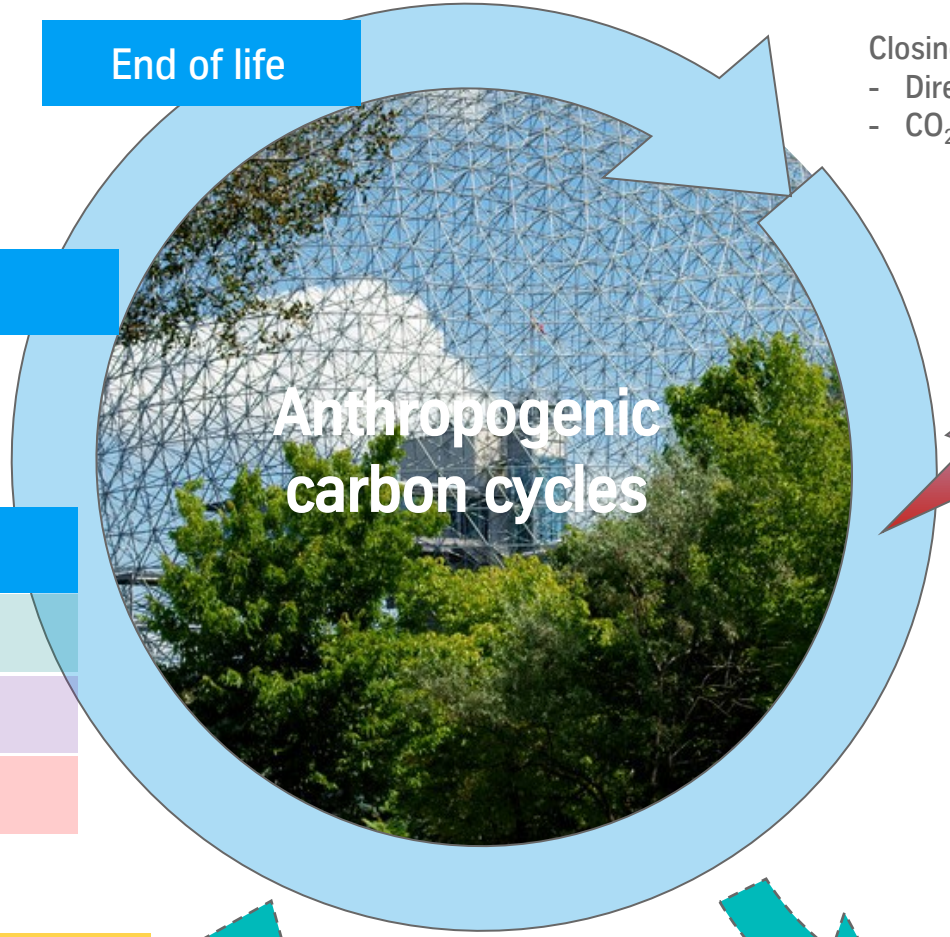
Carbon2Chem®:
Routes towards commodity scale production of high-value platform chemicals

13/04/2023 | thyssenkrupp Steel Europe AG

There is no life without any Carbon in nature

There is no life without any Carbon in plants

Carbon will remain a key element alos in the future



Closing the cycle by
- Direct or indirect reuse
- CO_2 in the atmosphere

Energy

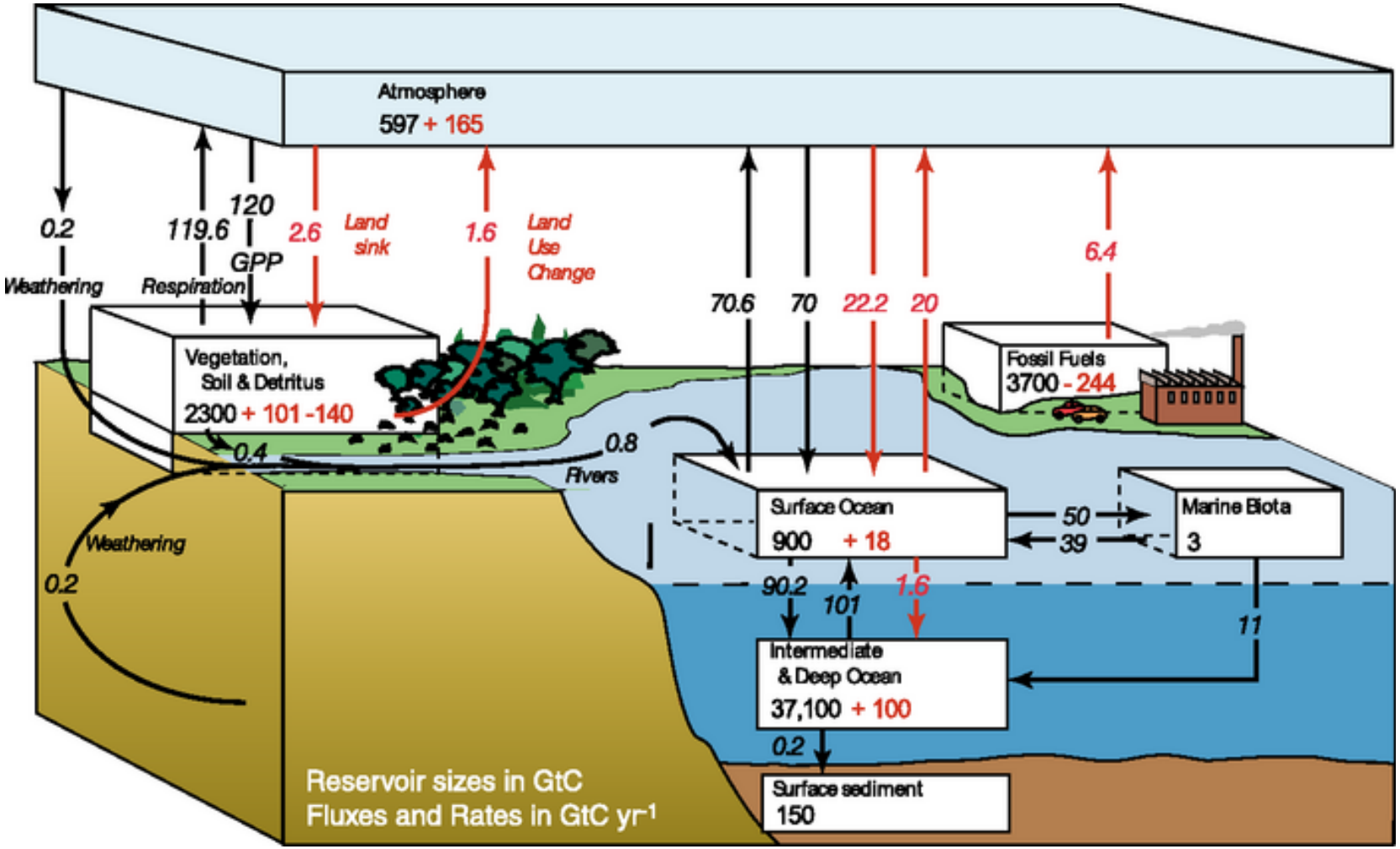
Driving the cycle with renewable energy sources

Balancing net fluxes of carbon fed into cycle and deposited carbon

Carbon Sources

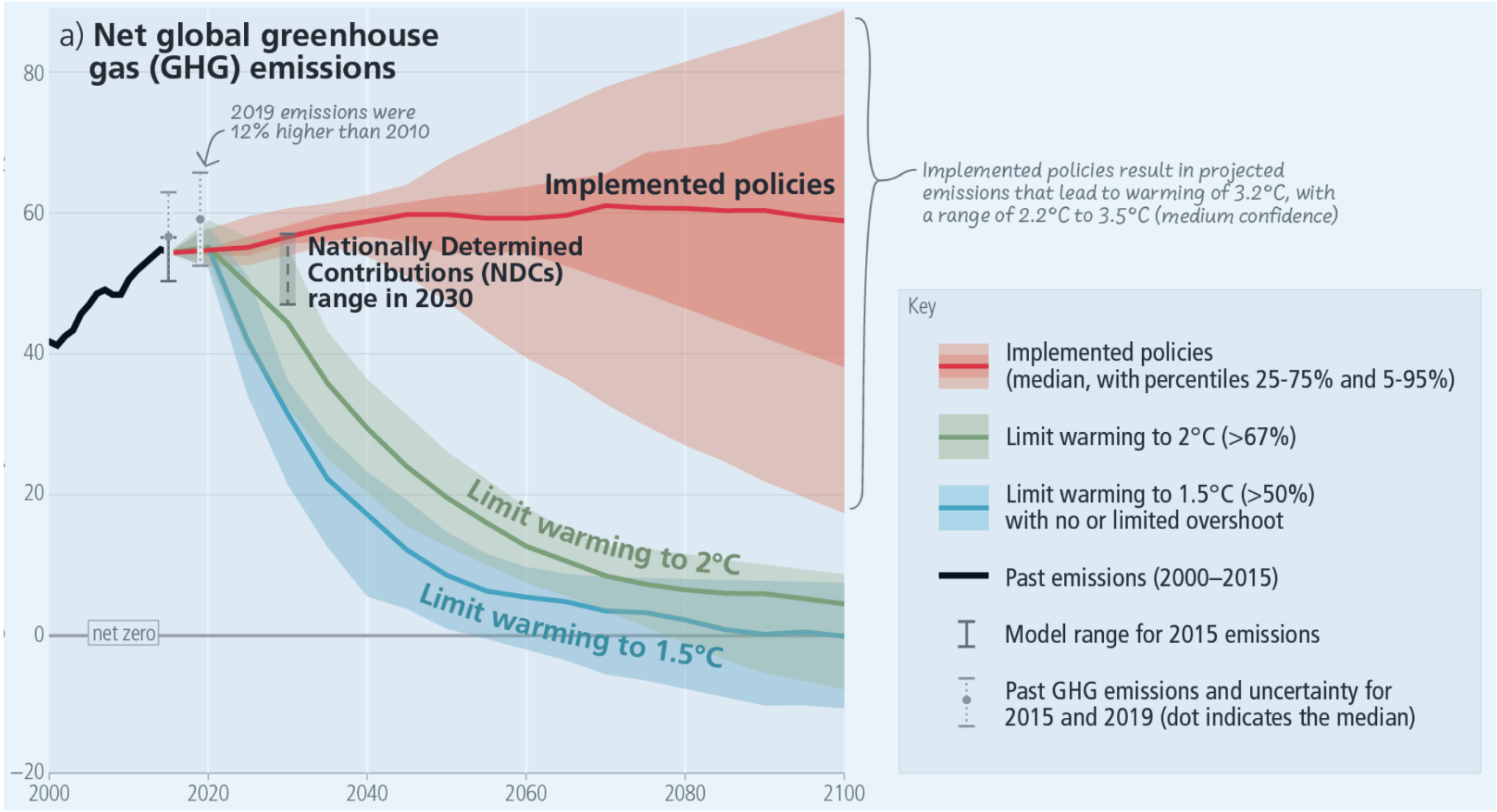
Carbon Sinks

The global Carbon Cycle can absorb huge amounts of Carbon, but ….



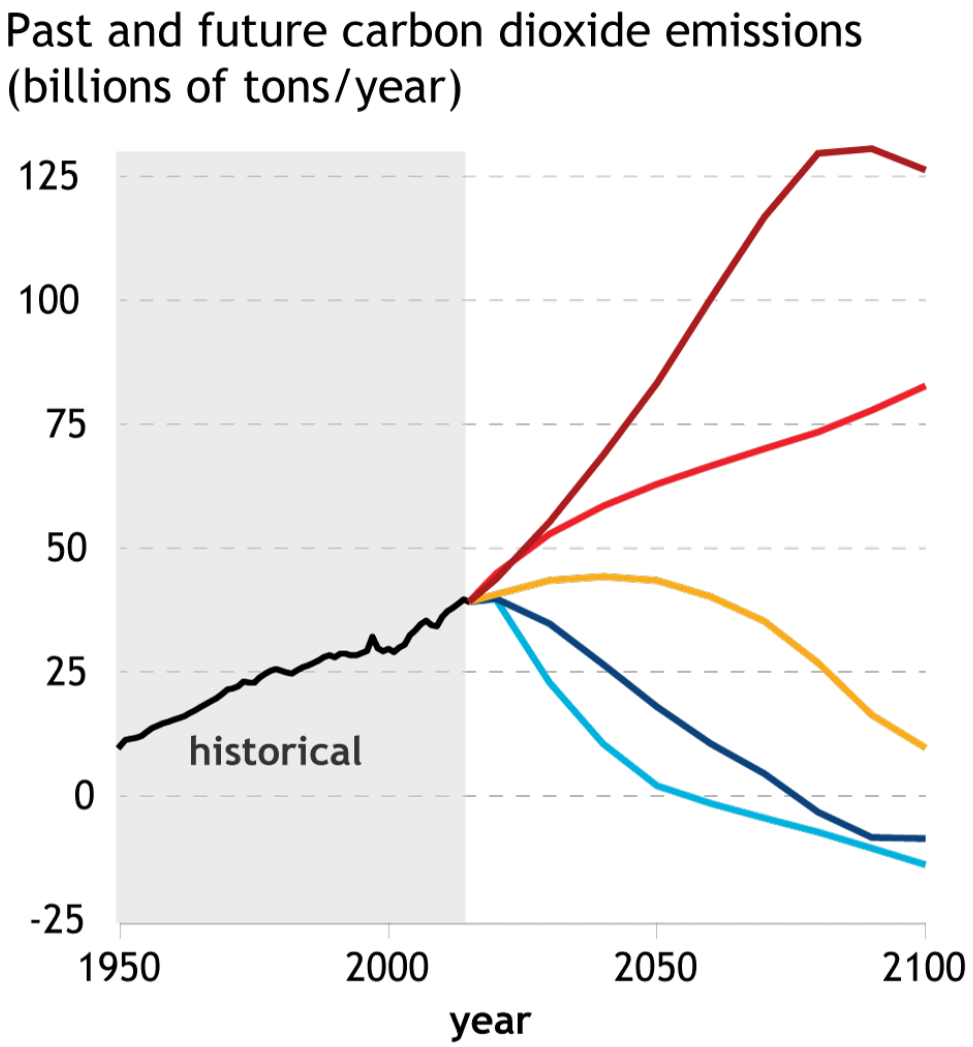
Scource: IPCC

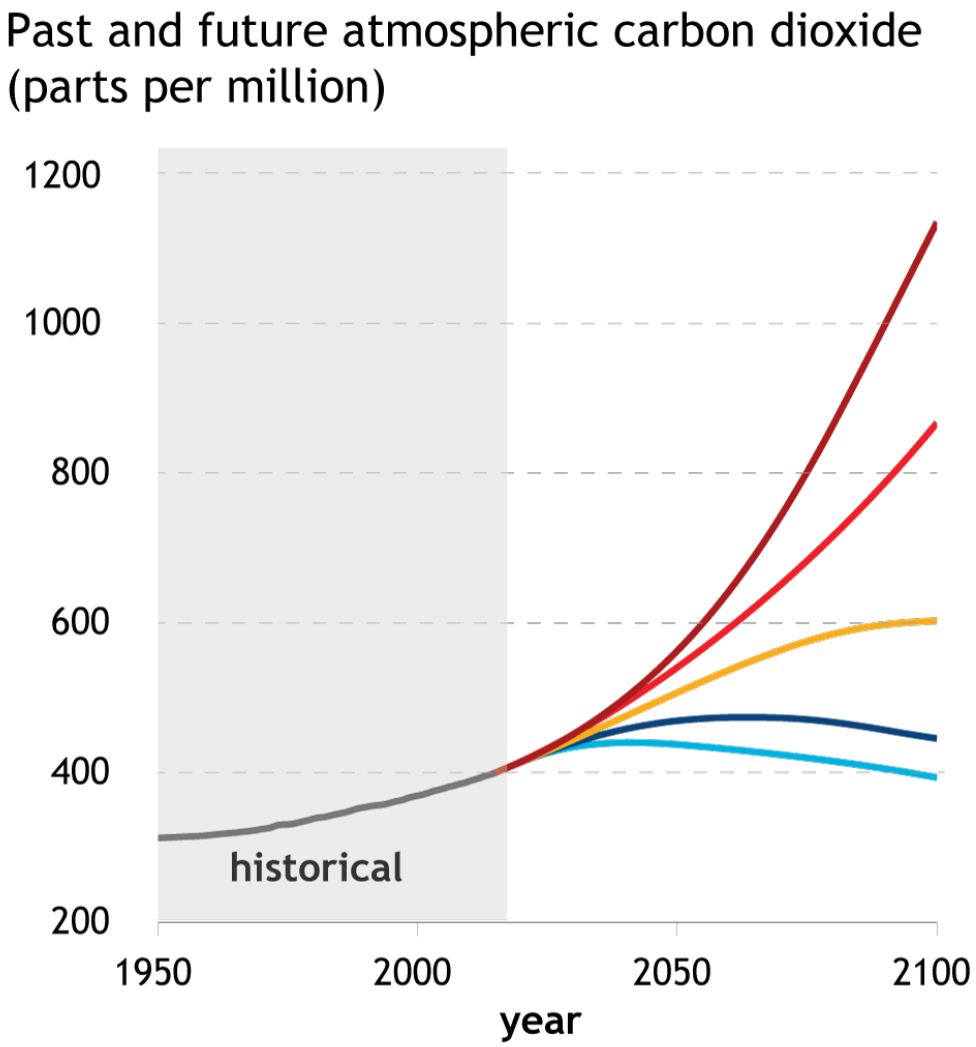
…we emmit more than nature can absorb



IPCC 2023

Accumulates CO2 emissions in the Atmosphere





NOAA Climate.govIPCC AR6 Figure TS.4 2023

What is the size of that CO_2 emissions in atmosphere

420 ppm = 913 Gt C

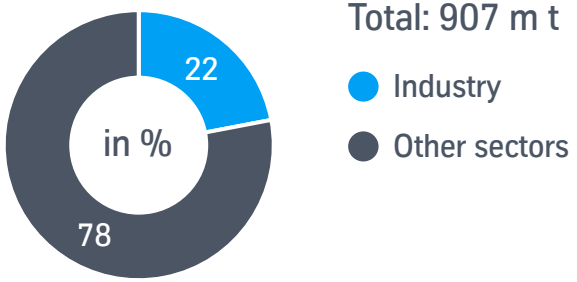
15 Volume of Bodensee

Map: Google

Industry has a major responsibility

With around 1/3 of Germany's CO_2 emissions

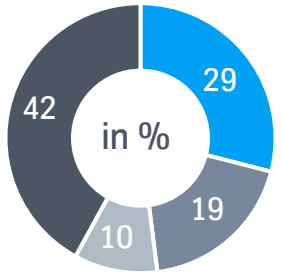
Breakdown of total CO_2 emissions Germany[1]



Total: 907 m t

- Industry
- Other sectors

Breakdown of industrial CO_2 emissions Germany[1]



Total: 200 m t

- Iron and steel
- Basic chemistry
- Cement
- Others

1 Source: Agora energy transformation: UBA, 2019a; WV Stahl, 2018; Wuppertal Institute, 2019; own calculations

thyssenkrupp Steel Europe takes responsibility and has set itself clear targets

Our goal by the year 2030[1]

>30 %

Reduction in CO_2 emissions (-6 m metric tons)

Our goal by 2045 at the latest

-100 %

CO_2 emissions (-20 m metric tons)

SCIENCE BASED TARGETS
DRIVING AMBITIOUS CORPORATE CLIMATE ACTION

CDP
DISCLOSURE INSIGHT ACTION

Responsible Steel standards & certification

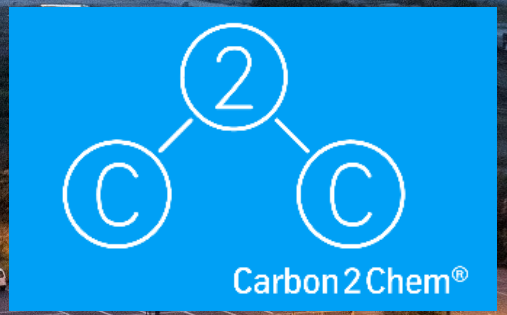
Stiftung KlimaWirtschaft

1. -30% CO_2 emissions in 2030 refers to Scope 1 and Scope 2 emissions (reference year 2018)

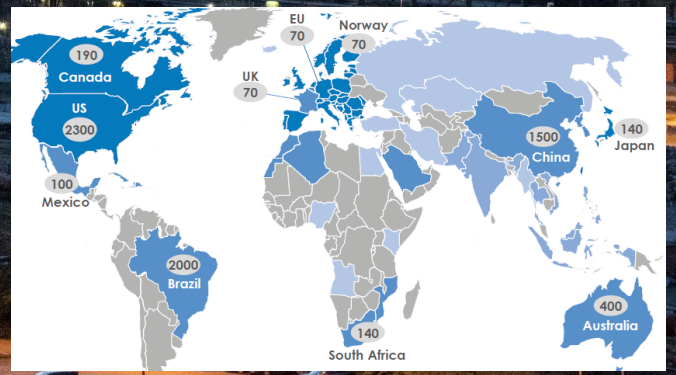
To fulfill the CO_2 Targets clear focus is necessary

1. Avoidance

2. Utilization



3. Storage



tkH$_2$Steel

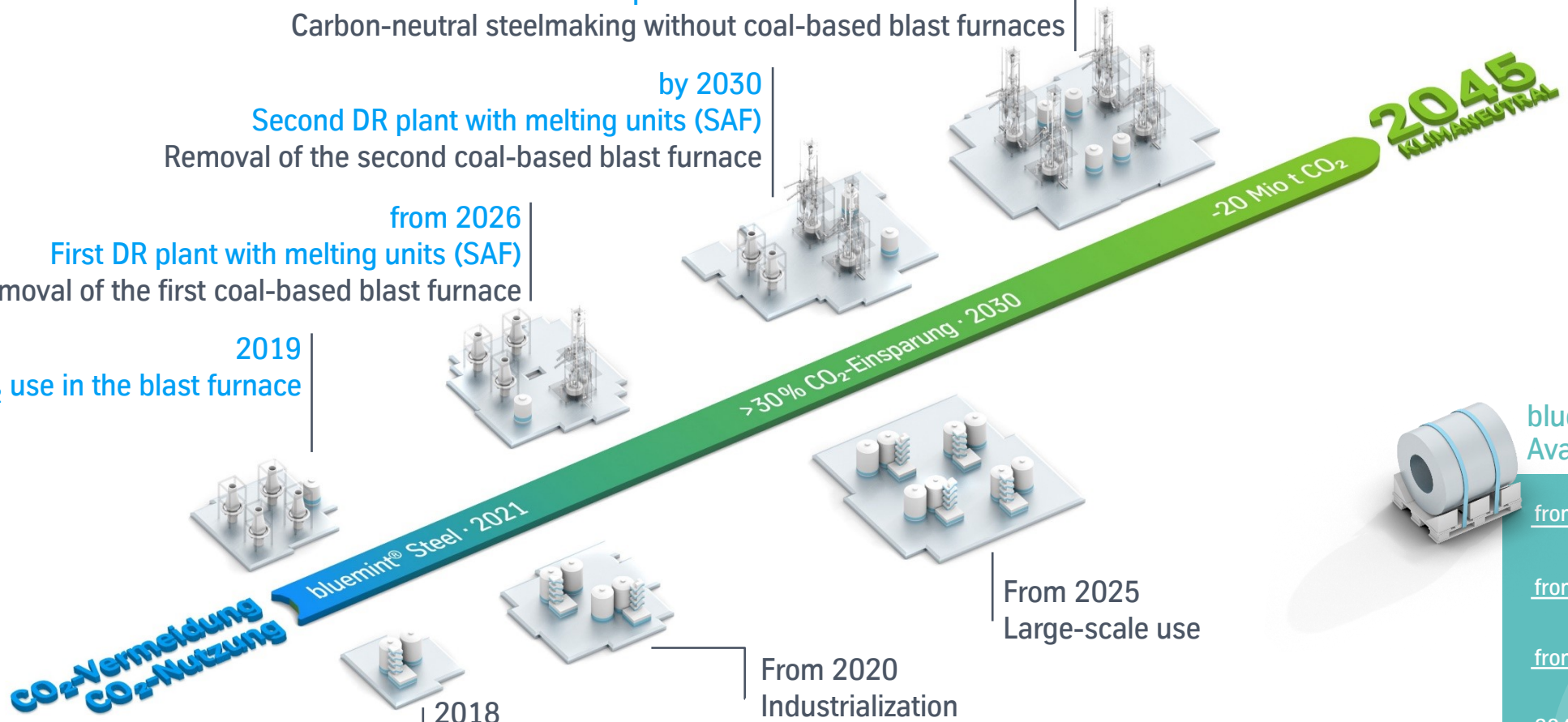
With hydrogen to carbon-neutral steel

before 2045
Full implementation of the transformation
Carbon-neutral steelmaking without coal-based blast furnaces

by 2030
Second DR plant with melting units (SAF)
Removal of the second coal-based blast furnace

from 2026
First DR plant with melting units (SAF)
Removal of the first coal-based blast furnace

2019
Trialling H_2 use in the blast furnace



From 2025
Large-scale use

From 2020
Industrialization

2018
World premiere of Carbon2Chem®
The pilot plant uses metallurgical gases to produce chemical precursors in a continuous process

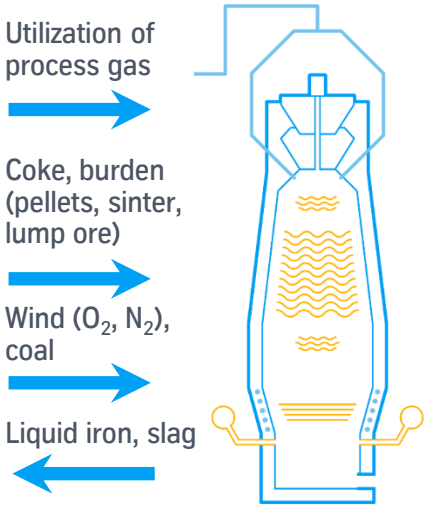
bluemint® Steel
Available quantity p.a.

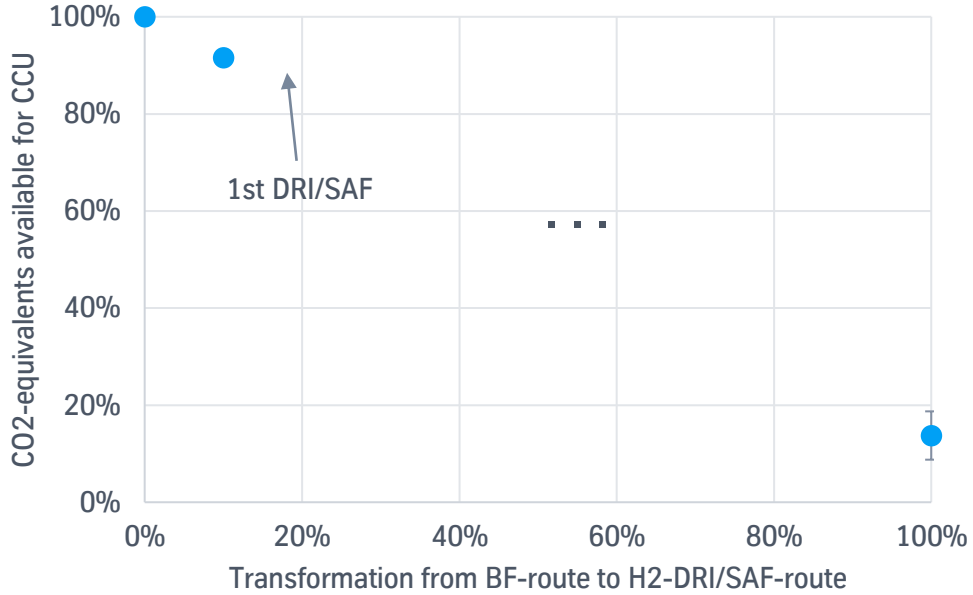
from 2022 – 2025	50 – 500 kt/a
from 2026	3 m t/a[1]
from 2030	5 mt/a[1]
2045	11.5 m t/a

1. Quantity after plant ramp-up

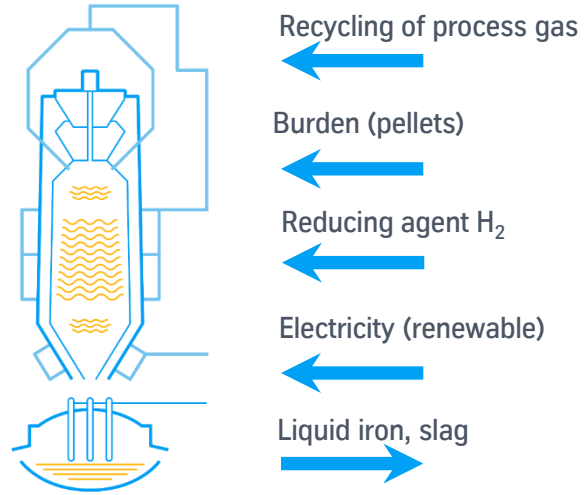
Carbon2Chem and CDA path complement each other to reach climate goals

Classical blast furnace





DR plant + melter



Today:

- Large volumes of blast furnace gas + coke oven gas available for CCU
- Feasibility of production of methanol and ammonia from real steel mill gases proven in technical center since 2018

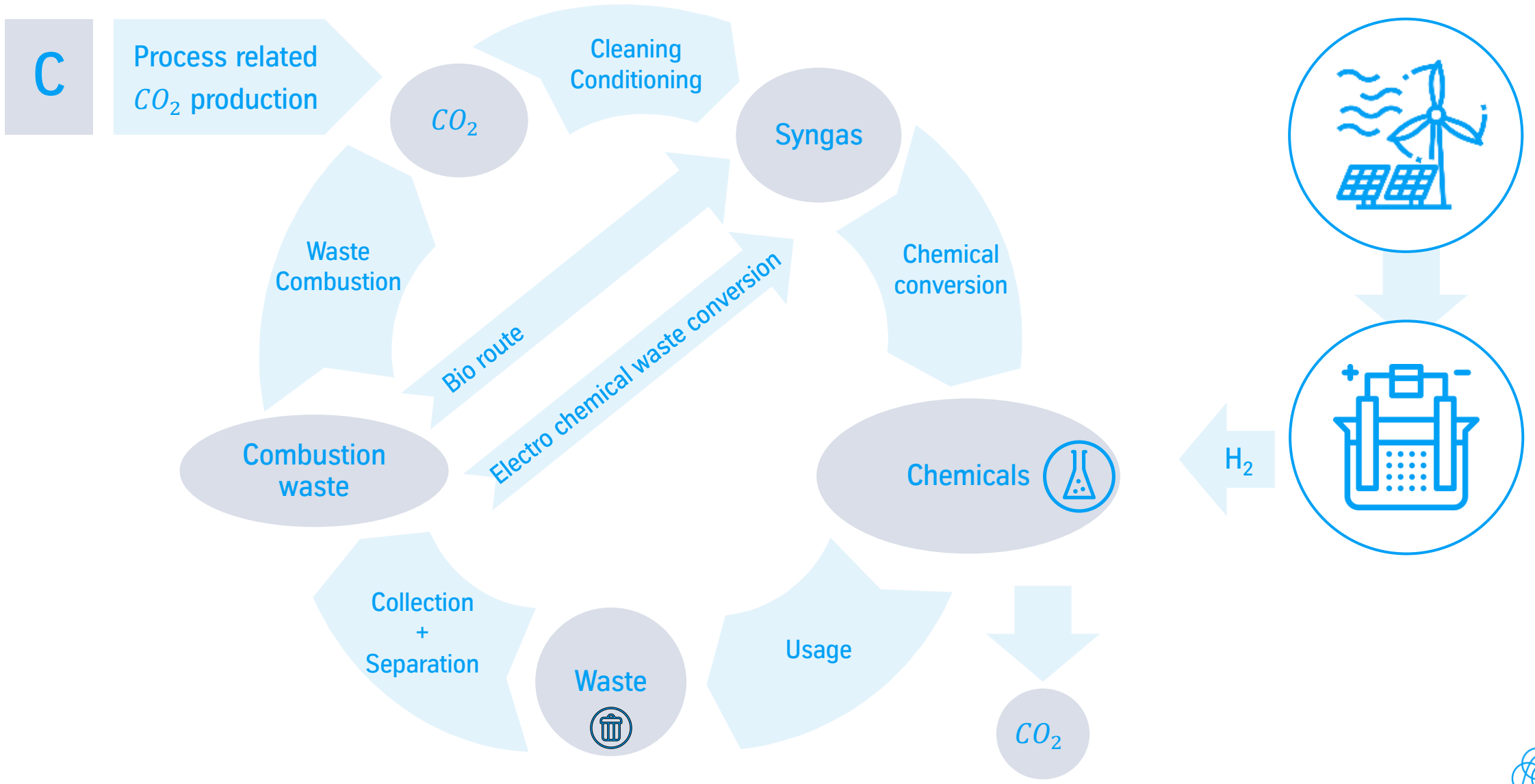
➢ Carbon2Chem can be implemented fast, can contribute to 2030 climate goals + provides rapid access to sustainable feedstock for chemical industry

After complete transformation:

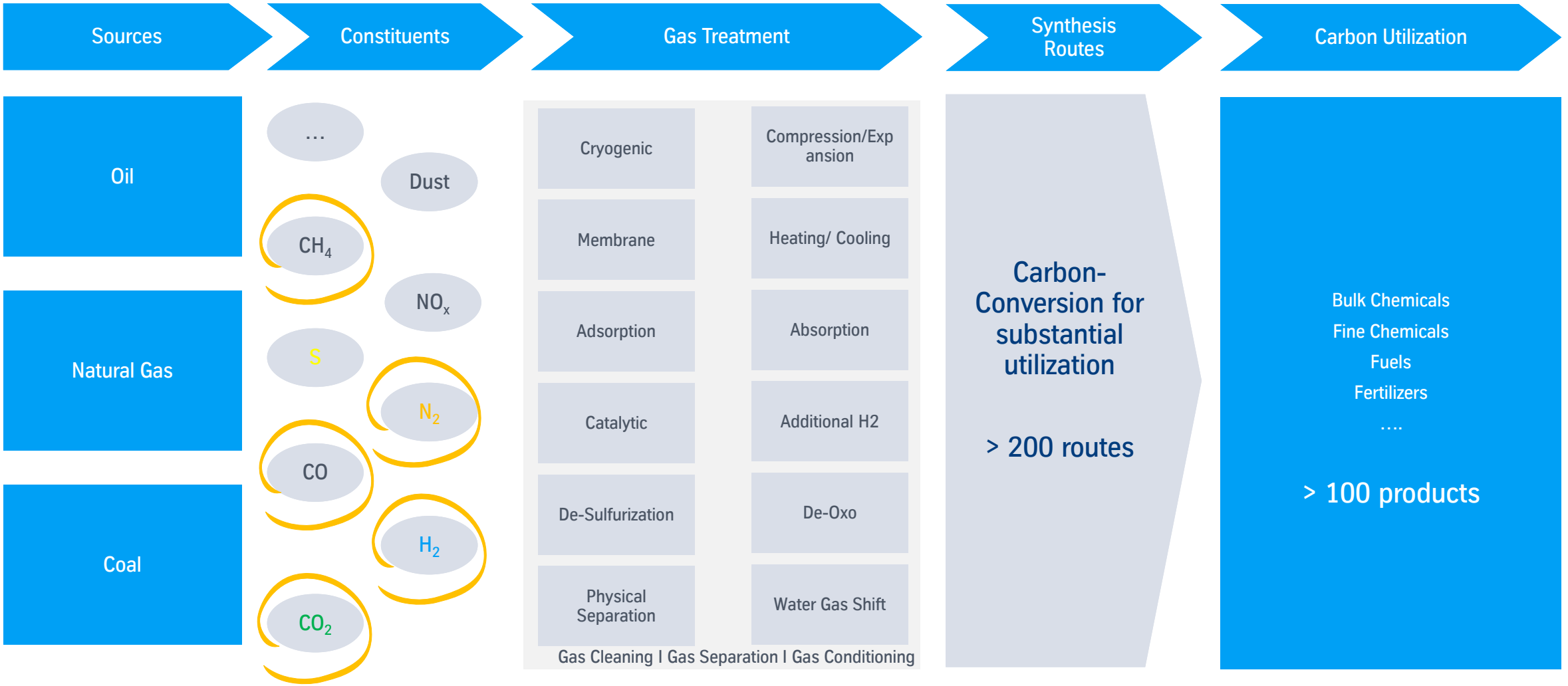
- Carbon in process gases is still available for CCU in suitable amounts, because carbon is needed in metallurgical process
- Composition attractive for chemical synthesis: high CO content
- Can be combined with biogenic / recycled carbon as feedstock

➢ Carbon2Chem provides solution for hard-to-abate residual emissions and for long-term, regional access to sustainable feedstock for chemical industry

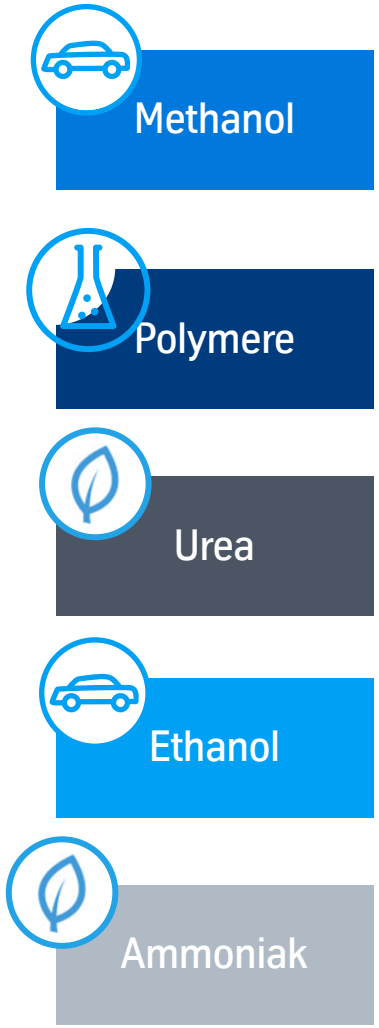
Carbon2Chem approach is inspired by nature:
Bring Carbon in the loop powered by renewable electricity and Hydrogen



First Question: Is there a technical approach to utilize CO_2 ?



Second Question: Is there a product at the end of the process ?



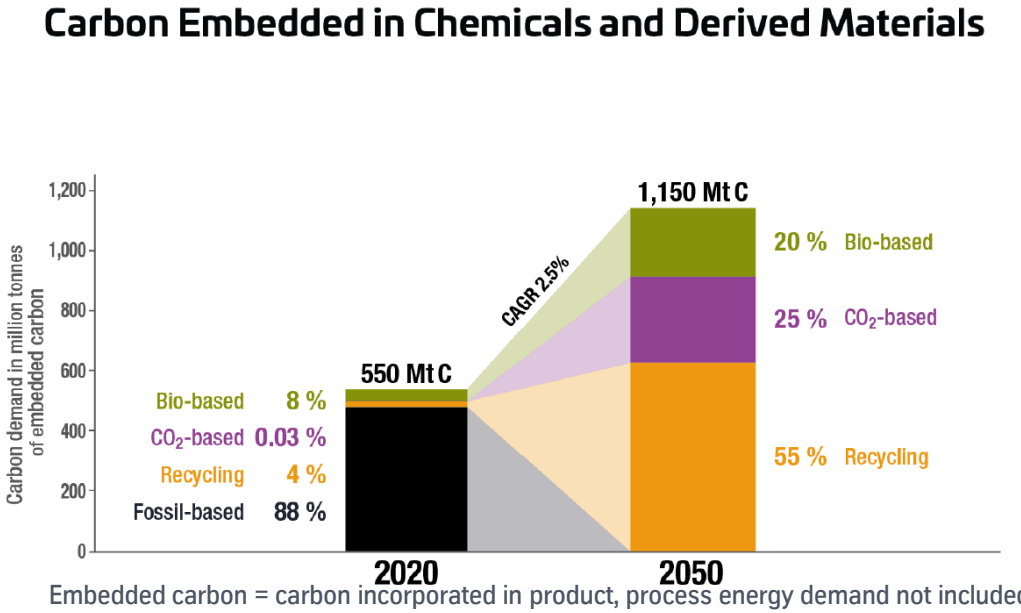
- Potential use for production of Base-Chemicals. Methanol downstream process
- For industrial use high CO_2 concentrations and amounts are preferred
- As fuel for ships and aviation

Third Question: Is there a market need ?

Germany

~35-40 Mio. t

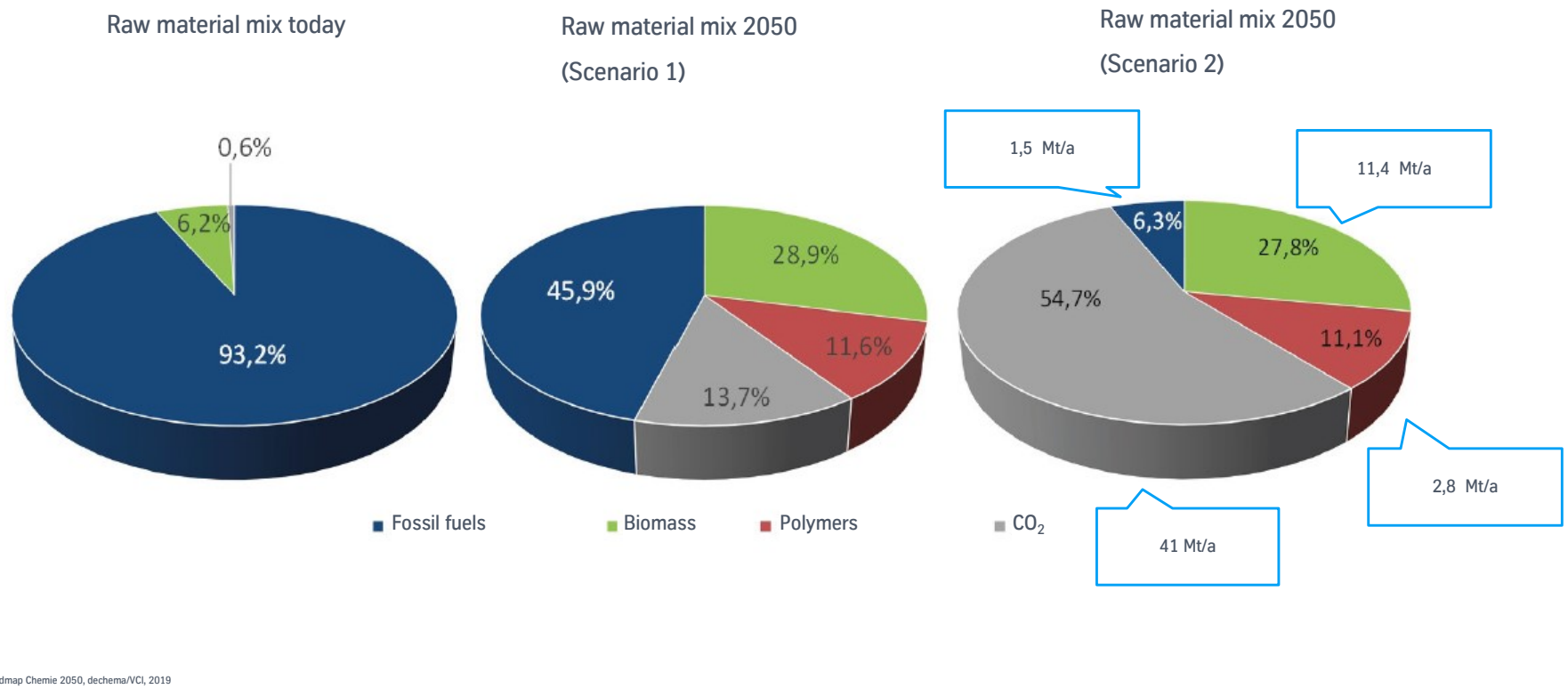
Global



- Carbon demand in chemical industry and for materials is growing globally, stays about the same in Germany

Sources: Roadmap Chemie 2050, dechema/VCI 2019; Kähler, F., Porc, O. and Carus, M. 2023. RCI Carbon Flows Report. Editor: Renewable Carbon Initiative, February 2023

Carbon demand of chemical industry can be covered to large extend by CO_2

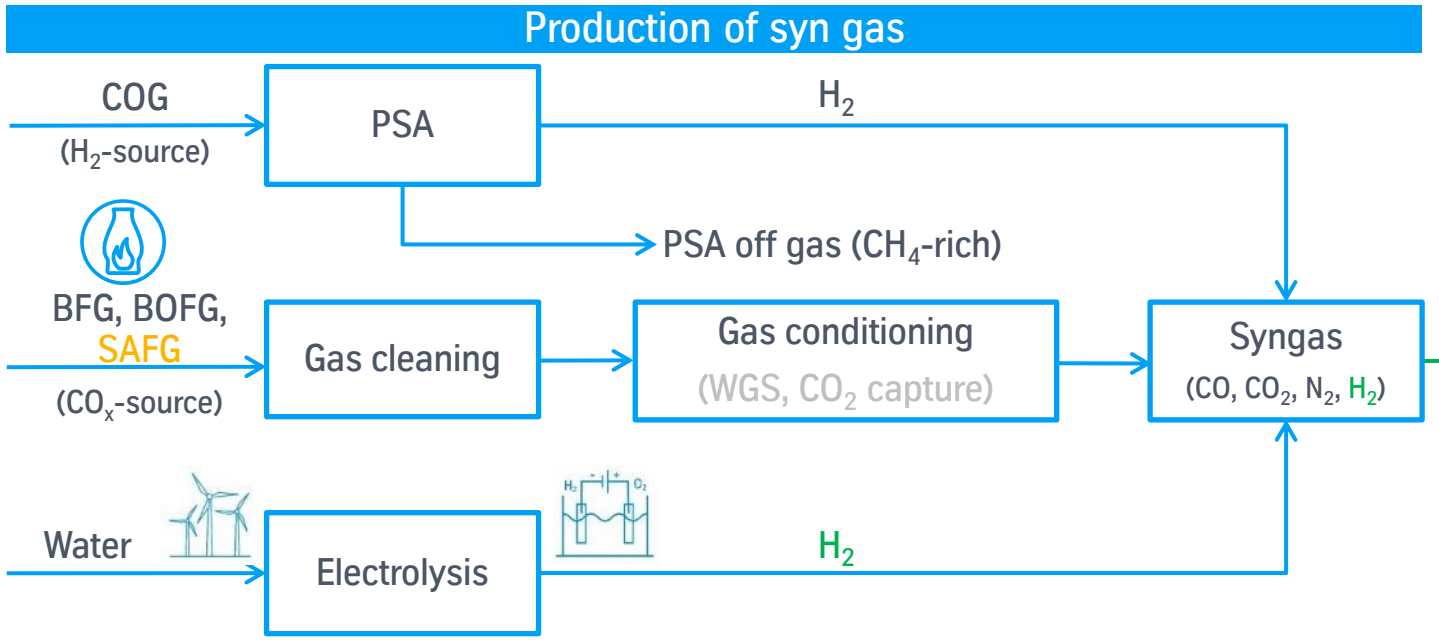


Roadmap Chemie 2050, dechema/VCI, 2019

- Today >80% fossil-based C-sources have to be substituted by renewable sources: no single source can meet demand
- Future share of CO_2 in differs varies in scenarios, but CO_2-demand will be in Mt/a scale in Germany and three digit Mt/a globally

Sources: Roadmap Chemie 2050, dechema/VCI 2019; vom Berg, C. and Carus, M. et al. 2022: Renewable Carbon as a Guiding Principle for Sustainable Carbon Cycles. Editor: Renewable Carbon Initiative (RCI), 2022

Gas treatment as central element for today's and tomorrow's steel mill gases



COG = coke oven gas

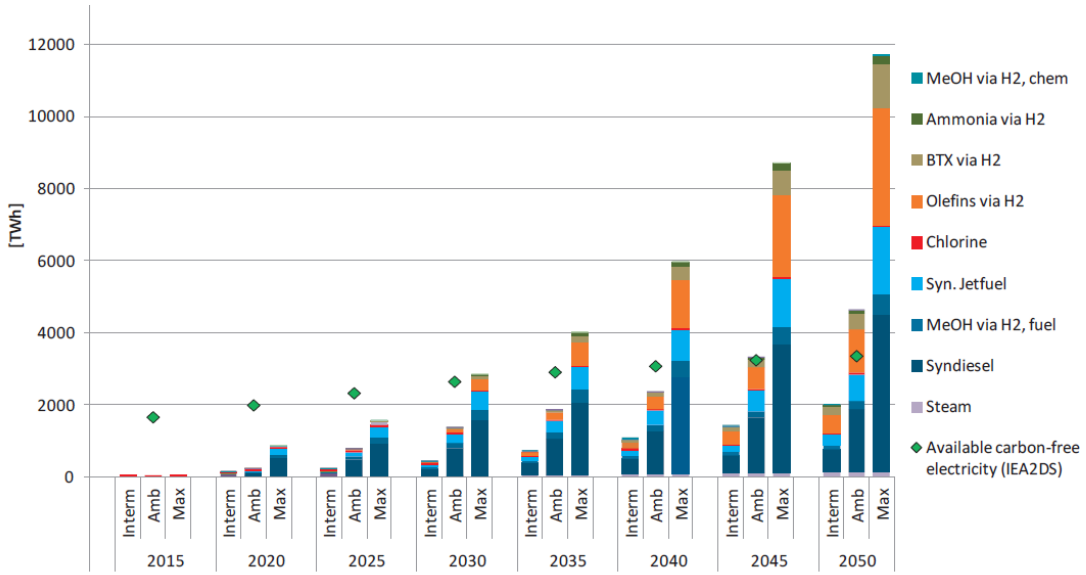
BFG = blast furnace gas

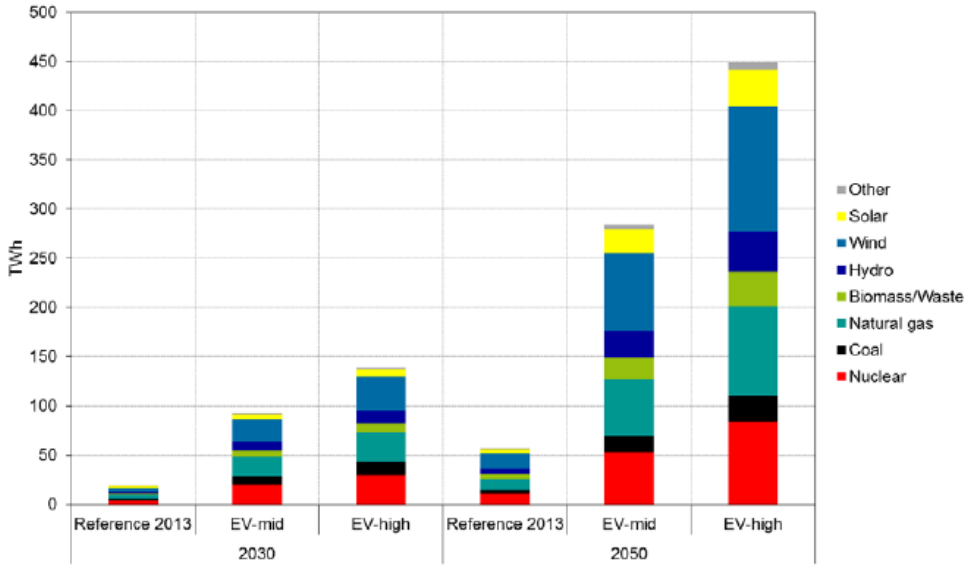
BOFG = basic oxygen furnace gas

SAFG = submerged arc furnace gas

PSA = Pressure swing adsorption

Increasing energy demand due to electrification





Ökoinstitut, TNO, TML, Trinomics (2016) Electric mobility in Europe – Future impact on the emissions and the energy systems

500-850 TWh ⊕ **2000-12000 TWh** ⊕ **300-500 TWh** ⊕ **1,000 TWh**

for 160 Mio. t steel

for cement in addition (~120 Mt of Clinker)

Steel | Chemistry | Transport | Buildings

Electrolysis connects the renewable energy sector with a wide range of industries and enables industry decarbonization

Renewable energy

Renewable electricity is expected to be the primary energy source for all market segments

Green hydrogen

- Electrolysis converts renewable energy into green hydrogen
- Enables use of renewables in wide range of industries
- Replaces fossil-fuel based processes

Hydrogen markets

Hydrogen decarbonizes industry processes: mobility, substitute natural gas, refineries, fertilizers, steel, chemicals, etc.

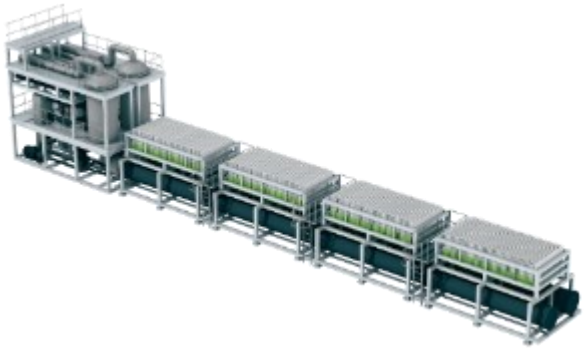
Green hydrogen economy drivers

Climate & environmental protection

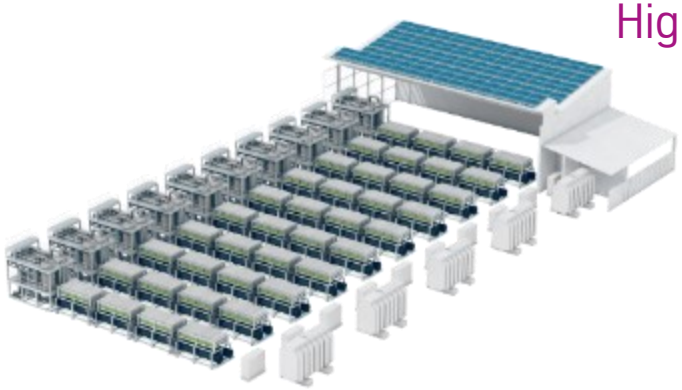
Growing renewable energy sector at low cost

Appropriate legal frameworks

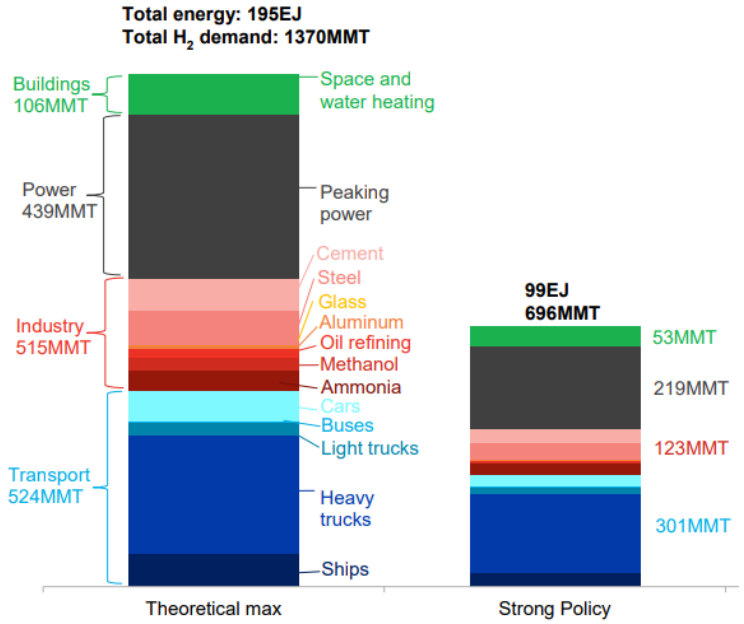
Hydrogen demand will increase in all sectors



20 MW electrolyzer unit



Highly scalable GW plants



2050

about

~5,500 GW electrolysis

…assuming 26,004 TWh at 80% market share of green H_2 at 75% energy efficiency and 5,000 full load hours of operation p.a.

Europe:

- Total hydrogen demand in 2018: around 115 mio tons
- Electrolysis Capacity for 150-115 mio tons >600GW
- Total Electrical Energy demand 5750 TWh

Germany:

- Total hydrogen demand in 2050: around 9-18 mio tons
- Electrolysis Capacity for 18 mio tons >100GW
- Total Electrical Energy demand 900 TWh

Need for hydrogen import from regions with huge renewable energy

Source: BloombergNEF.

Carbon2Chem®: Products in Cross-Industrial Network Aligned with Customers Needs

Project coordination and communication

System integration

thyssenkrupp

CO_2-sources and infrastructure
- Cement
- Lime
- MVA
- H_2-Route Steel

Syngas
- Gas cleaning
- Ammonia/Urea

Linde

Sustainable methanol

Nouryon

Higher alcohols

EVONIK INDUSTRIES

Other products
- Polymers

covestro

(Synthetic) Fuels

Main addressed markets (world markets)

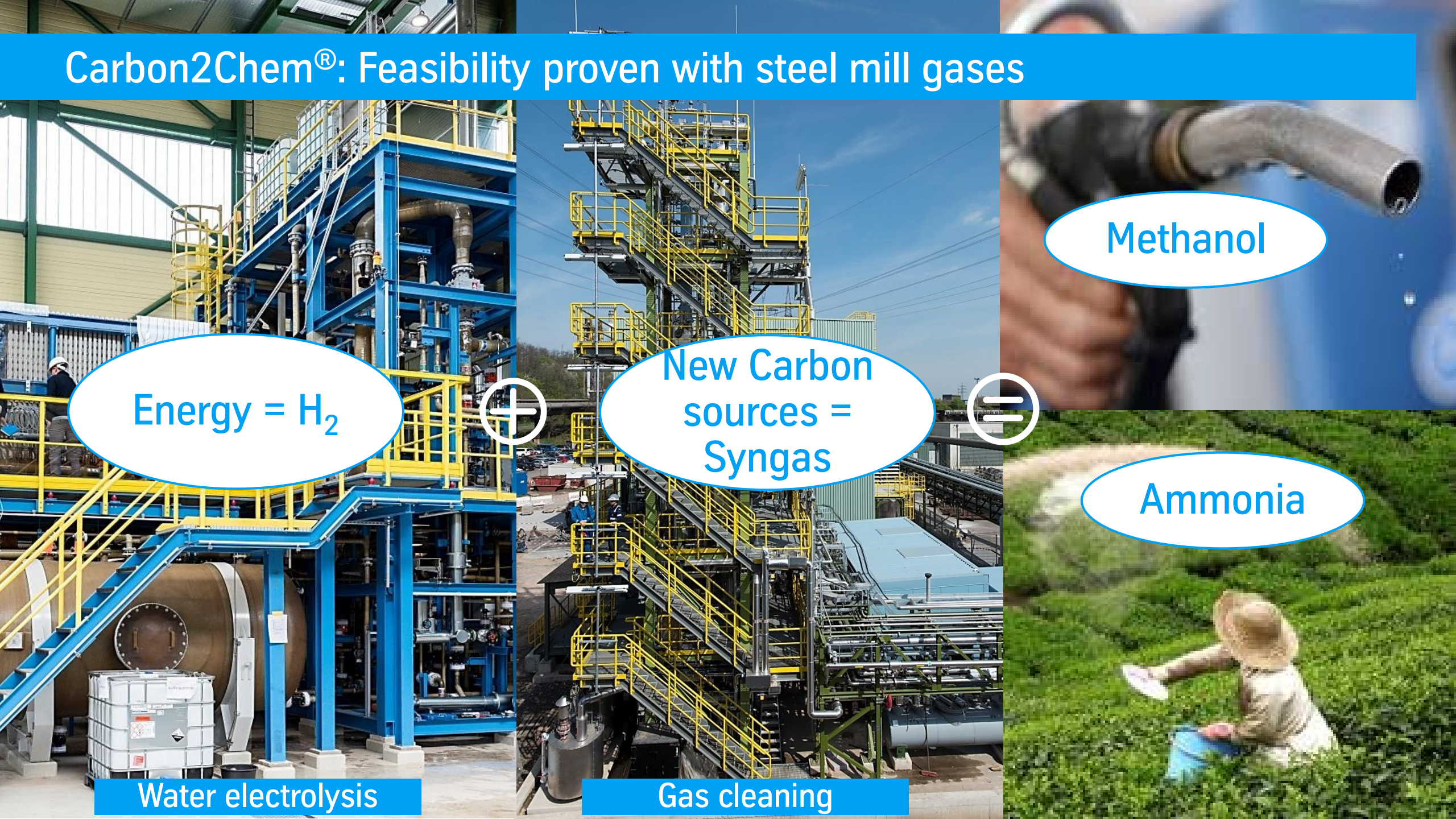
(Synthetic) fuels 64.5 bn. EUR (2016)

Polymers 4,800.0 bn. EUR (2017)

Fertilizer 140.0 bn. EUR (2019,exp.)

Carbon demand of Chemical and Petrochemical Industry in Germany: 56 mio t/a

Carbon2Chem®: Feasibility proven with steel mill gases



Thank you for your attention!

Dr. Markus Oles
Head of Carbon2Chem
Sustainable Production
P: +49 201 844-553444
m: Markus.Oles
@thyssenkrupp.com

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Contact:
thyssenkrupp Steel Europe AG
Kaiser-Wilhelm-Straße 100
47166 Duisburg
Germany