THE ROLE OF HYDROGEN IN DECARBONISING INDUSTRY

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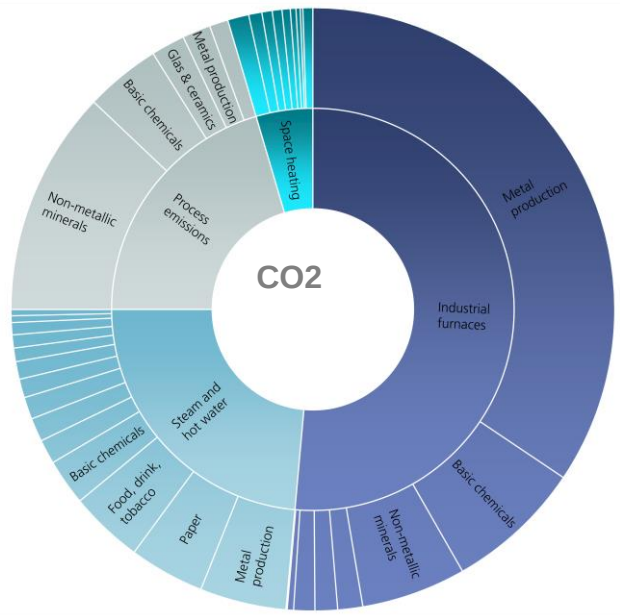

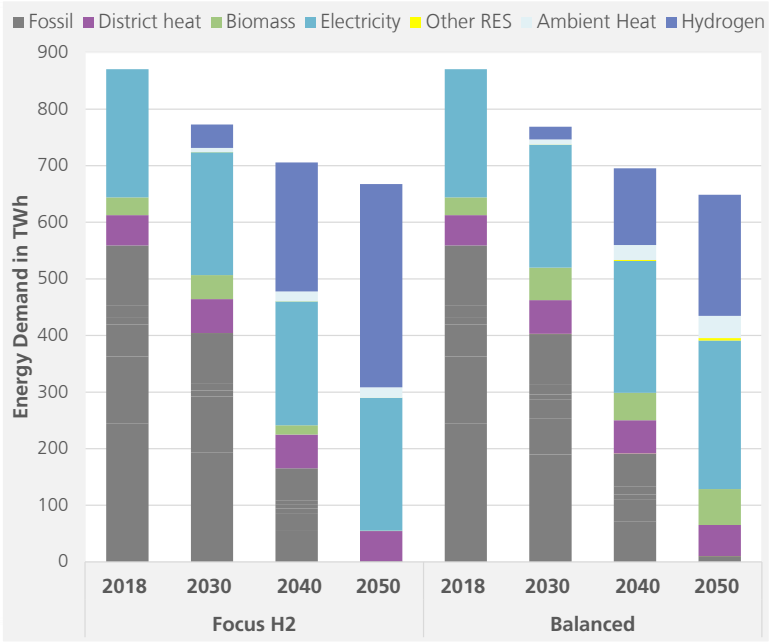

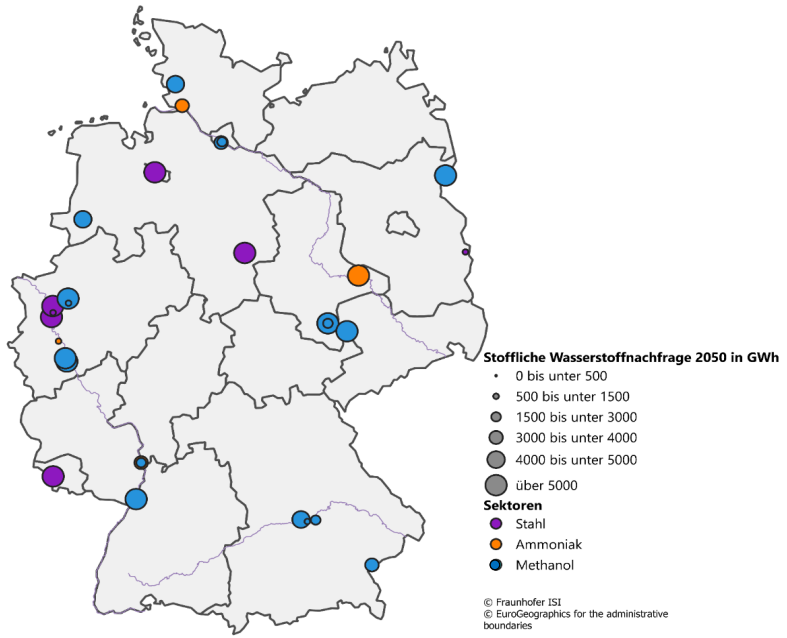

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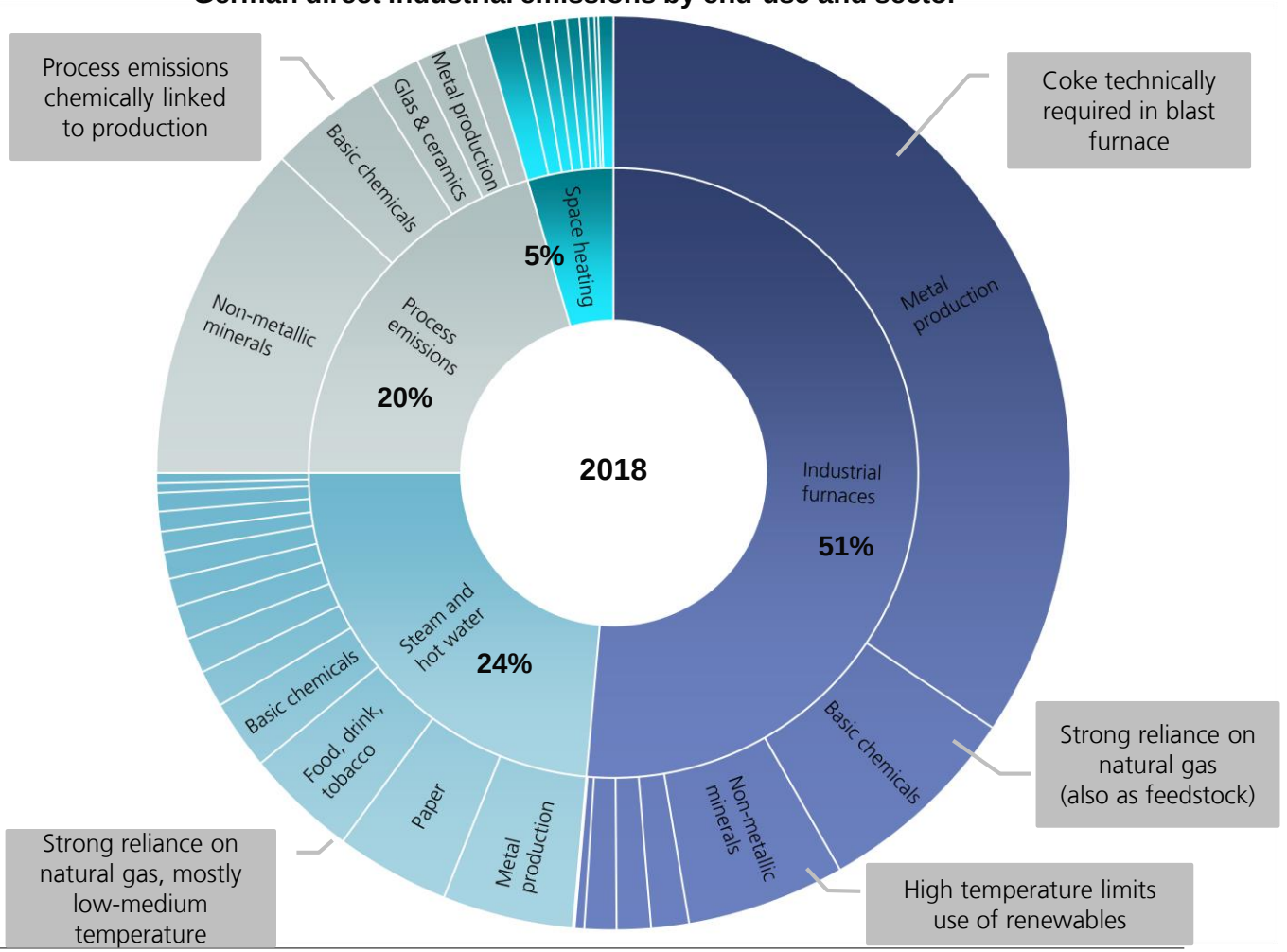
The industrial sector is responsible for about 23% of GHG emissions in Germany

- About **70 % of industrial energy demand** is located in **energy-intensive industries**
- To achieve long-term GHG neutrality, industrial emissions must also **trend towards zero** in the long term
- Largely **unclear** which **technology path** industry can and will take towards decarbonisation
- **Various measures** such as energy efficiency, biomass, electrification, hydrogen, power to gas (PtG), circular economy, material efficiency, process switch and CCU/S are on the table
- Individual contributions are **strongly debated**
- Innovative technologies differ greatly in **maturity and distance to market**
- Availability of **resources and infrastructure**

German direct industrial emissions by end-use and sector



Source: Fraunhofer ISI

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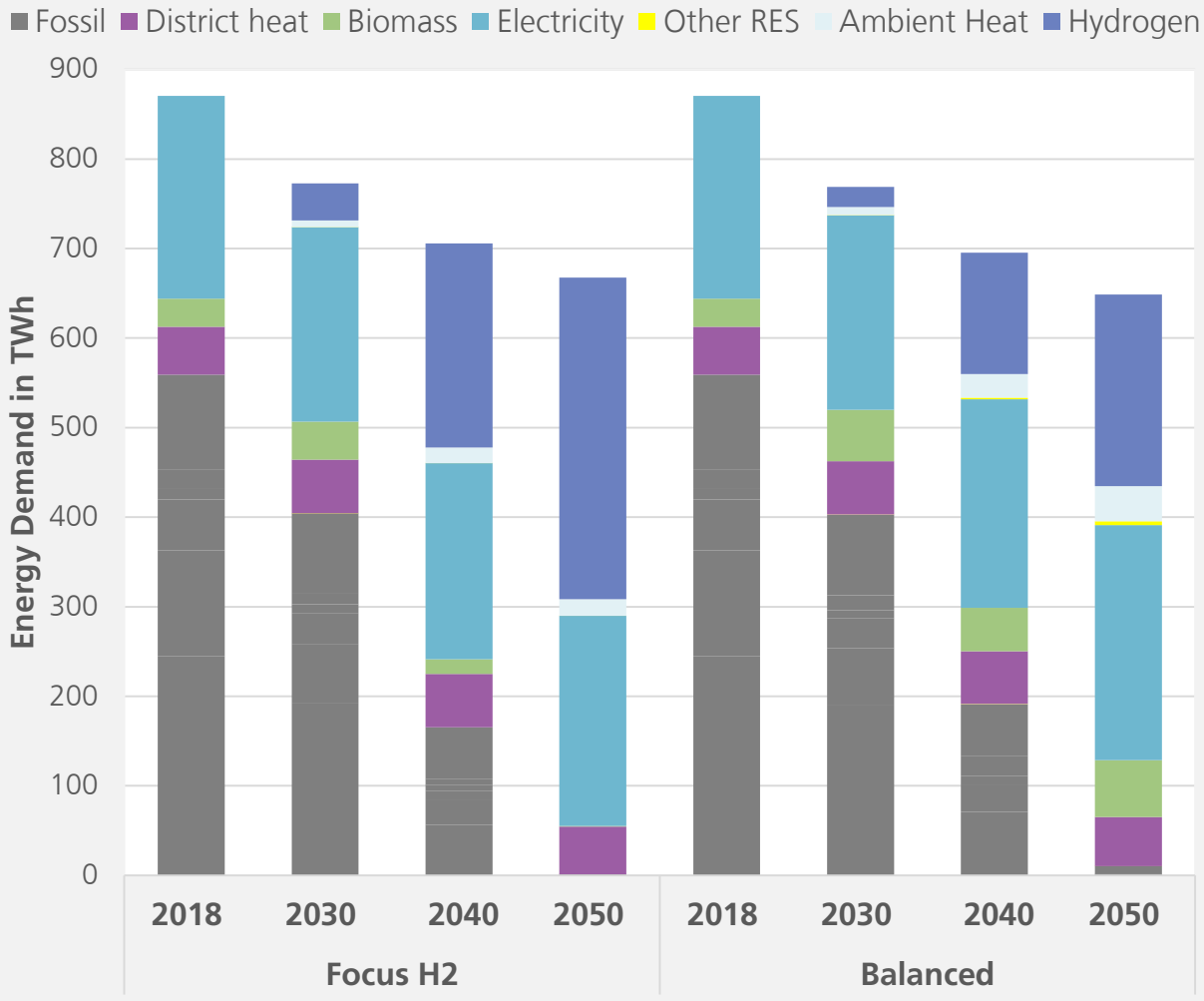
Hydrogen based technologies with different levels of maturity are under development

Industrial subsector	Process/Product	Conventional Technology	Alternative Technology	TRL	Example
H2 as feedstock (and energy)					
Iron and steel	Steel	Blast Furnace	H2-DRI	5-7	HYBRIT, H-DRI Hamburg, SALCOS,...
Basic Chemicals	Ammonia	Methane Steam Reforming	H2 from Electrolysis	7-8	Yara Norway
	Methanol	Methane Steam Reforming	H2 from Electrolysis CO2 from Flue gases	7-8	Power-to-Methanol Antwerp BV, MefCO2, CRI...
	Olefins	Steam Cracking	Methanol-to Olefins	7-8	Mostly realized in China (CtM)
Refineries	Crude Oil Refining	H2 from Methane Steam Reforming	H2 from Electrolysis	8-9	REFHYNE, Lingen Green Hydrogen, ...
H2 for Process Heat					
Non-ferrous metals	Aluminium	Natural Gas Furnace	H2 Furnace	5-7	n.a.
	Casting				
	Rolling				
Non-metallic minerals	Container Glass	Natural Gas Glass Melting	H2 Glass Melting	5-7	HyGlass
	Flat Glass				
	Ceramics	NG Fired Furnace	H2 Fired Furnace	5-7	TCKI &DNVGL
	Cement				
	Limestone				
Paper and printing	Various Paper	Natural Gas Steam Generation	H2 Burner	7-8	Toyota, E&M Combustion, ...
	Recovered Fibres				
	Mechanical Pulp				
	Chemical Pulp				

Source: Neuwirth et al. (2021), DECHEMA (2017), project websites

Hydrogen could play a key role in the transition towards a CO2-neutral industrial production

- **Decrease in final energy demand** in both scenarios of ~25%
  - Energy efficiency, material efficiency, circular economy, new & efficient processes
- **H2 dominant energy carrier** in 2050 in ‚extreme' **Focus H2 scenario**
  - **~359 TWh** total H2 demand
  - 116 TWh feedstock use in the chemical sector (ammonia, methanol, MtO)
  - 52 TWh H2-DRI steel
  - 191 TWh H2 for other process heat
- More **balanced process heat approach** still leads to a **strong increase in H2** demand (**214 TWh**) in 2050
- Higher potentials for biomass, electricity & ambient heat



Final energy and feedstock use by energy carrier [DE]

Source: Langfristszenarien für die Transformation des Energiesystems in Deutschland (ongoing project funded by BMWi), ARIADNE (Copernicus project funded by BMBF)

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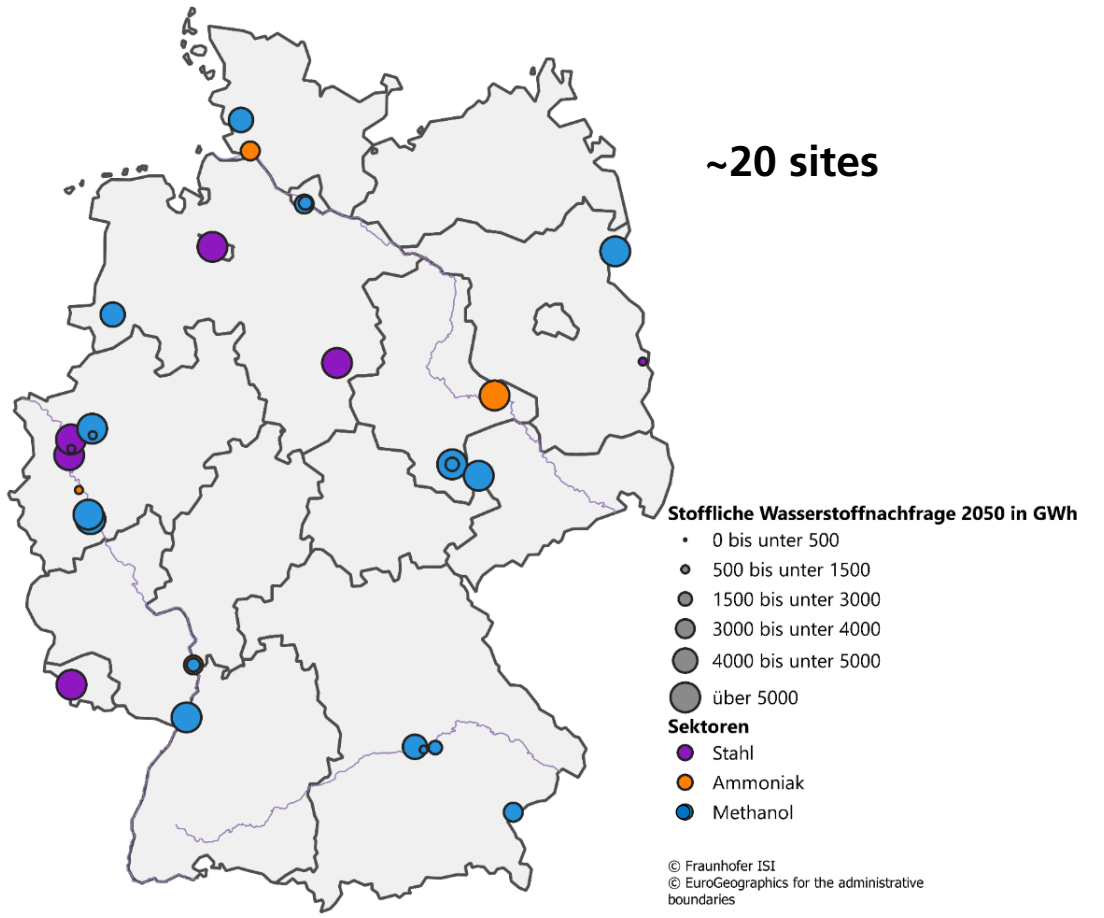
GHG reduction of >95% compared to 1990 in industry is possible, under the condition that...

- New **CO2-neutral production processes** are marketable from **2025/2030** and achieve **100%** stock **diffusion by 2050**
- **Green hydrogen is available** and completely replaces fossil fuels
- **Green hydrogen** supplies the **chemical and steel** industries
- **Circular economy** continues to gain relevance
- **Material efficiency** along the value chain increases significantly
- **CO2 becomes a raw material**: CO2 cycle via plastics life cycle is established
- **Infrastructure:** conversion/expansion & planning security necessary, especially in strongly affected regions; time dependency with conversion of industrial plants

H2-feedstock demand 2050 [DE]



Source: Langfristszenarien für die Transformation des Energiesystems in Deutschland (ongoing project funded by BMWi)

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Hydrogen is discussed as a promising option for decarbonising the basic industry

... however, not all questions have been answered yet:

- **H2 steel industry promising and widely discussed**
  - Currently no production of "green steel" from hydrogen DRI. First plants, e.g. in Sweden/Finland, under construction/planning
  - Natural gas DRI required as an intermediate step in order to avoid missing out on recent investment cycles?
- **H2 feedstock in the chemical sector**
  - **Ammonia** production is relatively simple and the product is easy to transport
    Migration to regions with favourable H2 conditions?
  - CO2 requirement for the production of **methanol** based on hydrogen
  - Change to H2 as raw material for **HVC** production (MtO) requires new CO2 source
    - Possible sources: air capture, biomass, remaining emissions (e.g. cement & lime) -> **closing the CO2-loop**
    - **CO2-infrastructure**: conversion of the gas transport network to CO2 transport possible?
    - High uncertainty about future locations (e.g. lime)

Hydrogen is discussed as a promising option for decarbonising the basic industry

… however, major barriers still prevent the large-scale deployment of hydrogen-based industrial processes:

- **Hydrogen not yet competitive**
  - Conversion to H2 requires high (individual) investments
  - Comparatively high operating costs and high abatement costs
  - Lack of planning certainty for investors
  - Currently no H2 infrastructure available

- **Hydrogen demand, supply and infrastructure**
  - H2 is either produced and used on site or decentralised, creating the need for H2 infrastructure
  - Integrated planning required
  - Starting point bivalent demands?

Summary: The role of hydrogen in decarbonising industry

1 Introduction

- **Available technologies** are **not sufficient** for the decarbonisation of the German industry sector

2 Technologies

- Many **hydrogen-based technologies are under development**
- They differ strongly in maturity and distance to market

3 Pathways

- **>95% decarbonisation is possible** – but requires:
  - Process innovations and related infrastructure (H2, CO2)
  - CO2-free and competitive secondary energy carriers,
  - Innovations in material efficiency and circular economy

4 Challenges

- **Efficient system:** H2 vs. electricity
- **Availability of resources** and dependencies with infrastructure
- Carbon leakage and international **competitiveness**
- **Political framework** and long-term **certainty** for investors
- Closing the **economic viability gap**
- Reduction of **uncertainties**

Thank you for your attention

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