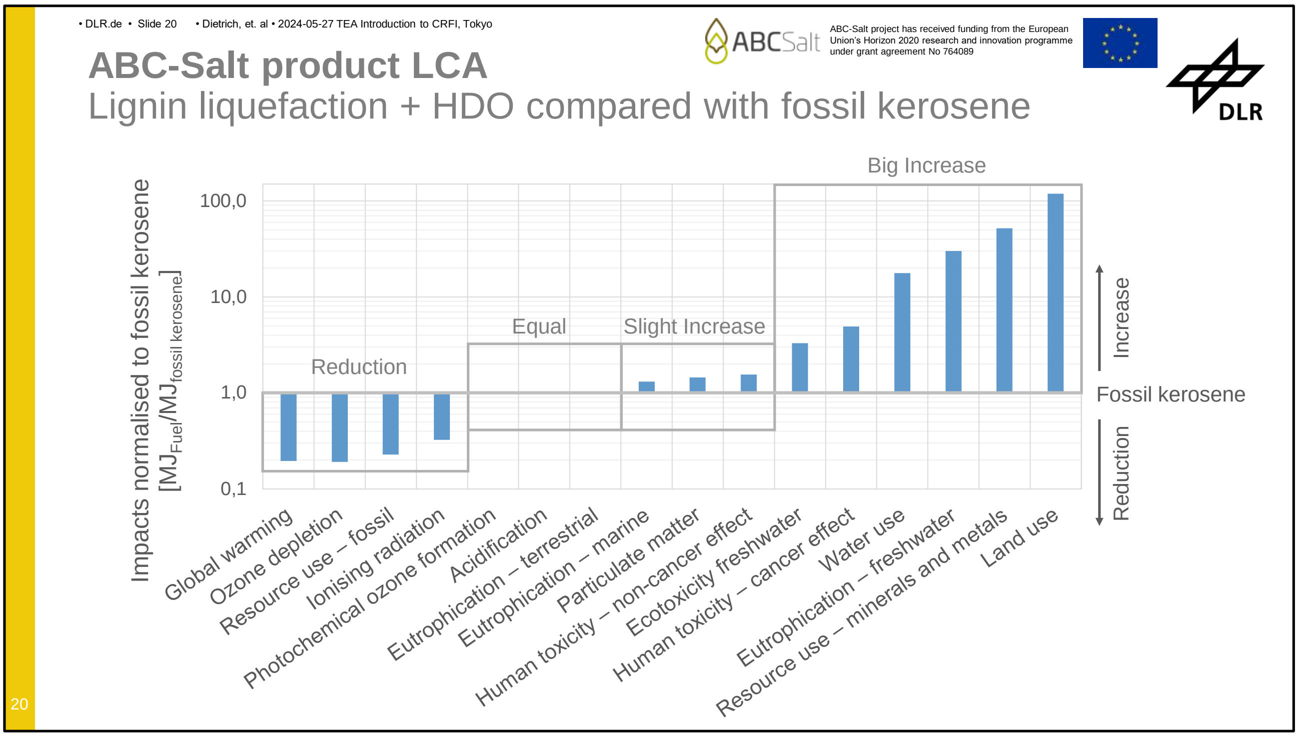
[1] Association of the Advancement of Cost Engineering. Cost estimate classification system - as applied in engineering, procurement, and construction for the process industries. Morgantown: AACE International; 2011.



- Economic assessment example:
  Net production cost (NPC) based on electricity cost and plant size for three different process routes.
- The results show beneficial SAF production options



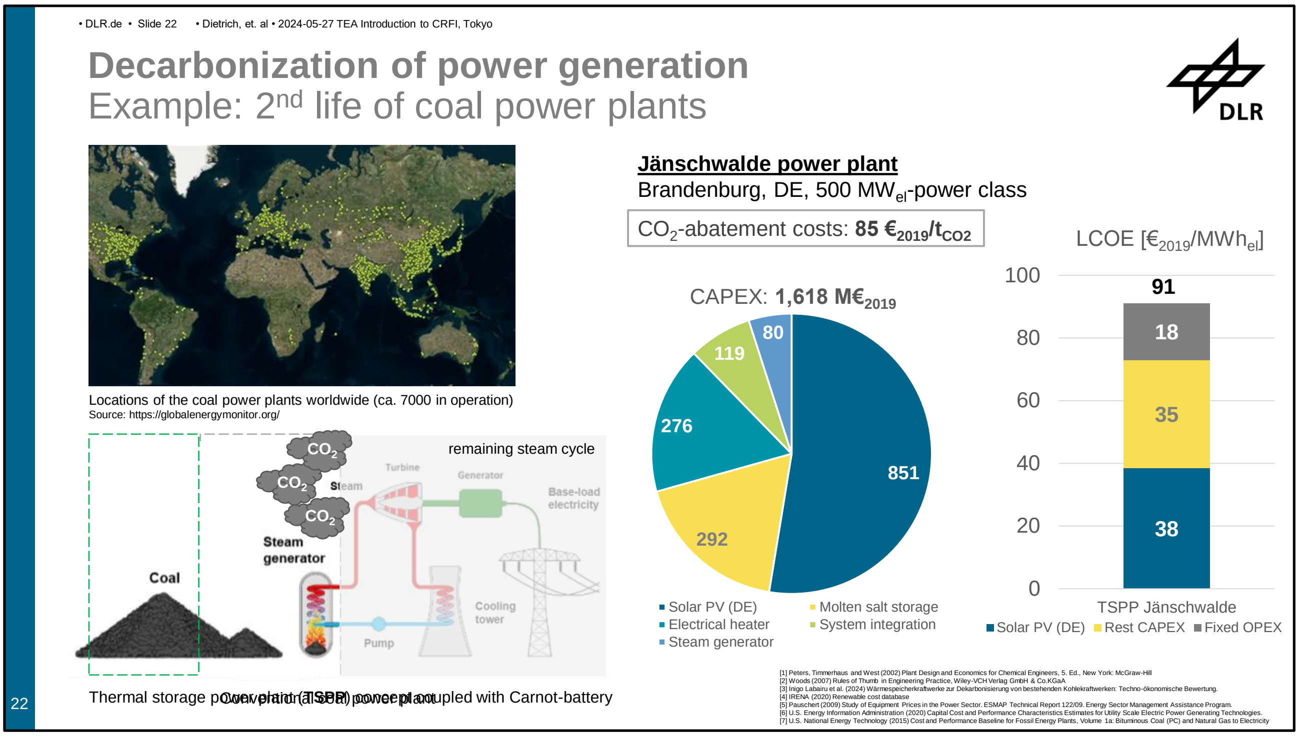
- In order to determine the environmental impact of renewables integration compared to state-of-the-art fossil based processes
- Committed to reduce greenhouse gas (GHG) emissions
- Environmental impact analysis



- LCA provides all environmental impacts of alternative production routes compared to fossil reference
    - Local impacts might outweigh global warming benefits
- Example: biofuels production from lignin liquefaction, hydropyrolysis plus hydrodeoxygenation (HDO) (ABC-Salt EU project)
    - Comparison with fossil kerosene shows impact categories with clear reduction, neglectable impact and increased environmental impact

Following are examples of techno-economic and environmental assessment for different decarbonization options

- Tackling scientific and industrially relevant questions.
- Applying the assessment methodology to processes in the fields of
    - Power supply
    - Transportation
    - Aviation
    - Basic chemicals
    - Renewable energy imports

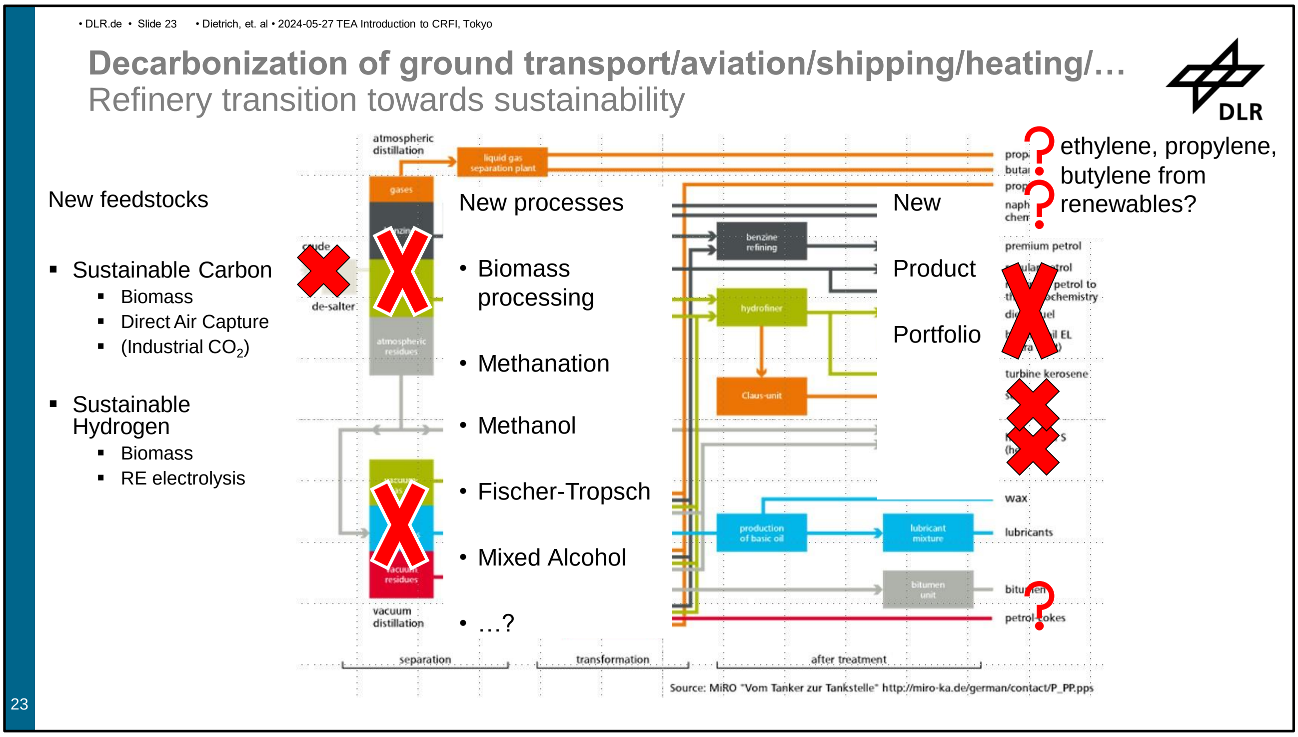


- Goal: Termination of 15.2 Gt CO_2 emissions from global coal power plants in 2022[1] (iea.org: 15.5 Gt from coal in 2022[2])
- Integration of high shares of RE into power systems operations, providing flexibility
- Reuse of steam cycle, auxiliaries to convert fluctuating wind and solar power into demand-driven base-load power
- Search for individual solution for each of 7.000+ global coal power plants

➔ To be included into Japans Green Transformation Policy, “GX Policy”?
➔ Technology option to help Japans international decarbonization initiative focusing on Southeast Asia: the “Asia Zero Emission Community” (ERIA’s Technology List)?
➔ Support for Japan/Asia to set coal power phaseout dates?

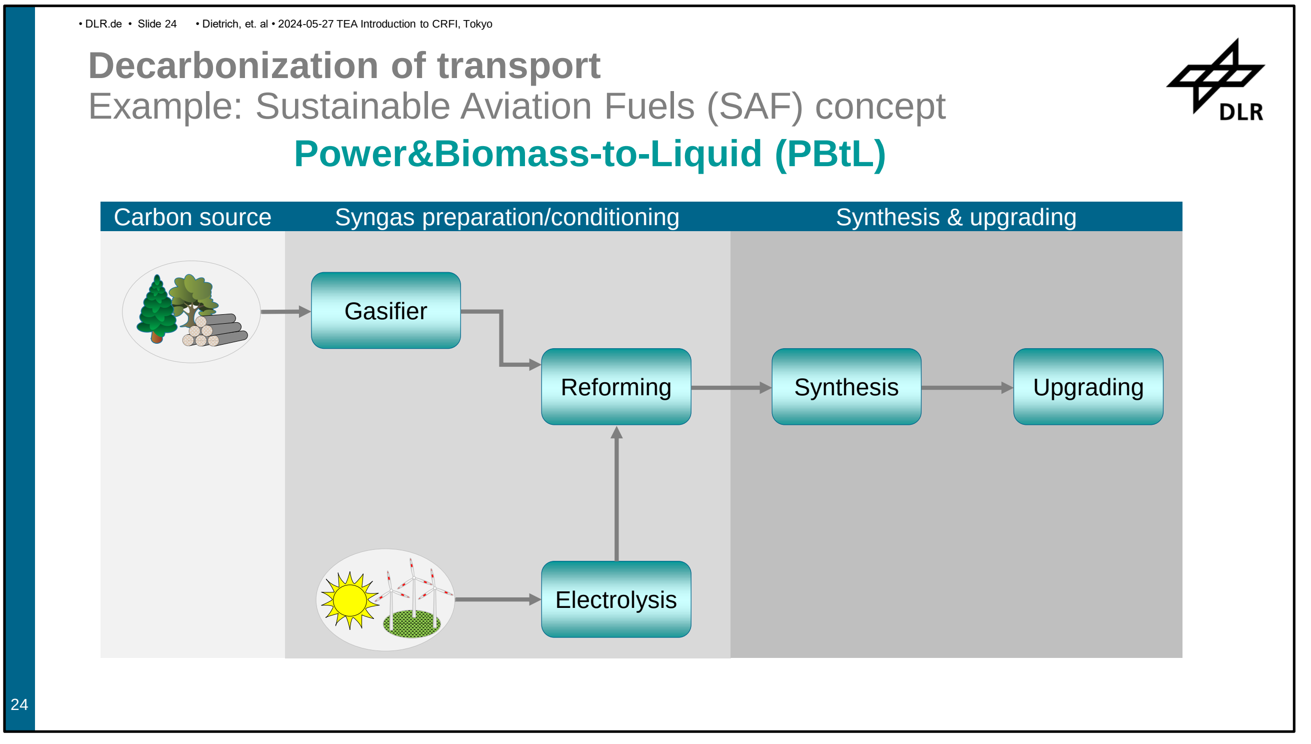
[1] https://ourworldindata.org/emissions-by-fuel

[2] https://www.iea.org/reports/co2-emissions-in-2022



- Goal: Termination of 11.9 Gt/a CO_2 emissions from oil consumption in 2022[1] (iea.org: 11.2 Gt from oil in 2022[2])
- Refinery transition towards sustainability requires new feedstocks /processes / product portfolio
- Increased pressure
    - Regulation
    - Customer base
- Search for individual solution for each refinery

[1] https://ourworldindata.org/emissions-by-fuel
[2] https://www.iea.org/reports/co2-emissions-in-2022



- Goal: Termination of 1.0 Gt/a CO_2 emissions from aviation in 2019[1] (last year before Corona), full rebound is expected soon
- Maximize SAF production from renewables
  - Adding hydrogen from renewable power increases carbon efficiency of SAF production
  - Local availability of renewable electricity, water and biogenic carbon required

[1] https://ourworldindata.org/global-aviation-emissions

Decarbonization of transport

Example: Average PBtL plant for European SAF

DLR

Key economic Assumptions

Investment costs:			Average plant size
AEL-Electrolyzer	**1**	M€/MW [1]	→ 900 MW_e Electrolyzer
Fischer-Tropsch SBCR:	**5.9**	k€/m^3 [2]	→ 400 kt/a SAF
Selexol:	**5.5**	k€/$kmol_{CO2}$/h [3]	
Fluidized bed gasifier:	**0.5**	M€/($kg_{dry\ biomass}$/s) [4]	→ 400 MW_{th} gasifier
Raw materials and utility costs			
Selexol:	**4.4**	€/kg [5]	
FT catalyst:	**33**	€/kg [6]	

General economic assumptions:

Year:	2020	*Plant lifetime:*	20 years
Full load hours:	8,100 h/a	*Interest rate:*	7 %

[1] Buttler, A., & Spliethoff, H. (2018). Current status of water electrolysis for energy storage, grid balancing and sector coupling via power-to-gas and power-to-liquids: A review. Renewable and Sustainable Energy Reviews, 82, 2440-2454.
[2] Gasification, B. B. (1998). Aspen Process Flowsheet Simulation Model of a Battelle Biomass-Based Gasification, Fischer-Tropsch Liquefaction and Combined-Cycle Power Plant.
[3] Hamelinck, C. N., & Faaij, A. P. (2002). Future prospects for production of methanol and hydrogen from biomass. *Journal of Power sources*, *111*(1), 1-22.
[4] Hannula, I. (2016). Hydrogen enhancement potential of synthetic biofuels manufacture in the European context: A techno-economic assessment. *Energy*, *104*, 199-212.
[5] Albrecht, F. G., König, D. H., Baucks, N., & Dietrich, R. U. (2017). A standardized methodology for the techno-economic evaluation of alternative fuels–A case study. *Fuel*, *194*, 511-526.
[6] Swanson, R. M., Platon, A., Satrio, J. A., & Brown, R. C. (2010). Techno-economic analysis of biomass-to-liquids production based on gasification. *Fuel*, *89*, S11-S19.

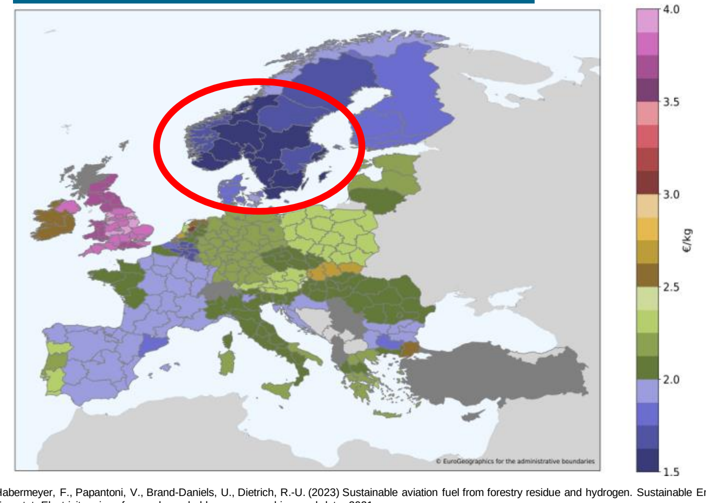
- In order to safe 1.0 Gt CO_2 emissions from aviation in 2019[1], 300+ Mt/a SAF production are required globally
- PBtL enables to maximize SAF production from renewables in Europe (about 60 Mt/a expected in 2030)
    - Unutilized woody biomass could be harvested in a sustainable forestry
    - Adding hydrogen from renewable power increases carbon efficiency of SAF production
    - Local availability of renewable electricity, water and biogenic carbon required

Base case definition for market roll-out:

- All process equipment of PBtL concept is commercially available
- Plant size depend on biomass transport options

Towards an ambitious European SAF Roadmap
Exploring local onshore wind power utilization[1]

Net Production Costs of PBtL SAF / $€_{2020}$/kg



Standard PBtL plant
- 900 MW_e Electrolyzer
- 400 MW_{th} CFB gasifier
- 400 kt/a fuel

➔ Search for cheap biomass residue [3] and inexpensive renewable power [2]

1. Norway (57 $PJ_{dry\ biom}$/a) @ 50.5 – 51.0 $€_{2022}/t_{biom}$
2. Sweden (276 $PJ_{dry\ biom}$/a) @ 57.5 – 64.8 $€_{2022}/t_{biom}$
3. Finland (201 $PJ_{dry\ biom}$/a) @ 61.5 – 61.9 $€_{2022}/t_{biom}$

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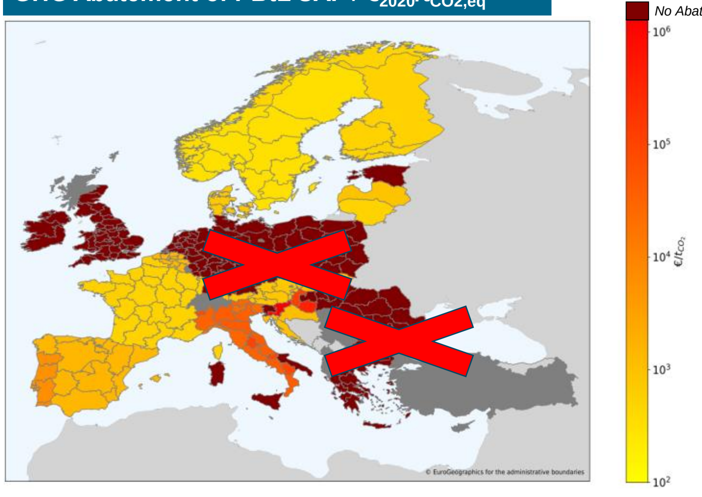
[1] Habermeyer, F., Papantoni, V., Brand-Daniels, U., Dietrich, R.-U. (2023) Sustainable aviation fuel from forestry residue and hydrogen. Sustainable Energy and Fuels(7), p. 4229-4246. Royal Society of Chemistry. doi: 10.1039/d3se00358b
[2] Eurostat, Electricity prices for non-household consumers - bi-annual data. 2021.
[3] Ruiz, P., Nijs, W., Tarvydas, D., Sgobbi, A., Zucker, A., Pilli, R., ... & Thrän, D. (2019). ENSPRESO-an open, EU-28 wide, transparent and coherent database of wind, solar and biomass energy potentials. *Energy Strategy Reviews*, *26*, 100379.

- PBtL cost distribution across Europe for one single plant configuration/size
- Local net production cost (NPC) depend mainly on electricity and biomass price

Towards an ambitious European SAF Roadmap
Exploring grid connected PBtL sustainability[1]

DLR

GHG Abatement of PBtL SAF / €$_{2020}$/t$_{CO2,eq}$



➔ Decarbonized national grids necessary for effective PBtL roll-out

➔ Production volume under 1'000 €/t$_{CO2\text{-}eq.}$: **27 Mt$_{C5+}$/a** (all biomass residue to fuel) @ average NPC of **1.84 €$_{2020}$/kg$_{C5+}$**

Country	SAF / Mt$_{C5+}$/a	Av. NPC / €$_{2020}$/kg$_{C5+}$
	8.3	1,63
	7.3	1.95
	6.1	1.83
	1.7	1.66

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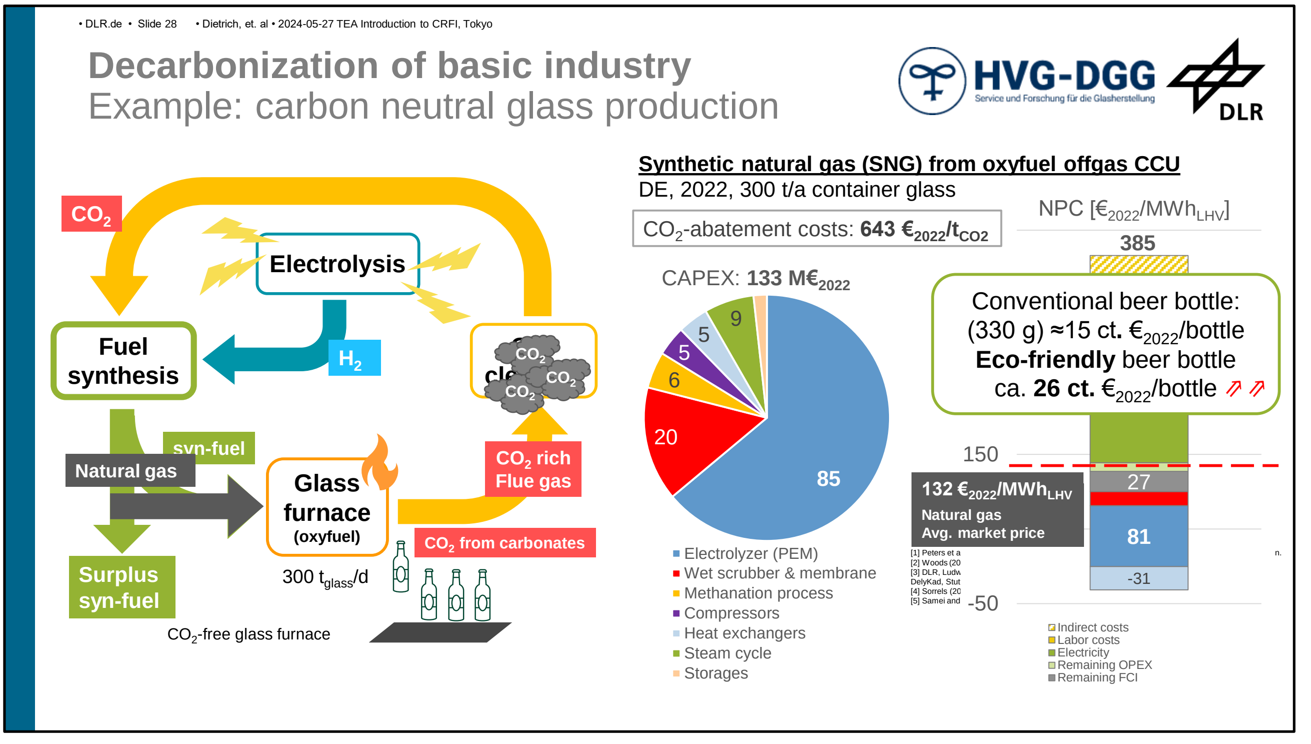
[1] Habermeyer, F., Papantoni, V., Brand-Daniels, U., Dietrich, R.-U. (2023) Sustainable aviation fuel from forestry residue and hydrogen. Sustainable Energy and Fuels(7), p. 4229-4246. Royal Society of Chemistry. doi: 10.1039/d3se00358b. 2021.

- PBtL abatement cost distribution across Europe for one single plant configuration/size
- GHG footprint of PBtL SAF depend on electricity emissions



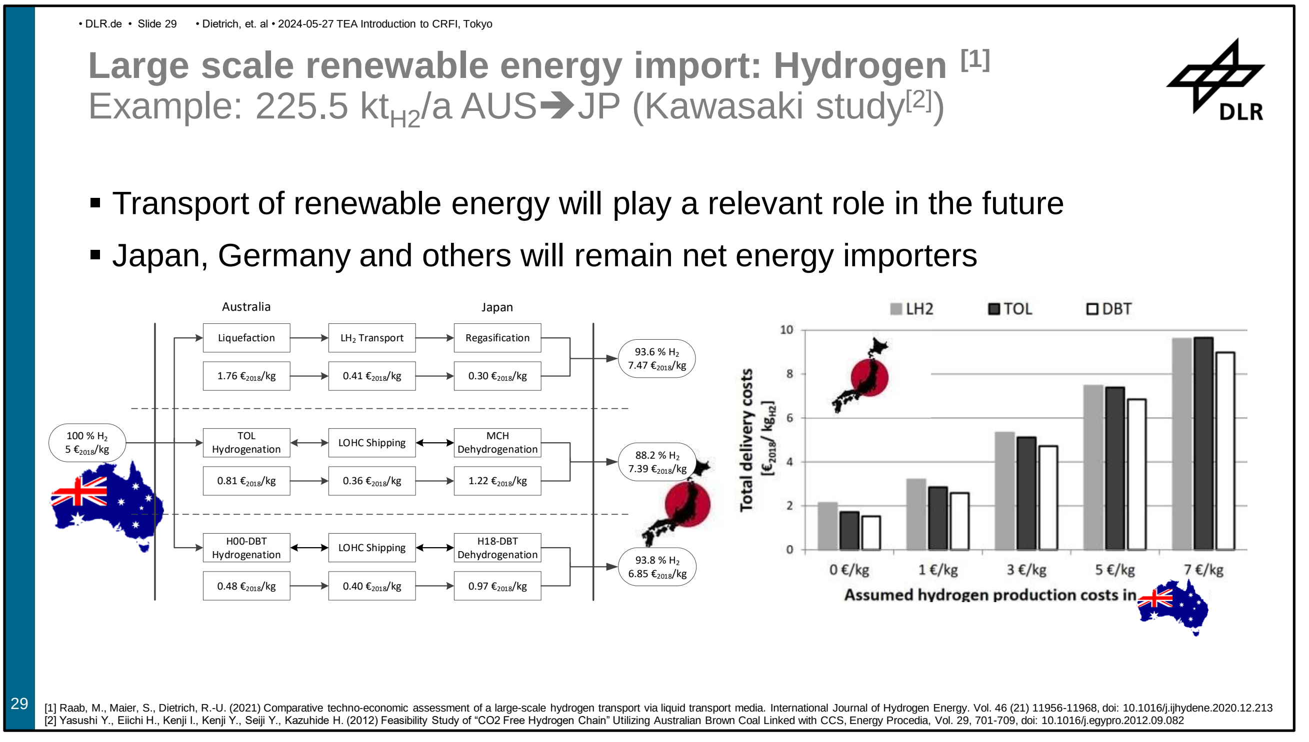
CCU to produce carbon neutral container glass (biggest GWP contributor in glass ind.)

- Termination of 9.2 Gt CO_2 emissions from industry in 2022[1], glass industry only minor part of GHG emissions compared to steel and cement production
- Glass industry faces the challenge of continuous 24/7 production while requested to shift to renewable fuels
- Process design of CCU-based SNG and methanol available, equipment performance and costs of state of the art technology are listed:

Reference function ($EC_{i,ref}$)	EC_{ref}	Currency	$sizing_{ref}$	Unit	n
Compressor	3 035	$	1	kW_{el}	0.68
Methanation reactor	57 794	$	14 000	m^3/h	0.52
PEM electrolysis	957	€	1	kW_{el}	1
Wet scrubber (limestone)	13 061	k$	14	MW_{th}	0.72
Membrane PMP	9.76	m$	525.6	kmol/h	0.6
Polynomial function ($EC_{i,poly}$)	**e**	**f**	**g**	**Sizing unit**	**Currency**
Shell & tube HEX*	0	201.29	3853.3	Heat transfer area [m^2]	$
Flash drum	-2.21	369.75	805.42	Length & diameter [m]	$

- Compared to fossil fuel - Energy supply costs: Factor 5, glass supply cost: Factor 2
- Applicable to multiple industry decarbonization options using CCU

[1] https://ourworldindata.org/emissions-by-fuel



- Comparison of renewable energy transport options from Australia to Japan
  - Hydrogen liquefaction costly
  - Liquid organic hydrogen carriers (LOHC) have dehydrogenation costs in Japan
  - Production cost of renewable hydrogen are still dominant
- Cheaper renewable electricity abroad brings transport options into focus
  - Reliability of supply chains
  - Cost competitiveness compared to domestic RE production
  - GHG footprint in producing countries

- See: Raab, M., Maier, S., Dietrich, R.-U. (2021) Comparative techno-economic assessment of a large-scale hydrogen transport via liquid transport media. International Journal of Hydrogen Energy. Vol. 46 (21) 11956-11968, doi: 10.1016/j.ijhydene.2020.12.213

Large scale renewable energy import: H_2 derivates [1]

Example: Namibia H_2 production (1 GW_{LHV}) from optimized Wind+PV

DLR

- Renewable H_2 derivate import might be attractive based on future demand

H_2: 98.4 $€_{2021} MWh_{LHV}^{-1}$

	Unit	LH_2	LOHC – H12-BT	LNG	MeOH	NH_3	FT - Diesel
Production rate	$t\ h^{-1}$	29.5	469.6	59.6	145.0	158.5	84
	$m^3\ h^{-1}$	417	536	141	183	232	59
	MW_{LHV}^{-1}	983.5	972.8**	827.6	801.1	817.9	639
η_{HtF}	% ($GW_{LHV,F}\ GW_{LHV,H}^{-1}$)	98.4	97.3*	82.8	80.1	81.8	63.9
η_{PtF}	% ($GW_{LHV,F}\ GW_{el}^{-1}$)	60.6	55.4*	57.3	54.7	53.6	43.3
η_C	%	-	-	98.5	95.2	-	95.5
NPC	$€_{2021}\ kg^{-1}$	**5.00**	**3.55****	**2.05**	**1.10**	**0.71**	**3.37**
	$€_{2021}\ MWh_{LHV,F}^{-1}$	**150**	**107.4****	**147.6**	**198.6**	**137.6**	**306.5**
Transport	$€_{2021}\ MWh_{LHV,F}^{-1}$	8.4	6.6**	5.9	3.9	5.3	5.0
Regasification	$€_{2021}\ MWh_{LHV,F}^{-1}$	9.0	26.7***	5.4	-	-	-
OPEX	$M€_{2021}\ a^{-1}$	1,035	230*	1,059	1,084	786	1,123

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[1] Dietrich, R.-U. et al (2024) Large-scale transport of renewable energy via hydrogen and derivates, Encyclopedia of Electrochemical Power Sources, 2nd Edition to be published 09/24)

- Comparison of renewable energy transport options from Namibia to Germany
  - Hydrogen liquefaction costly
- Hydrogen derivates might provide higher user benefits
  - Energy import cost benefit for LOHC
  - Ammonia seems attractive, if used for urea/fertilizer
  - Demand expectations versus cost differences

- See: Dietrich, R.-U. et al (2024) Large-scale transport of renewable energy via hydrogen and derivates, in Encyclopedia of Electrochemical Power Sources, 2nd Edition - September 2, 2024, Editor: Jürgen Garche, Elsevier, Hardback ISBN: 9780323960229, eBook ISBN: 9780323958226, https://shop.elsevier.com/books/encyclopedia-of-electrochemical-power-sources/garche/978-0-323-96022-9

- DLR's techno-economic and ecological assessment can provide transparent and standardized assessment of each measures scale/impact
    - Support policy makers for efficient regulation
    - Support technology development to improve climate change mitigation
    - Support demonstration, deployment, market ramp-up
- Towards decarbonization of aviation, transport, chemicals and power generation

Outlook

DLR

- Climate change mitigation is urgent on a global scale
  - GHG emission reduction required from 35.8 Gt/a to ZERO
- Developed countries need to provide technical solutions, international regulations need to ensure its commercial viability
  - Japan, Germany and others can be demonstrators, large emitters have to adapt
- Techno-economical and ecological assessment can provide transparent, technology-agnostic guidance
  - Choosing preferred technologies and locations
  - R&D demand and optimization potential
  - Purposeful regulation
- DLR standard is globally applicable ➔ TEPET – Standardizing economic process evaluations

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DLR is able to provide assessment support regarding

- What are urgent measures for climate change mitigation?
  - High impact, low cost?
- What technology is available short-term?
- Further development/improvement needs

Partner search towards Decarbonization

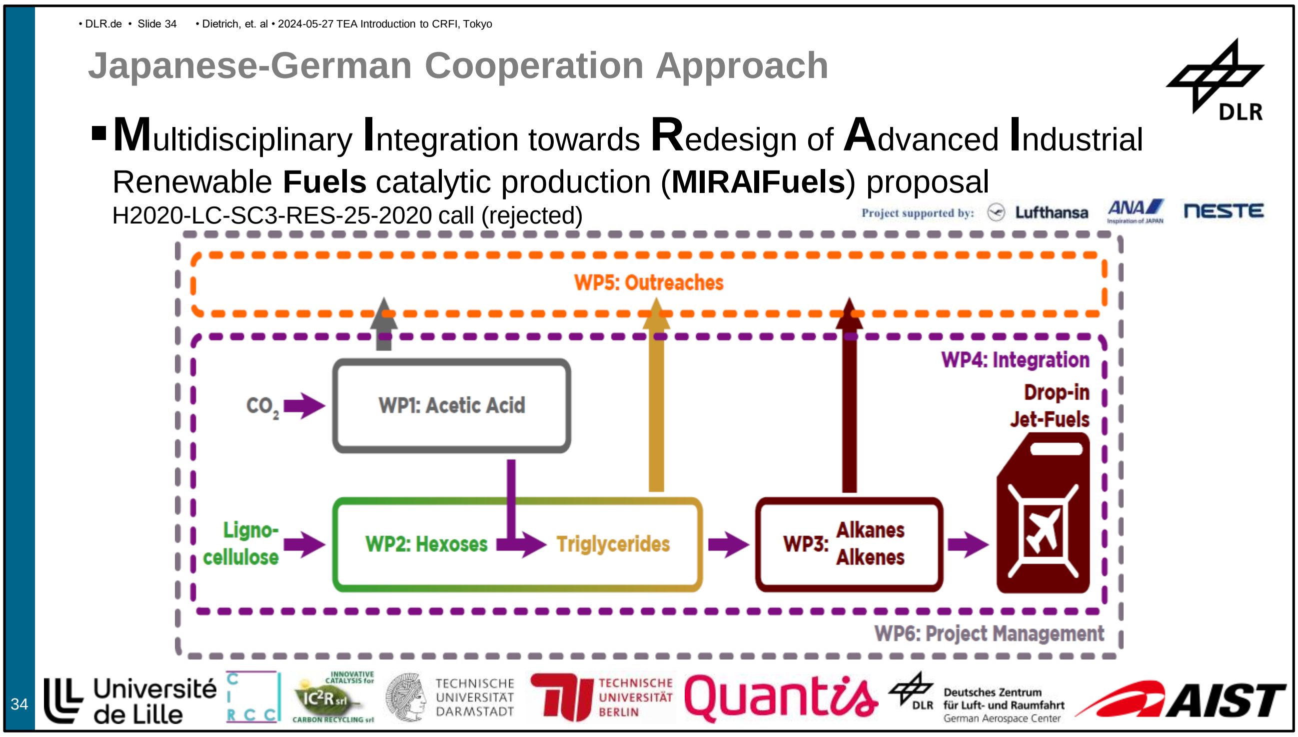
DLR

Looking for research partner

- Fuel consumer on the way to sustainable transport
  - Explore new fuels and its impact on your environmental footprint and costs
- Energy / fuel / chemicals supplier with pressure to become sustainable
  - Explore the integration of renewables into your production scheme
  - Find electrolyzer applications that fit into your production scheme
- Technology supplier for fuels and chemicals
  - Explore new process routes that include renewable feedstocks
- Technology developer for sustainable products
  - Search for the economic and ecological optimal production
  - Quantify opportunities for improvement, localize bottlenecks
  - Predict new processes market rollout

Japanese – German cooperation can address different fields

- New fuels, new processes, new feedstocks, new locations
- Joint technology development, demonstration, deployment, market ramp-up

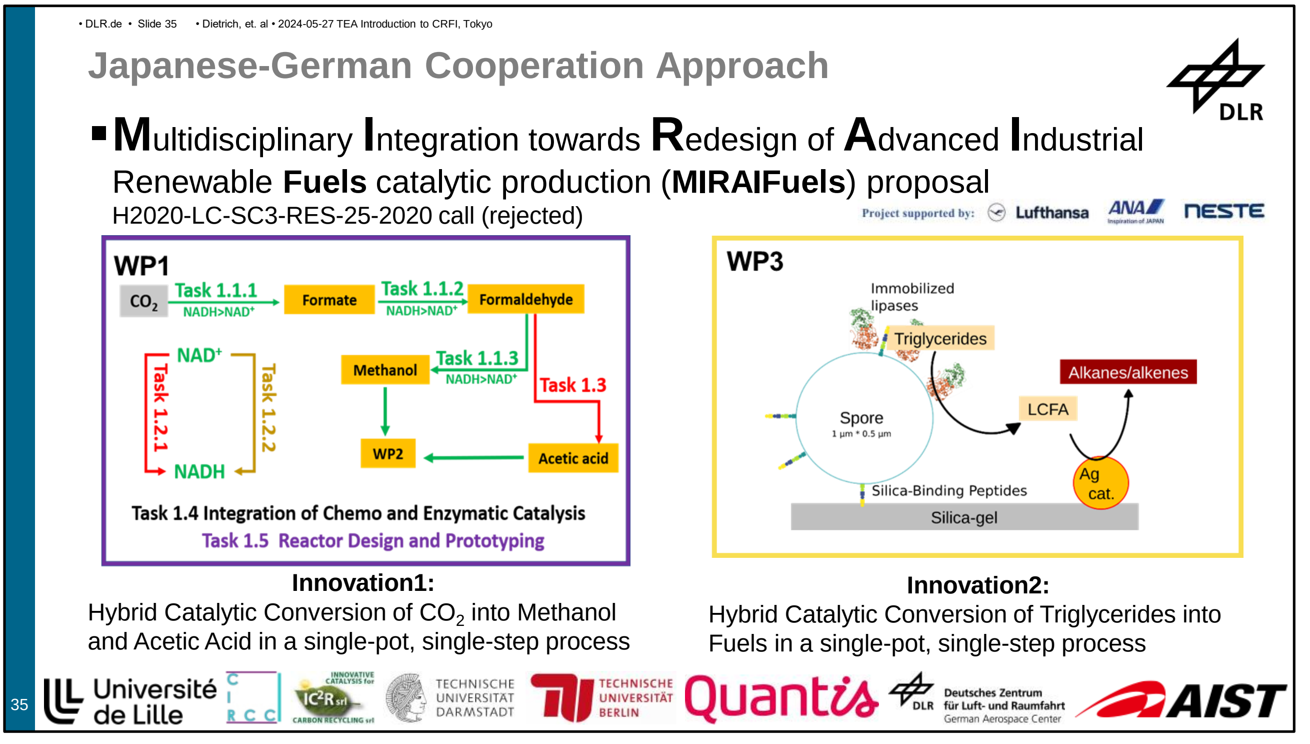


Japanese – German cooperation example: EU collaboration project funding

- Targeted topic: LC-SC3-RES-25-2020 - International cooperation with Japan for Research and Innovation on advanced biofuels and alternative renewable fuels

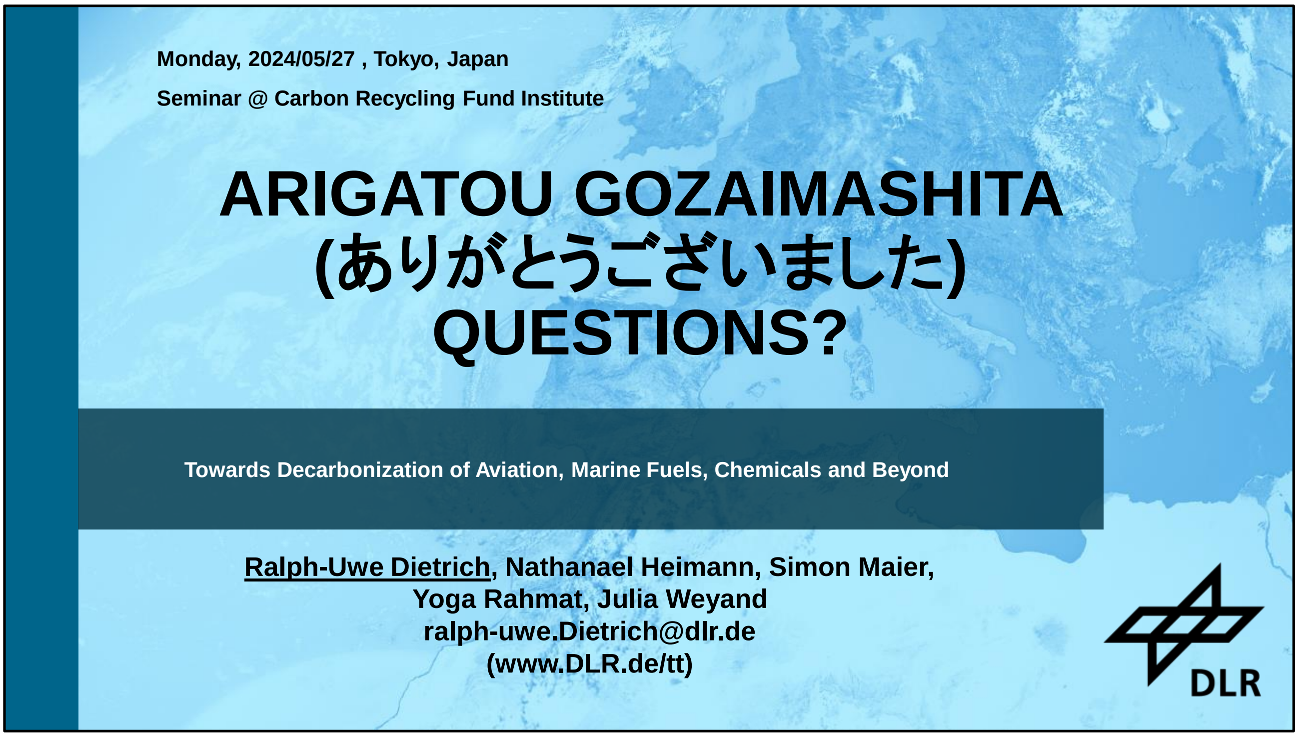
https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/lc-sc3-res-25-2020

- Project coordinator: University of Lille (FR)
- To develop disruptive catalytic strategies for the conversion of CO_2 and lignocellulosic feedstocks into alternative renewable jet-fuel.
- Exploit two emerging concepts at the catalyst and process integration scale: hybrid catalysis ((electro)-chemo- and bio-catalysts) and biorefineries.
- Proposal rejection letter: the score obtained does not suffice (Total score: 13.00)
  Criterion 1 – Excellence: Score: 4.00 (max. 5.00)
  Criterion 2 – Impact: Score: 4.00 (max. 5.00)
  Criterion 3 - Quality and efficiency of the implementation Score: 5.00 (max. 5.00)



- MIRAIFuels intended to develop disruptive catalytic strategies
  - Conversion of CO_2 into methanol via formate* and formaldehyde using three enzymes (F_{ate}DH, F_{ald}DH, ADH) at ambient pressure and temperature
  - Improved stabilization of enzymes via encapsulation into beads, supporting the enzymes on mesoporous materials or phosphates
  - Design and prototype a lab-scale reactor that may maximize the conversion of CO_2 into methanol and/or acetic acid
  - Acetic acid and methanol usage as co-substrates for yielding triglycerides
  - Combining cell wall-degrading enzymes with chemo-catalysts for depolymerization of lignocelluloses into fermentable sugars
  - Develop a batch reactor for lignocelluloses conversion to triglycerides
  - Develop a hybrid catalysis process for the triglycerides conversion into hydrocarbons.
  - Develop an innovative biorefinery concept with optimal integration of different process units to maximize energetic efficiency and biocarbon usage of a bio-jet fuel production pathway.

* Formate (IUPAC name: methanoate) is the conjugate base of formic acid. Formate is an anion (HCO_2^-) or its derivatives such as ester of formic acid.



何事も始めるのに遅すぎるということはない。
Nanigotomo hajimeru no ni ososugiru to iu koto wa nai;