GEFÖRDERT VOM

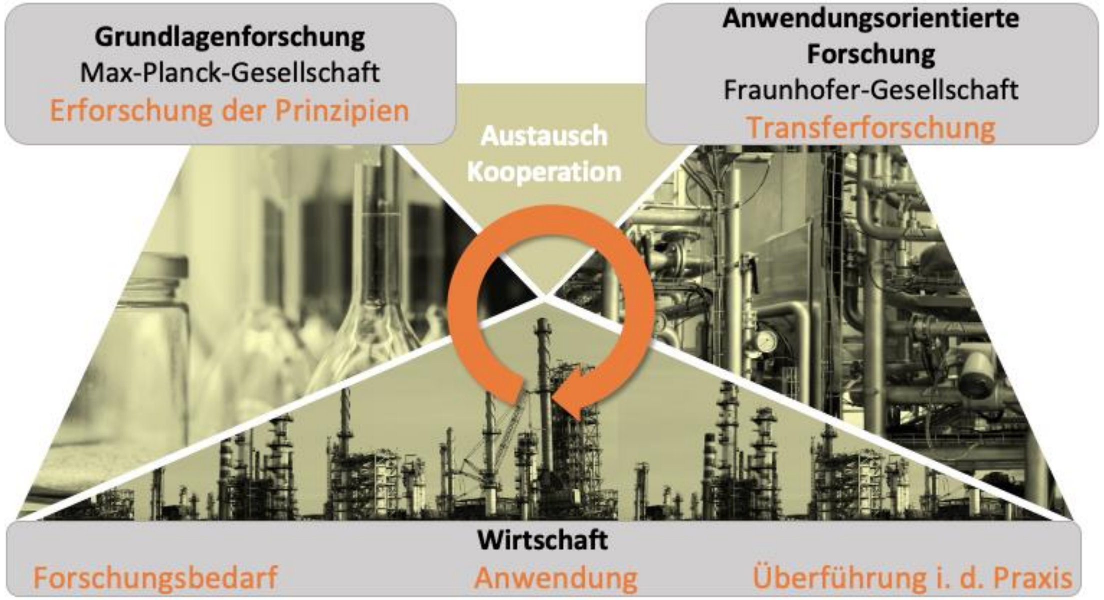
Bundesministerium
für Bildung
und Forschung

CARBON2CHEM®

A Contribution to Sustainable Industries

Selected Results (2016 – 2020)

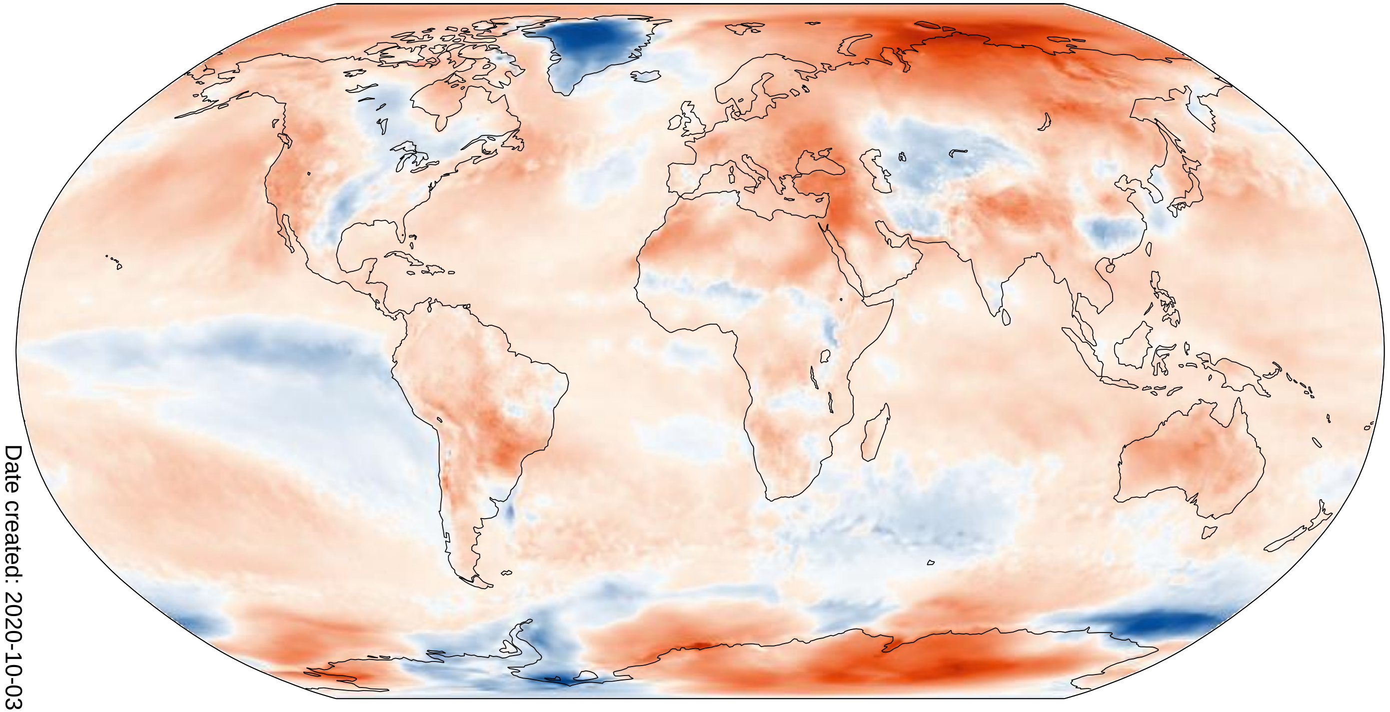
Acknowledgement



C2C practices with over 250 participants the collaboration between science organisations, science disciplines and across industry sectors on relevant scales of dimension and effort.

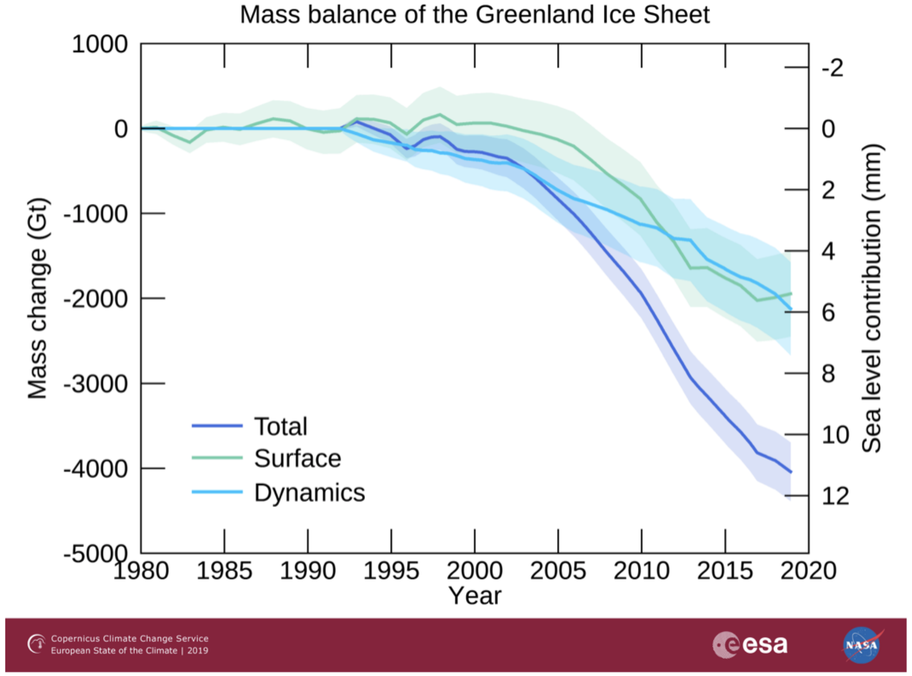
Stop this now!

Surface air temperature anomaly for September 2020



Date created: 2020-10-03

(Data: ERA5. Reference period: 1981-2010. Credi



Total cumulative Greenland ice sheet mass change, partitioned into surface and dynamics components. Change relative to 1992. Data source: IMBIE (Shepherd et al., 2020), Credit: IMBIE/ESA/NASA.

European Commission

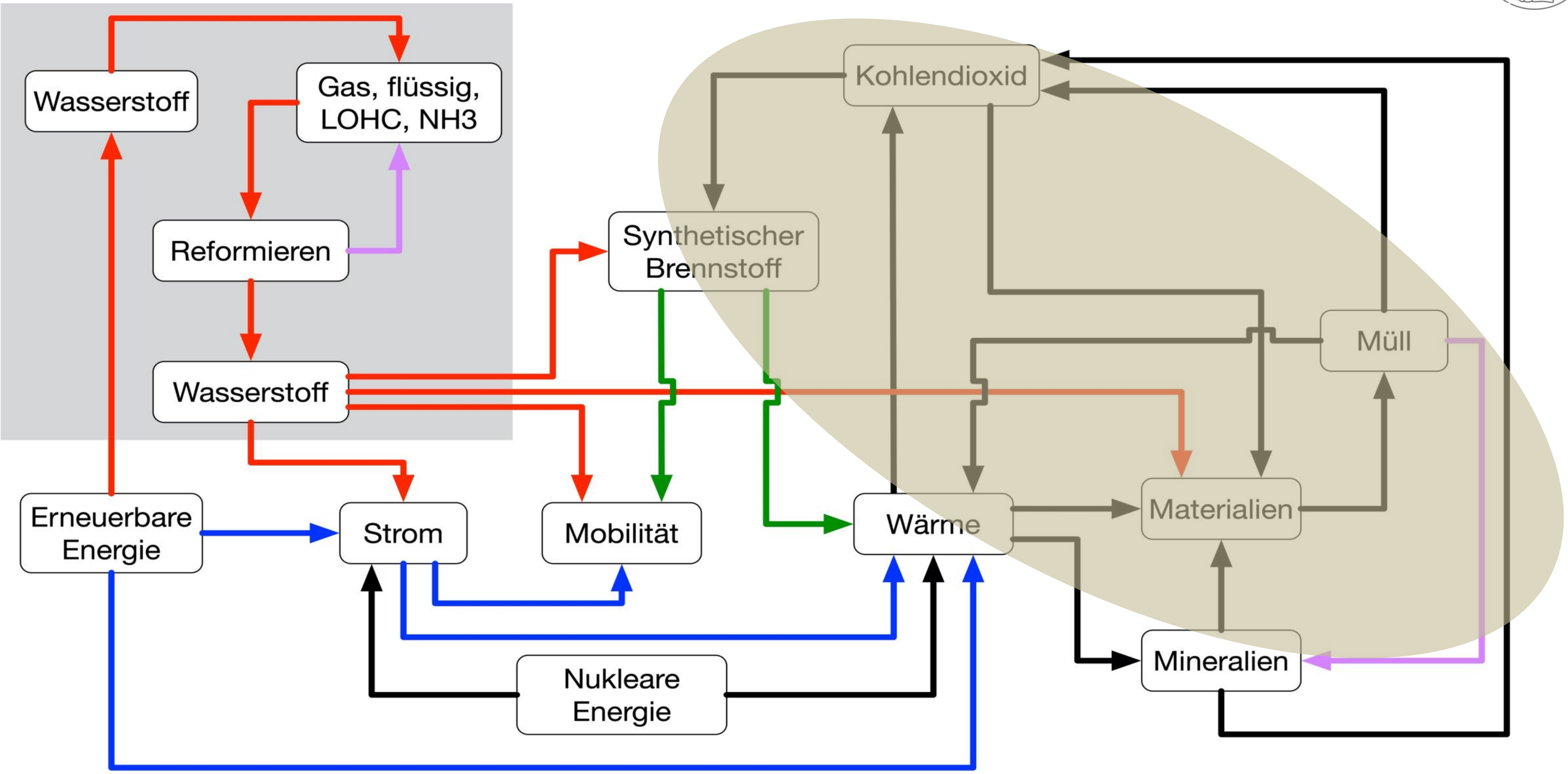
Copernicus Europe's eyes on Earth

IMPLEMENTED BY ECMWF

Climate Change Service climate.copernicus.eu

GHG levels rise with 2.5 ppm/a

A sustainable energy system

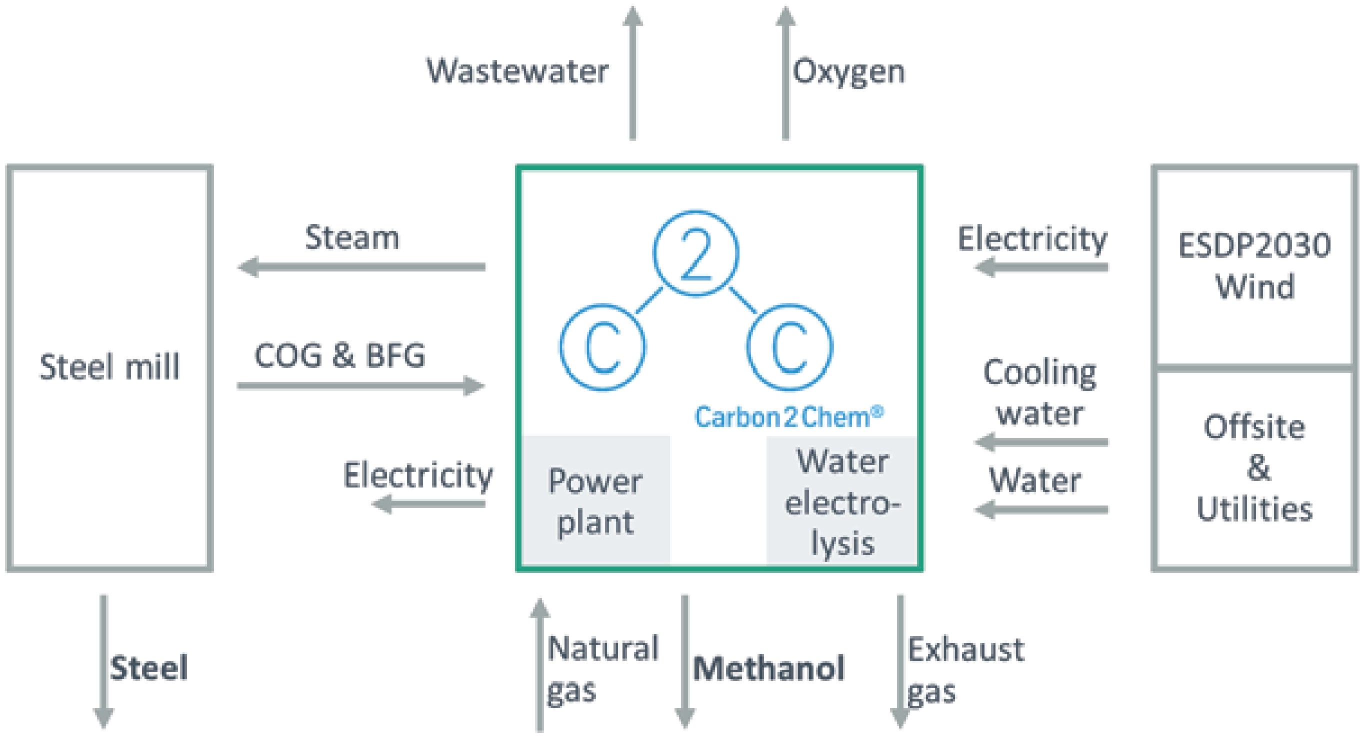


MAX-PLANCK-INSTITUTE FOR CHEMICAL ENERGY CONVERSION

C2C: Put carbon in a loop

Steelmaking in DE
43 Mt/a
167 TWh Energy
58 Mt CO_2
0,35 Mt/TWh
(Power DE 0,48 Mt/TWh)

Final energy 2018	Energy (TWh)	Emission (Mt)
Total	2492	704
Industry	1085	467 (0,43)
Mobility	642	126 (0,20)
Domestic	645	83 (0,13)
Air/marine	121	36 (0,30)

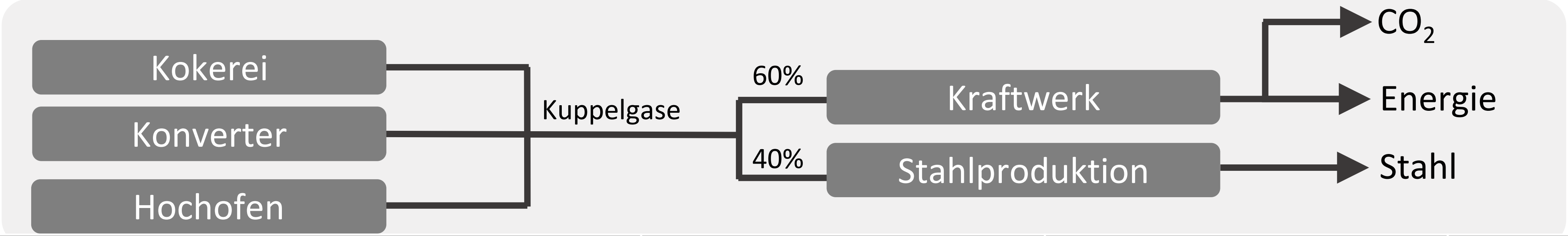


C2C engages further in the synthesis of urea and of selected other chemicals

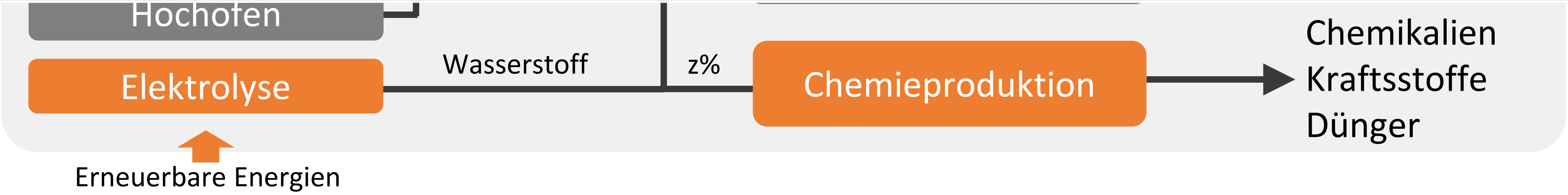
C2C operates in a system-oriented fashion and knowledge-based.

The tasks

Aktuell: Integrierte Hütte



Komponenten	Koksofengas	Hochofengas	Konvertergas
Stickstoff (N_2)	5%	49%	14%
Wasserstoff (H_2)	61%	4%	4%
Kohlenstoffmonoxid (CO)	6%	25%	65%
Kohlenstoffdioxid (CO_2)	2%	23%	17%
Menge (Bsp. Hütte Duisburg)	180 000 m³/h	2 000 000 m³/h	100 000 m³/h



Project Coordination

Prof. Dr.-Ing. Görge Deerberg, Fraunhofer UMSICHT
Dr. Markus Oles, thyssenkrupp
Prof. Dr. Robert Schlögl, MPI-CEC

Carbon2Chem®

L-KK
Coordination and Communication
Fraunhofer UMSICHT
MPI-CEC

L-0
System-Integration
thyssenkrupp
Fraunhofer UMSICHT | MPI-CEC | Siemens AG | Siemens Gas and Power

L-I
CO_2-Sources
thyssenkrupp
Fraunhofer UMSICHT
Lhoist Rheinkalk Germany
Remondis
Thyssen Vermögensverwaltung

L-II
Methanol
Nouryon
Clariant
Fraunhofer ISE
Fraunhofer UMSICHT
Ruhr-Universität Bochum
thyssenkrupp

L-III
Synthesis Gas
Linde
Clariant
Fraunhofer UMSICHT
Ruhr-Universität Bochum
thyssenkrupp

L-IV
Higher Alcohols
Evonik
Fraunhofer UMSICHT
Ruhr-Universität Bochum
RWTH Aachen
thyssenkrupp Industrial Solutions

L-V
Carbon2Polymers
Covestro
MPI-KoFo
RWTH Aachen

L-VI
Synthetic Fuels
N.N.

Carbon2Chem® laboratory
Fraunhofer UMSICHT | MPI-CEC

Carbon2Chem® technical shop
thyssenkrupp

Organizational chart Carbon2Chem®

Alternative Industrial CO_x Sources

Steel making

Alternative Processes
Direct reduction with CO/H_2
Direct reduction with H_2 (future)

In each process like in the blast furnace process tail gasses result in substantial quantities with albeit greatly varying composition.

Use the modular C2C technology train to deal with them in a systemically most effective manner.

Unavoidable point sources

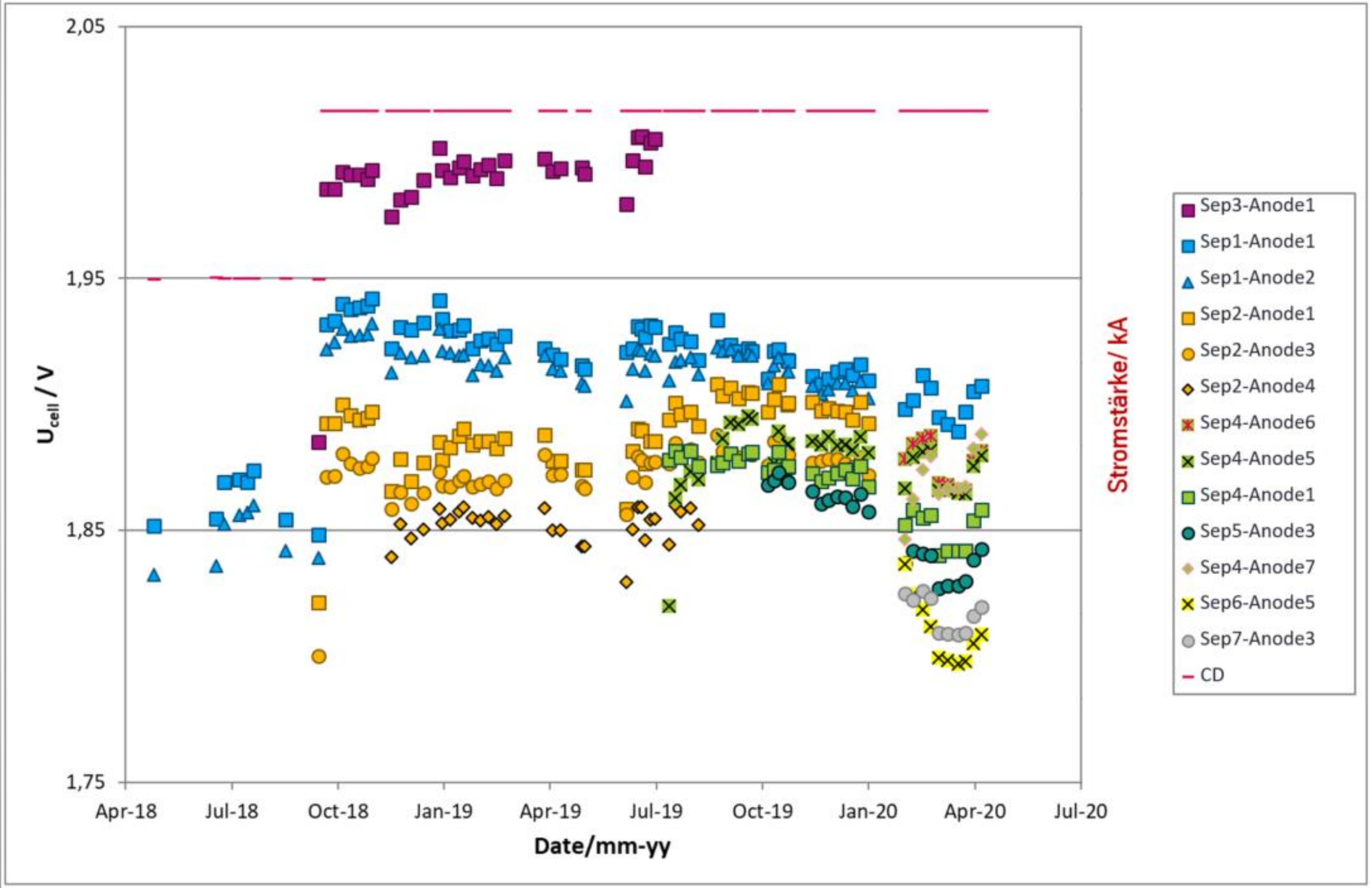
Cement/ lime production

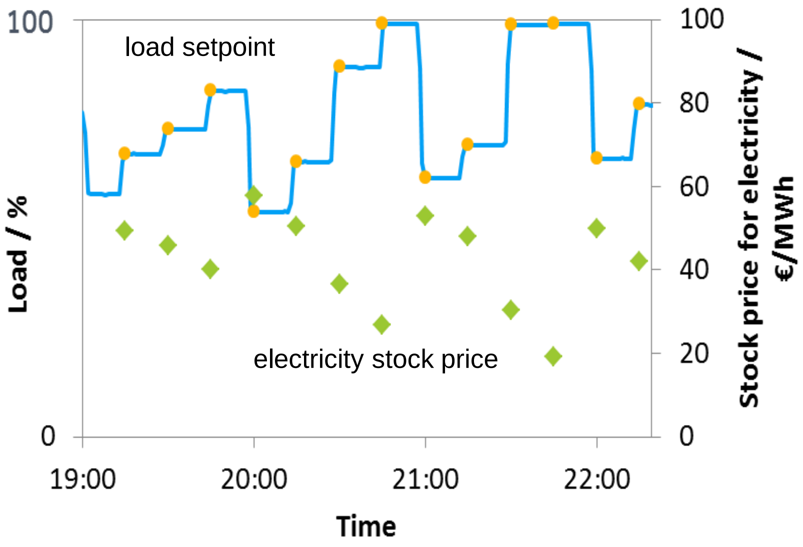
Waste incineration.

Use the modular C2C technology train to synthesize *e-kerosene* und *Syn Fuels* for heavy duty applications.

C2C sets up prototypical circular economies with carbon

The Electrolyzer (AEL)





Cost of Hydrogen for Industry

Production costs AEL 2030 (€ t^{-1} H_2), CAPEX 450 € kW^{-1}						
Load factor	25 %	40 %	50 %	60 %	75 %	90 %
25 €/MWh	3,600	2,800	2,500	2,300	2,100	2,000
40 €/MWh	4,400	3,500	3,200	3,000	2,800	2,700
50 €/MWh	4,800	4,000	3,700	3,500	3,300	3,200
60 €/MWh	5,300	4,500	4,200	4,000	3,800	3,700
75 €/MWh	6,100	5,200	5,000	4,800	4,600	4,400
100 €/MWh	7,300	6,500	6,200	6,000	5,800	5,700
125 €/MWh	8,600	7,700	7,400	7,200	7,000	6,900

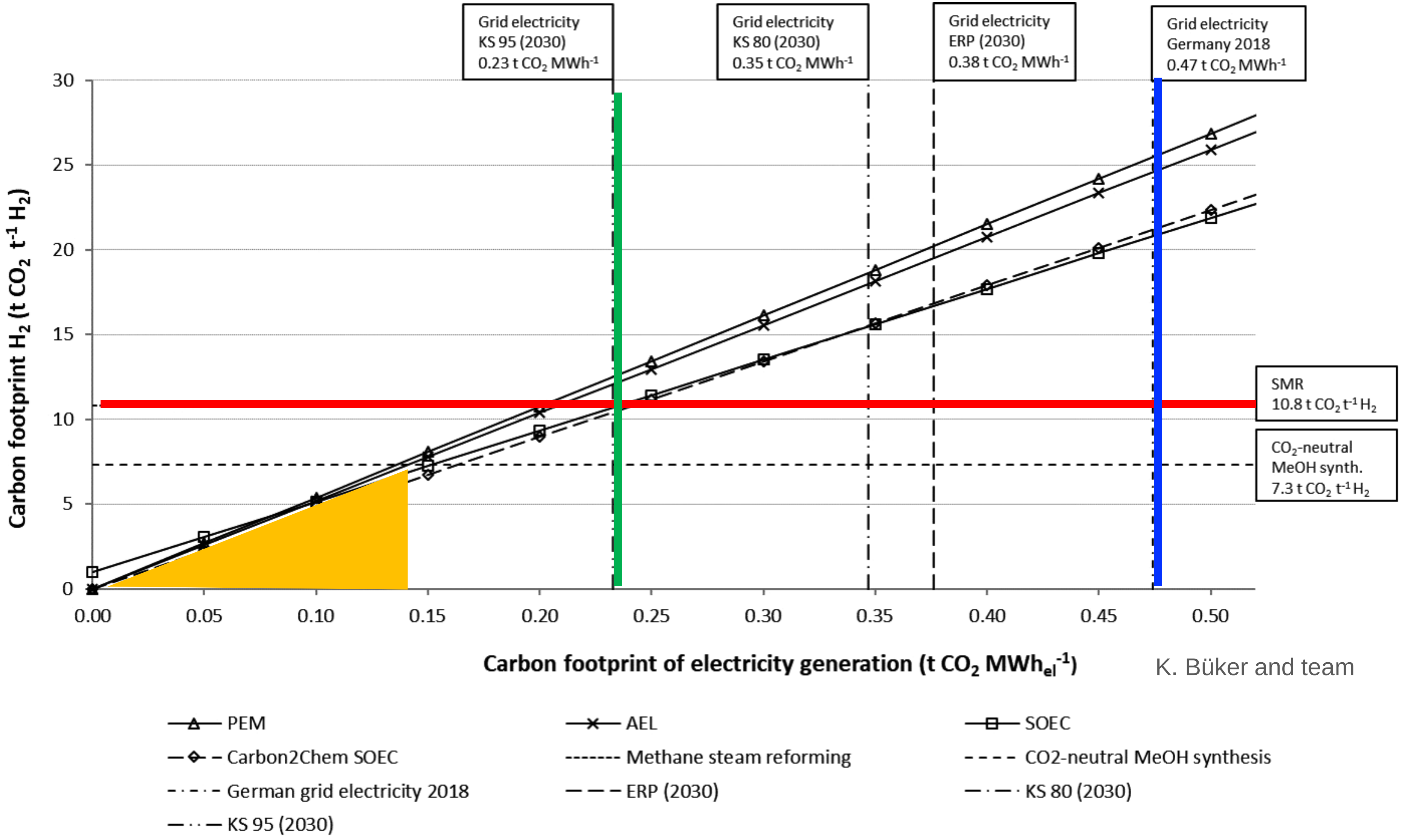
Production costs PEM 2030 (€ t^{-1} H_2), CAPEX 810 € kW^{-1}						
Load factor	25 %	40 %	50 %	60 %	75 %	90 %
25 €/MWh	5,300	4,000	3,500	3,200	2,900	2,700
40 €/MWh	6,200	4,800	4,400	4,100	3,800	3,600
50 €/MWh	6,700	5,400	4,900	4,600	4,300	4,100
60 €/MWh	7,300	5,900	5,500	5,200	4,900	4,.600
75 €/MWh	8,100	6,700	6,300	6,000	5,700	5,500
100 €/MWh	9,400	8,100	7,600	7,300	7,000	6,800
125 €/MWh	10,800	9,500	9,000	8,700	8,400	8,200

K. Büker and team

Cost depends critically on power price (political) and on load factor. CAPEX is an additional factor that can be improved by industrial manufacturing.

In DE today barely possible to generate economically green hydrogen (different in other European countries): DE has a critical disadvantage here.

Electrolysis and Power Mix

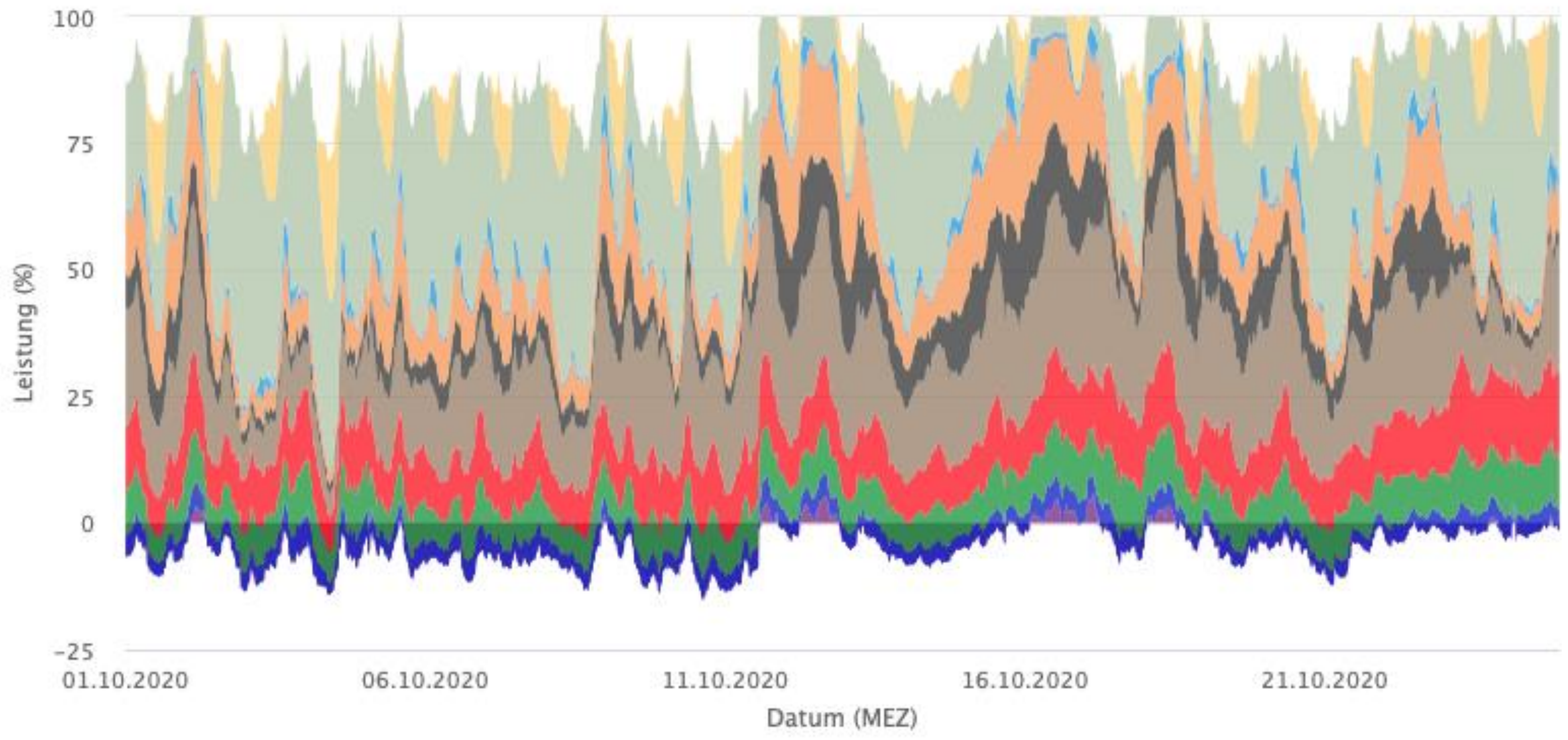


K. Büker and team

Water splitting for „green“ hydrogen is within the coming decade not feasible in DE.

Taking coal out of the power system is of utmost priority far more than agreed in legislation.

Volatility and RES expansion in the German Power System



Quelle:
Fraunhofer ISE
Energy Charts
Oktober 2020

The present power system in DE reaches its limits in dealing with volatile RES. More RES could allow some hydrogen generation (planned 5GW) but only when grid infrastructure and pipelines are suitably interconnected and upgraded now.

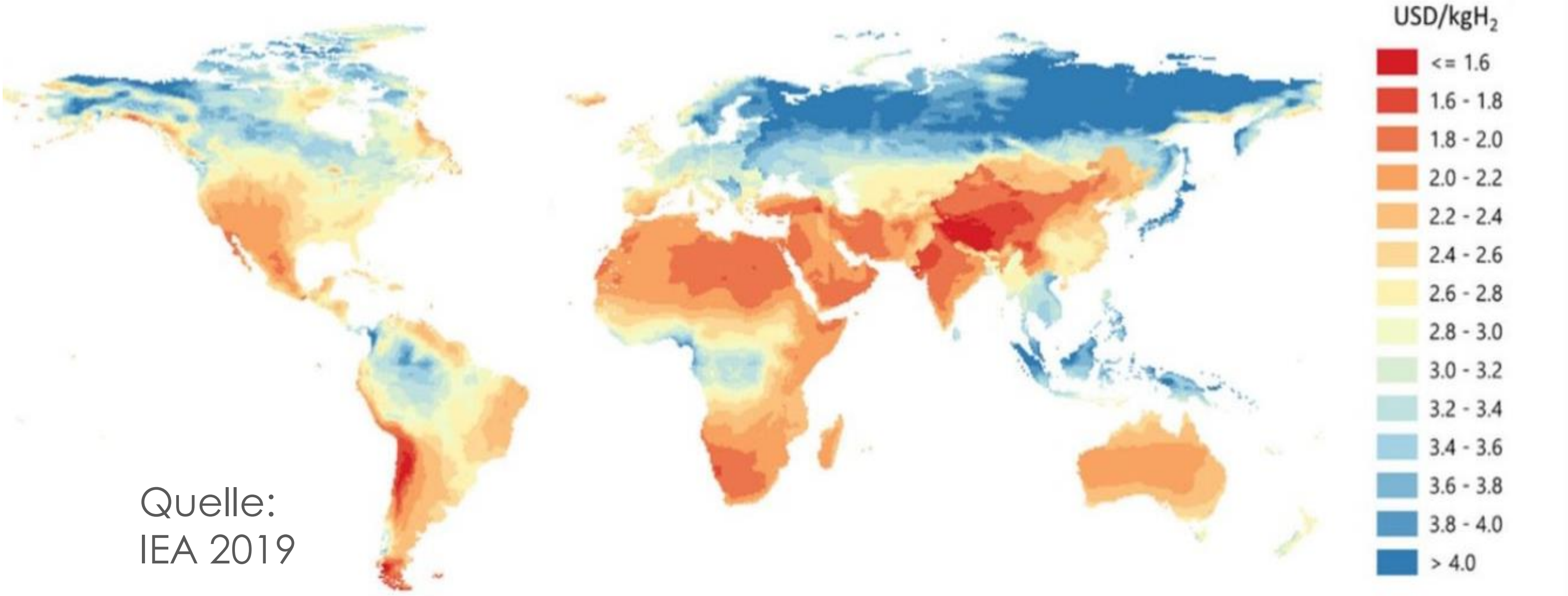
Where from will we get sufficient hydrogen?

Transport of hydrogen through derivatives (e-fuels) is a small contribution to cost.

Transport forms induce substantial energy losses.

Tolerable by the vast excess of available energy and improved processes.

Mind non-technical consequences of this global technology.



Quelle:
IEA 2019

Science and Technology are needed now

Chemistry in C2C

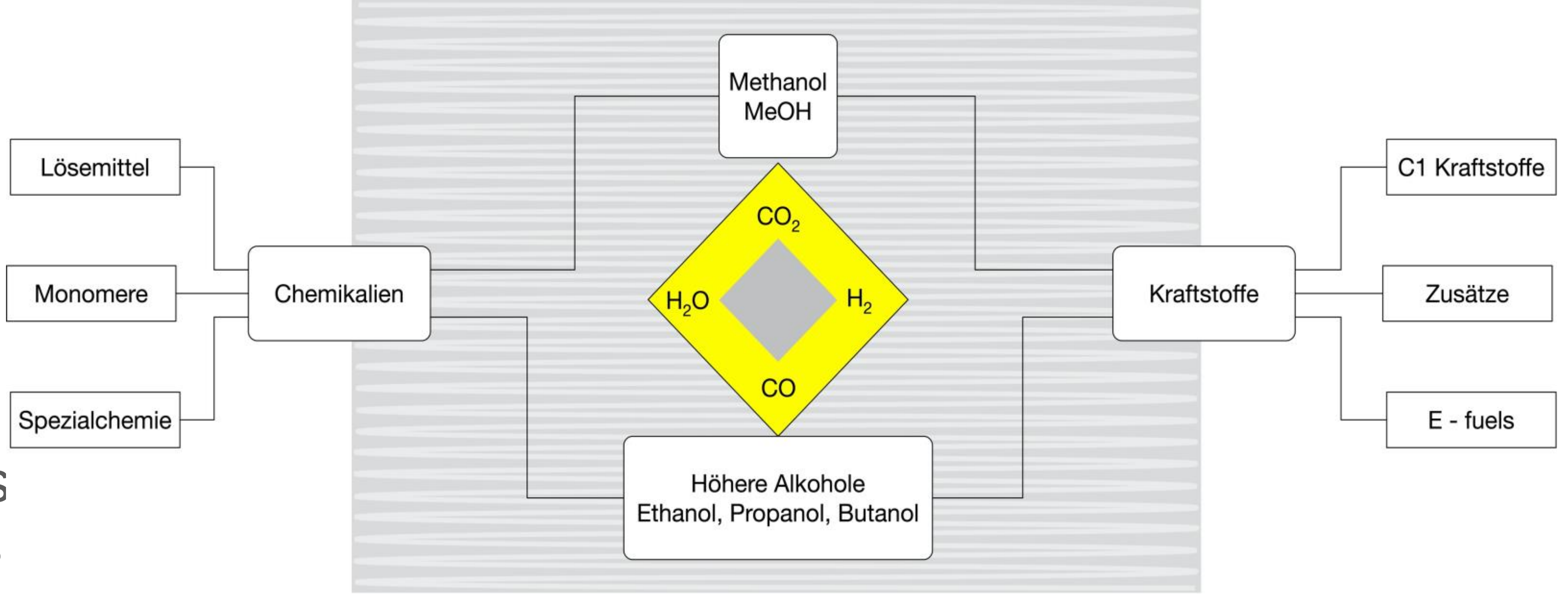
Alcohols are versatile platform molecules for future and changing markets.

They are well accessible from CO_2 and hydrogen.

MeOH is today a 80Mt/a commodity chemical.

Higher alcohols from synthesis gas /MeOH by heterogeneous catalysis are novel products on technical scales. C2C contributes substantially to this endeavour.

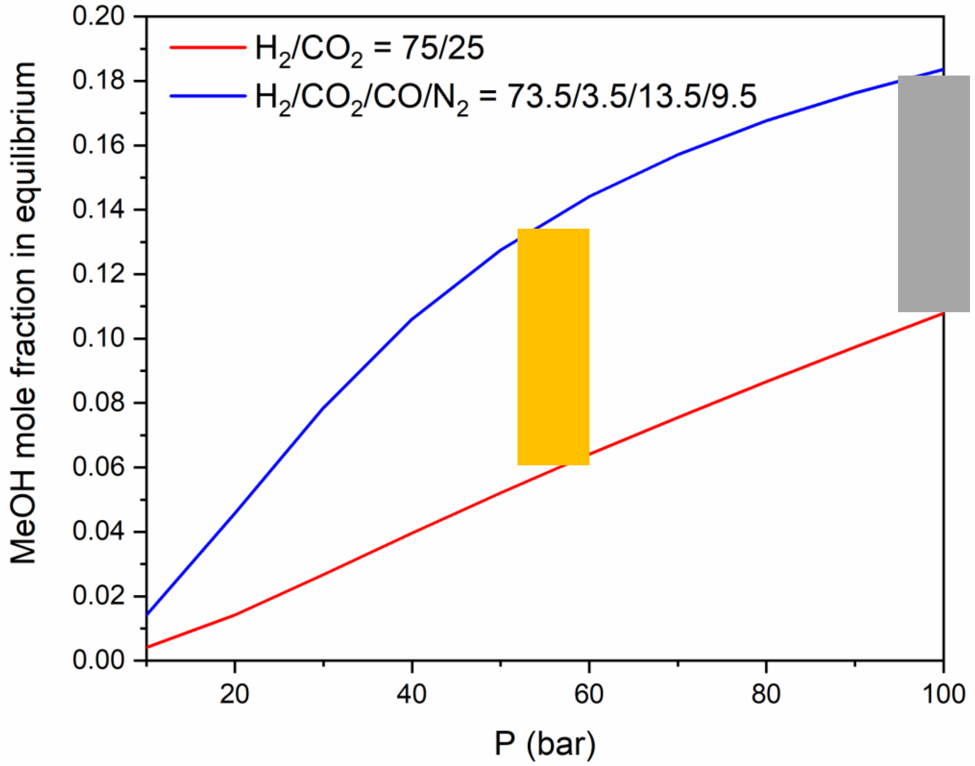
In the Franco-German sister project CatVic novel concepts of olefin synthesis from CO_2 at a chemical parc are being explored.



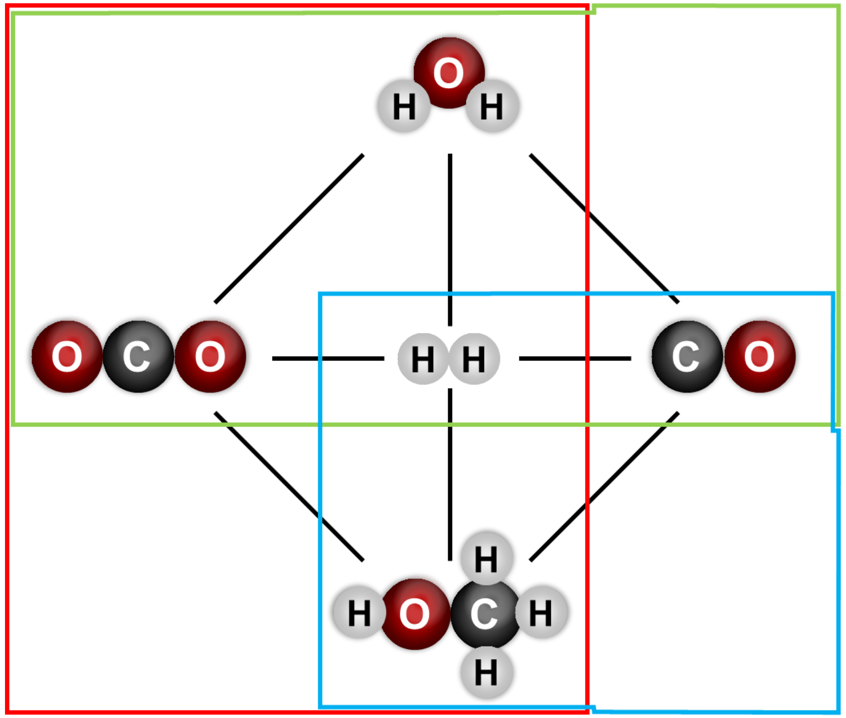
In addition, C2C deals with various pathways to urea, the synthesis of monomers for polymers and with the exploration of innovative process concepts using molecular catalysis.

Methanol Synthesis: Opportunity and Limitation

Synthesis of MeOH requires for thermodynamic reasons a recycle strategy (breakthrough alternatives are searched in the C2C lab). Critical are usage of hydrogen and accumulation of inerts and catalyst poisons.



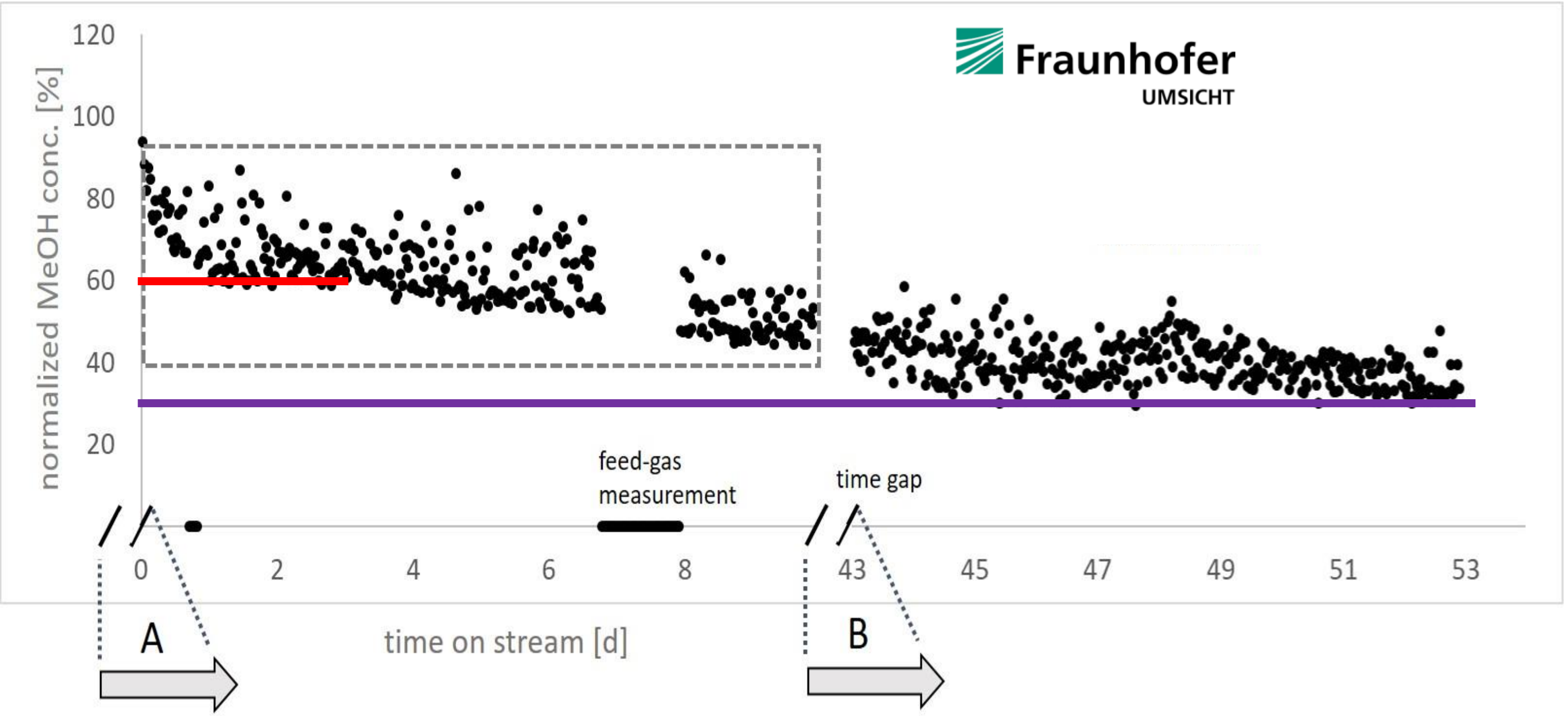
Complex optimization of pressure, recycle scheme and gas cleaning strategy to achieve stable and cost-effective process.



Case 1: $H_2:CO_2$ = 3:1, T = 250°C, P = 10-100 bar

Case 2: 13.5% CO, 3.5% CO_2, 73.5% H_2, 9.5% N_2, T = 250°C, P = 10-100 bar

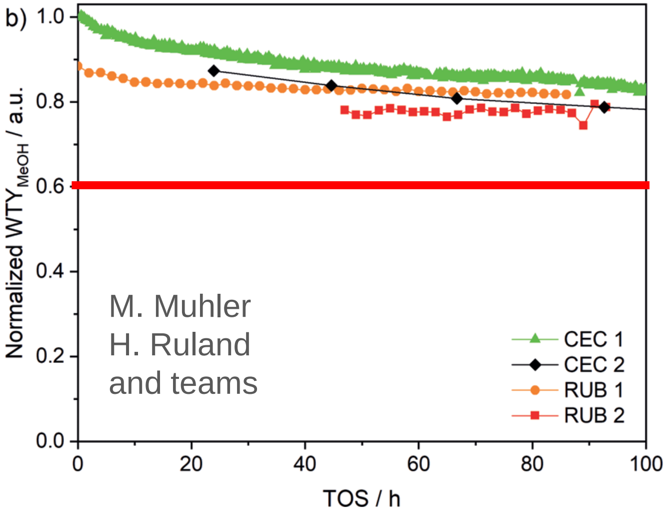
Methanol Synthesis: Beware of Unsuitable Conditions



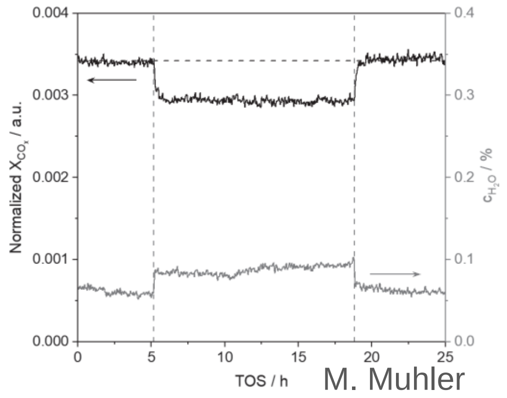
A:
1) 4 days reference-gas test
2) 2 days down-time
3) 1 day reference-gas test

B:
1) 4 days reference-gas test
2) 2 days synthetic H_2-enriched Blast-Furnace-Gas
3) 27 days down-time

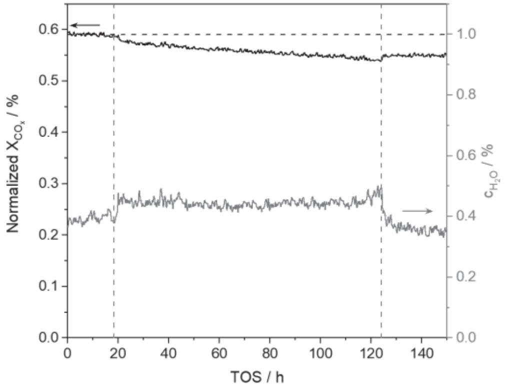
BFG enriched with additional H_2, S_N=2.4
10.3% CO, 9.5% CO_2, 58.6% H_2, 23.4% N_2, T = 250°C, P = 84 bar



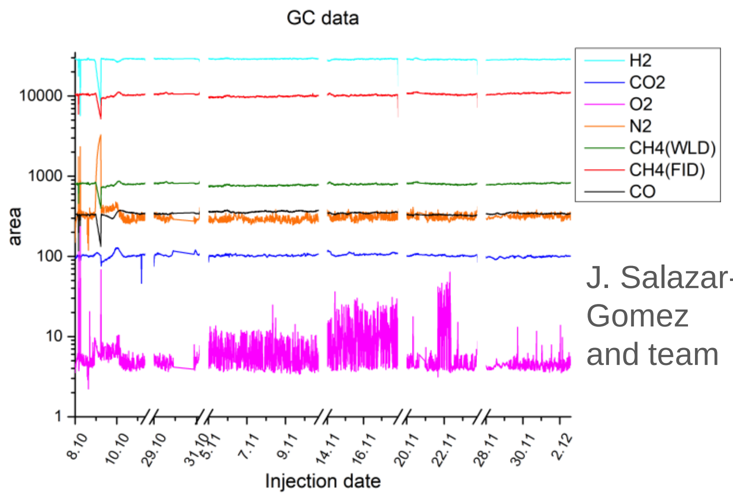
MeOH Synthesis: Dynamics and Deactivation



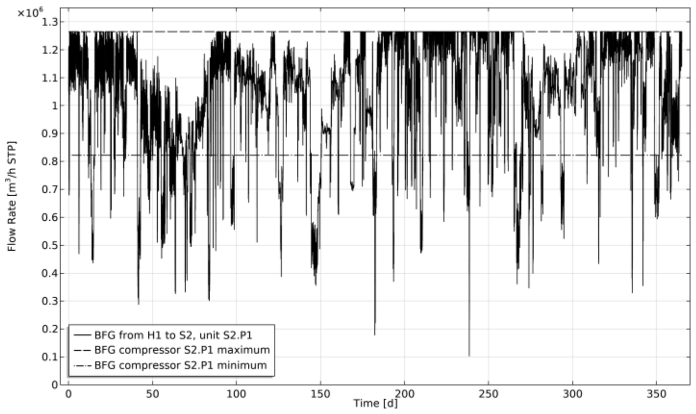
M. Muhler and team



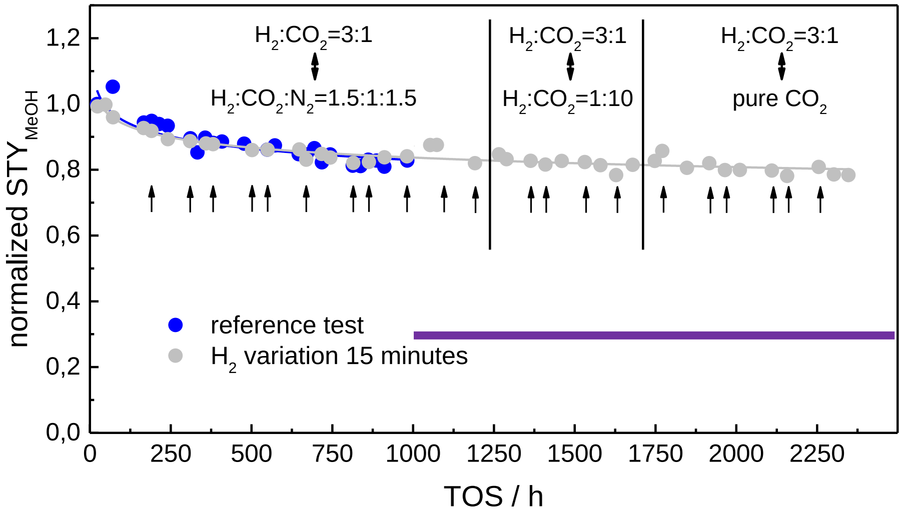
Deactivation by oxygen:
0,6 % O_2 permanent;
0,5 % reversible.

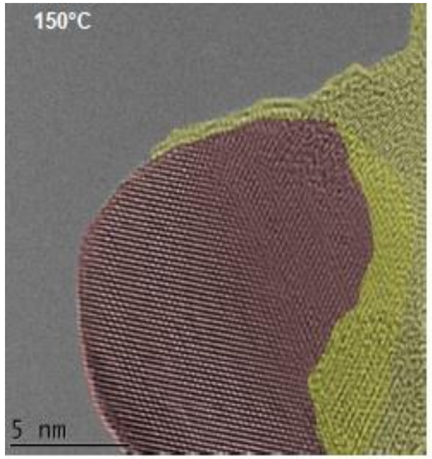


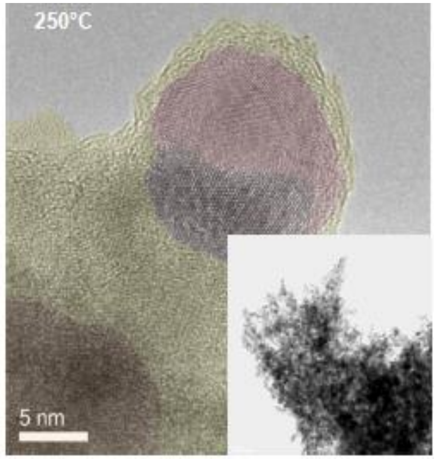
J. Salazar-Gomez and team



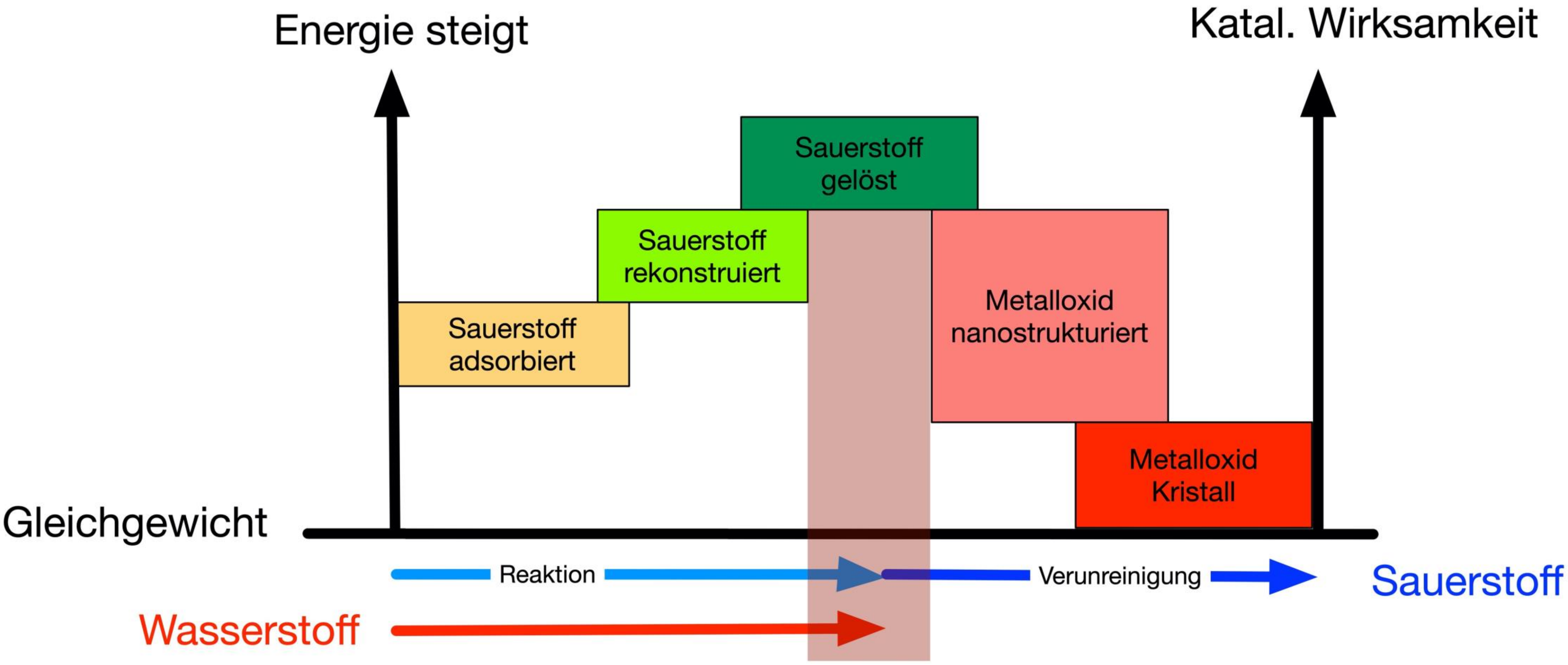
S. Schlüter and team
Fraunhofer Umsicht





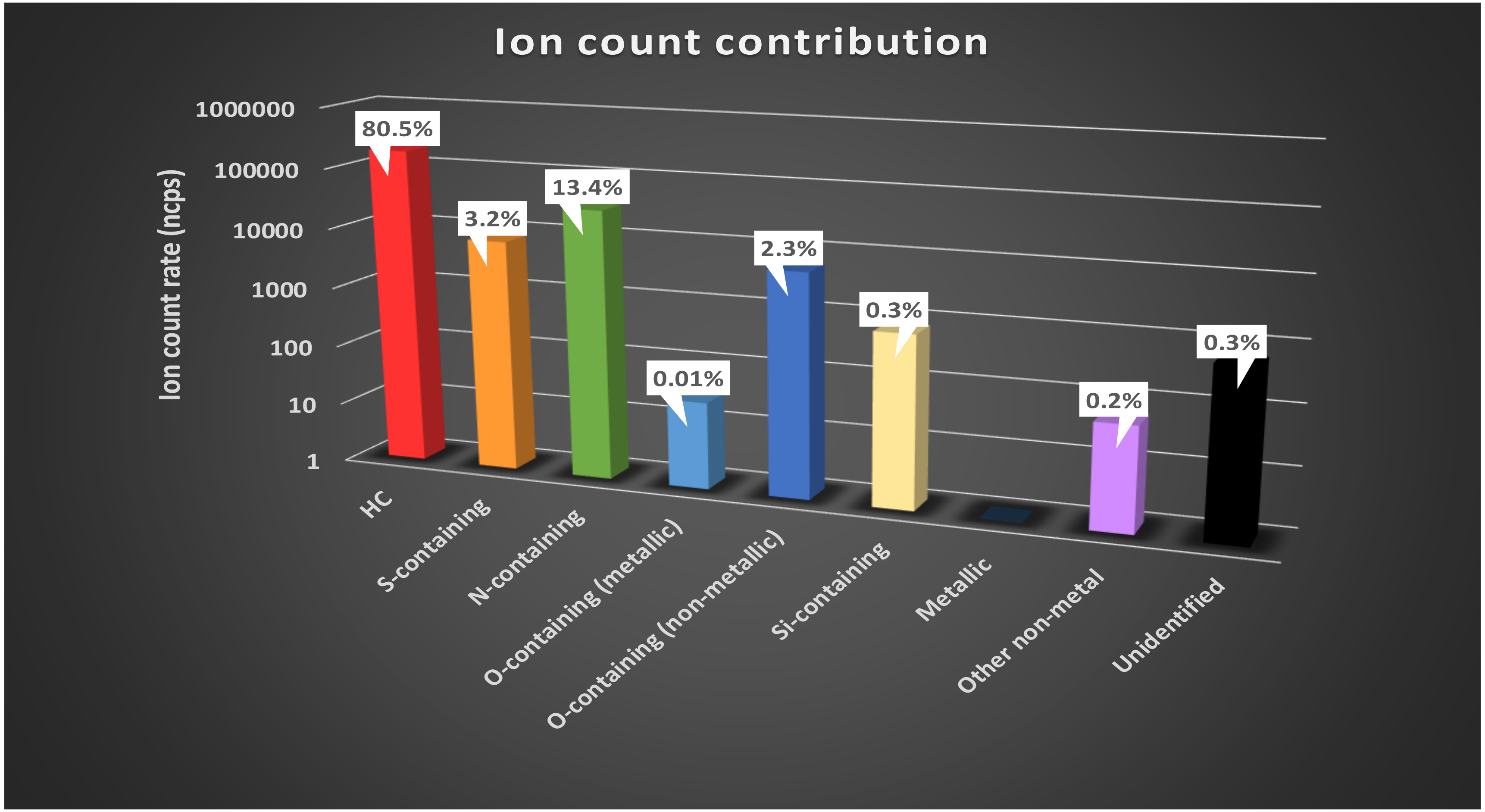


The Dynamical Catalyst (Cu, H_2,O_2, 673 K)



Trace gas analysis

Intensity (cps)

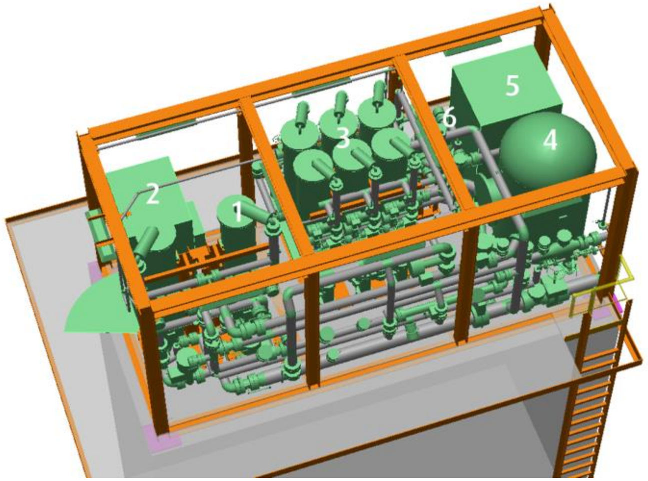


Design and validation of a multi-component ultra-sensitive on-line probing instrumentation based upon the PTR-MS-TOF technique. More than 540 components were identified and mapped in their compositional dynamics.

Gas cleaning (Linde)
Scaling of MeOH synthesis (Fraunhofer)

Gas cleaning has to purify the dynamical gas flows to an optimum between cost and stability of downstream processing.

Innovative process designs and electrostatic desorption are tested and plasma technologies are validated.



- Voradsorber[1]
- Schaltschrank[2]
- DWA[3] (6 Adsorber)
- Restgaspuffer[4]
- Analysenschrank[5]
- DeOxo (Produkt)[6]

Re-vamping and validation of a MeOH synthesis pilot plant demonstrating industrial production concepts. It includes closing all material streams and implements industrial energy flow patterns. Connection of its performance to laboratory experiments (downscaled version by MPI for dynamic operation testing). Real feed gas early next year.

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MAX-PLANCK-INSTITUTE FOR CHEMICAL ENERGY CONVERSION

Summary C2C

Defossilising steel making creates large demands for RES that will need import and exchange of hydrogen within Europe.

The scientific and systemic basis for C2C in the steel industry and in related applications is verified leading now to process design.

Present RES availability in Germany impedes scaled roll out of any „green“ steel technology without imports.

The C2C technology basis is sound and firm; challenges in dynamic operation and in unusual feed compositions were addressed and solved.

The C2C technology is generic for steelmaking and other industries with unavoidable carbon emissions.

Implementation of larger demonstrators for different usage scenarios should be started now; different energy systems throughout the EU call for collaborative action in critical dimensions (10^4 t/a). C2C is ready for that!

Only then the closure of the carbon circular economy can be demonstrated with downstream processing of platform chemicals to materials and fuels.

Scaling of C2C and CCU: Outside of science

1. Understand that CCU is an element of future energy systems; implement technology-openness (REDII!).
2. Implement now circular economy for carbon; close the loop for mobility without double counting.
3. A CO_2 pricing mechanism is needed for carbon in all energy sectors EU wide.
4. A reliable and long-term stable price is needed for industrial power.
5. Large quantities (5000 TWh) of certified hydrogen with free exchange within the EU need to be available.
6. Create now a trans-European infrastructure with high availability and maximal operational safety as critical first step.

Albert Einstein

There is no fundamental law requiring simplicity in natural processes

We cannot solve our problems with the same thinking we used when we created them

Thank You