Power-to-X - From vision to industrial implementation

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Process4 Sustainability

Cluster for climate-neutral process industries in Hesse

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Power-to-X - From vision to industrial implementation

R. Dittmeyer

4th International Workshop on Innovation and Production Management in the Process Industries (IPM 2022), May 12-13, 2022

Institute for Micro Process Engineering

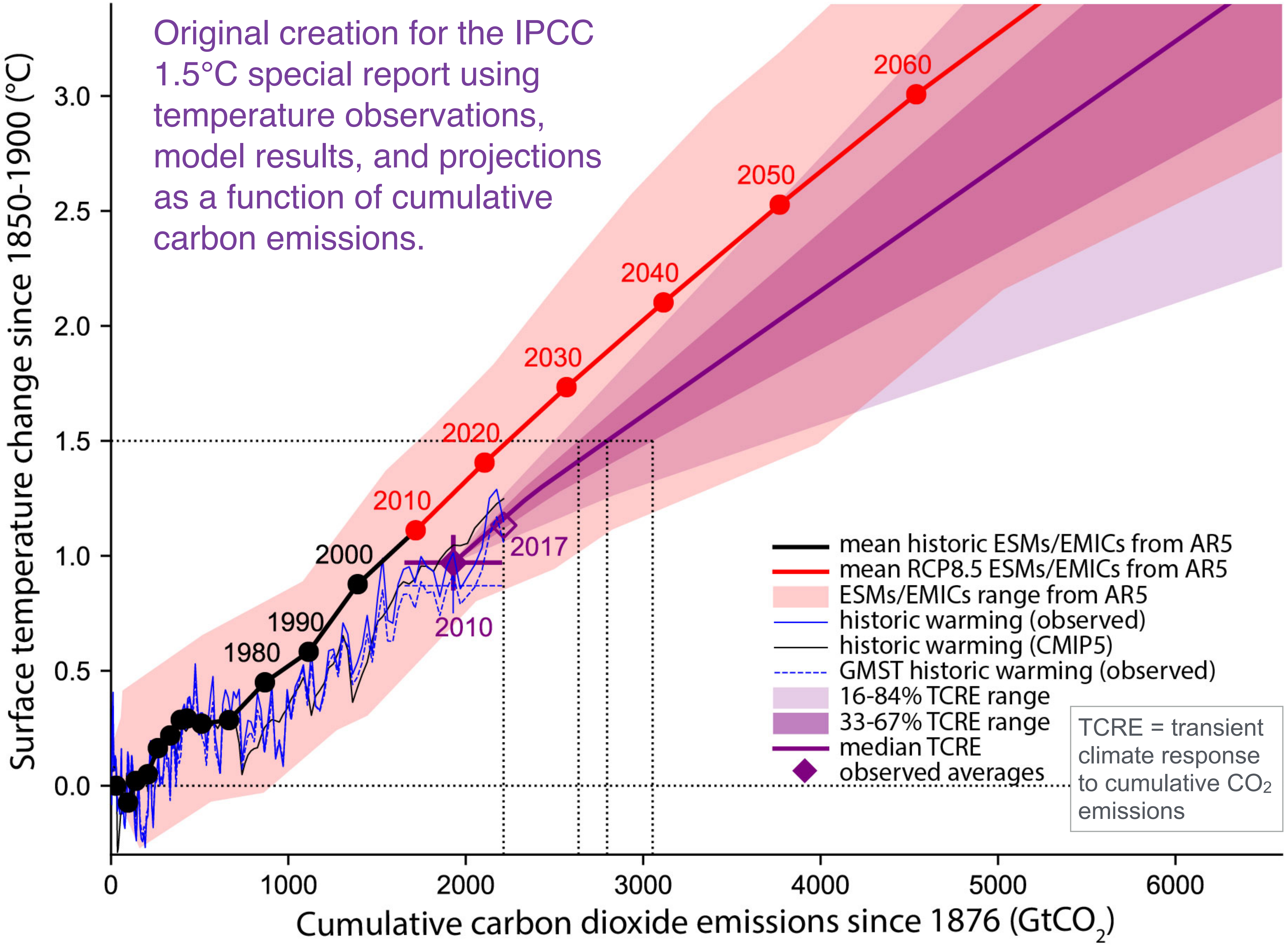
Agenda

- The global climate crisis
- General overview of Power-to-X
- Challenges
- Current status in R&D and steps towards implementation

The Guardian, 21 Sep 2019, The best climate strike signs from around the globe in pictures. A sign held by a protester in London depicts global heating. Photograph: Will Oliver/EPA

Every ton of net CO_2 emissions has an impact on temperature

Temperature changes from 1850–1900 versus cumulative CO_2 emissions since 1st January 1876



Original creation for the IPCC 1.5°C special report using temperature observations, model results, and projections as a function of cumulative carbon emissions.

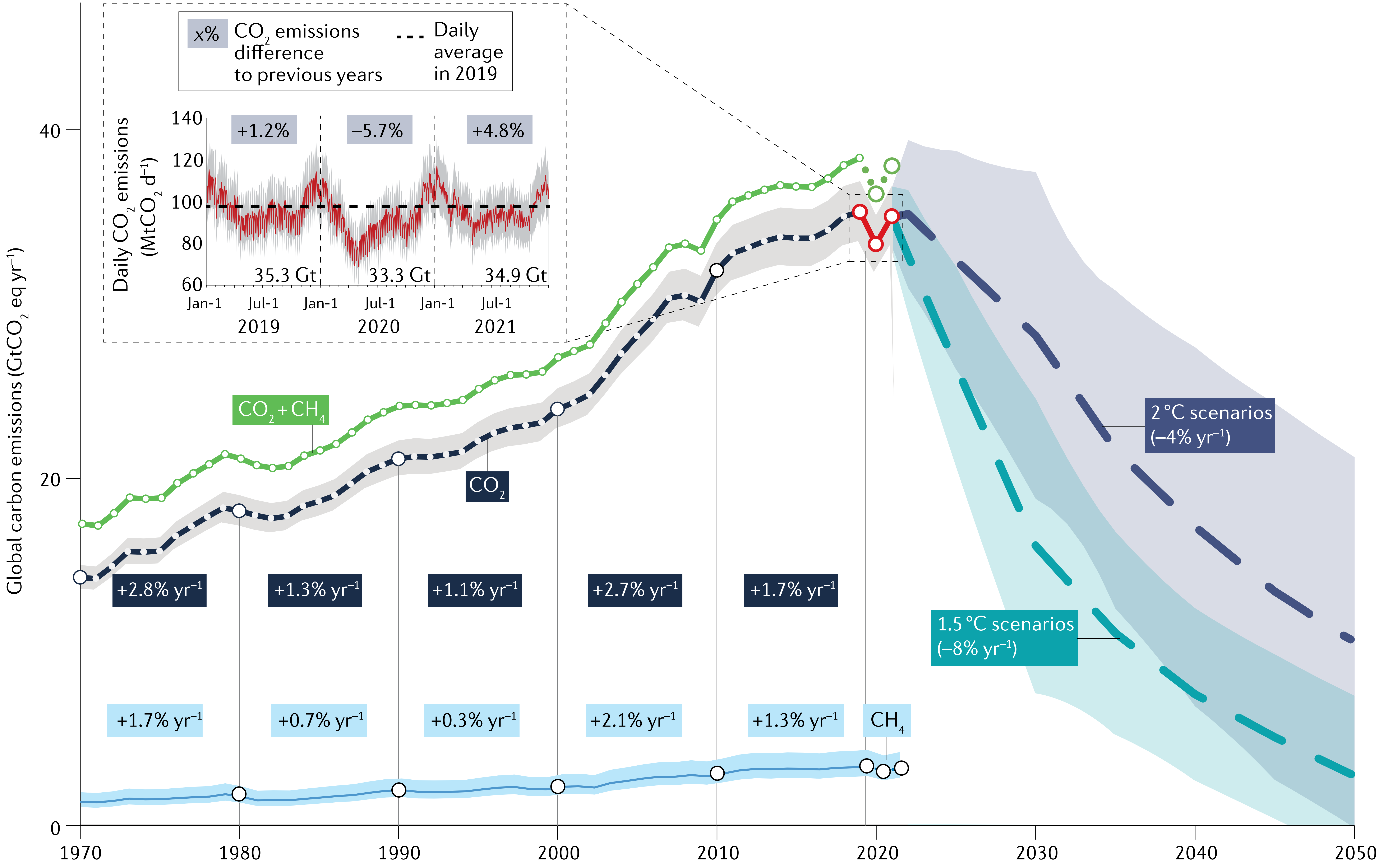
Solid lines with dots reproduce the globally averaged near-surface air temperature response to cumulative CO_2 emissions plus non-CO_2 forcers as assessed in Figure SPM10 of WGI AR5, except that points marked with years relate to a particular year, unlike in WGI AR5 Figure SPM.10, where each point relates to the mean over the previous decade. The AR5 data was derived from 15 Earth system models and 5 Earth system models of Intermediate Complexity for the historic observations (black) and RCP8.5 scenario (red), and the red shaded plume shows the range across the models as presented in the AR5. The purple shaded plume and the line are indicative of the temperature response to cumulative CO_2 emissions and non-CO_2 warming adopted in this report. The non-CO_2 warming contribution is averaged from the MAGICC and FAIR models, and the purple shaded range assumes the AR5 WGI TCRE distribution (Supplementary Material 2.SM.1.1.2). The 2010 observation of surface temperature change (0.97°C based on 2006–2015 mean compared to 1850–1900, Chapter 1, Section 1.2.1) and cumulative carbon dioxide emissions from 1876 to the end of 2010 of 1,930 $GtCO_2$ (Le Quéré et al., 2018) is shown as a filled purple diamond. The value for 2017 based on the latest cumulative carbon emissions up to the end of 2017 of 2,220 $GtCO_2$ (Version 1.3 accessed 22 May 2018) and a surface temperature anomaly of 1.1°C based on an assumed temperature increase of 0.2°C per decade is shown as a hollow purple diamond. The thin blue line shows annual observations, with CO_2 emissions from Le Quéré et al. (2018) and estimated globally averaged near-surface temperature from scaling the incomplete coverage and blended HadCRUT4 dataset in Chapter 1. The thin black line shows the CMIP5 multimodel mean estimate with CO_2 emissions also from (Le Quéré et al., 2018). The thin black line shows the GMST historic temperature trends from Chapter 1, which give lower temperature changes up to 2006–2015 of 0.87°C and would lead to a larger remaining carbon budget. The dotted black lines illustrate the remaining carbon budget estimates for 1.5°C given in Table 2.2. Note these remaining budgets exclude possible Earth system feedbacks that could reduce the budget, such as CO_2 and CH_4 release from permafrost thawing and tropical wetlands (see Section 2.2.2.2).

Source: IPCC Special Report Global Warming of 1.5°C, 8. October 2018, Chapter 2 - Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development, Figure 2.3.

Global CO_2 emissions in 2021 jumped back to pre-covid levels

Global CO_2 and CH_4 emission trends

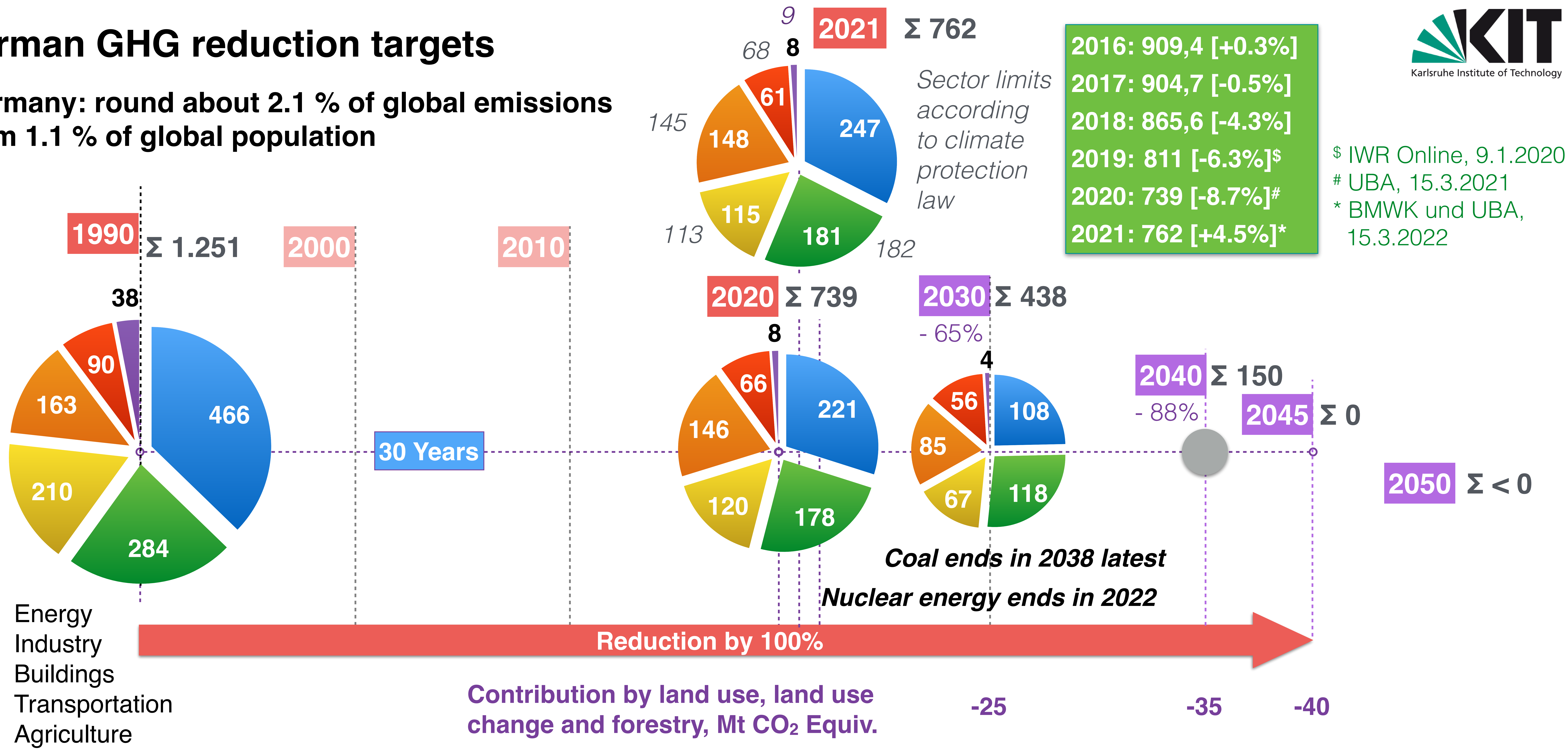
Temporal evolution of historical CO_2 emissions [5] (navy; including emissions from fossil fuel combustion and the process of cement production), near-real-time CO_2 emissions [1,3] (red), projected CO_2 emission mitigation pathways [10] (dark blue and aqua), and historical fossil CH_4 emissions [4] (light blue; 1970–2018 data from EDGARv6.0, scaled to 2021 with IEA data). Solid/dashed lines and shading represent the median and range, respectively. The inset depicts daily near-real-time CO_2 data over 2019 to 2021, and the corresponding year-on-year changes in annual CO_2 emissions. Current emission trends will use up the allowed future emissions for limiting anthropogenic warming to 1.5 °C (the remaining carbon budgets) within 10 years.



Source: Z. Liu et al., Monitoring global carbon emissions in 2021, Nat. Rev. Earth Environ. **2022**, *3*, 217-219, doi: 10.1038/ s43017-022-00285-w

German GHG reduction targets

Germany: round about 2.1 % of global emissions from 1.1 % of global population



Sector limits according to climate protection law

2016: 909,4 [+0.3%]
2017: 904,7 [-0.5%]
2018: 865,6 [-4.3%]
2019: 811 [-6.3%]$
2020: 739 [-8.7%]#
2021: 762 [+4.5%]*

$ IWR Online, 9.1.2020
# UBA, 15.3.2021
* BMWK und UBA, 15.3.2022

Coal ends in 2038 latest

Nuclear energy ends in 2022

Contribution by land use, land use change and forestry, Mt CO_2 Equiv.

Climate Protection Law, German Federal Government, 12.05.2021

Source: BMU, Berlin, 05/2021

#***Estimated by Agora Energiewende:*** Erneuerbare Energien, 17.08.2021, https://bit.ly/3BRYl62

Why converting green power into chemical energy carriers?

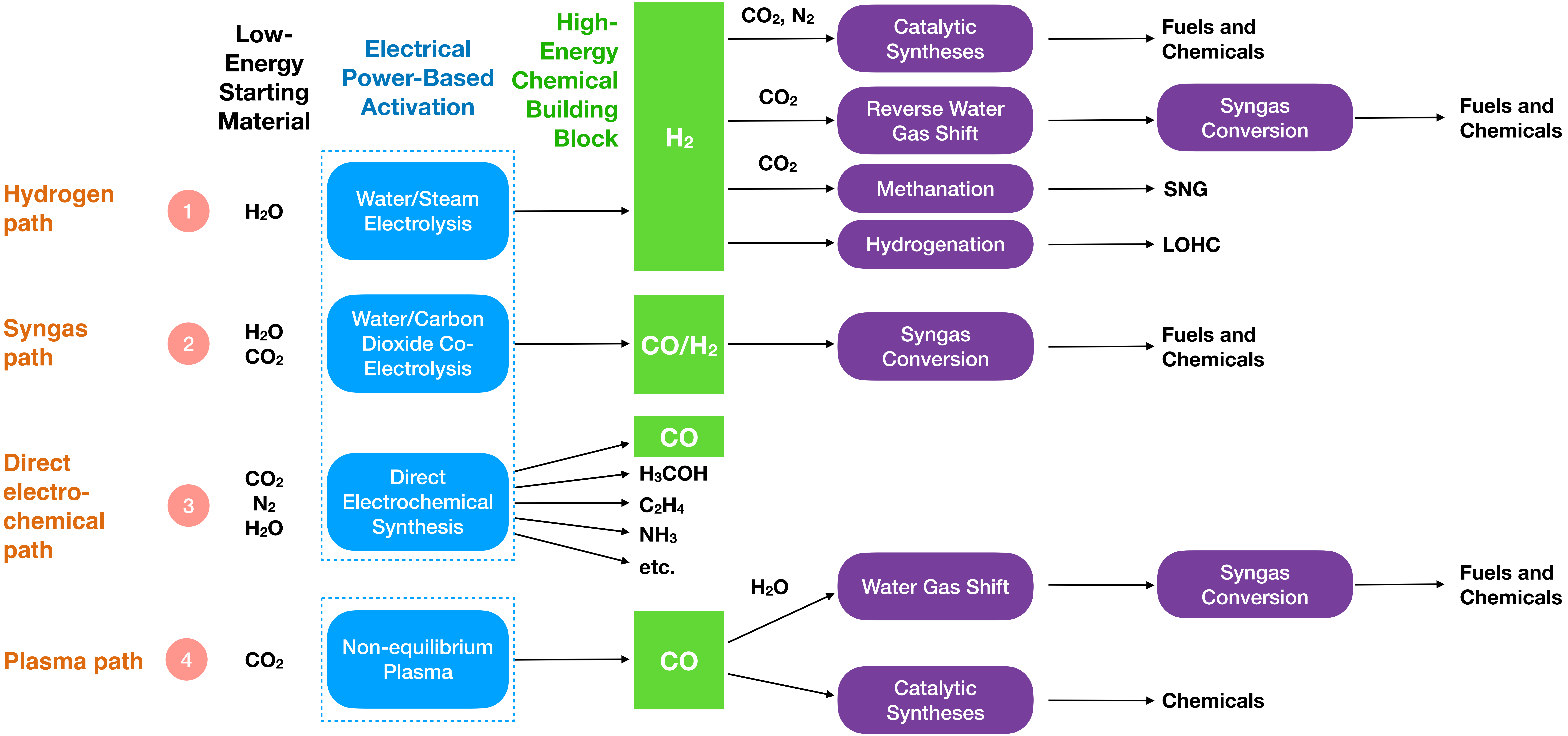
1. For rapid and deep defossilisation mainly of the transport and industry sectors
    - as an alternative to a continued use of fossil energy carriers combined with DACCS or BECCS
2. For storage of large amounts of green energy for power generation when needed
    - operational flexibility
    - compensation of a lack of renewable power generation at times and in places
    - maximisation of the energy gain from intermittent renewables
    - holding available a reserve
3. For transport of large amounts of green energy over long distances
    - import of green energy carriers
    - limit need for grid expansion
4. For optimisation of the overall energy system
    - economics
    - GHG footprint

DACCS: Direct Air Capture and Carbon Storage (CO_2-Capture from the atmosphere with permanent storage)
BECCS: Bioenergy with Carbon Capture and Storage (CO_2-Capture by biomass and energetic use of that biomass while capturing the produced CO_2 from the effluent for purification and permanent storage)

General scheme of „Power-to-X“

Conversion Processes (indicative)

Karlsruhe Institute of Technology



Low-Energy Starting Material

Electrical Power-Based Activation

High-Energy Chemical Building Block

Hydrogen path ① H_2O → Water/Steam Electrolysis → H_2

H_2 + CO_2, N_2 → Catalytic Syntheses → Fuels and Chemicals

H_2 + CO_2 → Reverse Water Gas Shift → Syntheses Conversion → Fuels and Chemicals

H_2 + CO_2 → Methanation → SNG

H_2 → Hydrogenation → LOHC

Syngas path ② H_2O, CO_2 → Water/Carbon Dioxide Co-Electrolysis → CO/H_2 → Syngas Conversion → Fuels and Chemicals

Direct electro-chemical path ③ CO_2, N_2, H_2O → Direct Electrochemical Synthesis → CO, H_3COH, C_2H_4, NH_3, etc.

Plasma path ④ CO_2 → Non-equilibrium Plasma → CO

CO + H_2O → Water Gas Shift → Syngas Conversion → Fuels and Chemicals

CO → Catalytic Syntheses → Chemicals

Challenges

- **High cost**
  - Operation (cost of power and eventually CO_2, conversion losses)
  - Capital investment (complex processes, limited number of full load hours)
- **Large volumes**
  - High power demand (renewable!)
  - International dimension (complex project structures)
  - High capital requirement and high financial risk (political stability)
- **Market introduction needs suitable regulatory boundary conditions and incentives for enabling successful business cases**
  - Pricing of fossil CO_2 emissions
  - Quota for admixing of PtX products, betterment in taxation, guaranteed prices for a given volume over a certain time, eventually increasing gradually with market ramp-up, etc.

Which products and where?

Fuels

- Primarily drop-in qualities of kerosene, diesel and gasoline in order to make continued use of existing infrastructures (distribution, storage, utilisation) and to reduce the CO_2 emissions quickly by admixing increasing amounts of PtL fuels over time („existing fleet“); Main routes are:
  - Fischer Tropsch (FT) synthesis followed by refinery processes such as hydrocracking, isomerisation, hydrogenation
  - Methanol synthesis followed by conversion into fuels via methanol to gasoline, kerosene, diesel
- As a perspective, methane, methanol or dimethyl ether (eventually also oxymethylene ether), ammonia (for combustion), or hydrogen (for FCEV) as alternatives to diesel for heavy duty transport (requires new infrastructures and power train technologies)

Chemical energy carriers

- Basic products which can serve as starting materials for chemical valorisation chains (hydrogen, synthesis gas, methanol, ethanol, hydrocarbons, higher alcohols, olefins, etc.)

Large dedicated plants in sweet spots versus agile and flexible modular PtX solutions for decentralised production

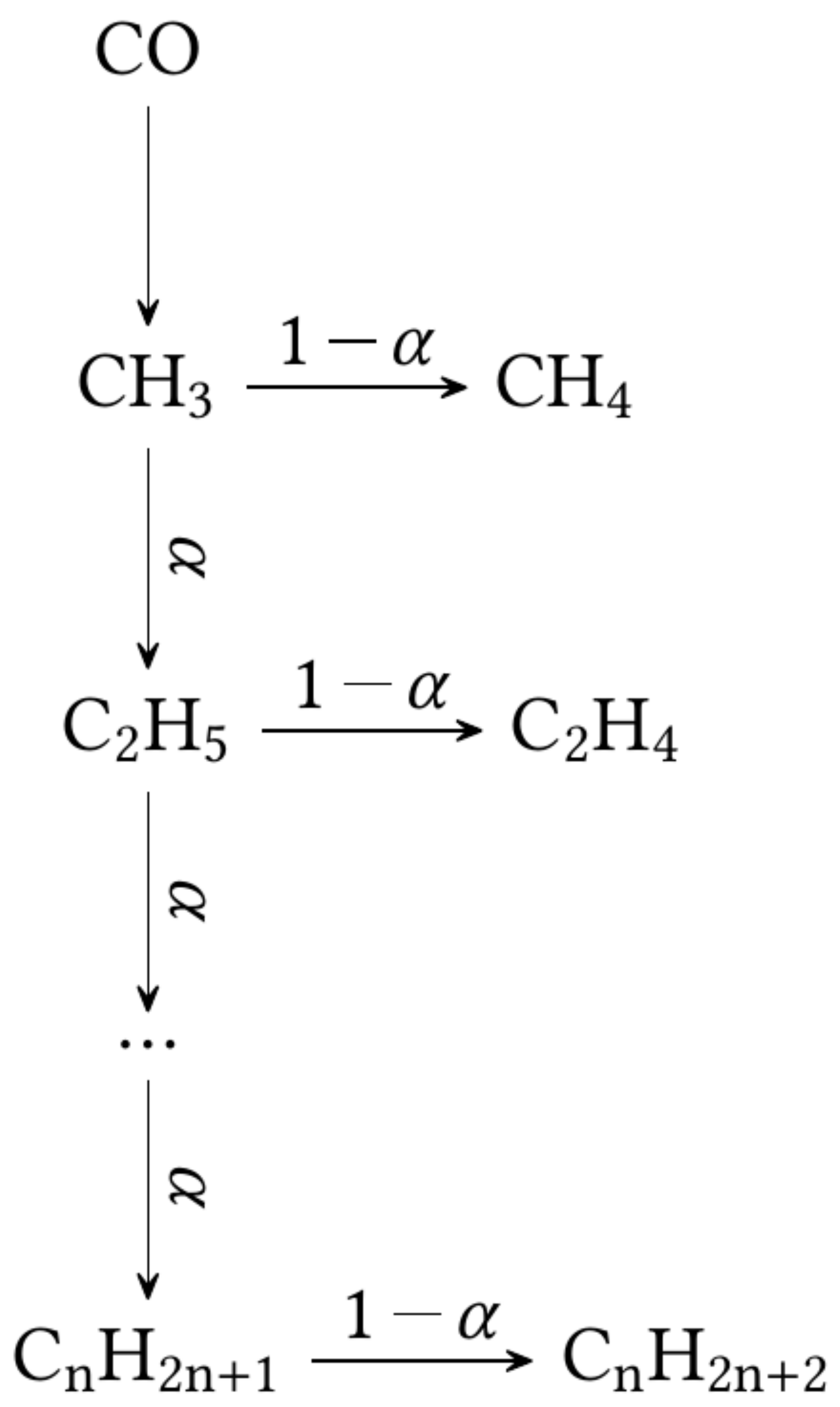
- Sweet spots: What should be imported? Renewable electrical energy, hydrogen, methanol / FT crude, finished e-fuels?
- Other questions: Cost and availability of renewable electrical energy, water, and CO_2, options for integration with existing infrastructures (industrial plants as point CO_2 sources, energy grids, pipelines, harbours, refineries), economic, social and ecological environment, perspectives for economic development and value creation, etc.

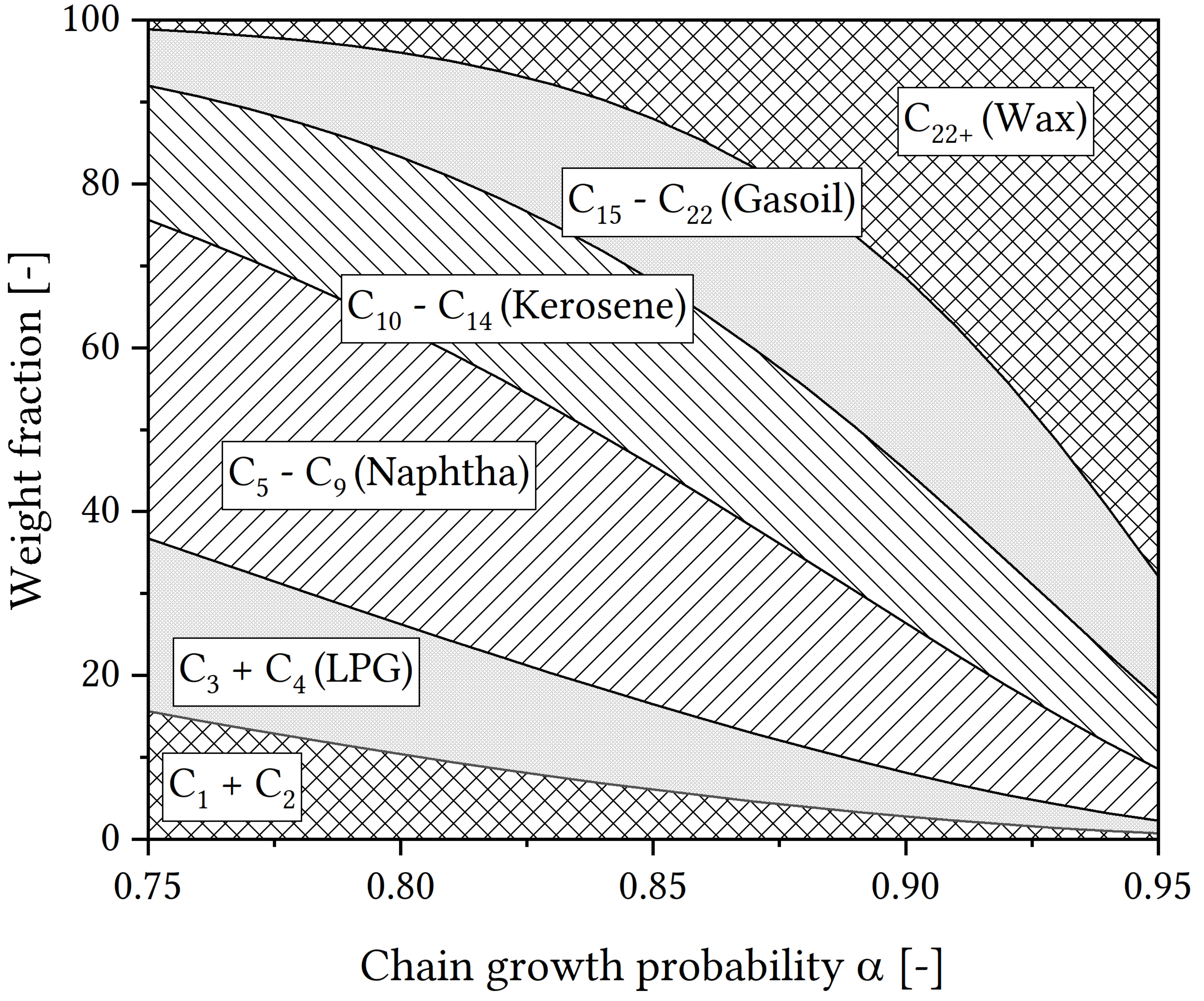
Synthetic fuels via low temperature Fischer-Tropsch (FT) Synthesis

Overall FTS reaction:

$$nCO + 2nH_2 \rightarrow -(CH_2)_n- + nH_2O \qquad \Delta H_R = -158\, kJ / mol_{CO}$$

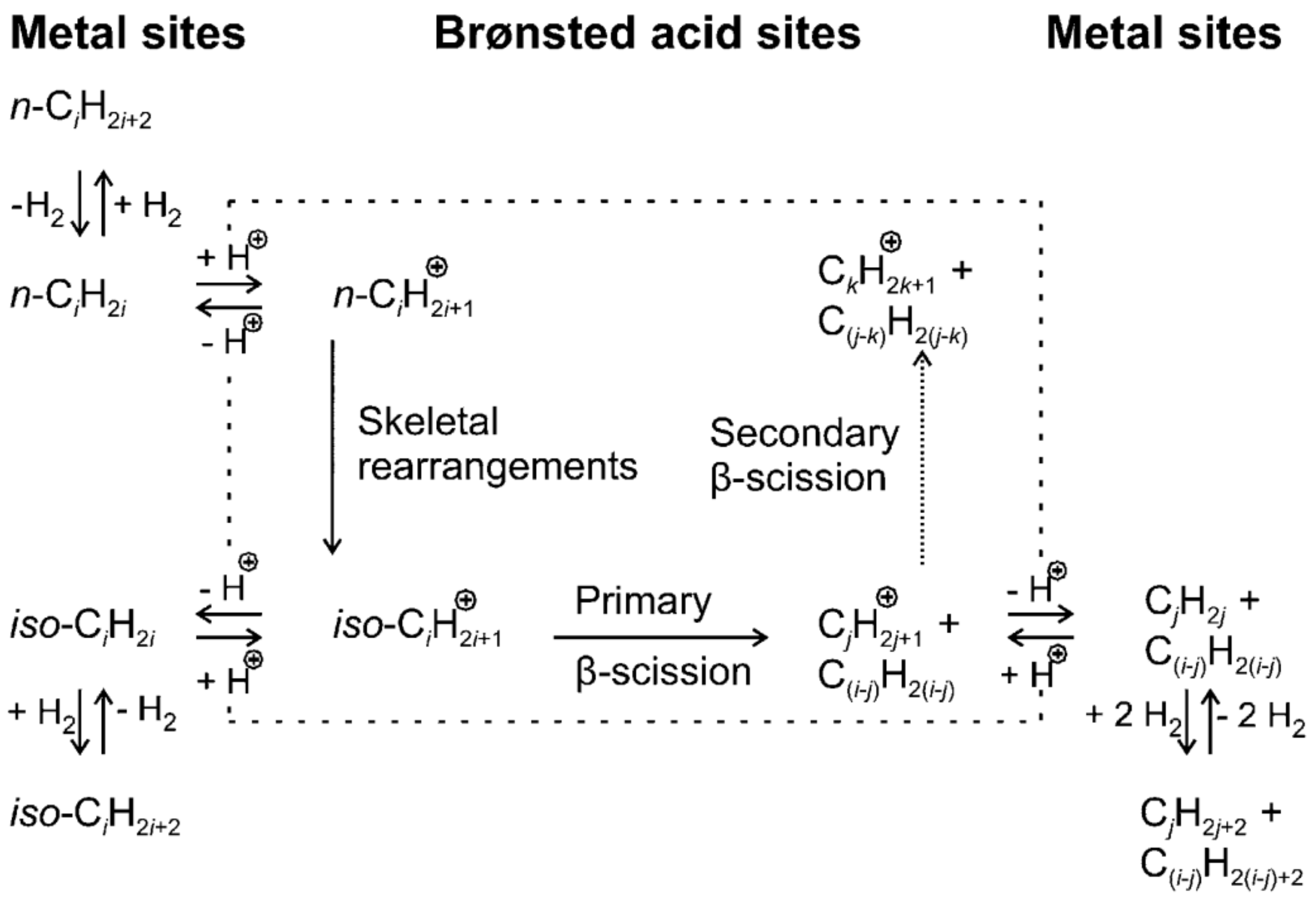
FTS chain growth mechanism:





$$\alpha = f(catalyst, T, p, etc.)$$

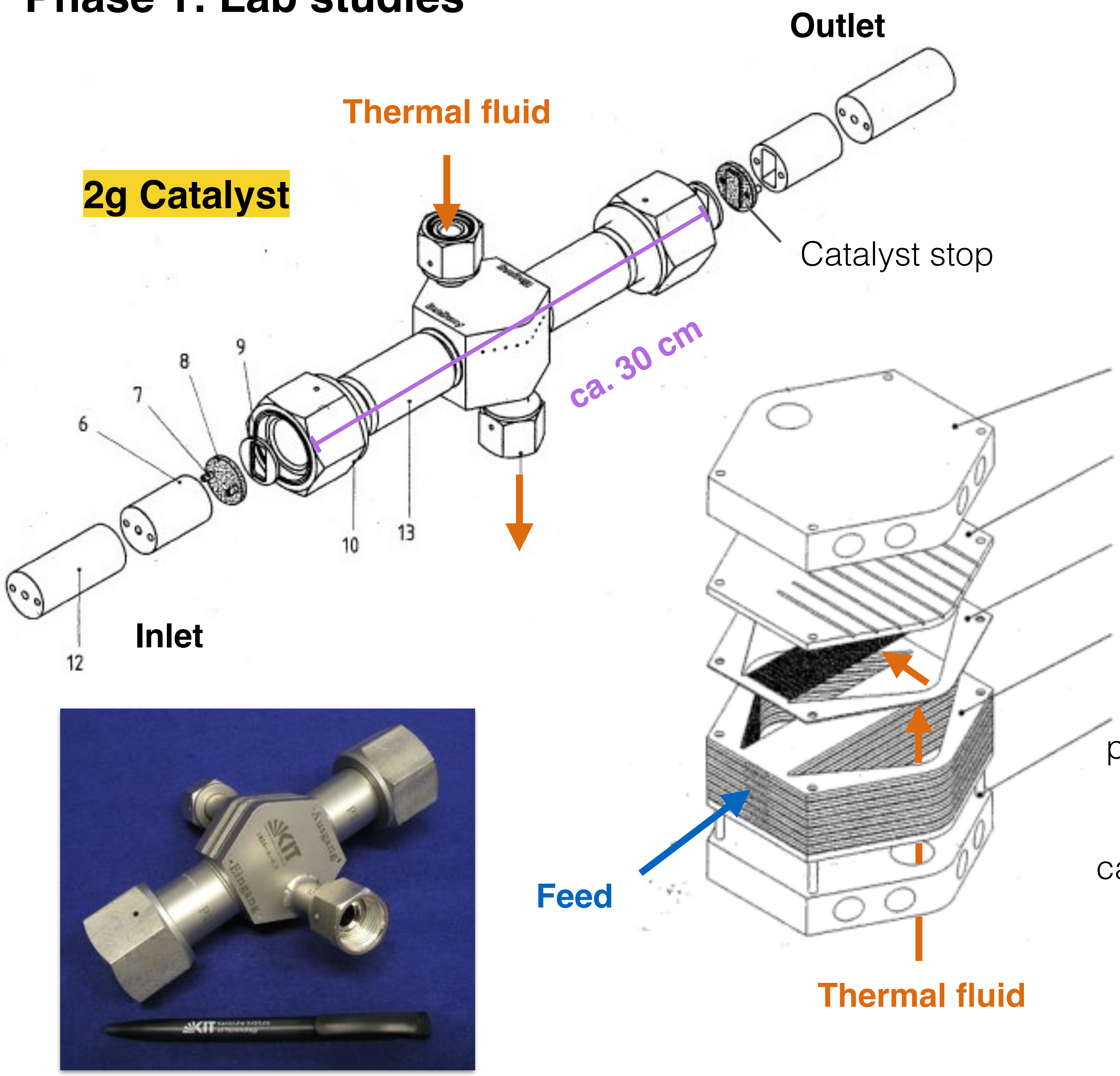
Hydroprocessing (bifunctional catalysts):



J. Weitkamp, *ChemCatChem* 4, **2012**, 292-306

Microstructured reactors - key technology for gas conversion in PtX

Phase 1: Lab studies



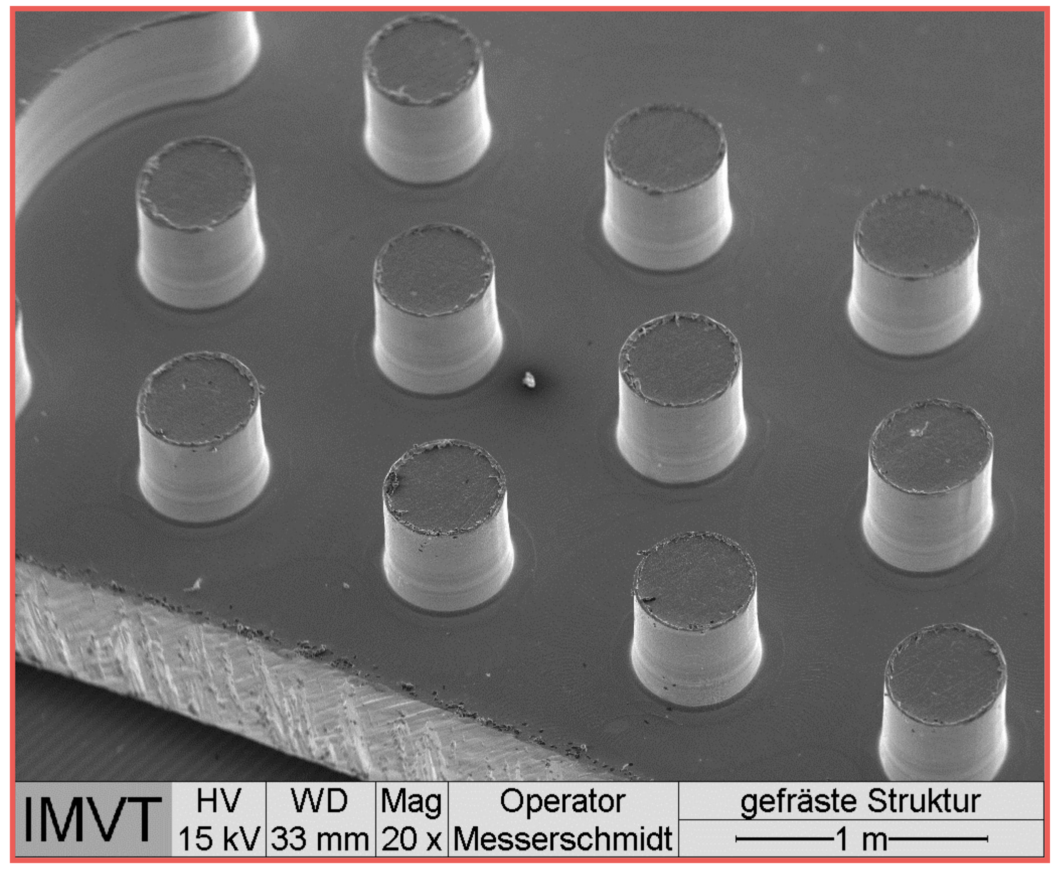
1 Cover plate with optional heating cartridges

4 Slits for thermo-couples

3 Cooling plates

2 Catalyst plate

5 Cover plate with optional heating cartridges



see also: Myrstad et al., *Catal. Today* **2009**, *147*, 301-304.

Productivity and Space-Time-Yield

	Productivity (C_{5+} per catalyst mass)	Productivity (C_{5+} per reactor mass)	Space-Time-Yield (C_{5+} per reactor volume)
KIT (IMVT)	2.1 g/gh	16.7 bpd/t	1785 kg/m^{3}h
velocys	-	13 bpd/t [1]	1600 kg/m^{3}h [1]
Oryx GTL - Sasol	-	8 bpd/t [2]	20.6 kg/m^{3}h [1]
Literatur	1.4 - 2 g/gh [3]	-	-

1) S. LeViness, FT Product Manager, Presentation "Velocys Fischer-Tropsch Synthesis Technology – Comparison to Conventional FT Technologies", AIChE Spring Meeting, San Antonio, Texas/USA (30-Apr-2013)

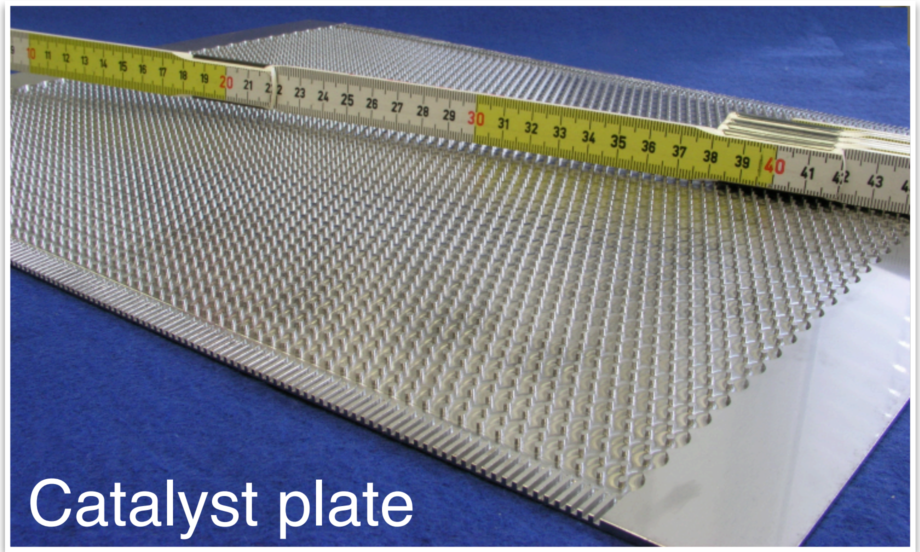
2) "2012 Interim Results", Presentation to analysts of the Oxford Catalysts Group 2012, www.velocys.com

3) C.H. Bartholomew, B. Young, History of Cobalt Catalyst Design for Fischer-Tropsch Synthesis, NGCS, Doha 2013

Microstructured reactors - key technology for gas conversion in PtX

Phase 2: Validation and Scale-up

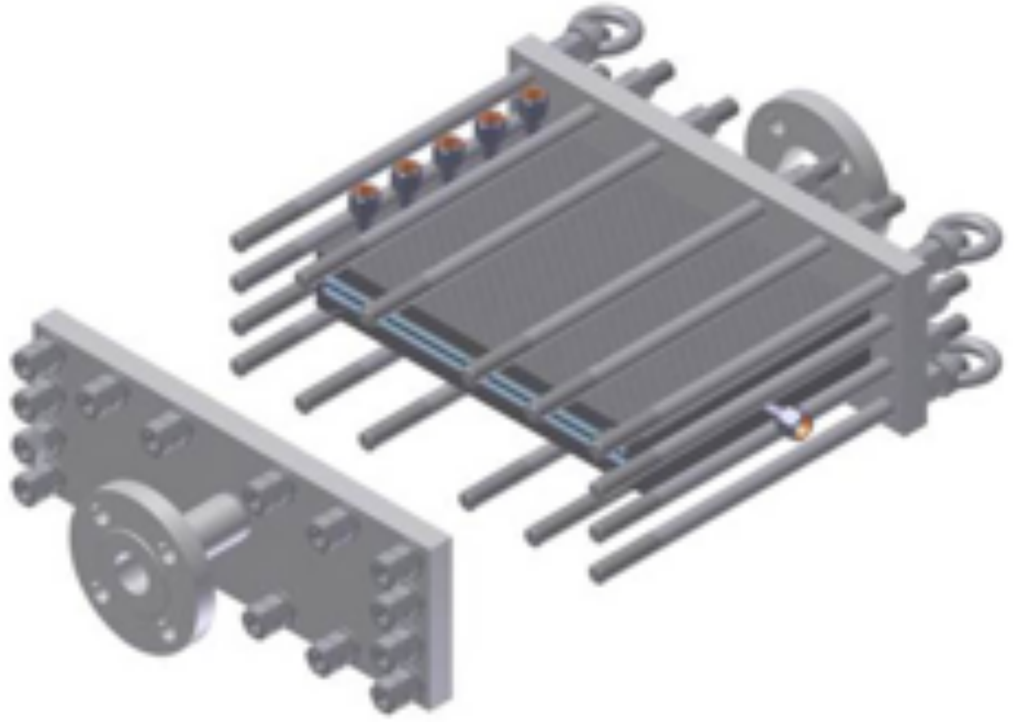
IMVT / INERATEC

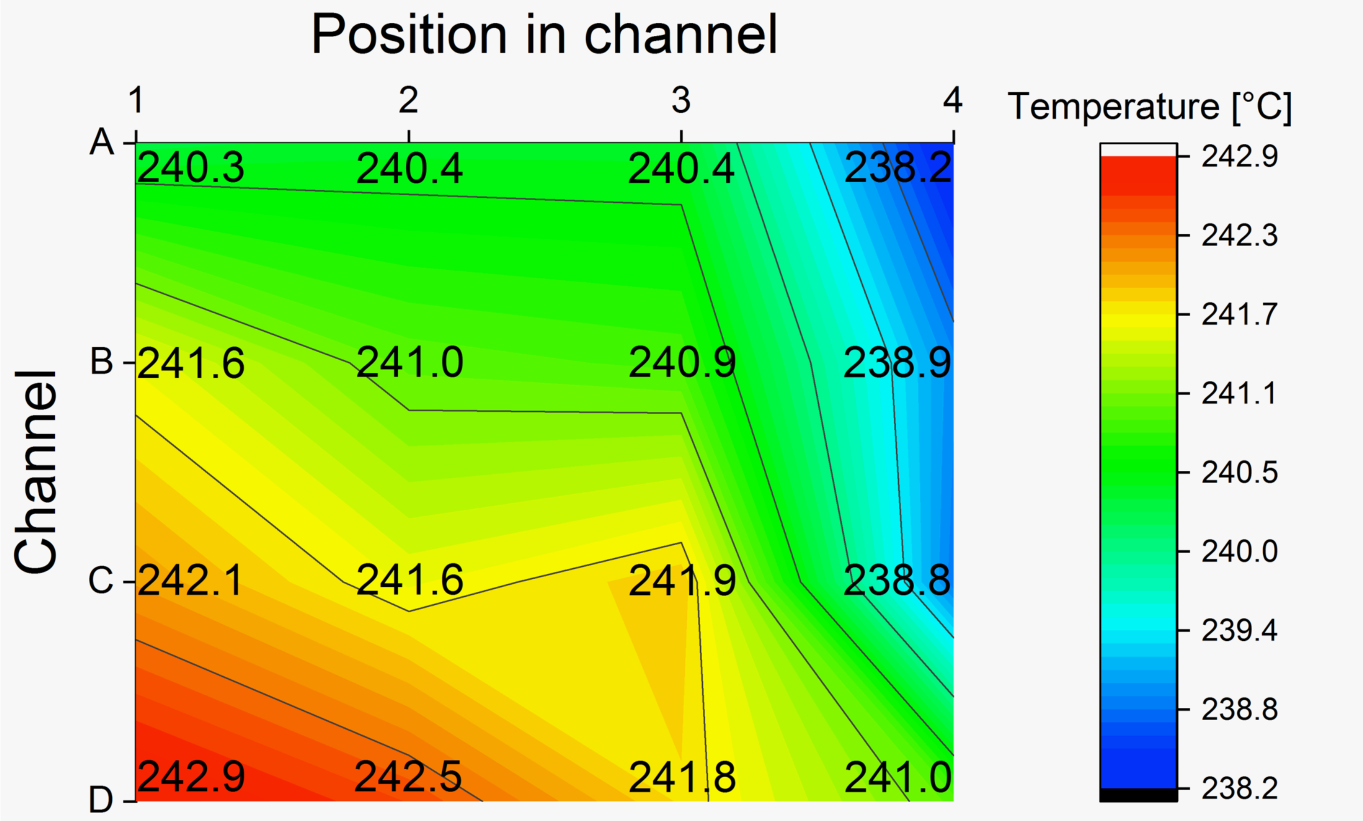


Catalyst is applied as powder(50 - 200 µm) and is not diluted with inerts

- Cooling by closed water/steam-cycle (20-40 bar)
- 30-40 l/min Synthesis gas
- 5 kg/d FT Products

120 g Catalyst

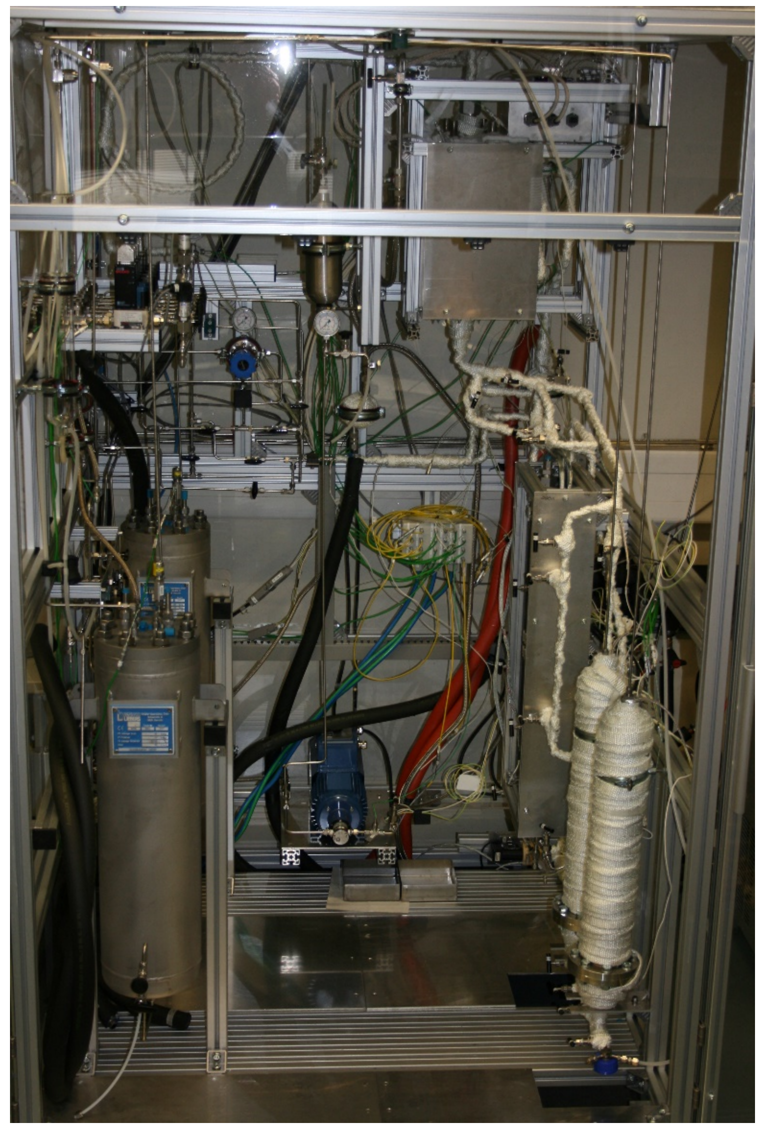




see also: www.ineratec.com

R. Dittmeyer et al., *Curr. Opin. Chem. Eng.* **2017**, *17*, 108-125. doi:10.1016/j.coche.2017.08.001

Process development



FTS - HC Pilot plant

FTS Pilot plant

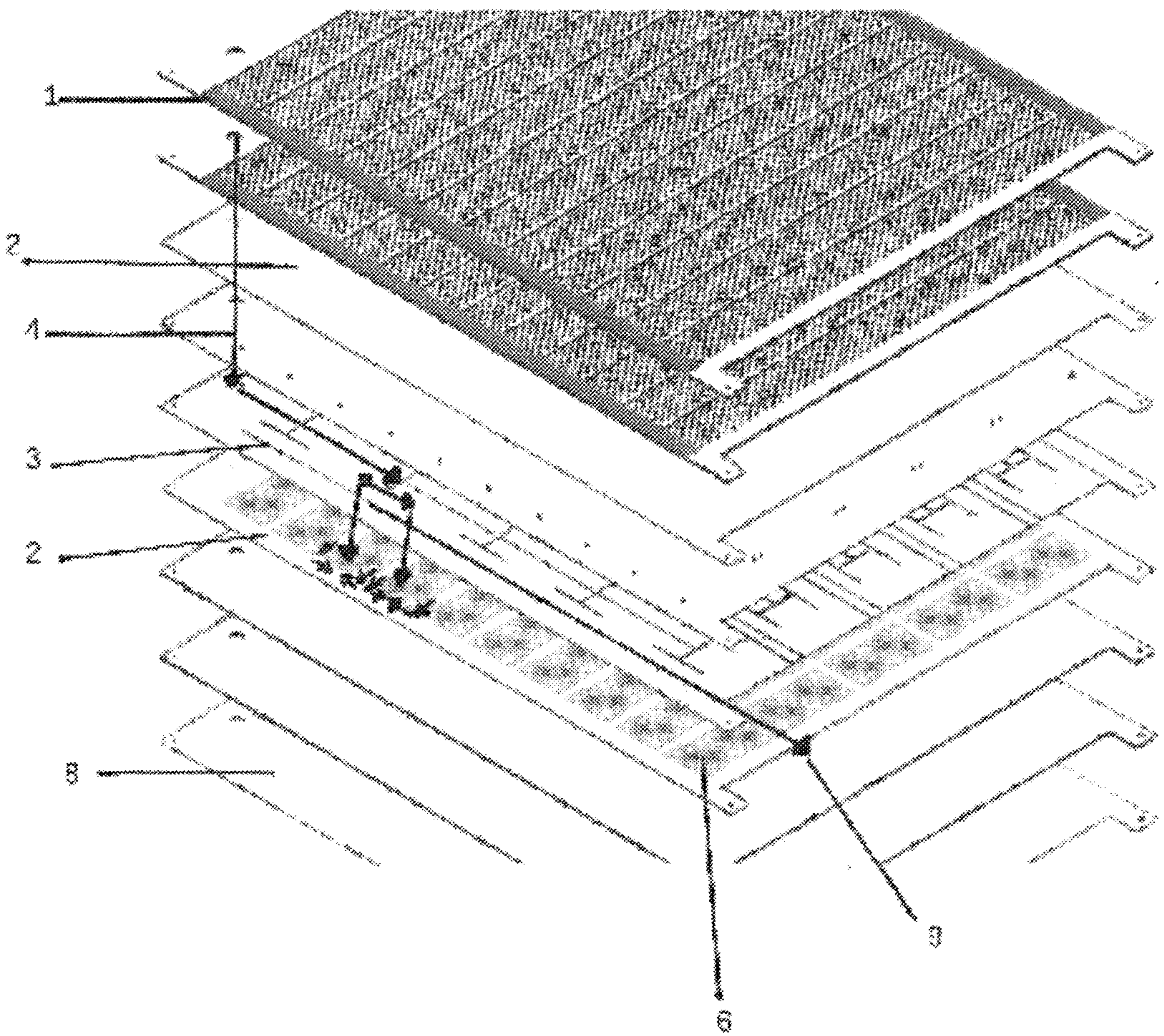
RWGS Pilot plant

Complete process chain from CO_2 to synthetic fuel (5 kg per day)

Combustion tests performed at DLR Stuttgart

Design principle of the evaporation-cooled microreactor

Basic stacking scheme



2 stacked reaction sheets (packed bed)

cooling sheet

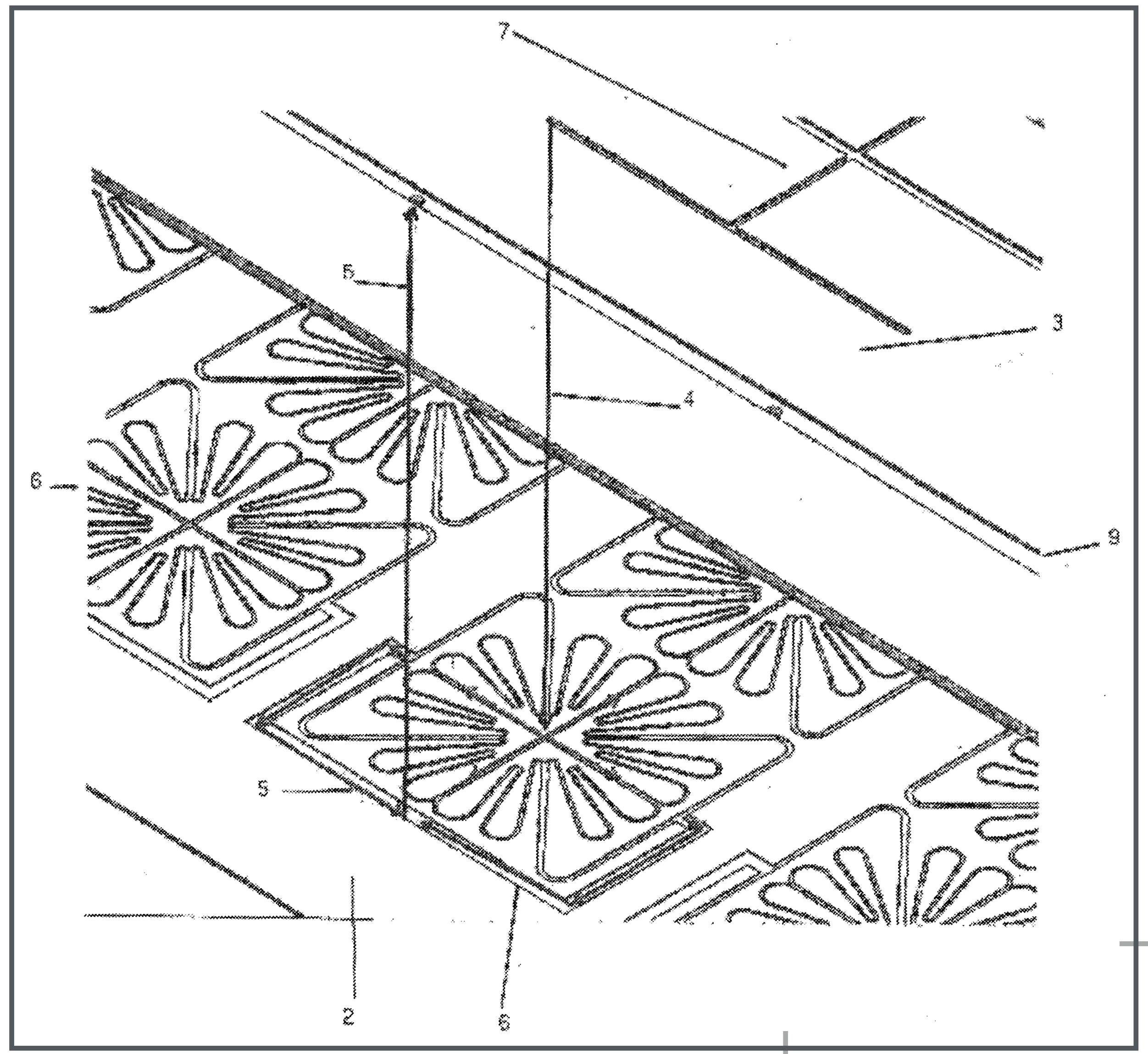
2 stacked coolant distribution sheets

cooling sheet

2 stacked reaction sheets

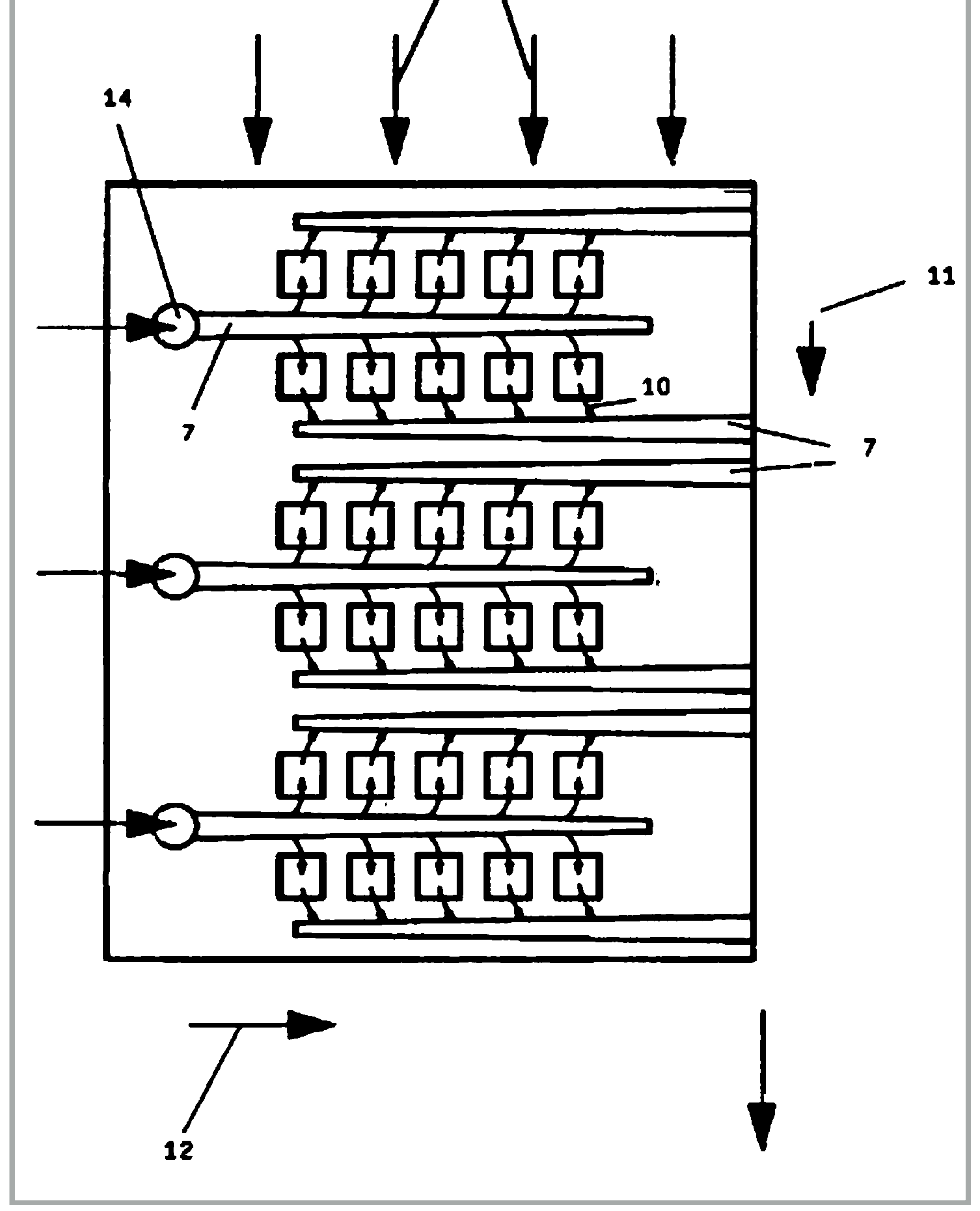
termination sheet

P. Pfeifer, P. Piermartini, A. Wenka, **2017**, *DE 10 2015 111 614 A1*



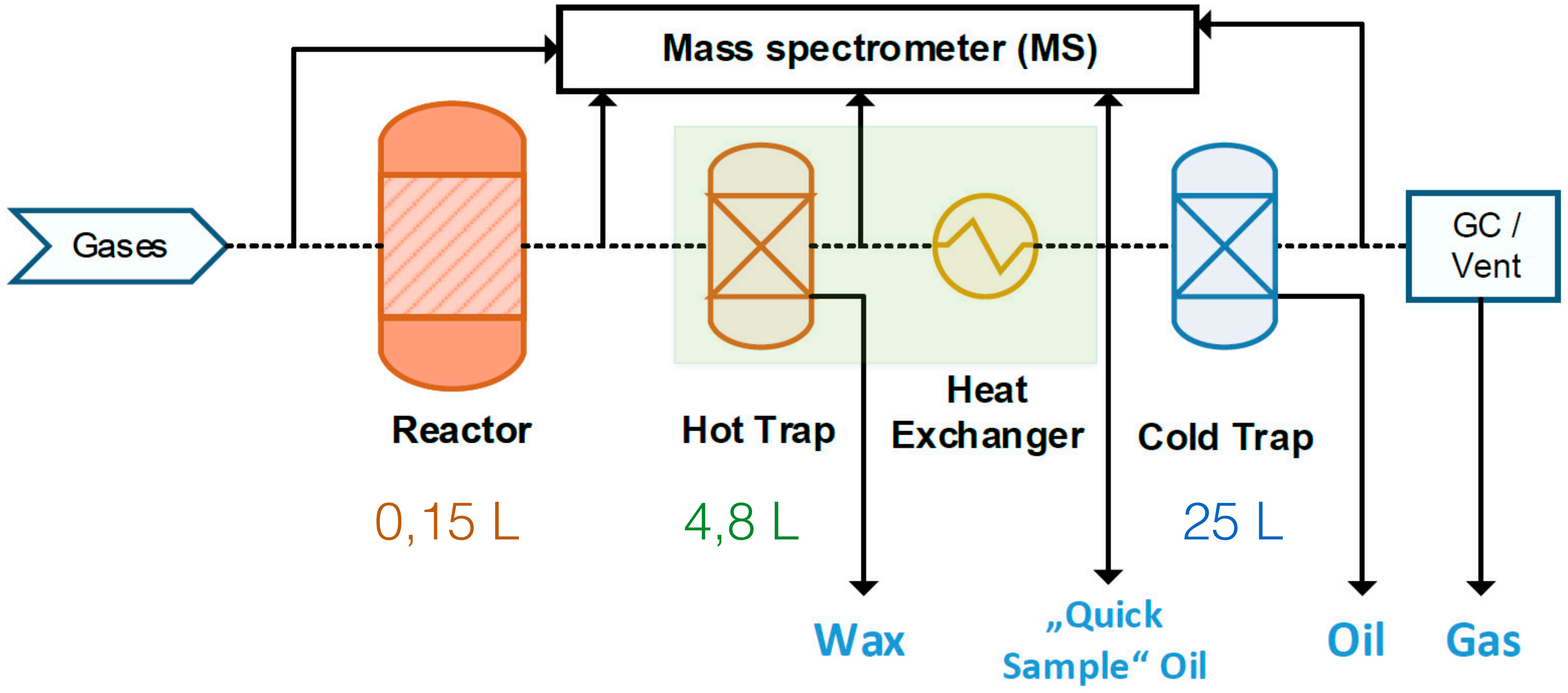
Detail of evaporation section

Arrangement of reactant and coolant flows in the stack



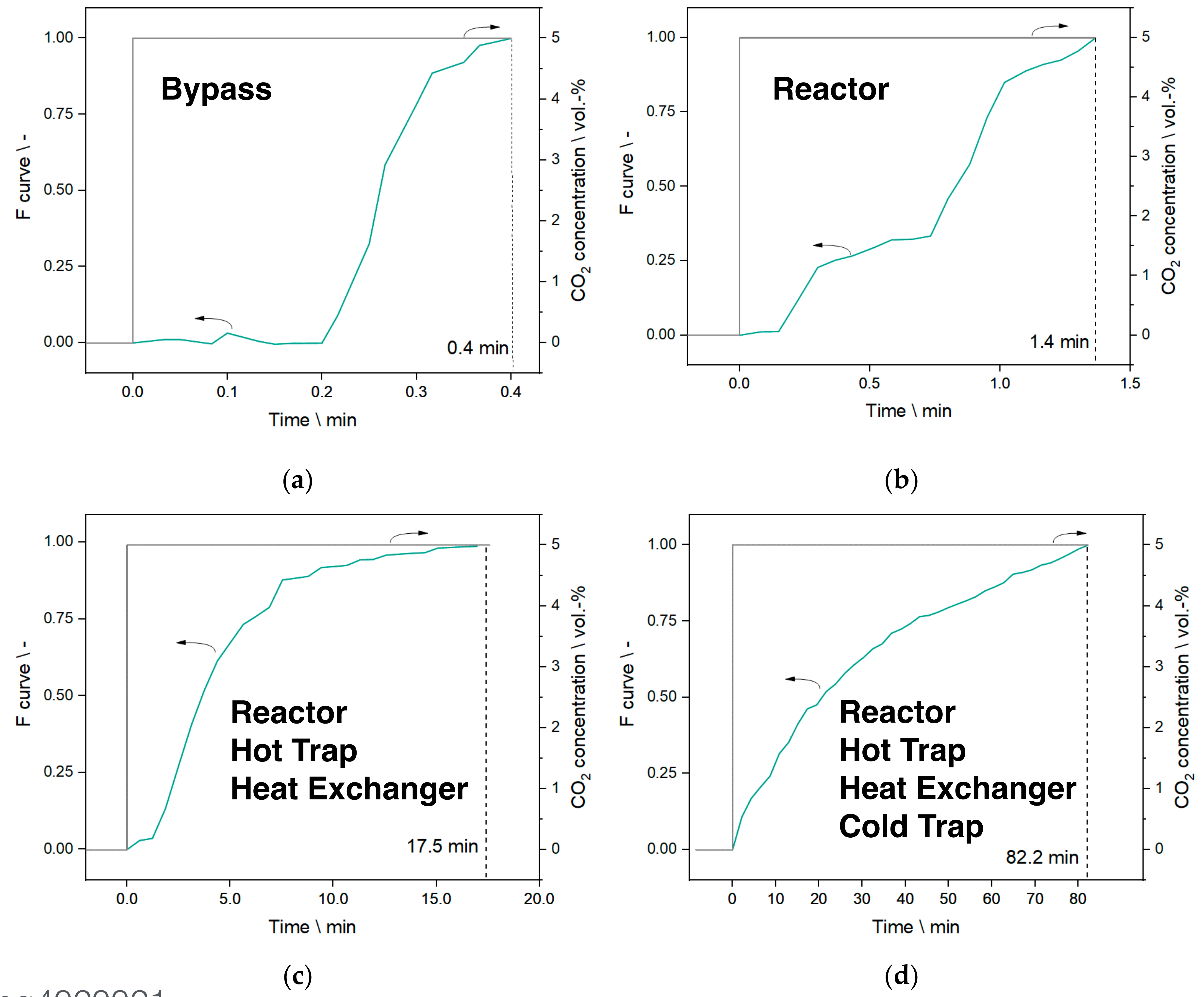
Studies on transient operation of the bench-scale FTS unit

Lab setup



Dissertation
Marcel Löwert,
KIT, 2021

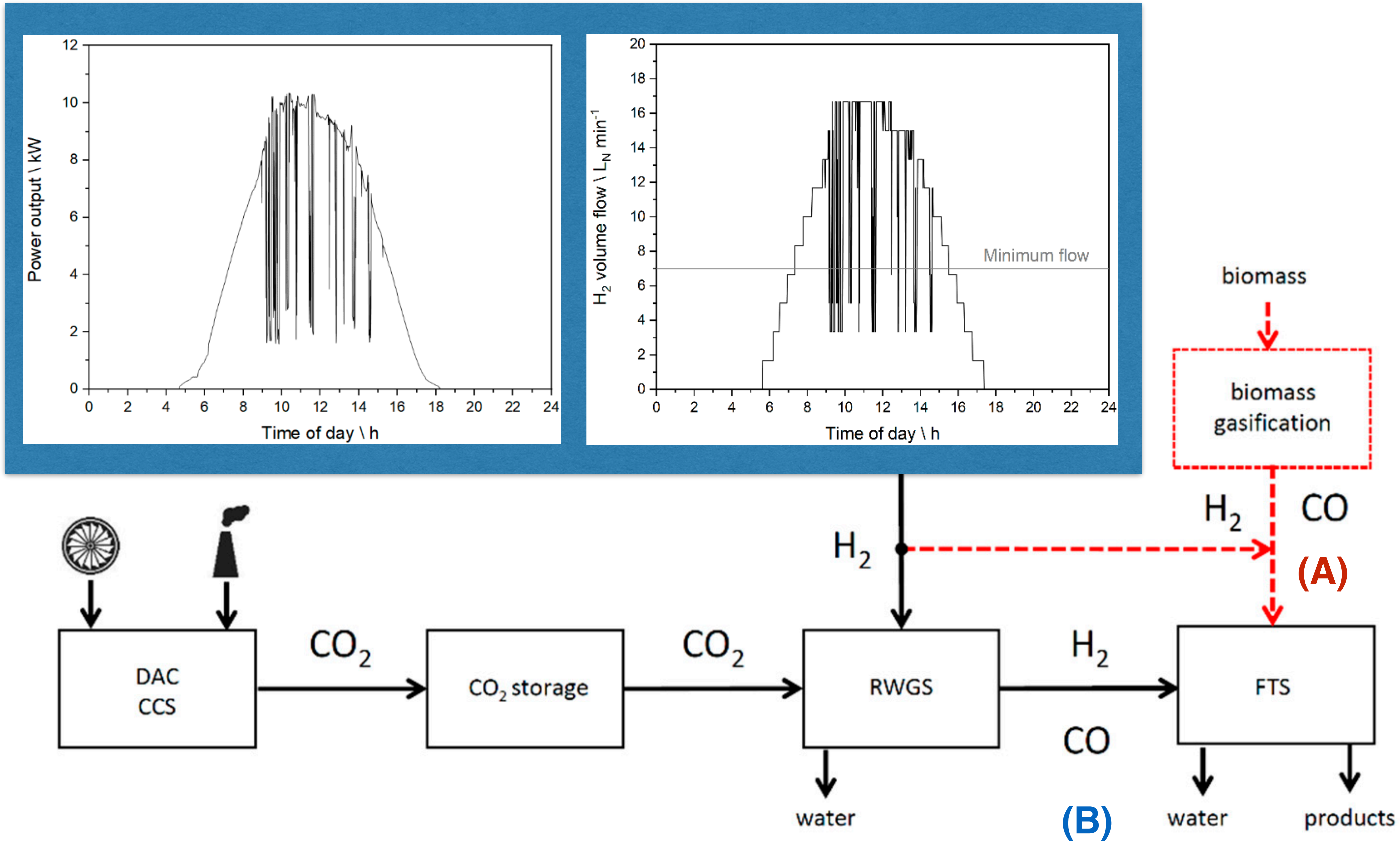
RTD in non-reactive mode - F curves

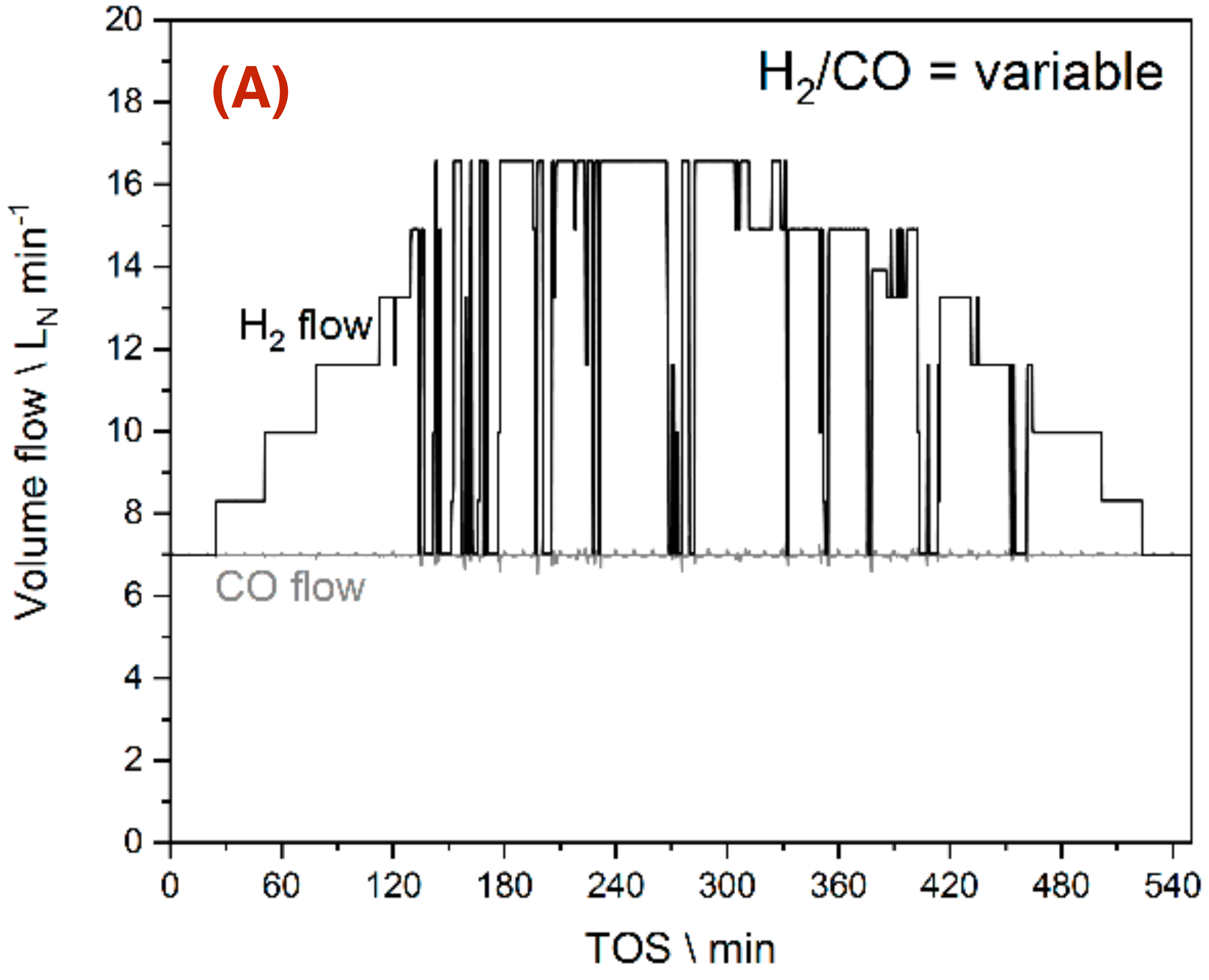


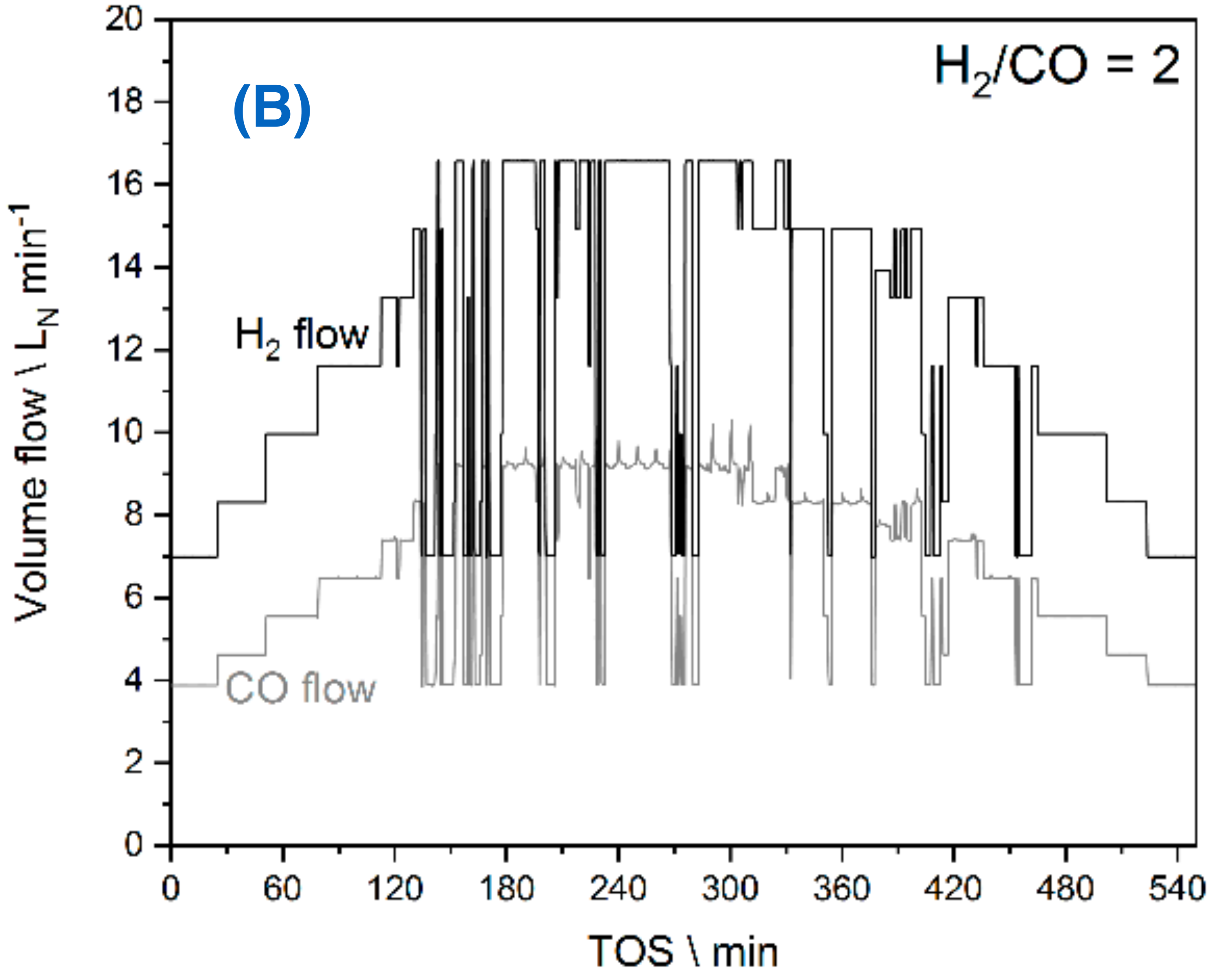
M. Löwert, P. Pfeifer, *ChemEngineering* **2020**, *4*, 21; doi:10.3390/chemengineering4020021

Transient operation of the bench-scale FTS unit

Transient operation assuming a H_2 generation profile determined by fluctuating power from PV for electrolysis





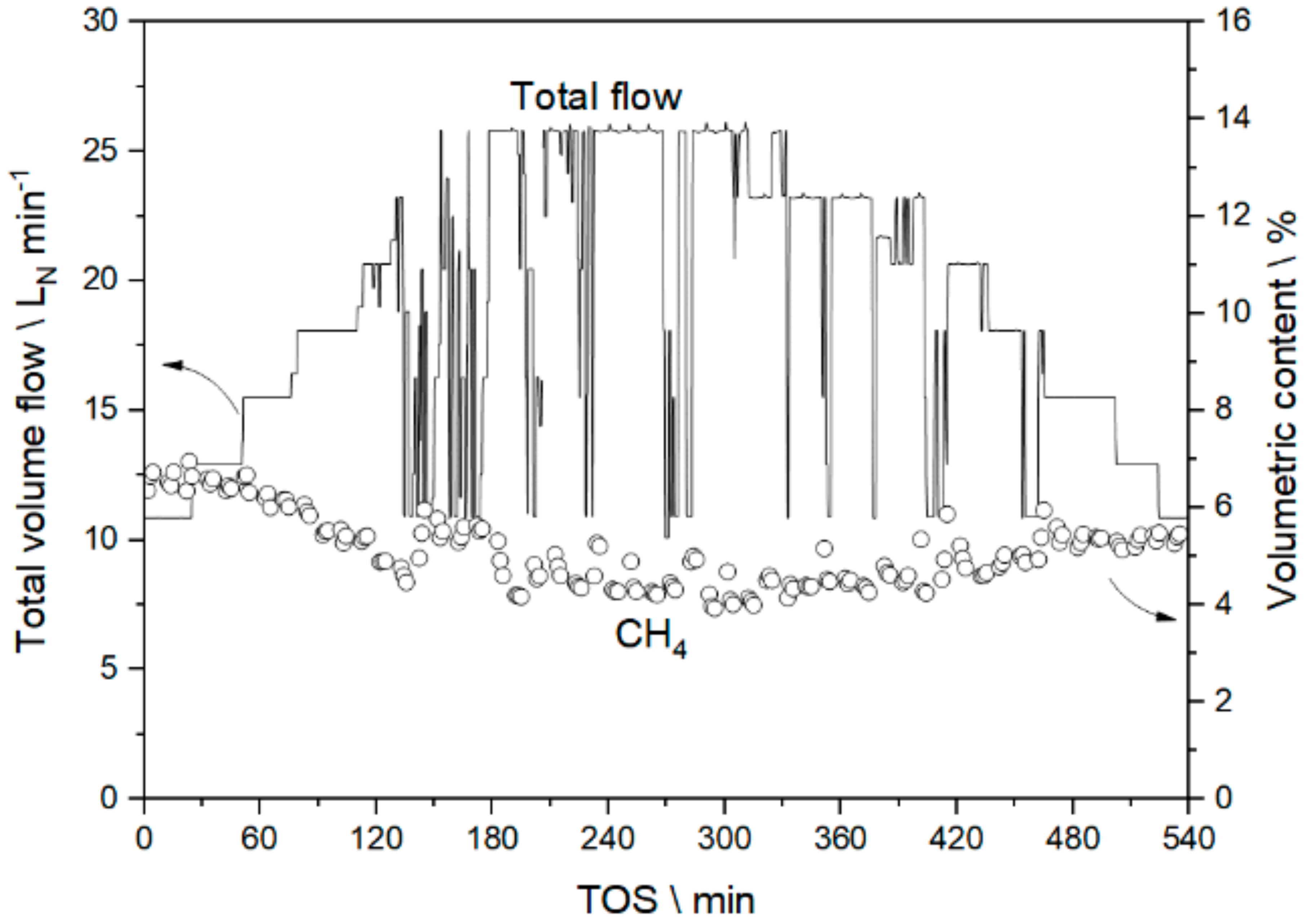


M. Löwert, M. Riedinger, P. Pfeifer, *ChemEngineering* **2020**, *4*, 27; doi:10.3390/chemengineering4020027

Transient operation of the bench-scale FTS unit

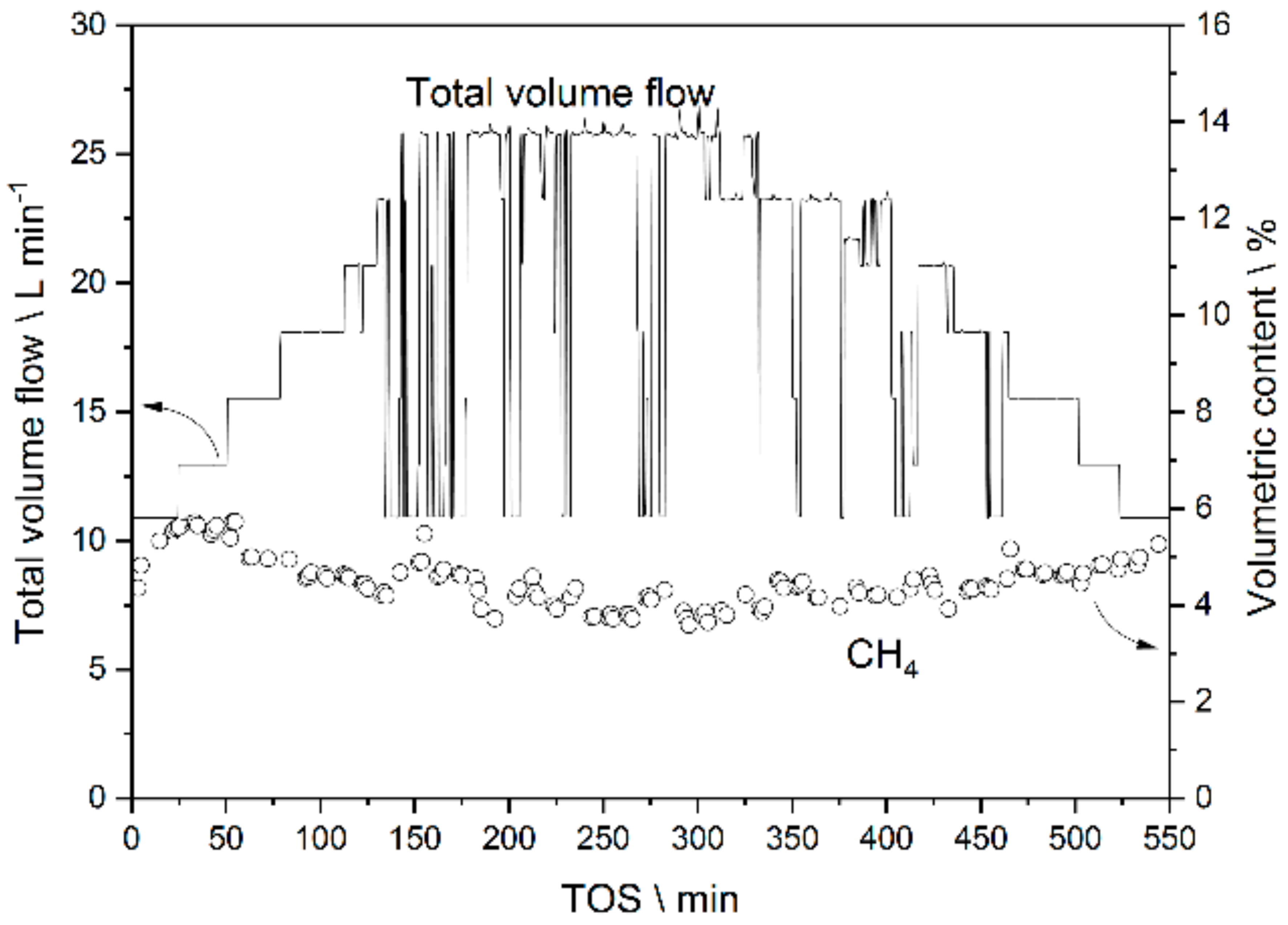
System response - case (B) with and without adjusted temperature for maintaining constant conversion

Reactor temperature varies depending of flow rate



Varying H_2 conversion

Reactor temperature was adjusted by setting the coolant pressure / temperature as to reach a conversion of 70% despite varying flow rate (interpolation of kinetic data)



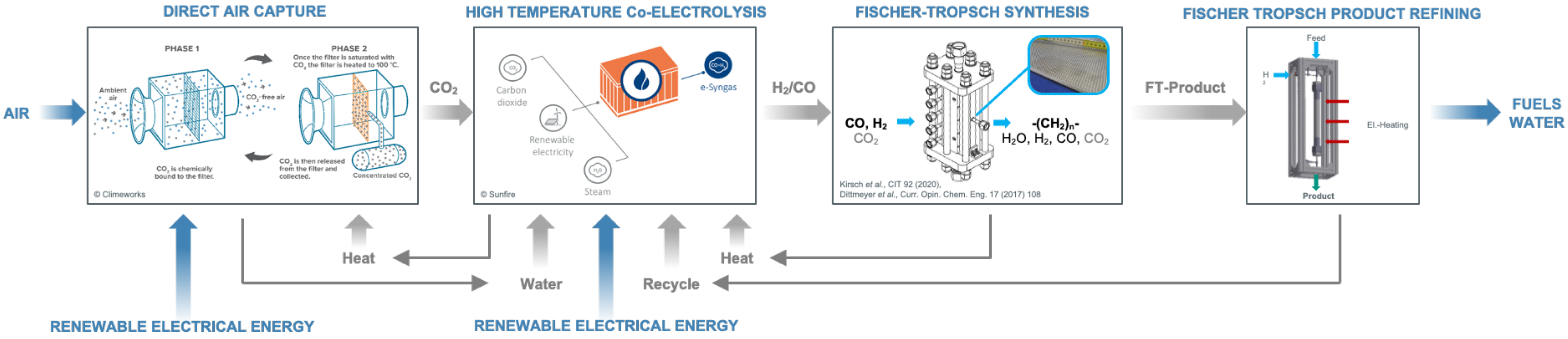
H_2 conversion 70%

M. Löwert, M. Riedinger, P. Pfeifer, *ChemEngineering* **2020**, *4*, 27; doi:10.3390/chemengineering4020027

Process integration for increased efficiency and reduced cost

Copernicus project P2X - Integrated plant for fuel synthesis from carbon dioxide from thin air

High efficiency through process integration; compact design of the synthesis unit enabled by micro process engineering; modular plant concept scalable over a wide range of capacity

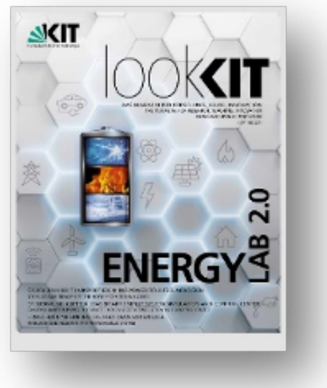


Funded partners:

Associated partners:
Audi AG, AVL List GmbH, Ford Werke GmbH, Volkswagen AG,
DB Energie GmbH, International Association for Systainable Aviation IASA e.V.

Copernicus project P2X - Scope of Phase II (2019-2022)

- Development of an optimized MW-qualified DAC unit for coupling with co-electrolysis SOEC and FT synthesis
- Development and manufacturing of a 250 kWel co-SOEC system for coupling with DAC and FT synthesis
- Reactor design optimisation for FT synthesis
- Modular technologies for FT product upgrading
- Integration of the DAC and co-SOEC systems into the Energy Lab 2.0
- Process synthesis and analysis
- Proposal for further scale-up to 1-2 MW for Phase III

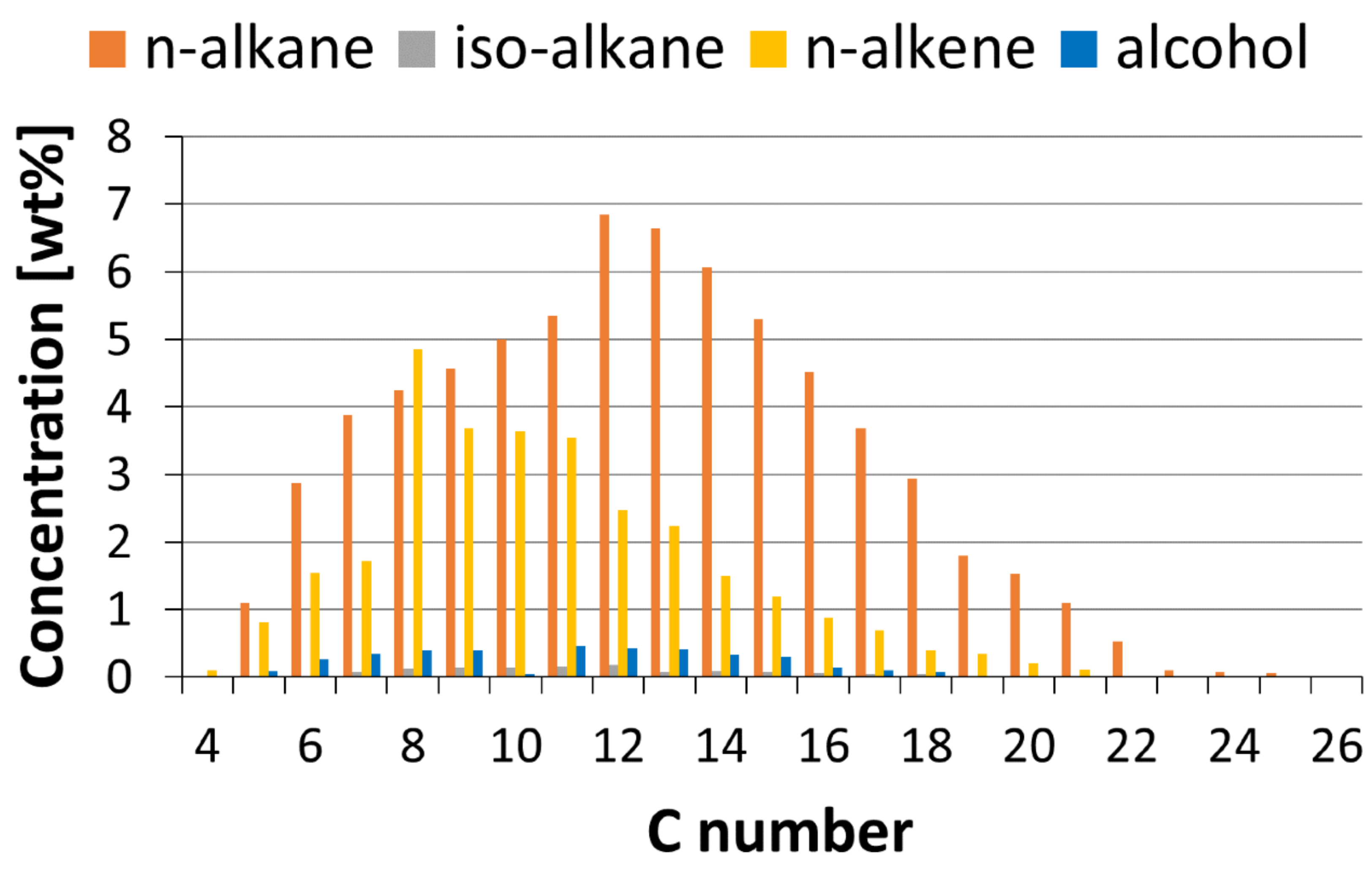


pdf download, 18 MB

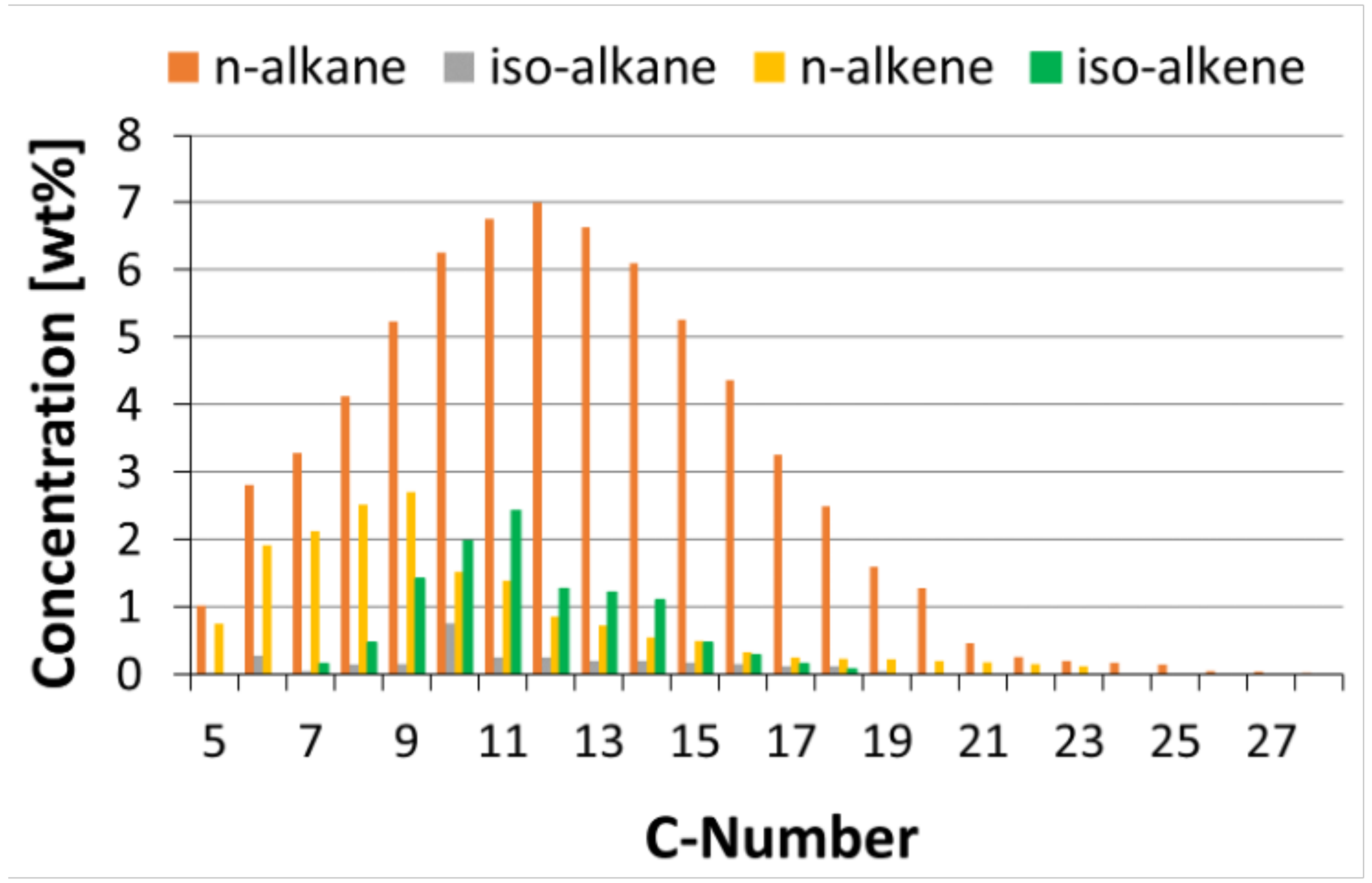
Photo: M. Breig / A. Bramsiepe

Copernicus project P2X - Scope of Phase II (2019-2022)

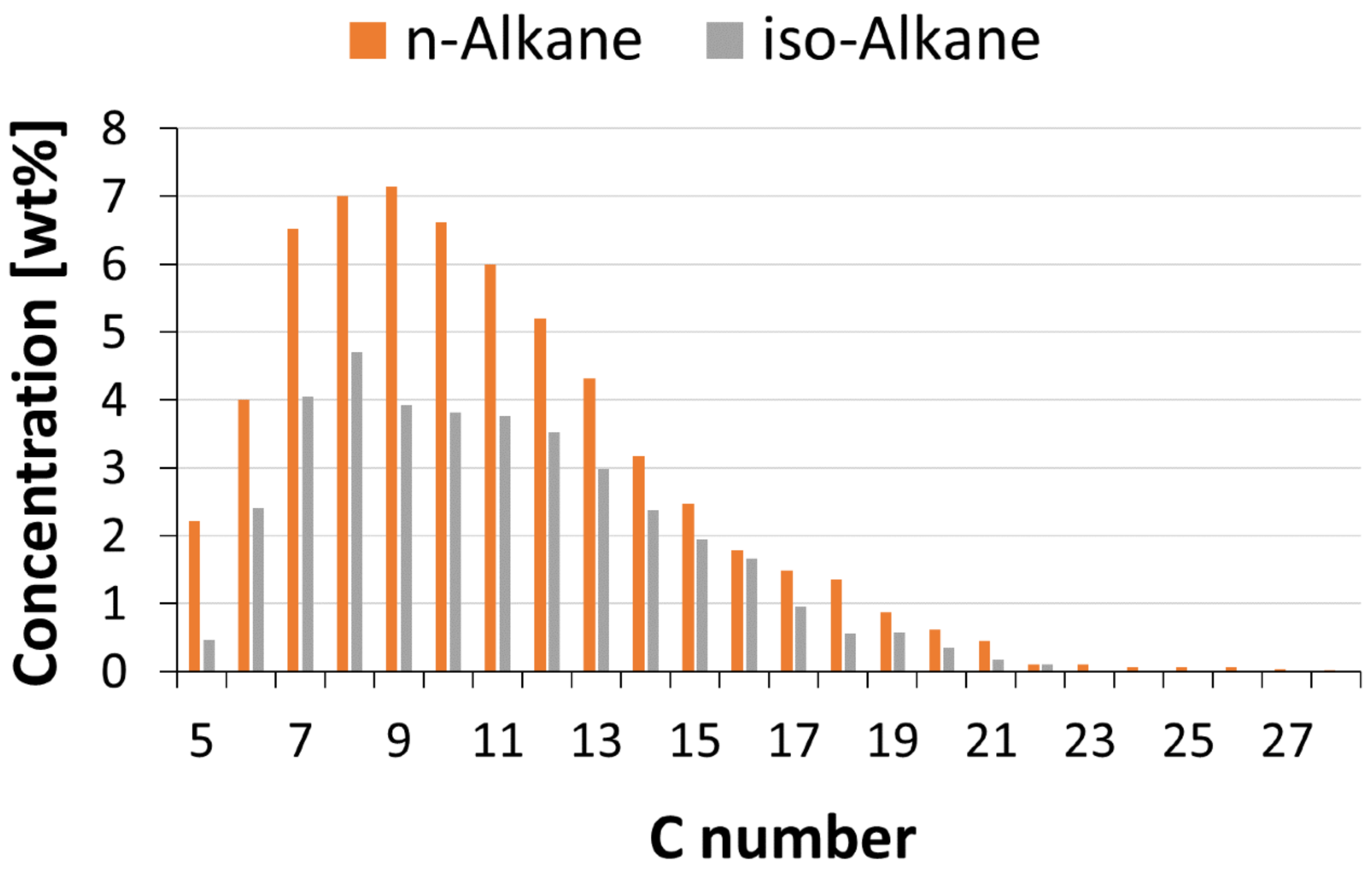
Fischer-Tropsch product upgrading: Kerosene, Diesel, Gasoline



Oil (FT-HC)



Oil (FT-HC-HT)



- Contains alcohols
- High alkene content (up to 1/3)
- Low *iso*-alkane content
- Wide carbon number range

- No more alcohols
- *n* and *iso*-alkenes
- *iso*-alkanes still low
- Wide carbon number range

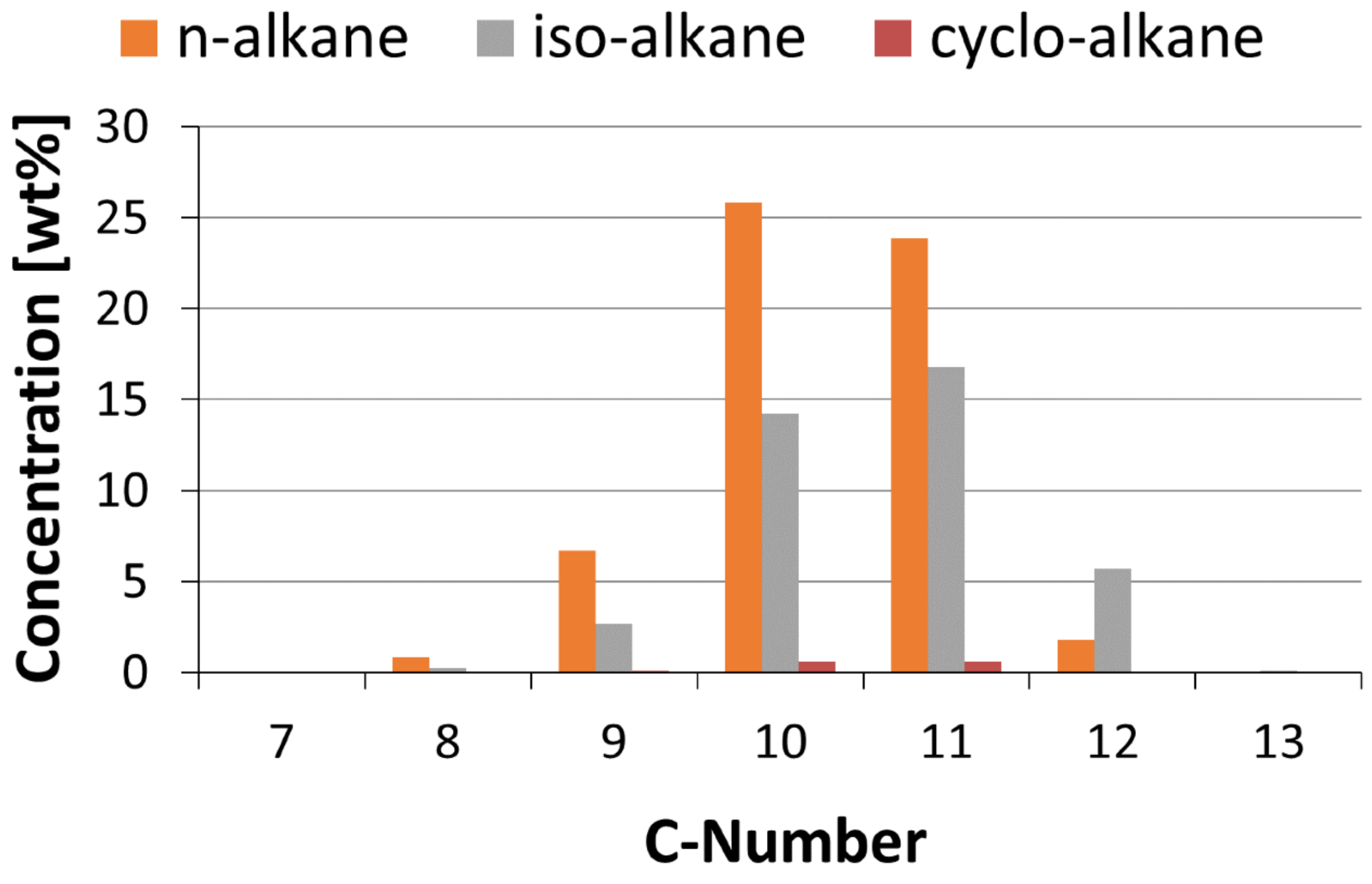
- **no** alcohols
- **no** alkenes
- **high** *i*-alkane content (ca. 38 %)

- Carbon number range still too wide

→ **Distillation**

Copernicus project P2X - Scope of Phase II (2019-2022)

Kerosene Fraction (165-205°C)



- Falls in the desired kerosene cut (maximum at C_{10})
- ca. 40% *iso* alkanes; *cyclo* alkanes represent a contamination from distillation
- T90 - T10 outside allowed range (17,3 < 22 °C)
- Acid number too high (0,017 > 0,015 mgKOH/g)

Specification	Method	Value	Target value (ASTM D7566)	Unit
Water content	ASTM D6304-16e1	27	≤75	mg/kg
Nitrogen	ASTM D4629-17	0,3	-	mg/kg
Lubricity	ASTM D5001-10	0,57	≤0,85	mm
Electrical conductivity	ASTM D2624-15	30	-	pS/m
Microseparometer	ASTM D3948-14	96	≥85	Rating
Existent gum	ASTM D 381-12	1	≤7	mg/100ml
Thermal Stability 325 °C	ASTM D 3241-18	0	≤25	mmHg
Corrosion - Copper strip (2h at 100°C)	ASTM D130-18	1b	1	Rating
Smoke Point	ASTM D1322-19	25,6	≥25	mm
Net heat of combustion	ASTM D3338-09e2	44,22	≥42,8	MJ/kg
Viscosity (-20 °C)	ASTM D7042-16e3	2,88	≤8	mm^2/s
Freezing point	ASTM D2386-18	-48	-40	°C
Flash point	ASTM D3828-16a-B	54,5	38	°C
Sulfur content	ASTM 5453-19a ASTM 2622-16	<1,0	15	mg/kg
Mercaptanschwefel	ASTM D3227-16	<0,0003	0,003	ma%
Density (15 °C)	ASTM D4052-18a	741,4	730 - 770	kg/m^3
Distillation	-	-	-	-
10 % recovered	ASTM D86-18	172,1	205	°C
50 % recovered	ASTM D86-18	178,3	report	°C
90 % recovered	ASTM D86-18	189,4	report	°C
Final boiling point	ASTM D86-18	202,8	300	°C
T90-T10	ASTM D86-18	17,3	≥22	°C
Distillation residue	ASTM D86-18	1	≤1,5	vol%
Distillation loss	ASTM D86-18	0,6	≤1,5	vol%
Acidity, total	ASTM D3242-11	0,017	≤0,015	mgKOH/g

→ **Adjust hydrotreating:** catalyst(s), process conditions

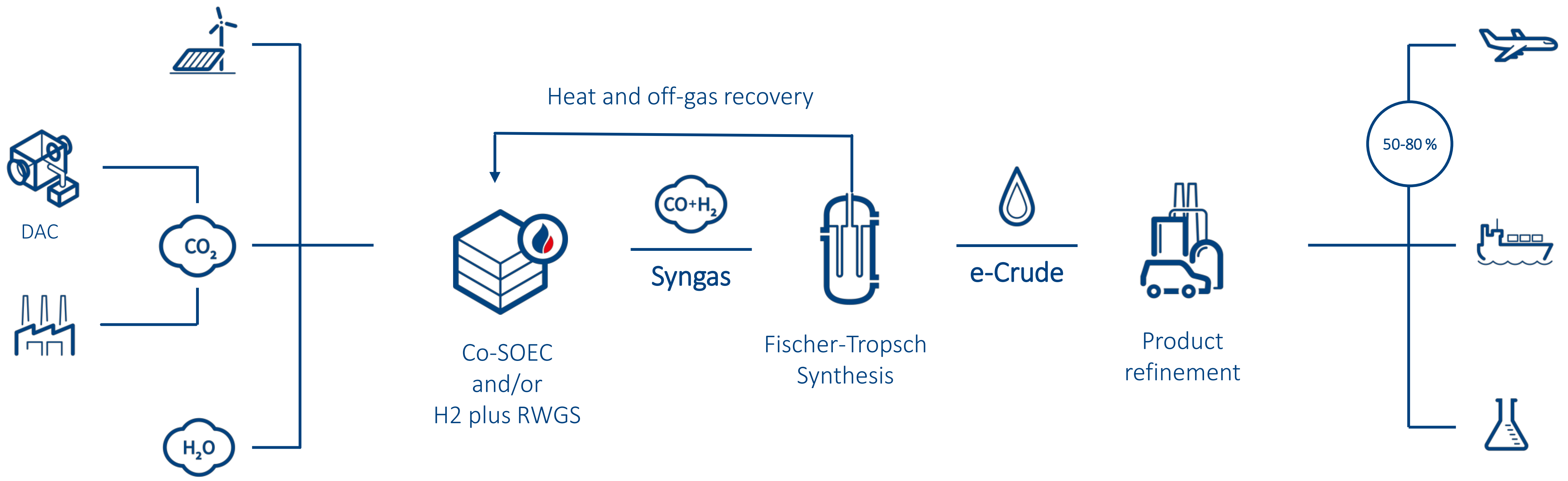
→ **Optimize distillation:** temperature window

Current Status at INERATEC - 1 MW PtL Plants (Werlte, Hamburg)

Inauguration at the EWE site in Werlte on October, 2021

First commercial plant for hydrogen based aviation fuel

- **Site:** Industry park Herøya, 150 km southwest of Oslo
- **Partners:** Sunfire GmbH, Dresden, Climeworks AG, Zürich, Paul Würth SA, Luxemburg, Valinor AS, Stabanker
- **Process:** DAC, Co-SOEC and FT-Synthesis; Upgrading in the Refinery; Utilisation of FT waste heat for Co-SOEC increases amount of FT-Crude per kWh of electrical energy by 30%
- **Capacity:** initially 10 Mio. L/a (8.000 t/a); at this stage 20-30% of CO_2 from DAC; later extension planned to 80.000 t/a; then all CO_2 from DAC
- **Electricity:** Green Hydropower
- **Investment:** upper two-digit million € range
- **Projected price:** initially well below 2 €/L, later 1.00 - 1.20 €/L
- **Timeline for Beginning of construction, Commissioning, Extension:** 2021, 2023, 2026



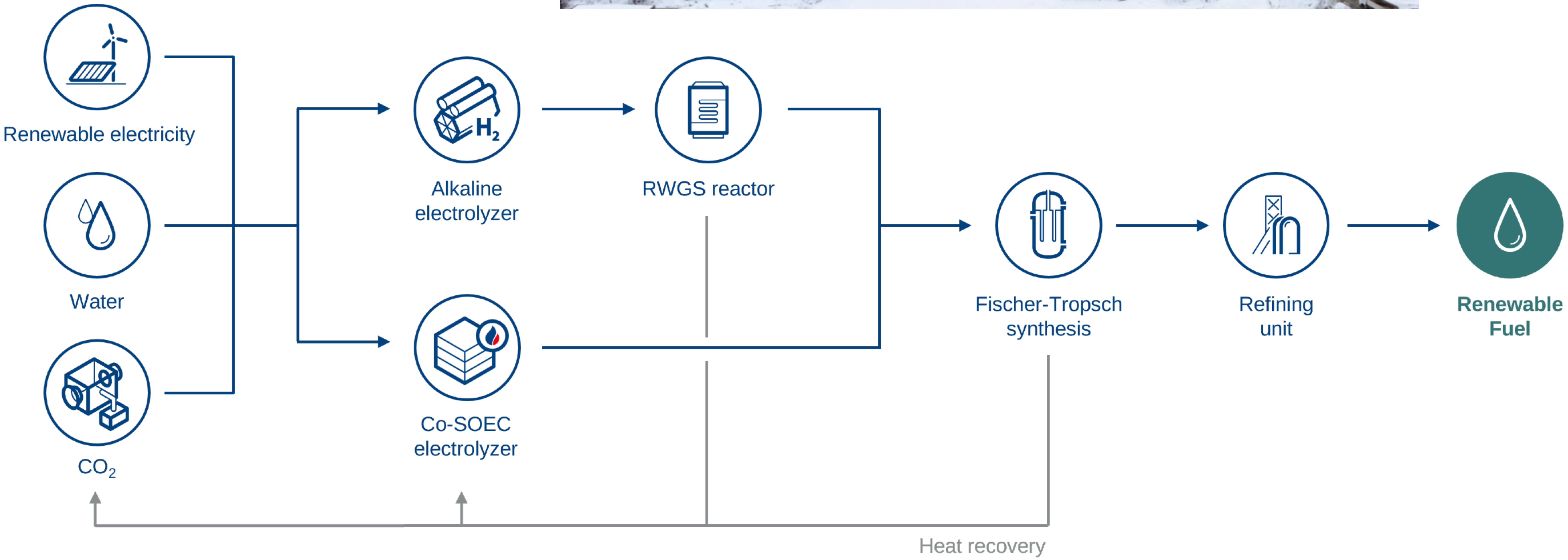
Source: A. Kamolz, Greener Skies Ahead Regional, 24.11.2021

Source: Business Portal Norway, 09.06.2020, https://bit.ly/2ZTI3tJ; future:fuels, 14.09.2020, https://bit.ly/3mI89IP

First commercial plant for hydrogen based aviation fuel

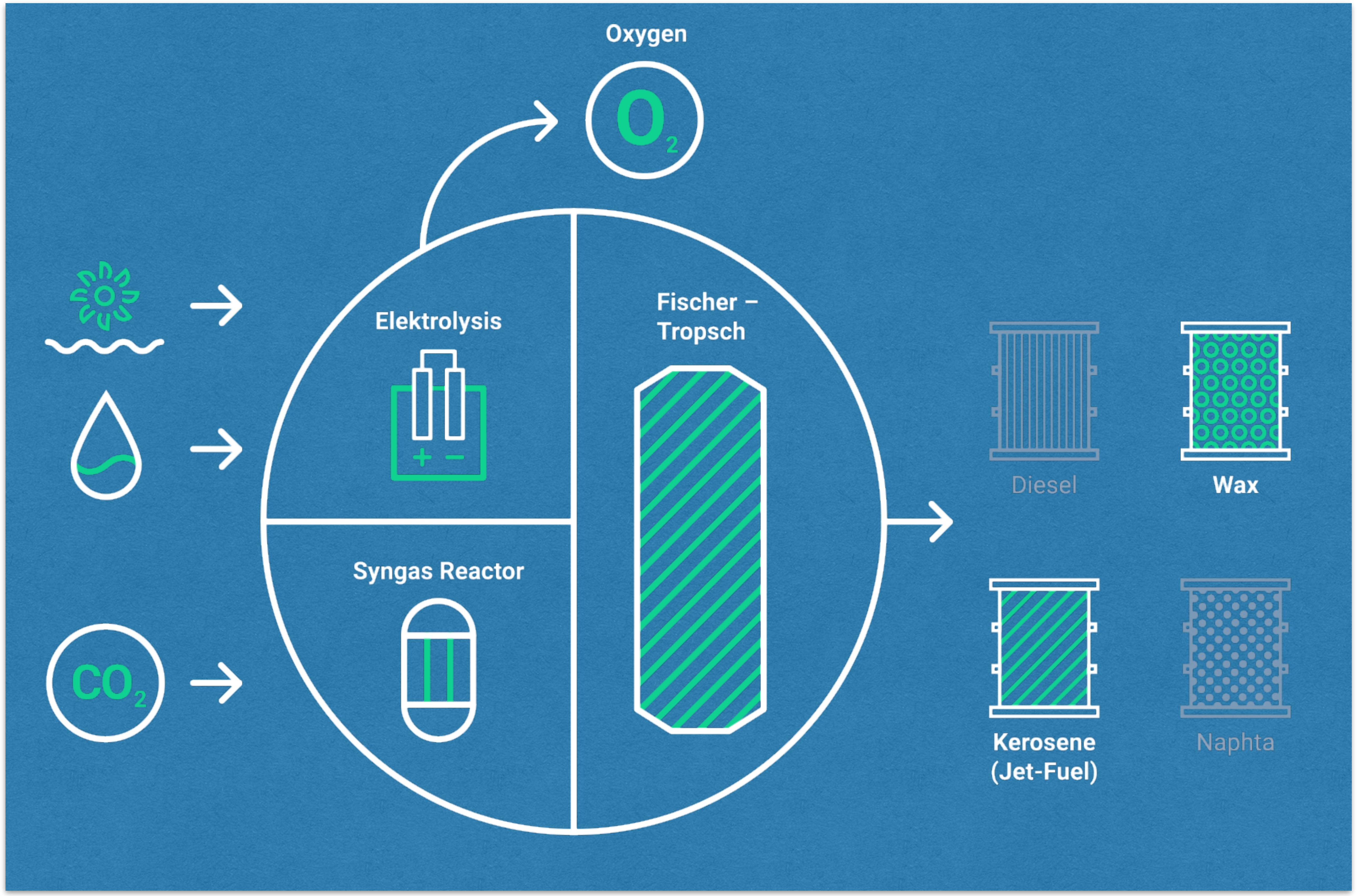
- **Site:** Mosjøen in Northern Norway
- **Partners:** Sunfire GmbH, Dresden, Climeworks AG, Zürich, Paul Wurth SA, Luxemburg, Valinor AS, Stabanker
- **Process:** DAC, AEL/rWGS (process line 1) and Co-SOEC (process line 2), FT-Synthesis, Refining; Utilisation of FT waste heat for Co-SOEC or RWGS, respectively

- **Capacity:** 12.5 Mio. L/a (10.000 t/a) from process line 1 by 2024; another 12.5 Mio. L/a from process line 2 by 2026; extension to 100 Mio. L/a (80.000 t/a) by 2029; start of construction of in 2023



Source: https://www.norsk-e-fuel.com

First commercial plant for hydrogen based aviation fuel

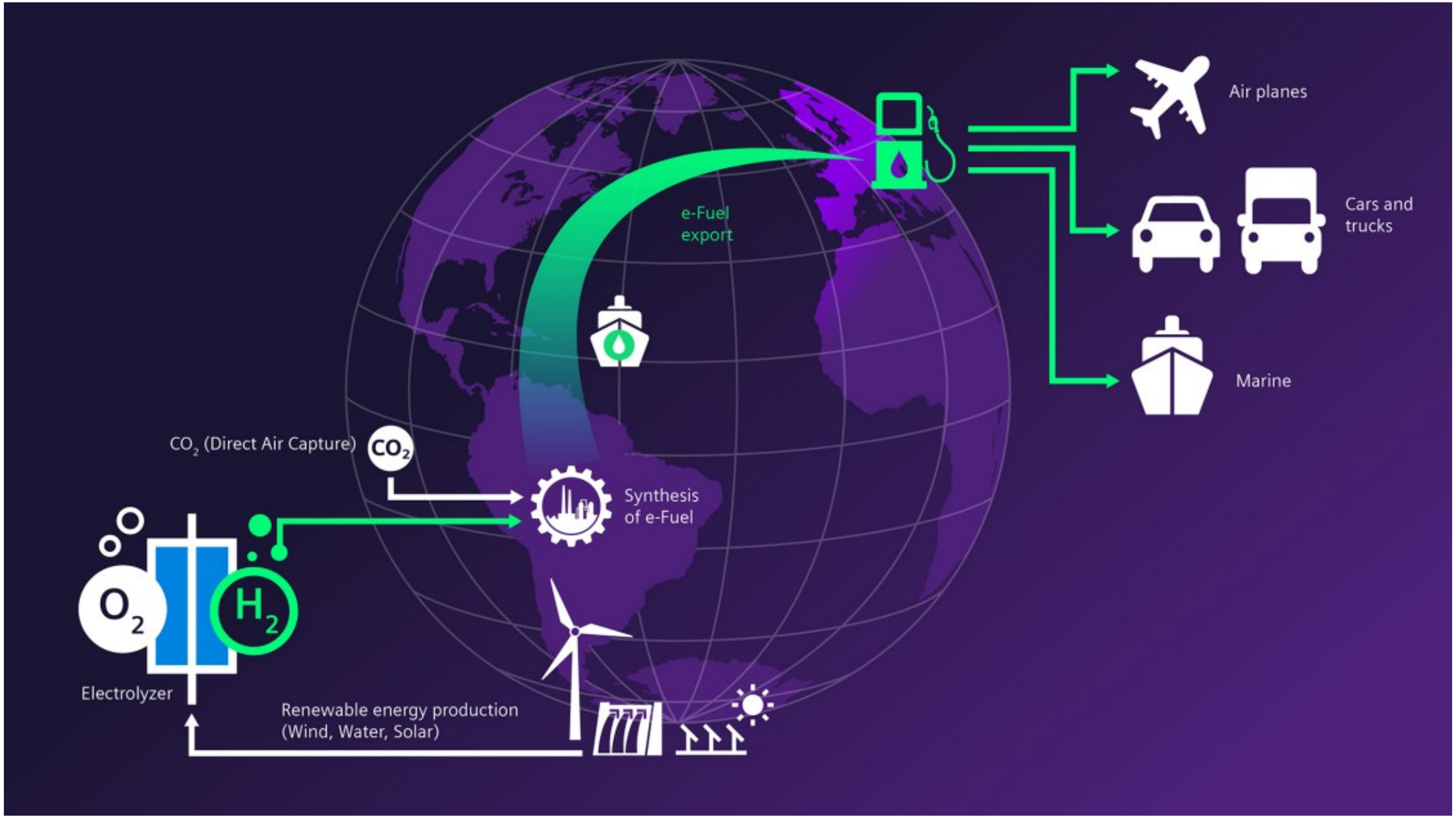


- **Focus on high TRL technologies:** CO_2 point source rather than DAC, proprietary rWGS rather than co-SOEC
- Started a few years earlier than norsk e-fuel as **Nordic Blue Crude**

- **Site:** Industry park Herøya, Porsgrunn, 150 km southwest of Oslo

Source: Nordic Electrofuel (https://nordicelectrofuel.no/#whatwedo, access on 12.05.2022)

Siemens Energy leads BMWi funded project Haru Oni



- Official project start was in December 2020

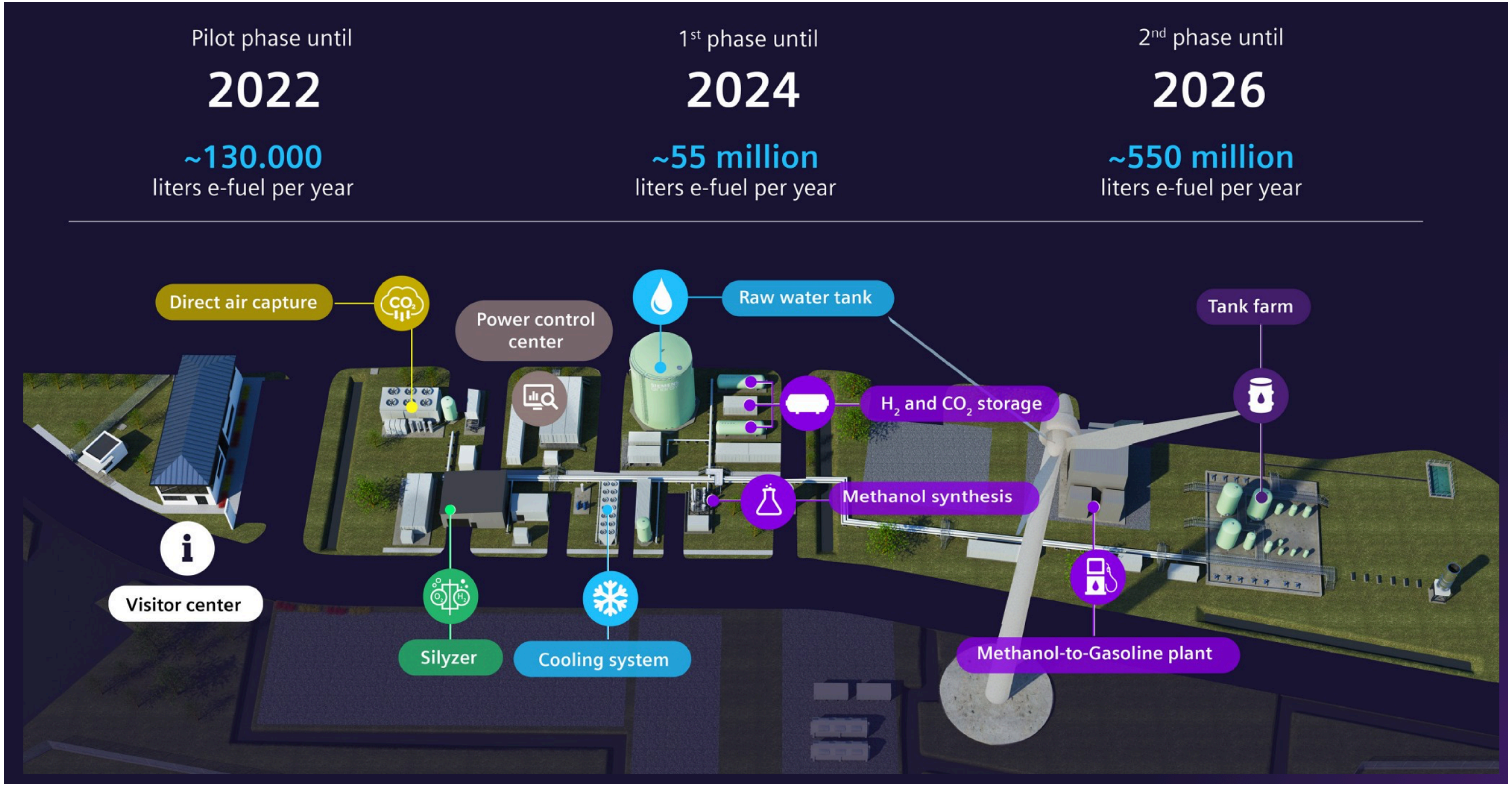
Bundesministerium
für Wirtschaft
und Technologie

PORSCHE
ENAP
ExxonMobil
AME
SIEMENS energy
enel

https://www.haruoni.com/#/en

https://bit.ly/2TdzYid

Plant layout and timeline for scaling up



Pilot phase until
2022
~130.000
liters e-fuel per year

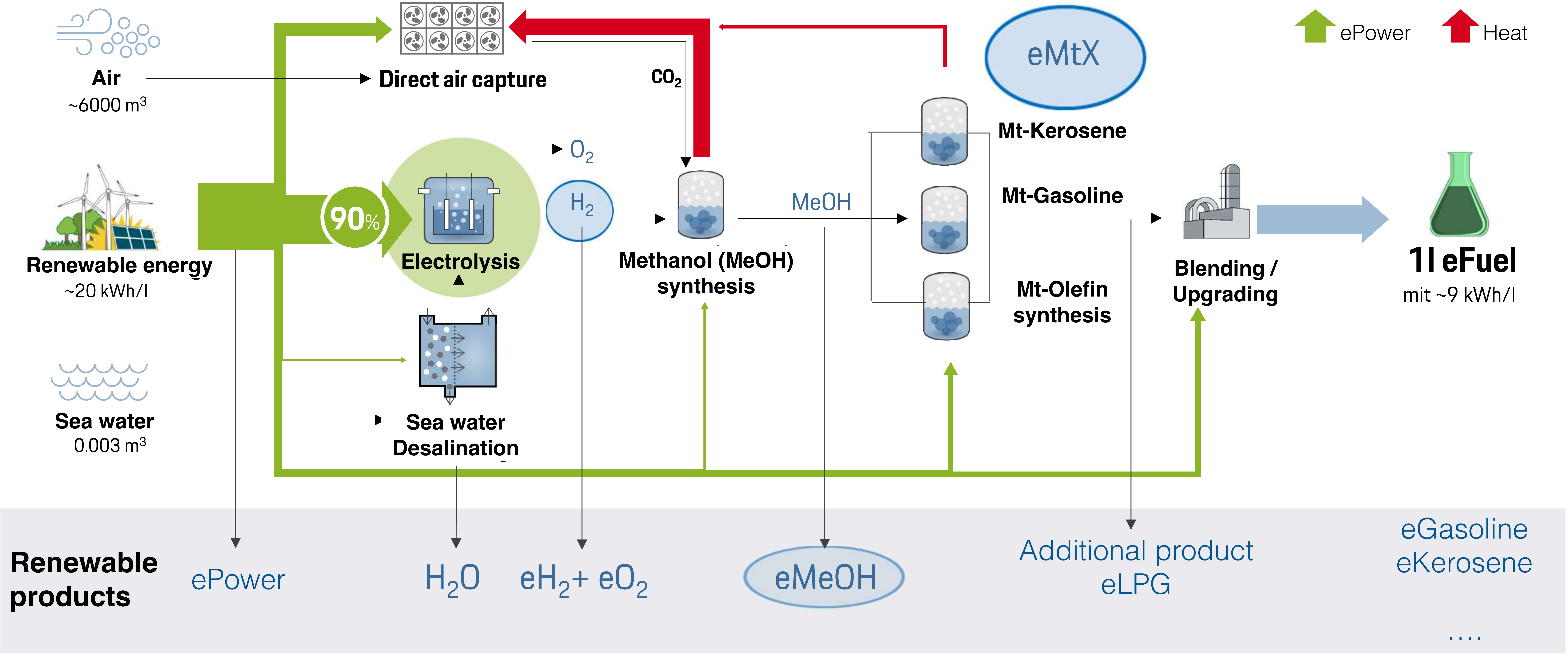
1st phase until
2024
~55 million
liters e-fuel per year

2nd phase until
2026
~550 million
liters e-fuel per year

- Construction is underway
- Start-up of the pilot plant scheduled for summer 2022

https://bit.ly/2TdzYid

Production of e-Fuels with a versatile intermediate enables high flexibility



ePower 🟩
Heat 🟥

Air
~6000 m^3

Direct air capture

CO_2

Renewable energy
~20 kWh/l

90%

Electrolysis

O_2

H_2

Sea water
0.003 m^3

Sea water
Desalination

Methanol (MeOH)
synthesis

MeOH

eMtX

Mt-Kerosene

Mt-Gasoline

Mt-Olefin
synthesis

Blending /
Upgrading

1l eFuel
mit ~9 kWh/l

Renewable products

ePower

H_2O

$eH_2 + eO_2$

eMeOH

Additional product
eLPG

eGasoline
eKerosene
....

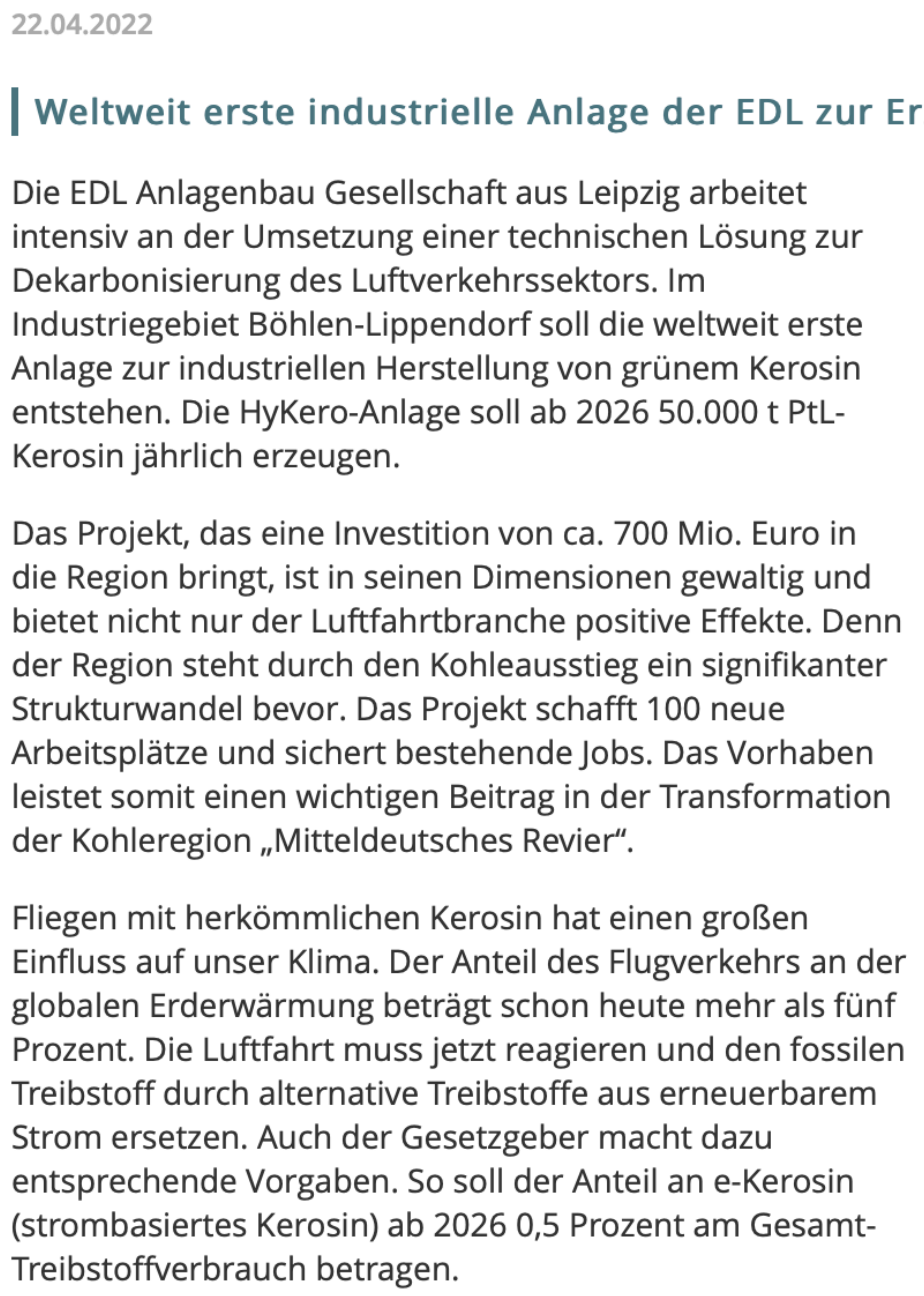
Source: K. Dums, Greener Skies Ahead Regional, 24.11.2021

More announcements…

Heidenheim-Mergelstetten: 50.000 t/a in 2028

Concept for PtL plant for Stuttgart Airport

Böhlen-Lippendorf: 50.000 t/a in 2026



22.04.2022

Weltweit erste industrielle Anlage der EDL zur Erzeugung von PtL-Kerosin

Die EDL Anlagenbau Gesellschaft aus Leipzig arbeitet intensiv an der Umsetzung einer technischen Lösung zur Dekarbonisierung des Luftverkehrssektors. Im Industriegebiet Böhlen-Lippendorf soll die weltweit erste Anlage zur industriellen Herstellung von grünem Kerosin entstehen. Die HyKero-Anlage soll ab 2026 50.000 t PtL-Kerosin jährlich erzeugen.

Das Projekt, das eine Investition von ca. 700 Mio. Euro in die Region bringt, ist in seinen Dimensionen gewaltig und bietet nicht nur der Luftfahrtbranche positive Effekte. Denn der Region steht durch den Kohleausstieg ein signifikanter Strukturwandel bevor. Das Projekt schafft 100 neue Arbeitsplätze und sichert bestehende Jobs. Das Vorhaben leistet einen wichtigen Beitrag in der Transformation der Kohleregion „Mitteldeutsches Revier“.

Fliegen mit herkömmlichen Kerosin hat einen großen Einfluss auf unser Klima. Der Anteil des Flugverkehrs an der globalen Erderwärmung beträgt schon heute mehr als fünf Prozent. Die Luftfahrt muss jetzt reagieren und den fossilen Treibstoff durch alternative Treibstoffe aus erneuerbarem Strom ersetzen. Auch der Gesetzgeber macht dazu entsprechende Vorgaben. So soll der Anteil an e-Kerosin (strombasiertes Kerosin) ab 2026 0,5 Prozent am Gesamt-Treibstoffverbrauch betragen.

Frankfurt Höchst: 3.500 t/a in 2023

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28.04.2022 Hessisches Ministerium für Wirtschaft, Energie, Verkehr und Wohnen

Pressemitteilung Luftverkehr

Pilotanlage für synthetisches Kerosin in Planung

Noch in diesem Jahr soll mit dem Bau der weltweit größten Pilotanlage für synthetisches Kerosin im Industriepark Frankfurt-Höchst begonnen werden. Dies teilte Wirtschafts- und Verkehrsminister Tarek Al-Wazir am Donnerstag in Wiesbaden mit.

Many thanks to…

- the colleagues at IMVT for extensive efforts in the different projects
- the KIC InnoEnergy for funding of the European project SYNCON
- the China Scholarship Council (CSC) for a scholarship (Chenghao Sun)
- the Peter and Luise Hager Foundation for funding of two doctoral projects (Tobias Jäger, Hannah Kirsch)
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- the Helmholtz Association and the German Ministries for Education and Research (BMBF) as well as Economics and Energy (BMWi) and the Ministry for Science, Research and the Arts Baden Württemberg for funding of the Energy Lab 2.0 large-scale research infrastructure project
- the German Ministry for Economics and Energy (BMWi) for funding of the start-up INERATEC through the national eXist programme as well as for funding of the PowerFuel project
- the German Ministry for Education and Research (BMBF) for funding of the Copernicus project P2X and the project H$_2$Mare
- the Ministry for Science, Research and the Arts Baden Württemberg for funding of the reFuels project
- the Helmholtz Association for the funding of the Helmholtz Initiative Climate Adaptation and Mitigation
- **you for your kind attention!**