



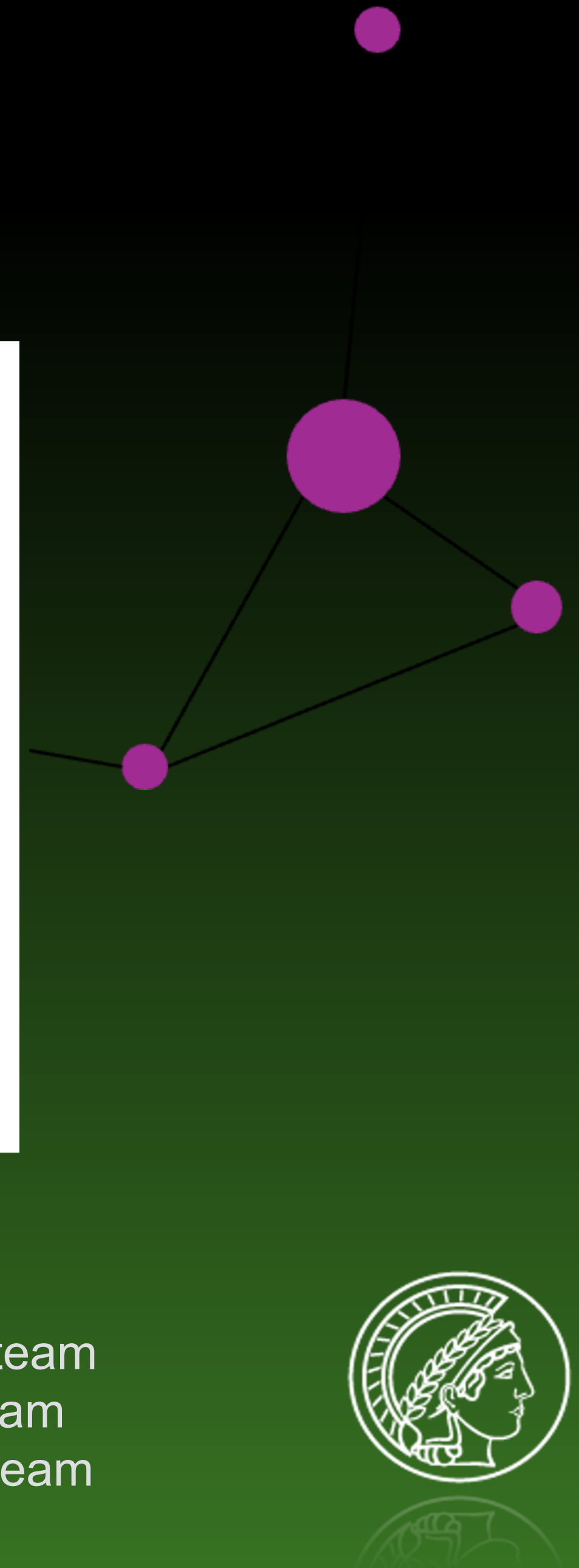
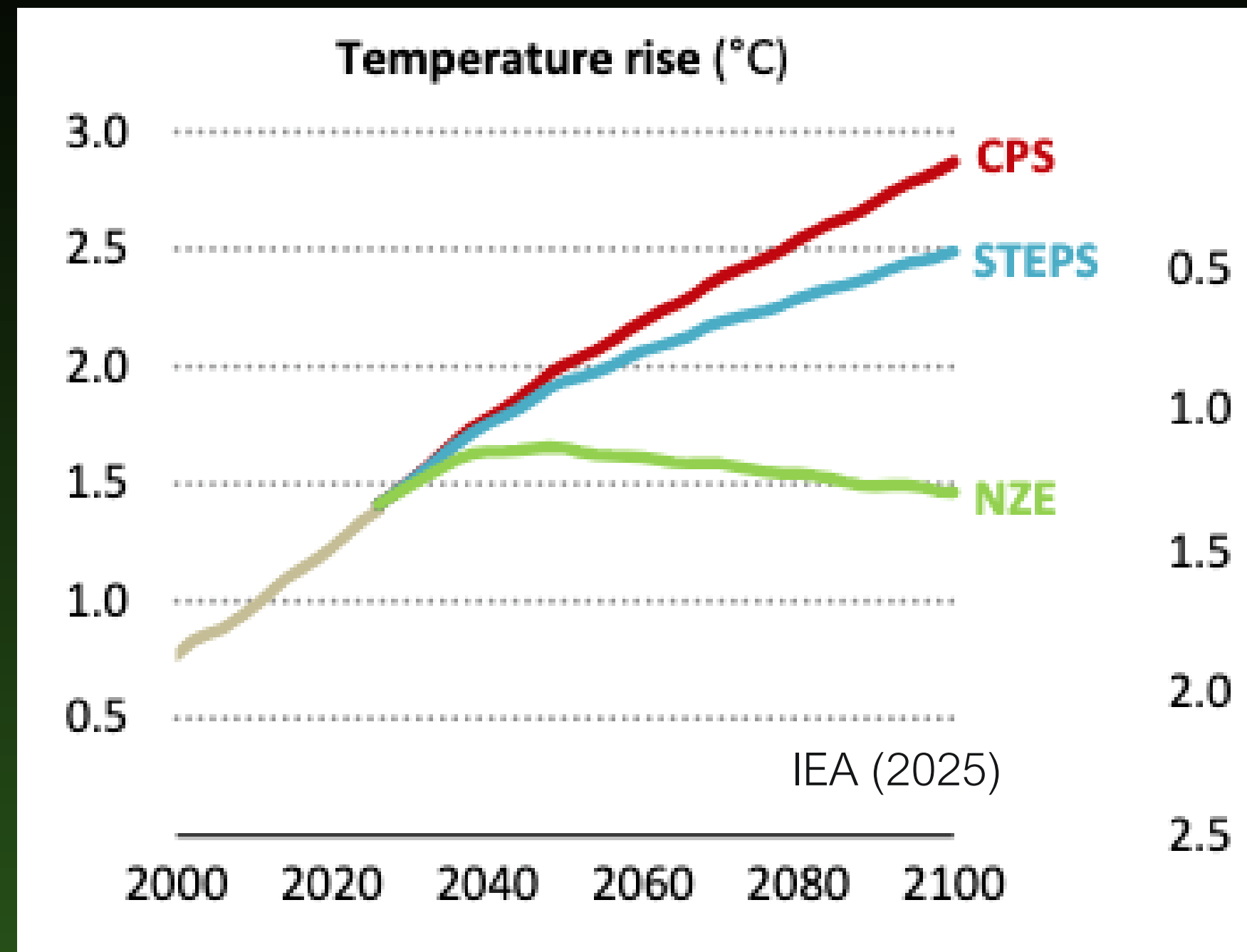
Carbon Utilisation: Challenges post Capture



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Bundesministerium
für Forschung, Technologie
und Raumfahrt

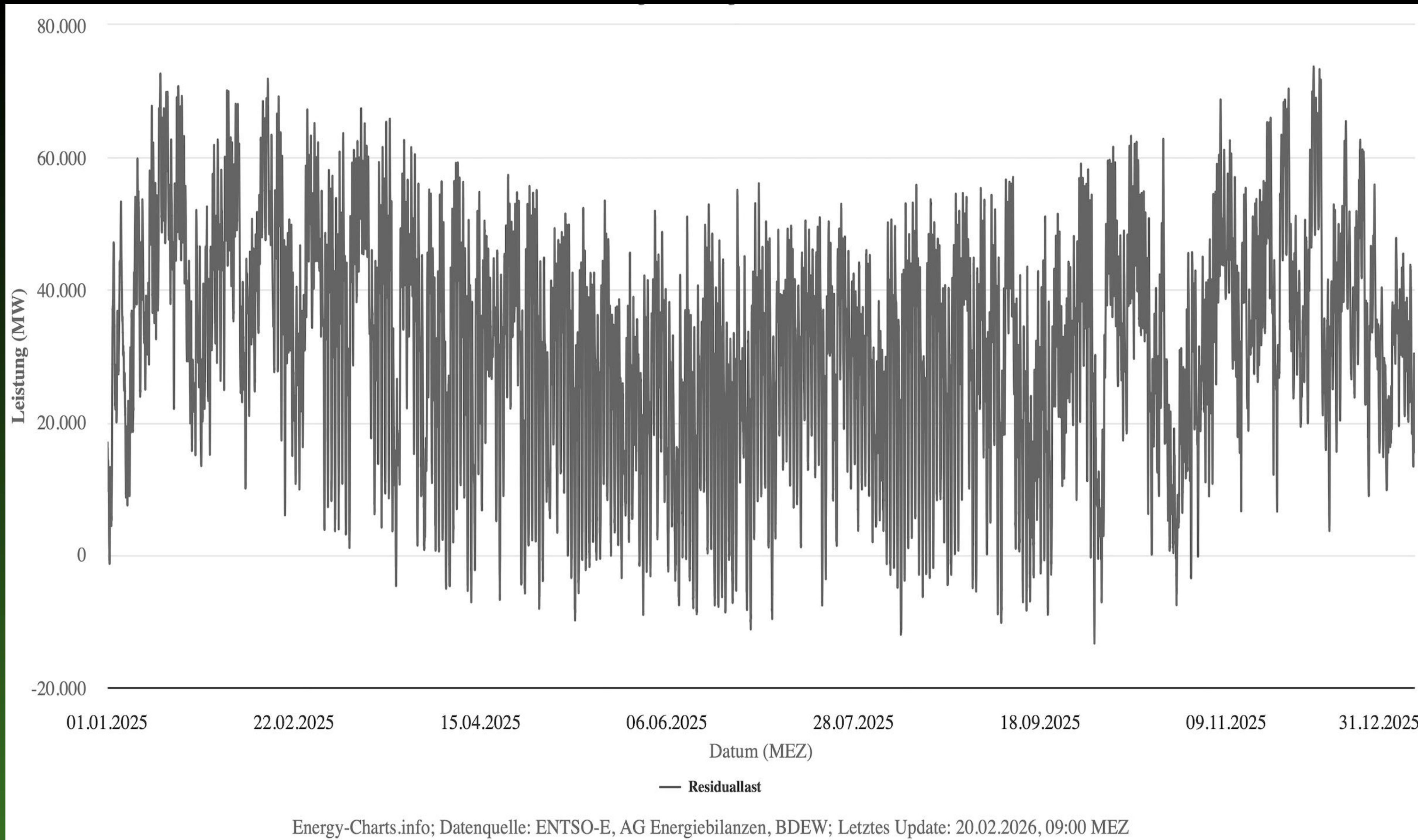
Credit to the whole C2C team:

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With data from
H. Ruland MPI CEC and team
K. Büker tk Uhde and team
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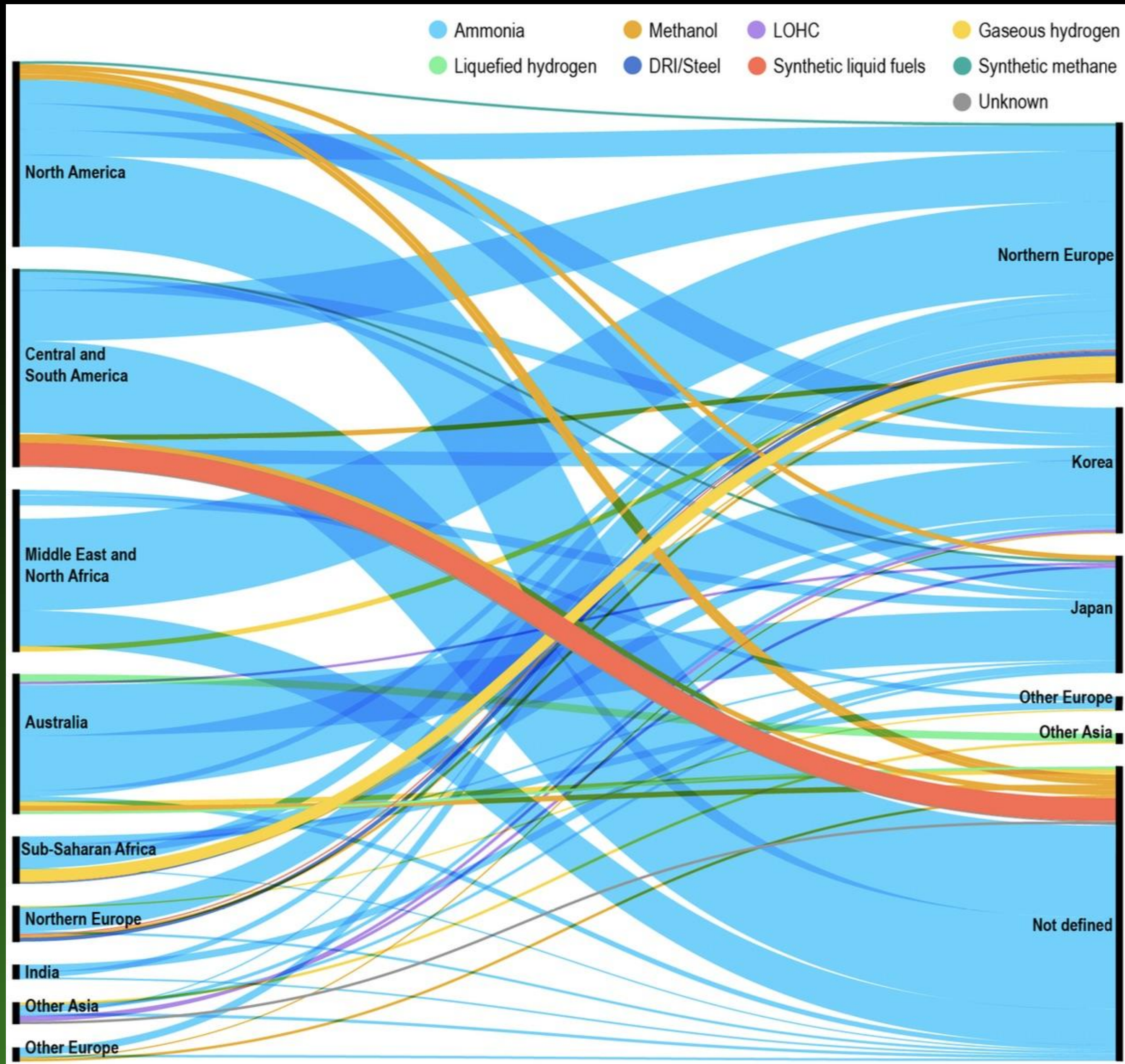


Sustainable Energy System



	H ₂ content (Kg/m ³ liquid)
Hydrogen	70
Ammonia	120
Methane	107
Methanol	100
Isobutanol	110
Isocatane	110

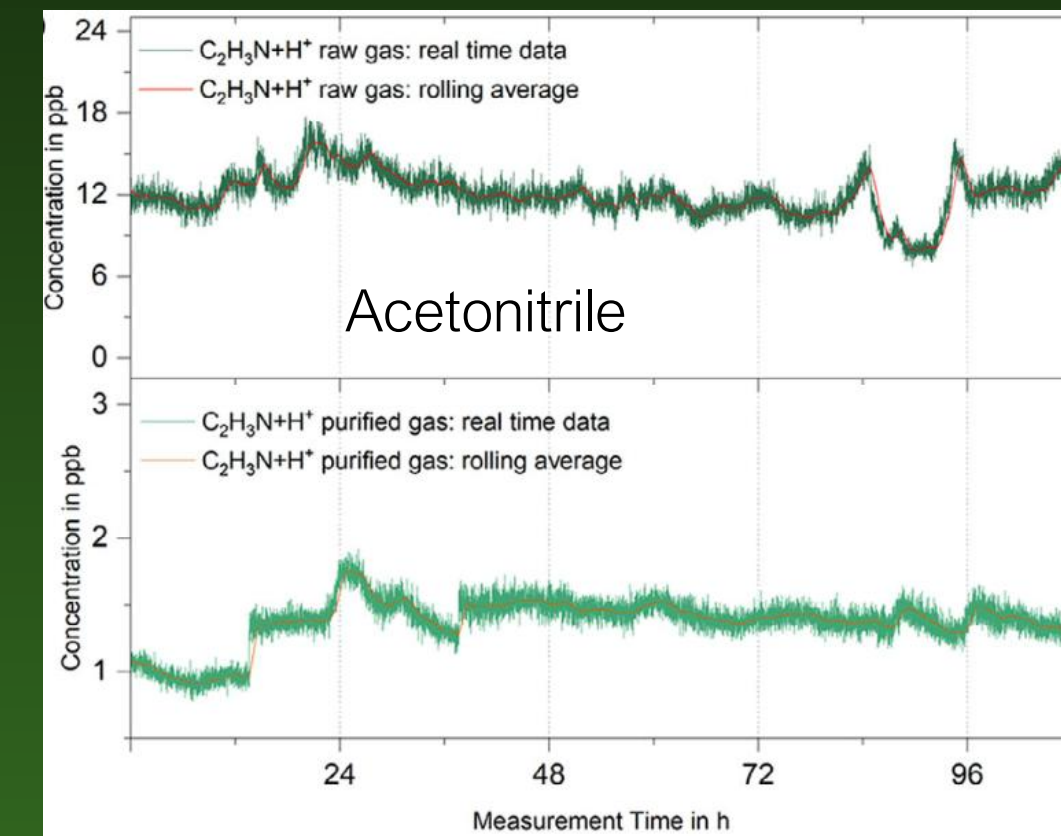
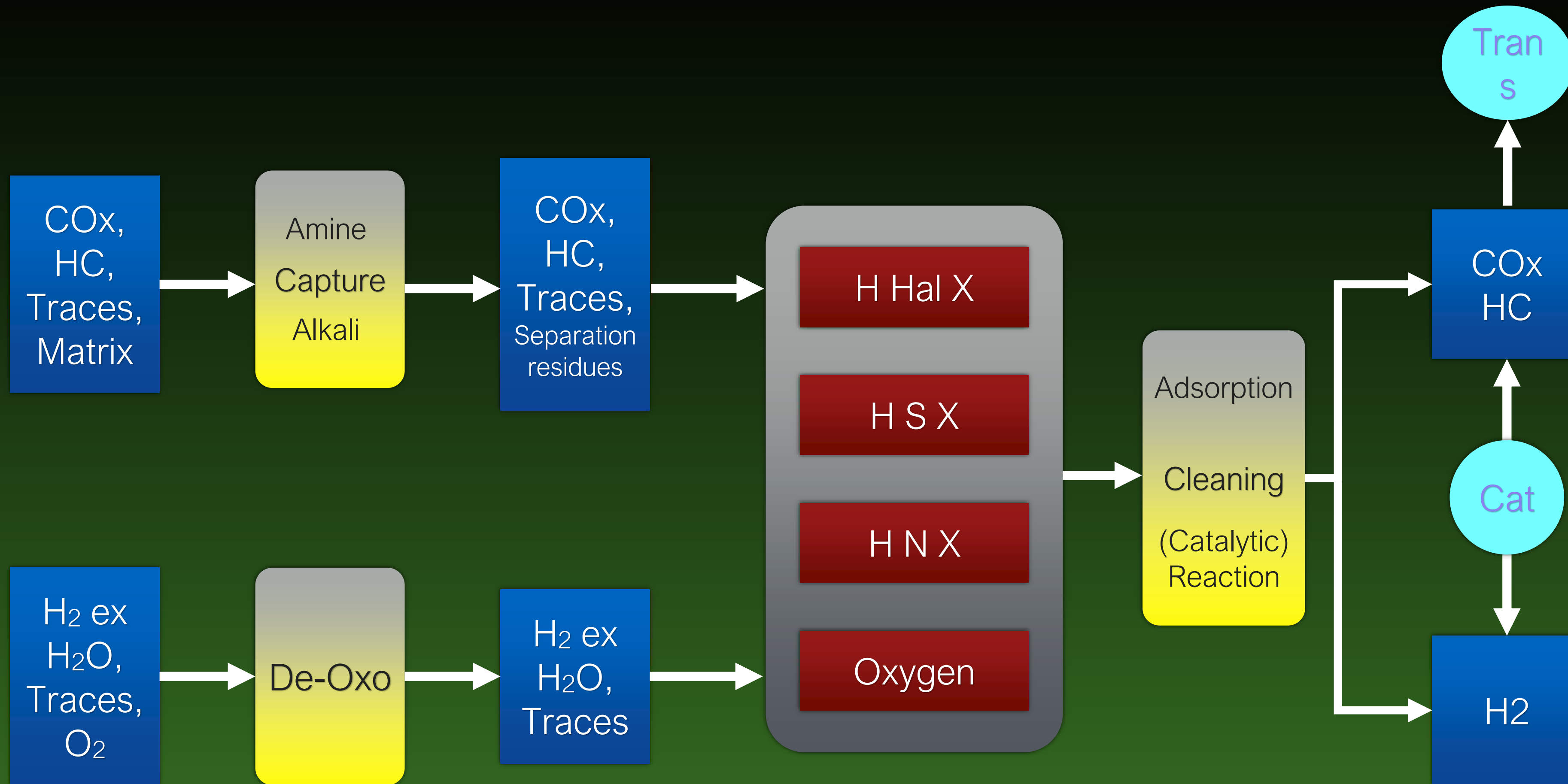
Trade



Source: IEA (2025), Green Hydrogen Review

- Diagram shows 10 Mtpa hydrogen (equivalents) in 2030 contracted volumes
- Represents about 60% of current ammonia production
- Regulatory rigor inhibits CCU fraction (chemicals, shipping)

CCU(S) Feeds



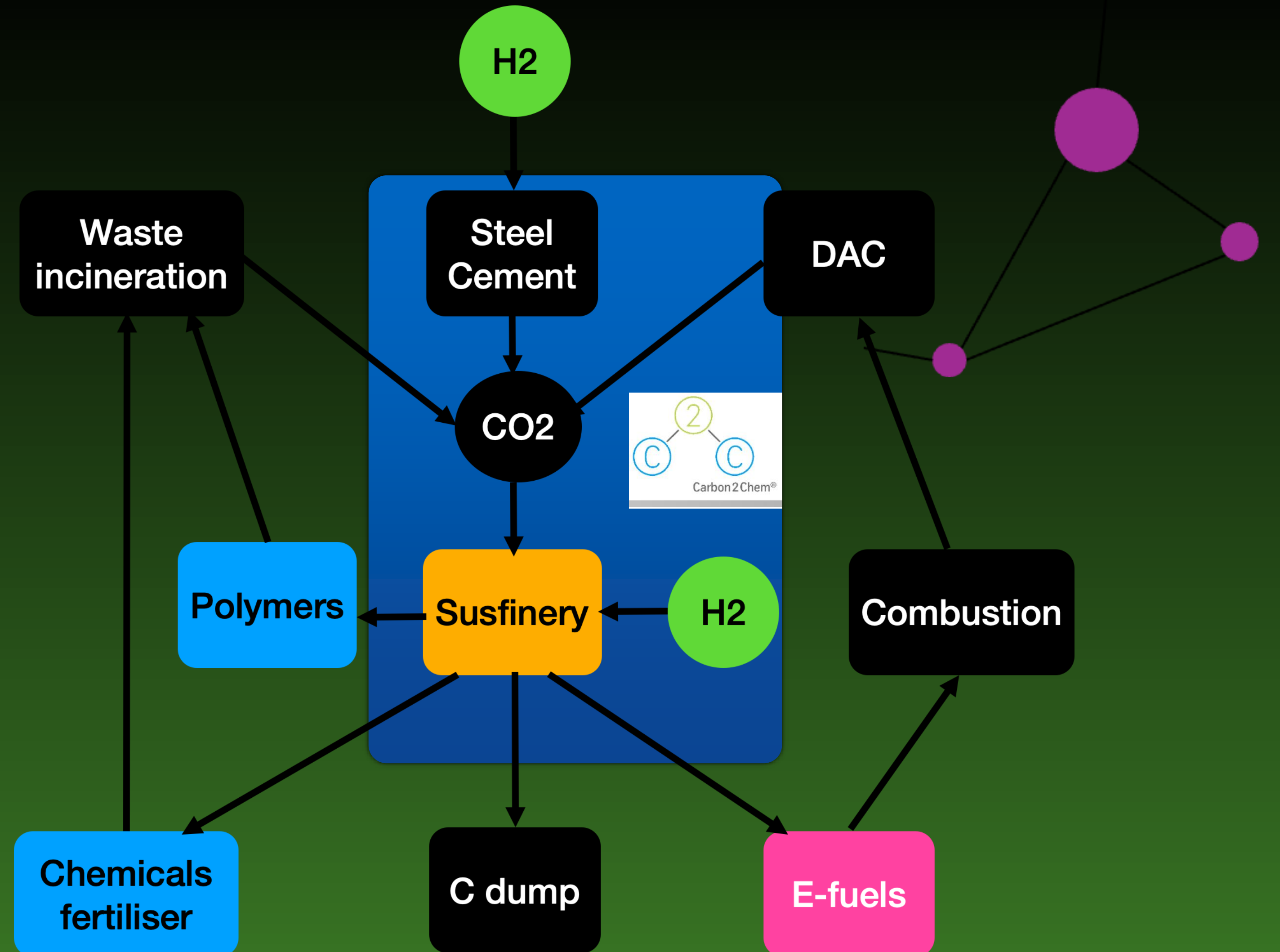
Multiple steps of conditioning required (analysis, standards, process control)

Carbon2Chem: Part of the Carbon Cycle

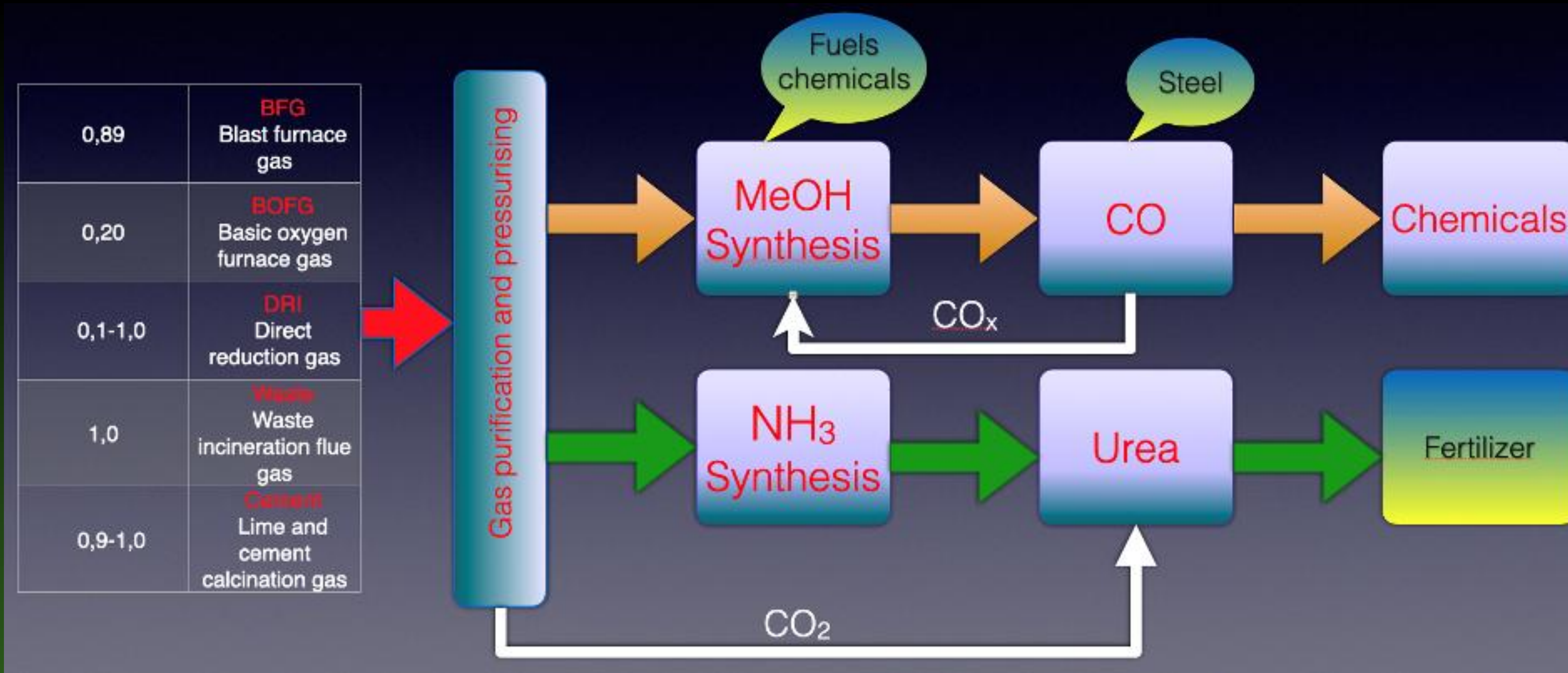
- C2C is a cross-industrial project to realise the first segment of the carbon cycle
- From tail gases to the platform molecule methanol
- Applications as e-fuel in serial hybrid car and feedstock for chemicals and SAF

80% energy loss with respect to primary electricity

Infinitely scalable, planet receives every year 4500 TWa electricity over land

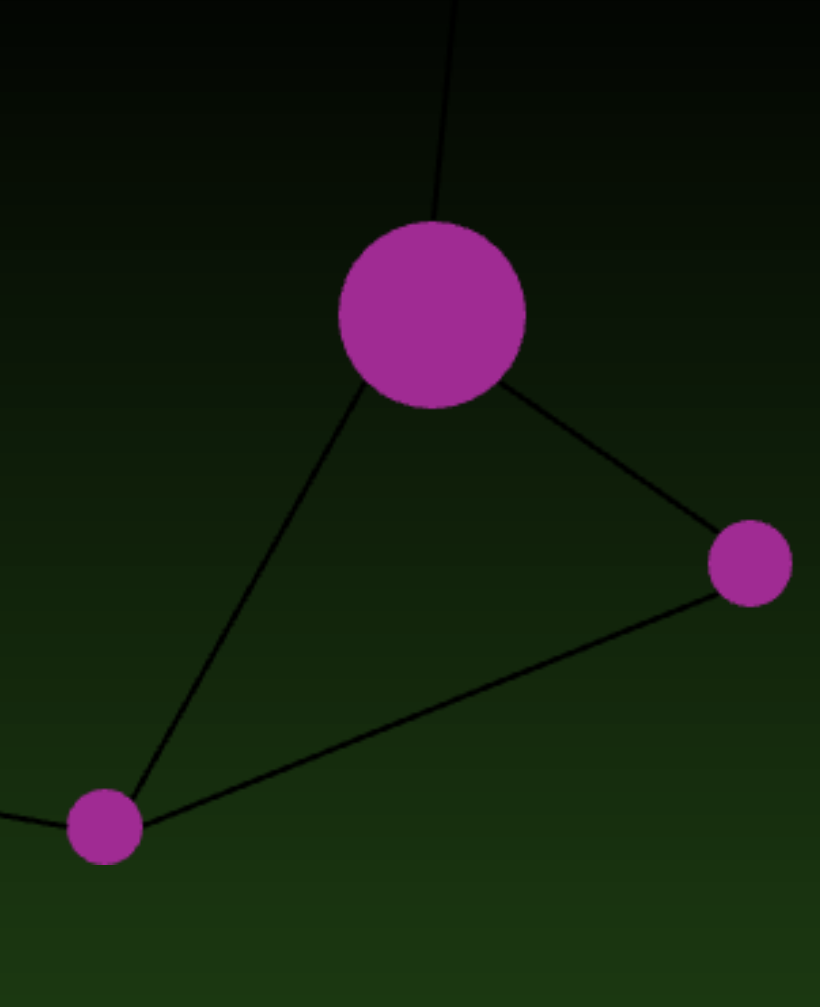
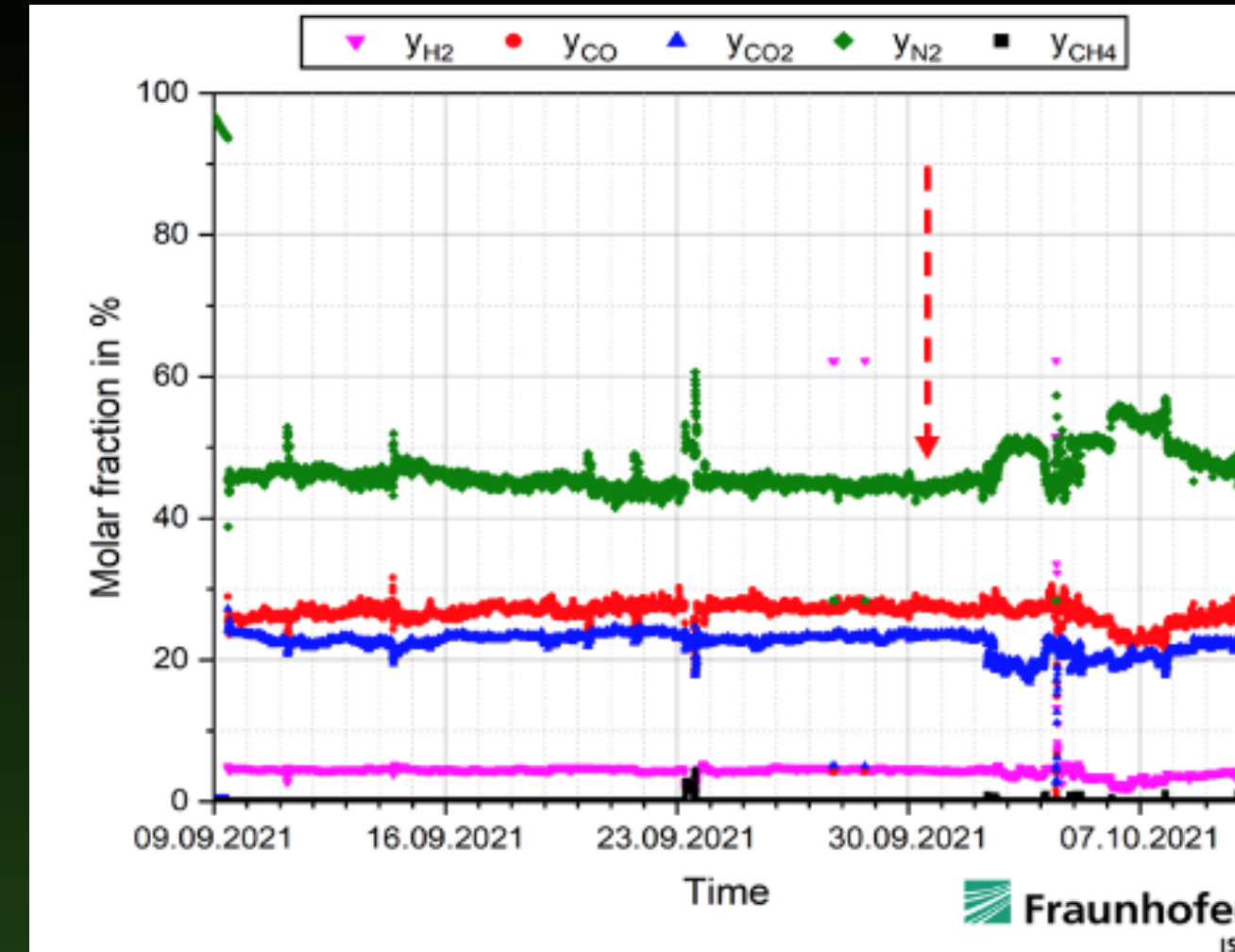
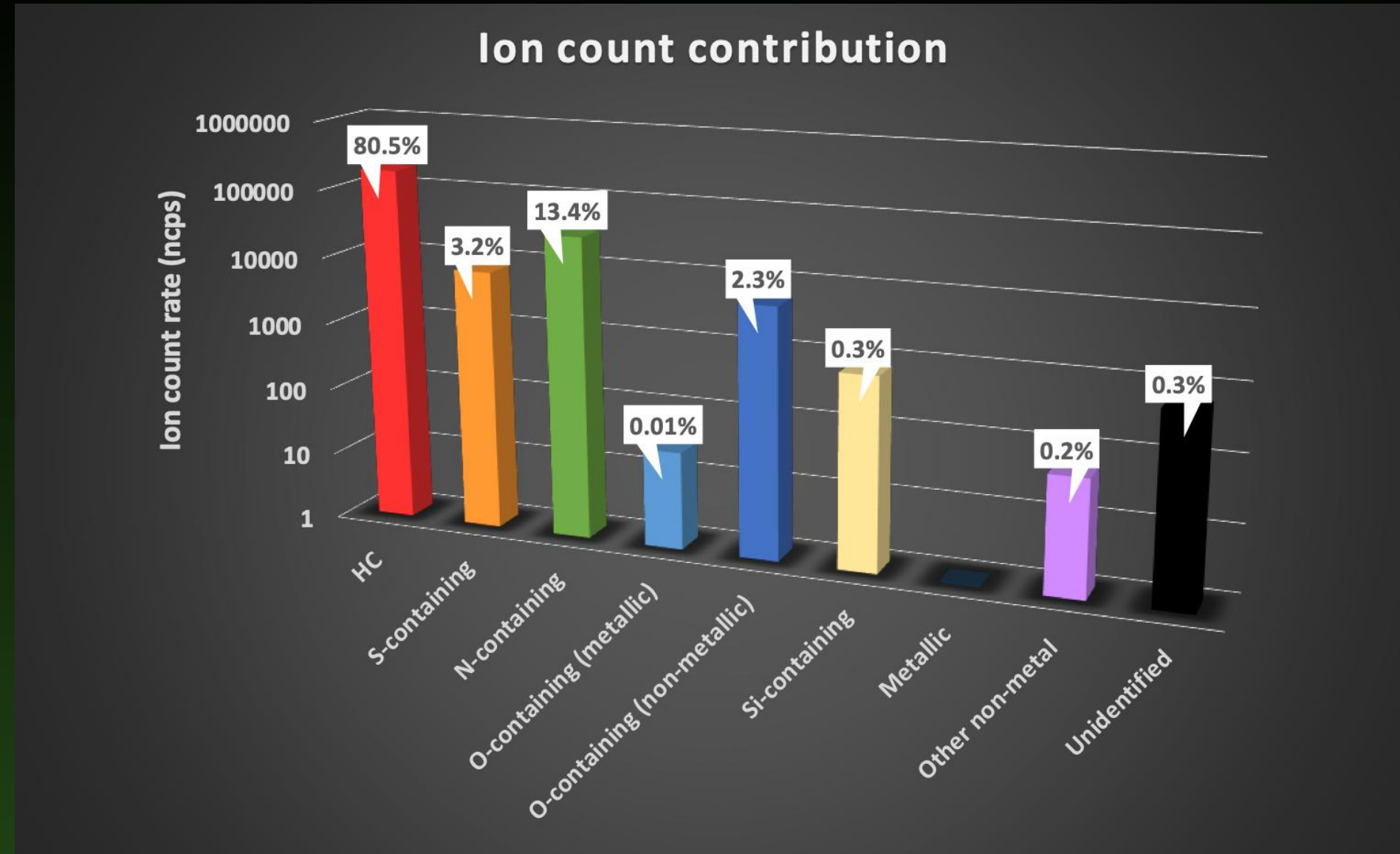


CCU as a Systems Approach

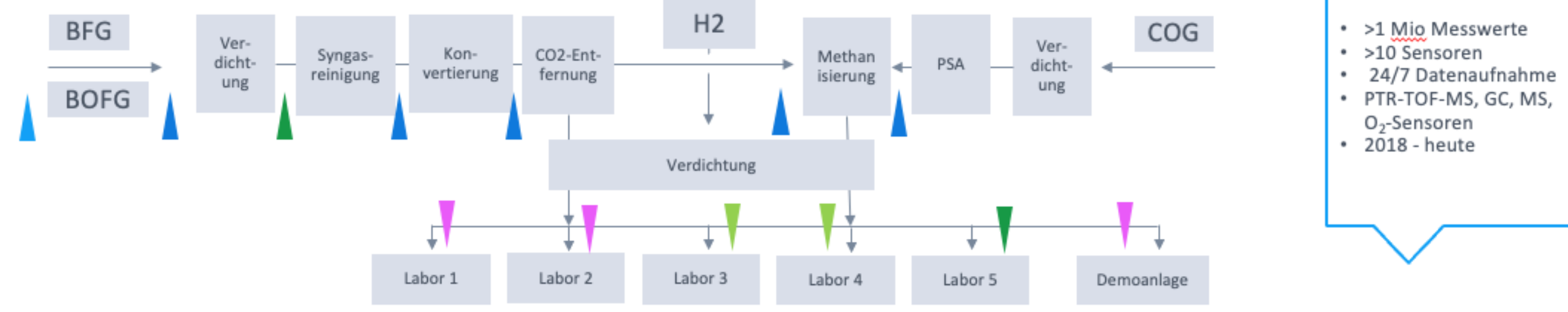


- Simulation using industrial data of CCU from various feedstocks to MeOH and ammonia with local and imported energy (hydrogen) under dynamic supply of sources and energy
- Only limited CO₂ saving within 2030 German energy system when island solution
- Highly useful with system-wide import of green energy (hydrogen)

Typical Feedgas for CCU: Steel

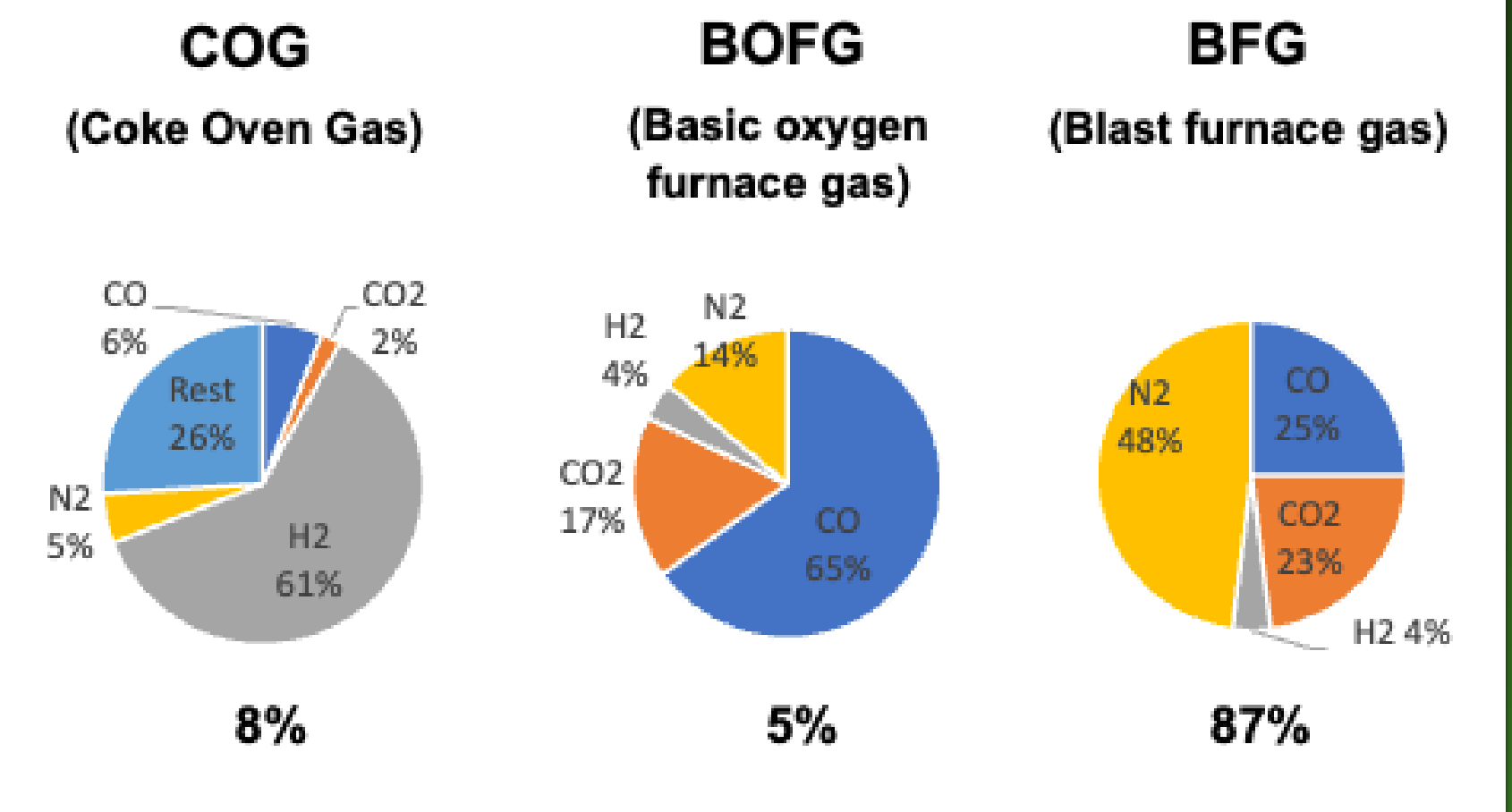


Oxygen	< 10,000	800 – 5,000	200 – 1,000
H ₂ S [ppm]	300 - 400	0.5 – 1.5	2 – 50
COS [ppm]	150 - 250	0.2 - 5	10 - 70



- >1 Mio Messwerte
- >10 Sensoren
- 24/7 Datenaufnahme
- PTR-TOF-MS, GC, MS, O₂-Sensoren
- 2018 - heute

tk Steel	tk Uhde	tk Uhde	MPI	Fraunhofer
Massenspektrometer	Massenspektrometer	GC, O ₂ -Sensoren, FTIR	Protonentransfer-TOF-Massenspektrometer, GC	GC, Dichte
CO, CO ₂ , H ₂ , N ₂ , Ar, H ₂ O, O ₂ , CH ₄	CO, CO ₂ , H ₂ , N ₂ , Ar, H ₂ O, O ₂ , CH ₄ , COS	Methanol, O ₂ , NH ₃	bis zu 3000 Substanzen, Fokus auf Katalysatorgifte HCN, COS, Benzol, H ₂ S, O ₂	MeOH, CO, CO ₂
100 ppm – Vol-%	1 ppm – Vol-%	ppm – Vol-%	ppb - ppm	ppm – Vol-%

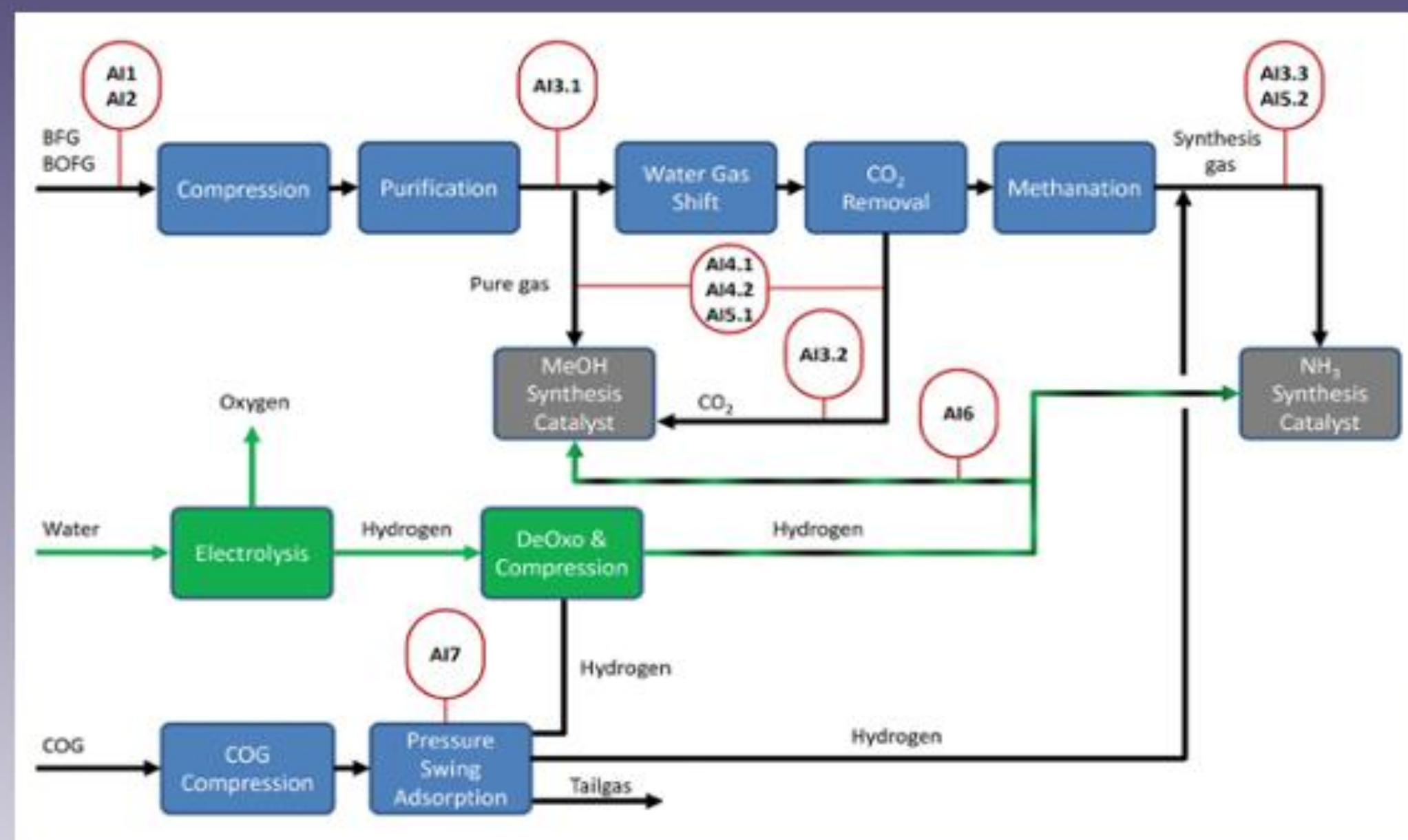


Gas Cleaning

Purification of Steel Mill Gases under Changing Feed Stock Conditions

Dr. Karsten Bucker, Dr. Olaf von Morstein, Dr. omer Yildirim, Nicolai Daheim, Dr. Andreas Frey, Dr. Christian Voss, Dr. Andreas Geisbauer

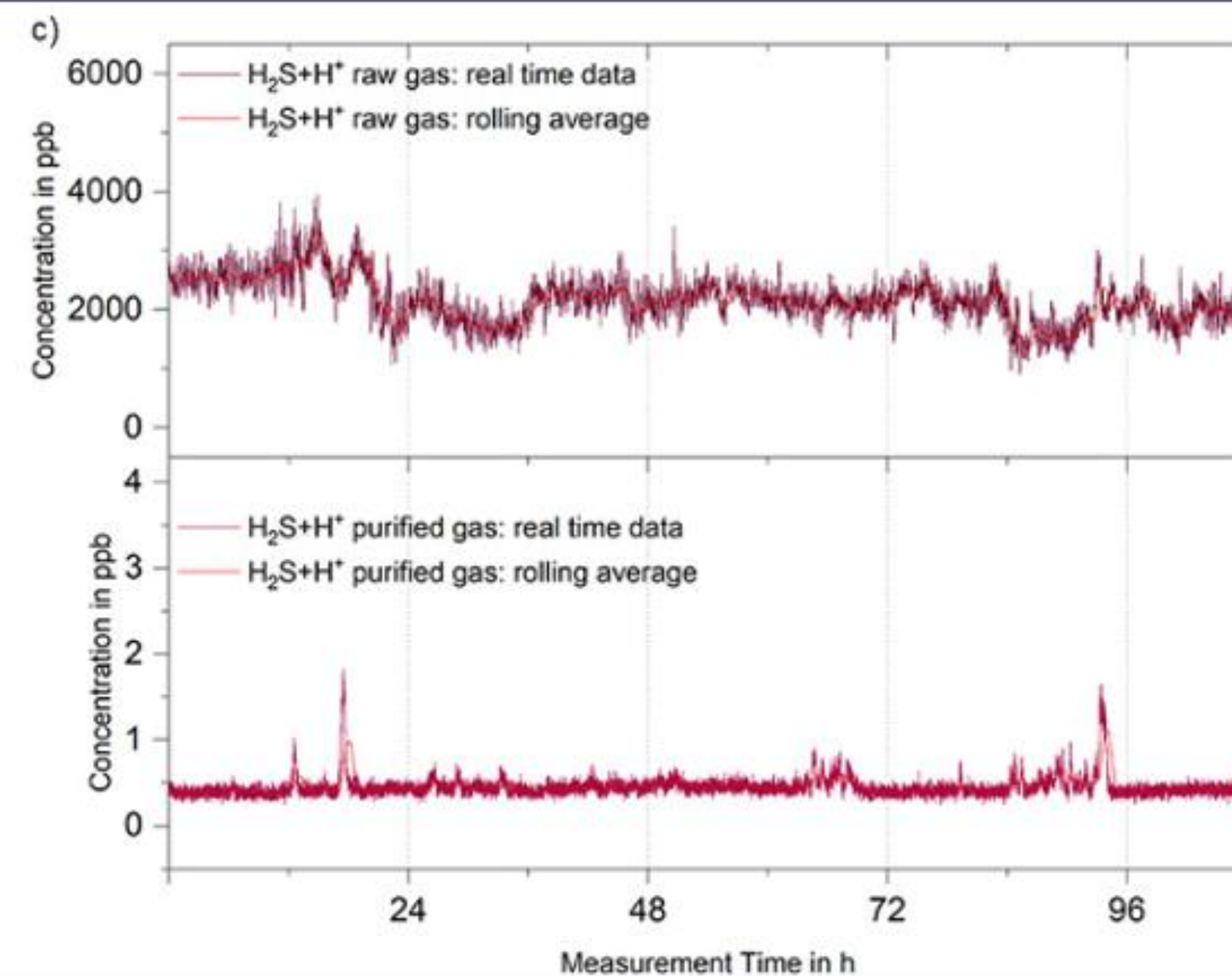
First published: 16 July 2024 | <https://doi.org/10.1002/cite.202400031> | Citations: 1



Concentration Fluctuations in Steel Mill Gases: Analytics as Key to Develop Steel Off-Gas Purification

Dr. Clara Markert, Dr. Corina H. Pollok, Dr. Florian Haakmann, Dr. Holger Ruland

First published: 17 July 2024 | <https://doi.org/10.1002/cite.202400028> | Citations: 1

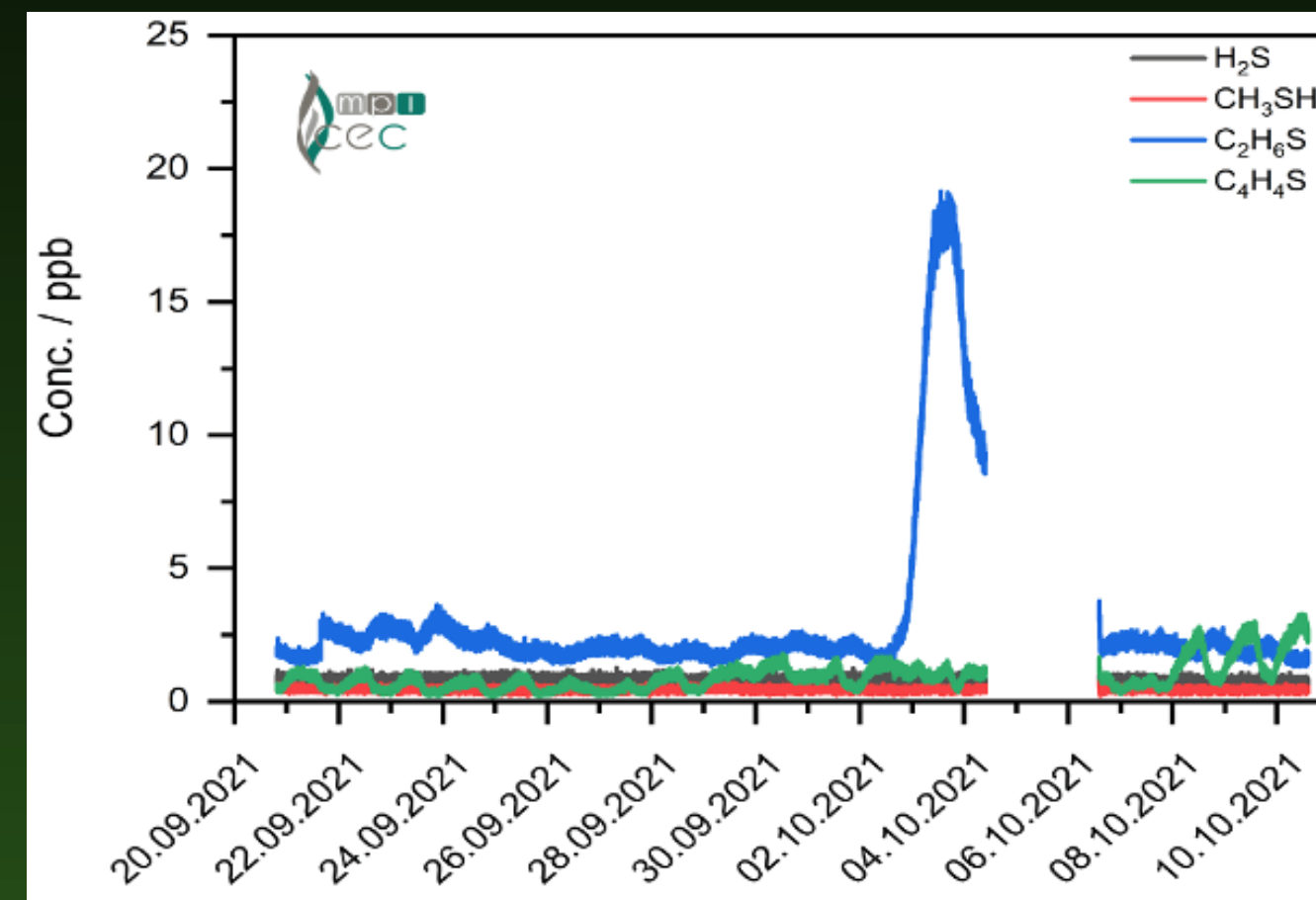
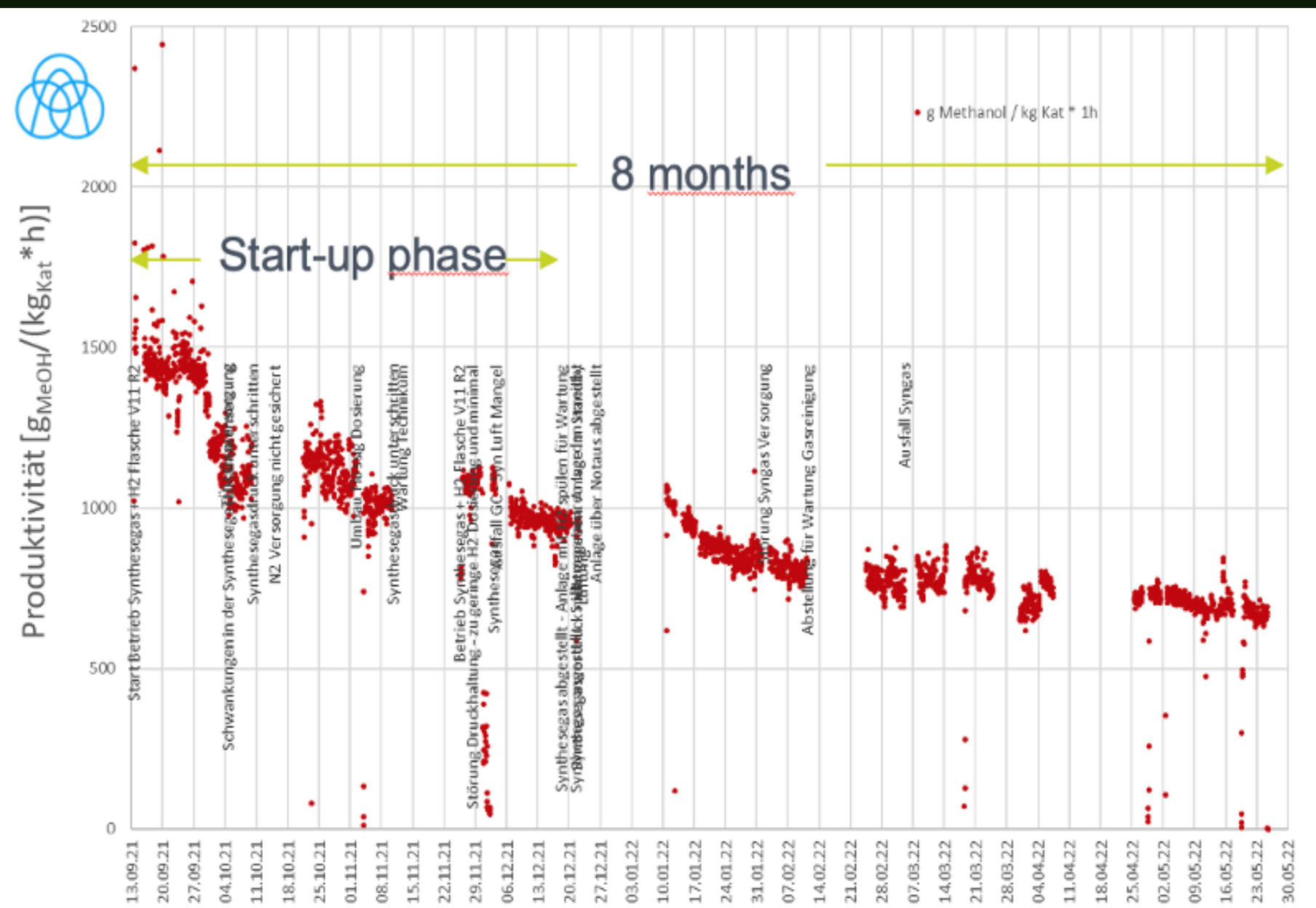


- Proved to be the critical point of the project when considering economics
- Process cost only 4% of the MeOH cost but uptime is critical for system

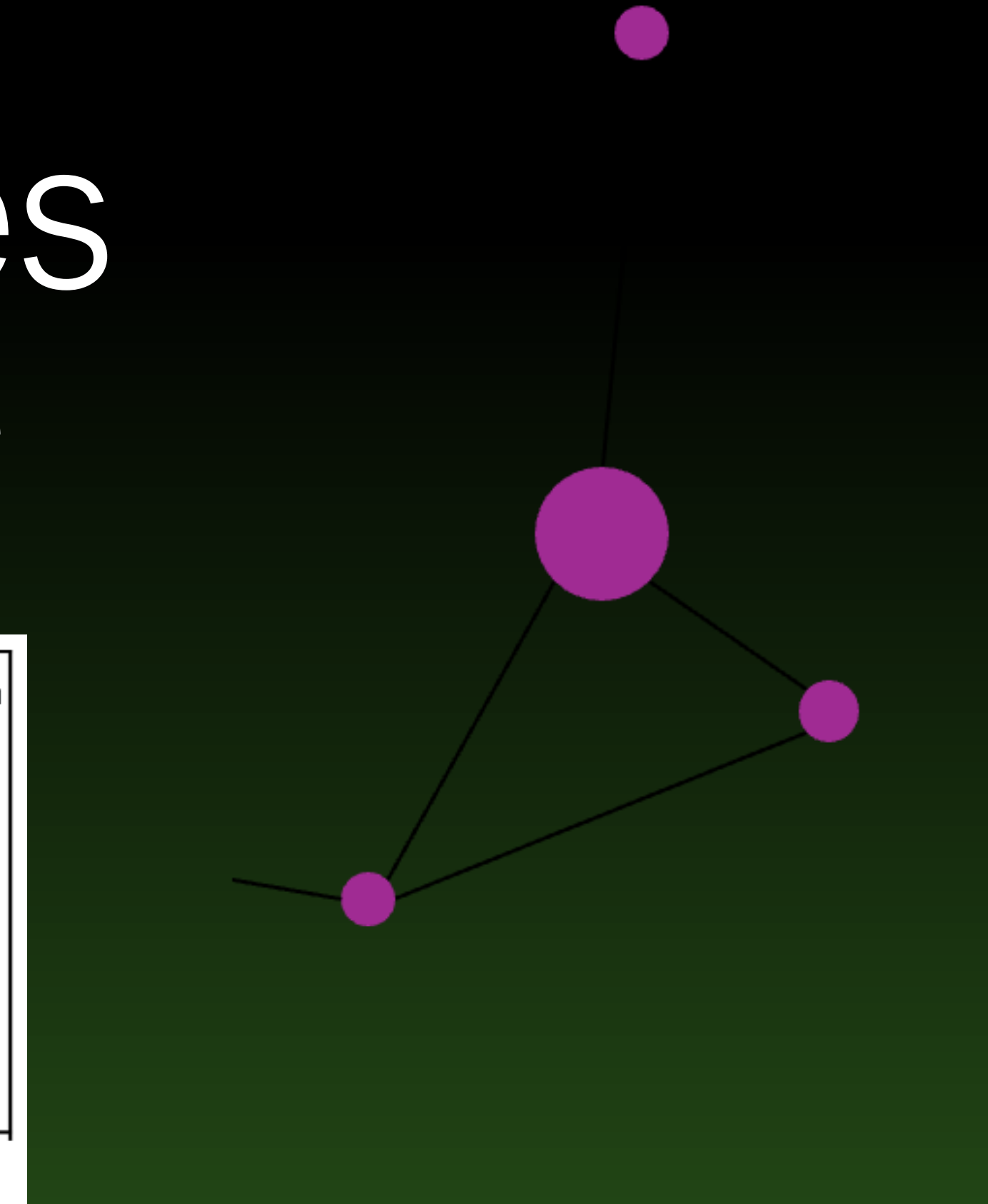
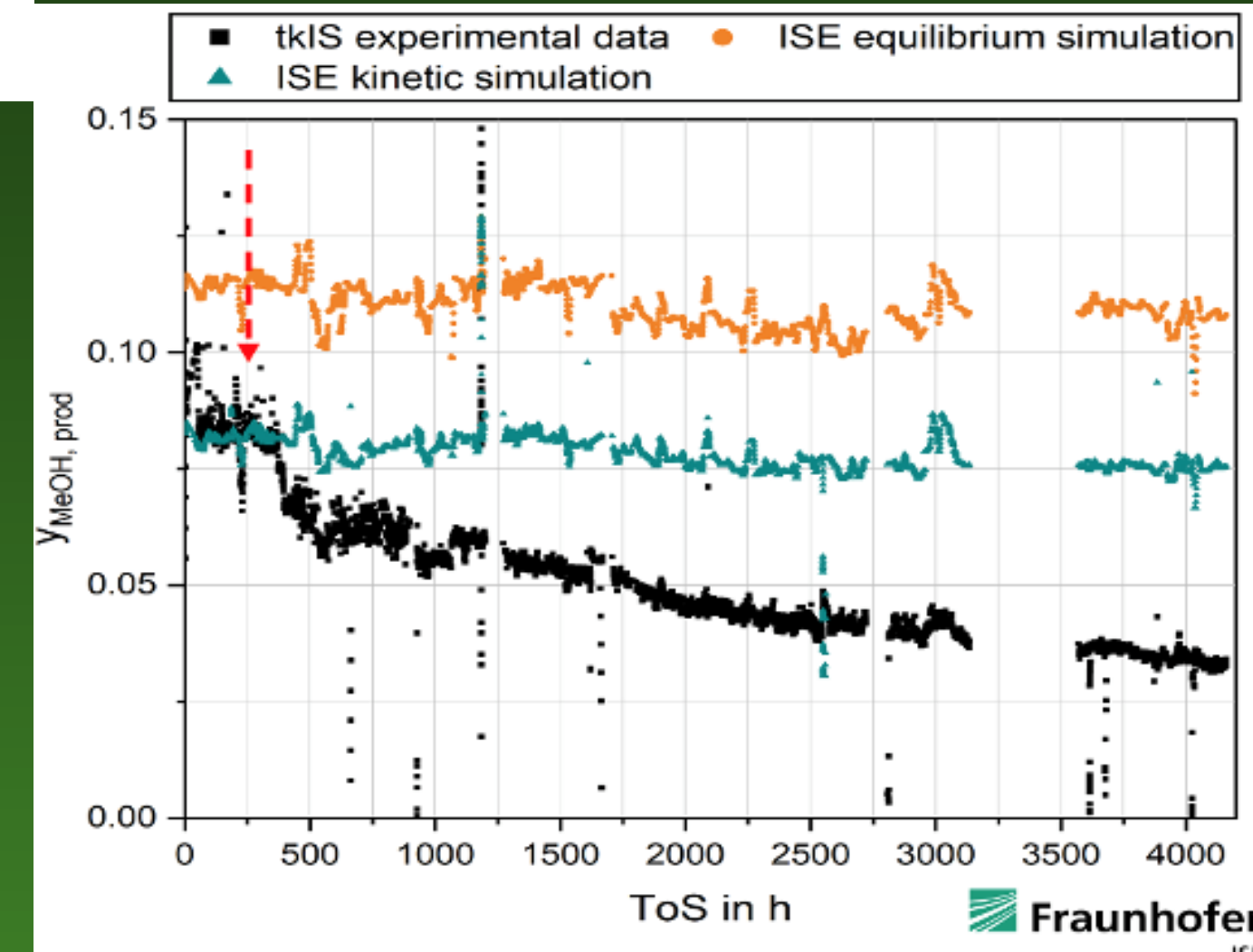
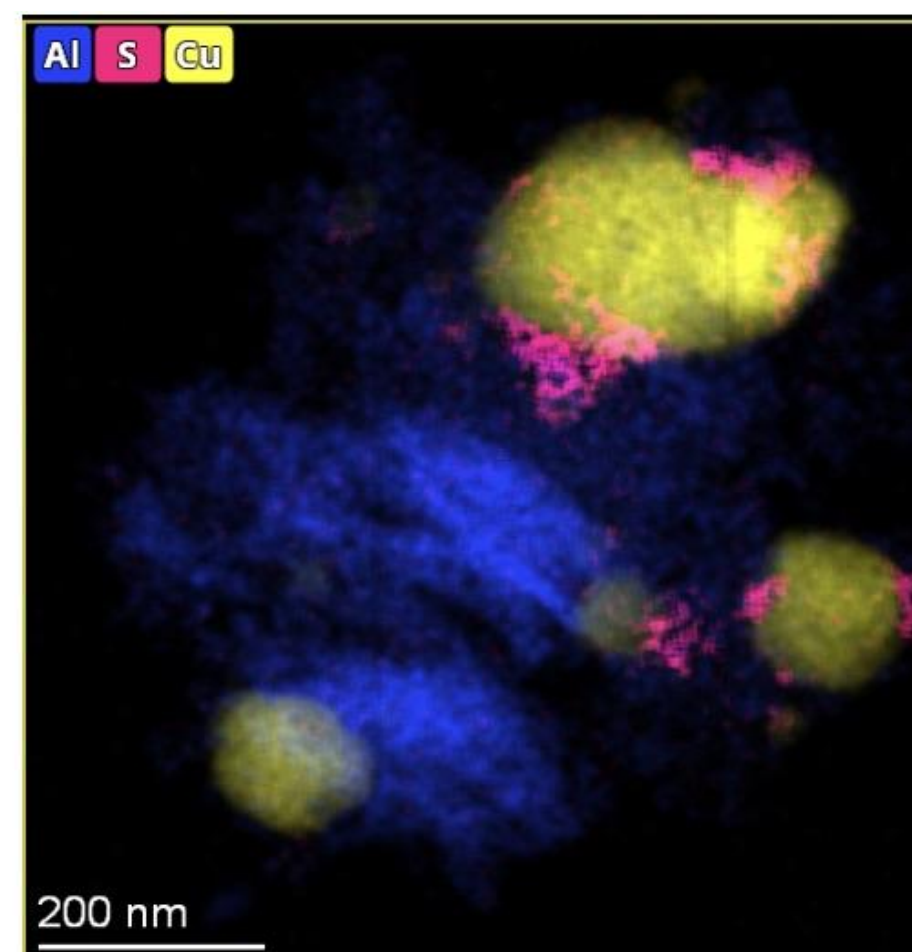


Effect of S Impurities

- Specific singular compounds in ppt concentrations give strong damage to catalytic processes

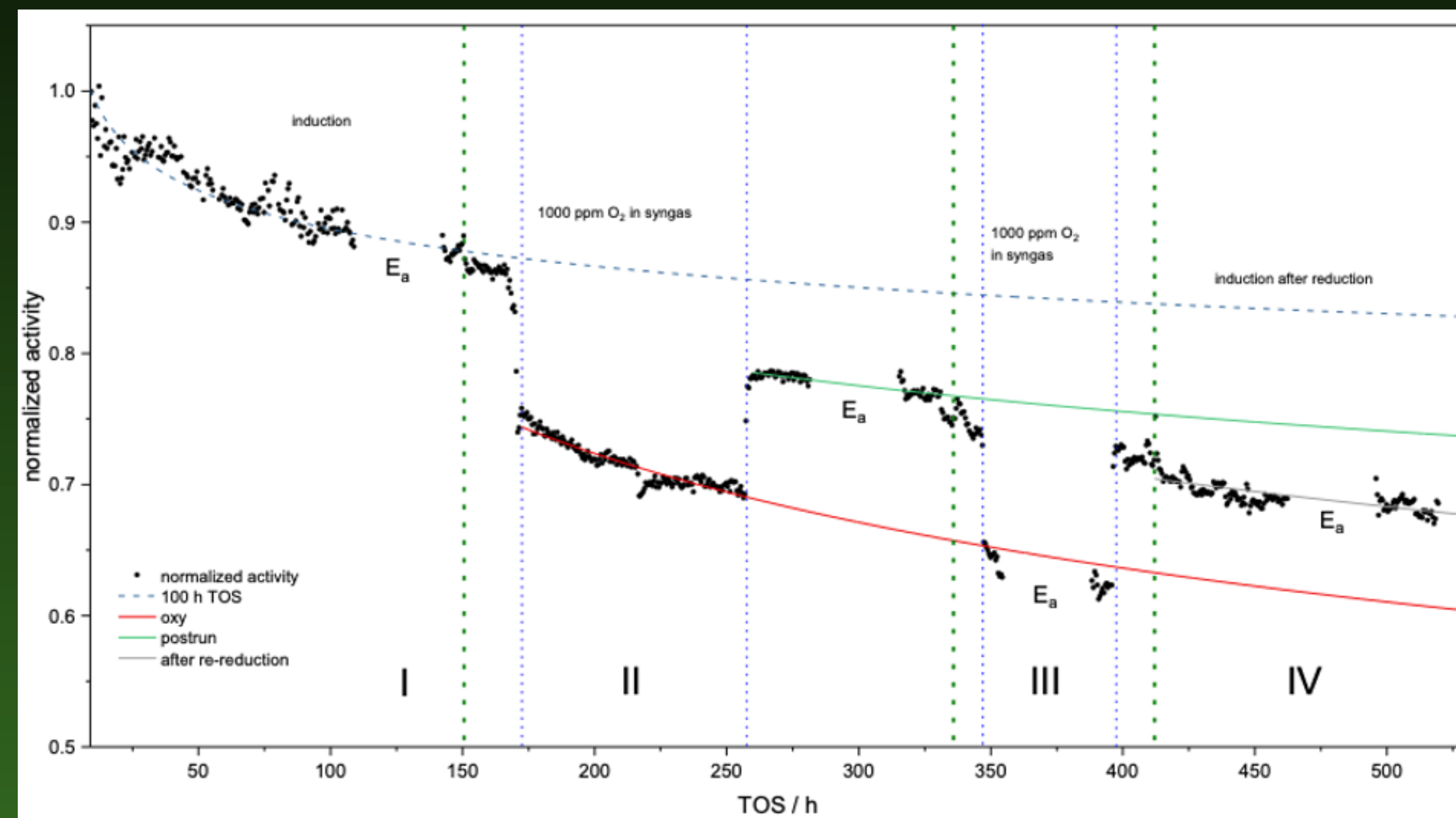


Element	Atomic Fraction (%)
C	5.09
O	24.16
Al	6.78
Si	0.11
S	2.80
Fe	0.31
Co	0.03
Ni	0.16
Cu	42.06
Zn	18.49

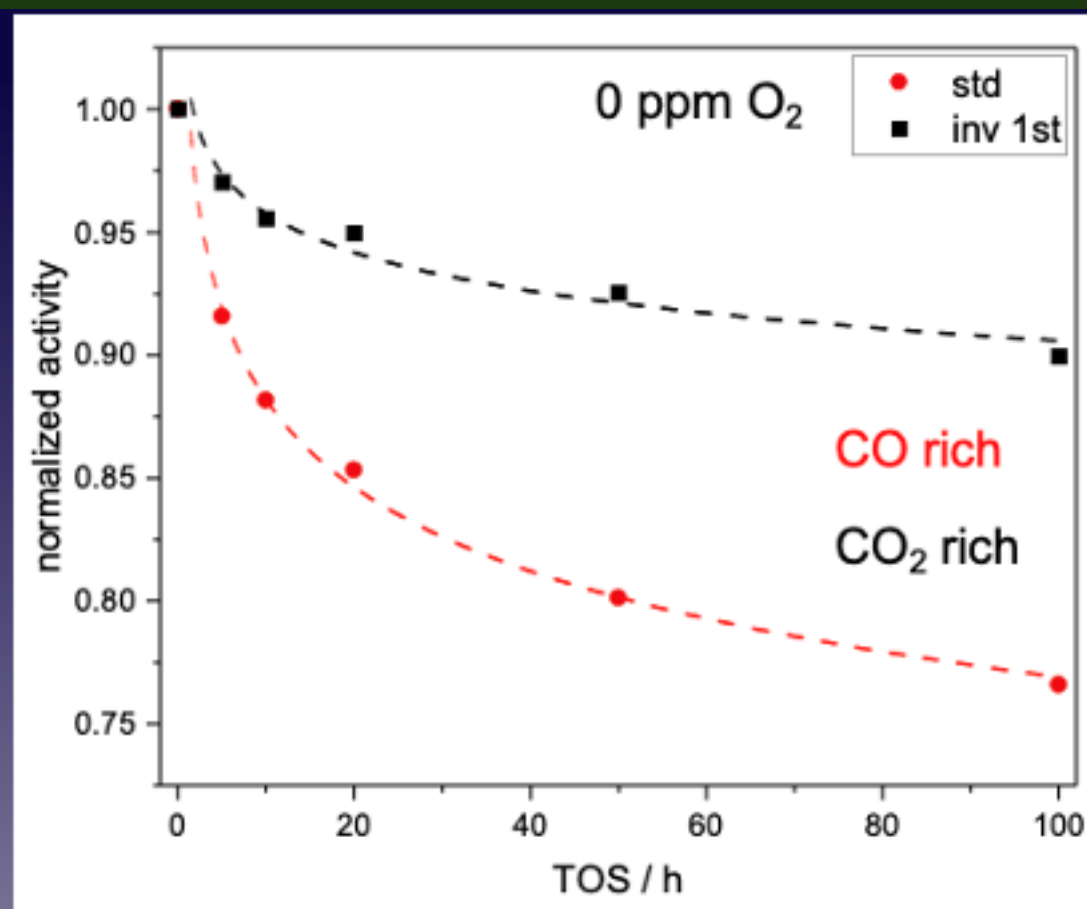


Effect of Residual Oxygen

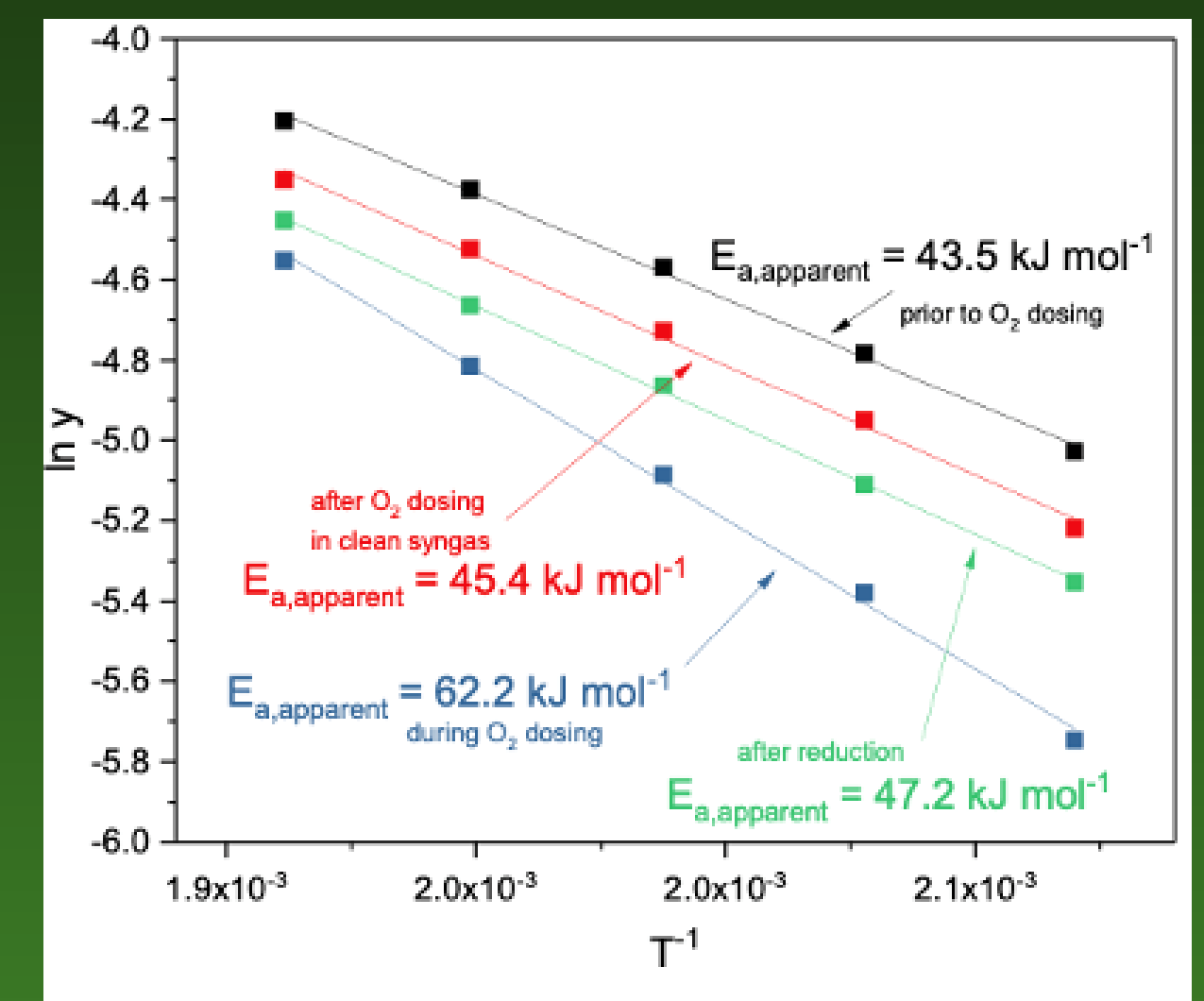
- Oxygen is an ubiquitous trace component in all gasses
- Complex function on metal catalysts, reversible (dissolution, restructuring) and irreversible phase change and segregation)
- Purification below ca. 50 ppm demanding



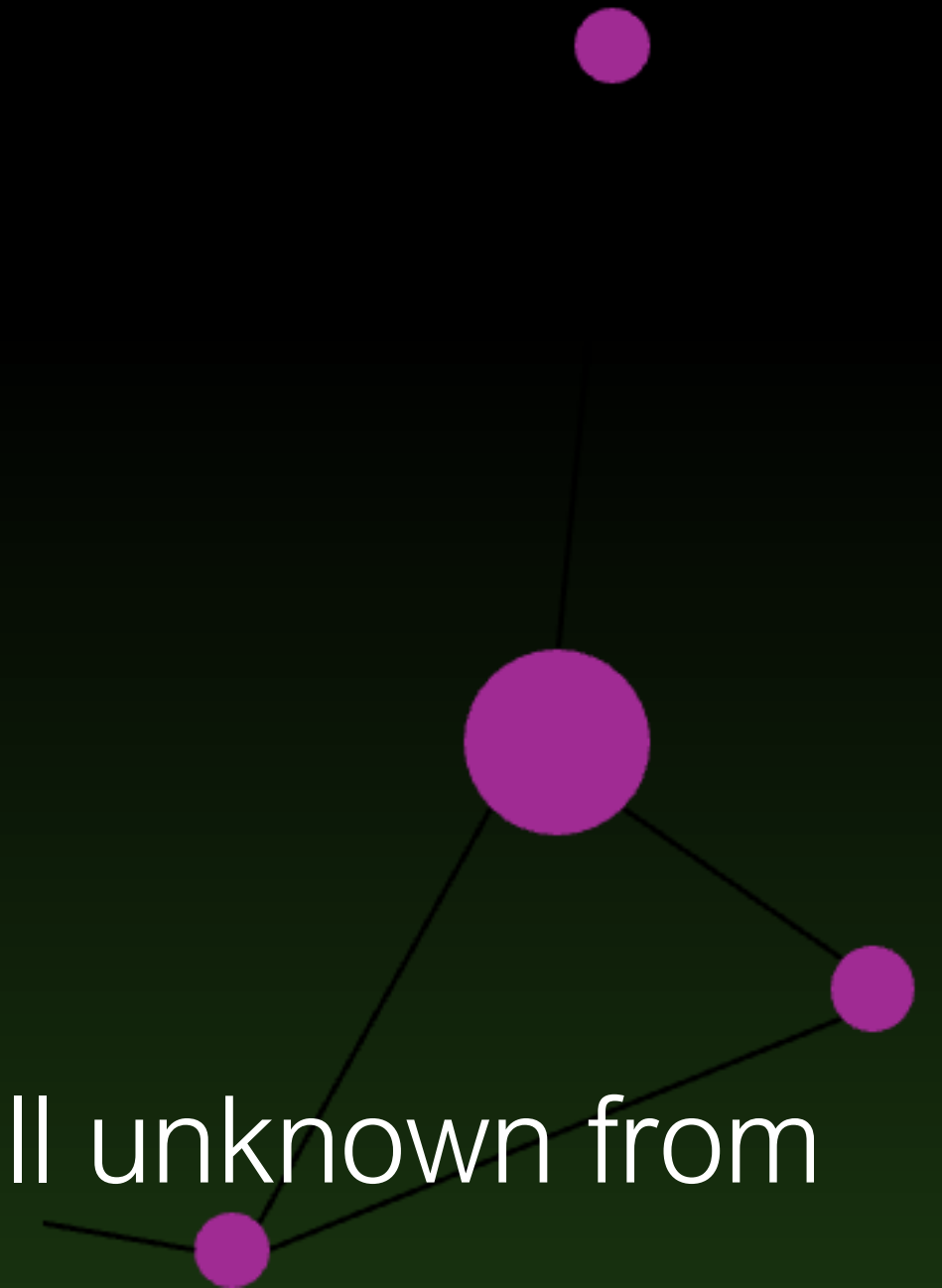
Strongest effect during activation, fully reversible at 300K
 Change in deactivation rates detrimental for process economics



Two feed conditions:
 CO₂: à 13.5%CO₂ / 3.5% CO / 73.5% H₂ / 9.5 N₂
 CO: à 3.5%CO₂ / 13.5% CO / 73.5% H₂ / 9.5 N₂



Learnings



- Hydrogenation of CO_2 is the critical step in all CCU
- Known reactions use metal catalysts (Cu, Fe, Ni)
- Dynamic supply of feed and energy couple to catalyst dynamics: much still unknown from fundamentals
- Enormous sensitivity to traces (ppt!) of poisons that are ubiquitous in real feed streams
- Capture and conditioning are critical elements in CCU applications
- Cleaning technologies need to be robust and are cost-sensitive (adsorbents)
- Analysis, avoidance and verification are critical requirements with limited attention

J.W. Goethe

Entscheide lieber ungenau in die richtige Richtung als genau in die falsche Richtung

Better decide with uncertainty into the right direction than with certainty into the wrong direction



A. V. Humboldt

Thank You for Your Kind Attention

Alles hängt mit Allem zusammen

Everything is interconnected to anything

