

AmmonVektor

Fraunhofer Flagship Project for Energy Sovereignty
H₂ Economy through NH₃ technology

PROJECT LEAD:
PROJECT TEAM:

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FRAUNHOFER-INSTITUT FÜR GRENZFLÄCHEN- UND BIOVERFAHRENSTECHNIK IGB
FRAUNHOFER-INSTITUT FÜR KERAMISCHE TECHNOLOGIEN UND SYSTEME IKTS
FRAUNHOFER-INSTITUT FÜR MATERIALFLUSS UND LOGISTIK IML
FRAUNHOFER-INSTITUT FÜR MIKROTECHNIK UND MIKROSYSTEME IMM
FRAUNHOFER-ZENTRUM FÜR INTERNATIONALES MANAGEMENT UND WISSENSÖKONOMIE IMW
FRAUNHOFER-INSTITUT FÜR TECHNO- UND WIRTSCHAFTSMATHEMATIK ITWM

Motivation

Limits of Hydrogen in the H₂ Economy

Low Hydrogen Energy Density

- Storage and Transport at cryogenic temperatures (-253 °C) or at very high pressures (700 bar).
- The energy required to liquefy is 30–40% of hydrogen's energy content.

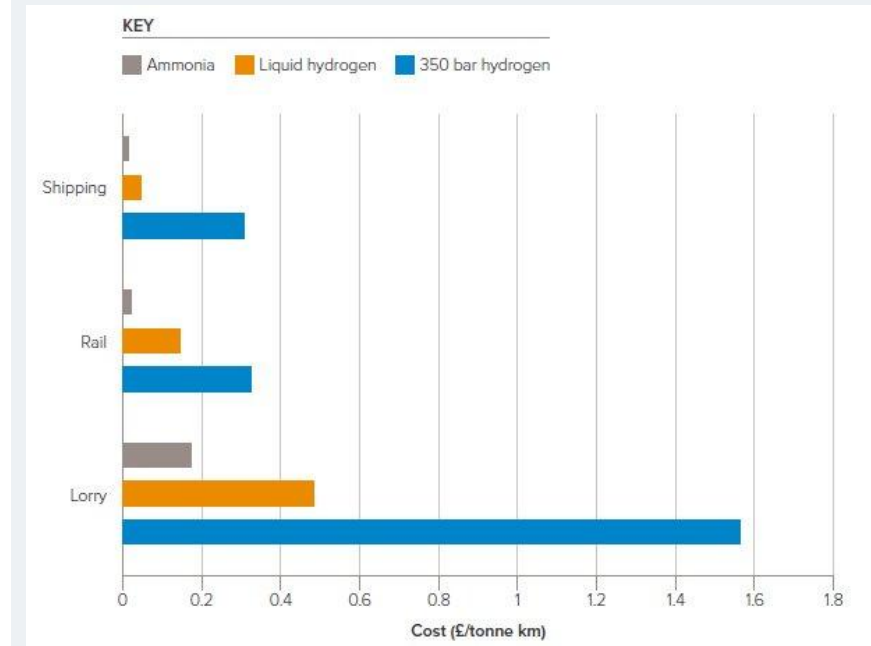
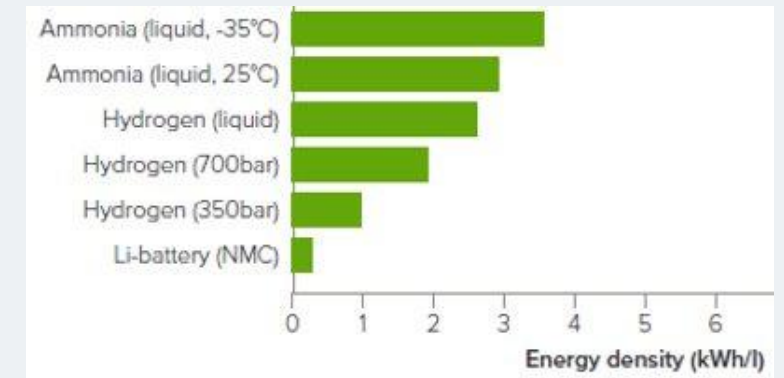
Use of Natural Gas Storage for Hydrogen

- Possible only to a limited extent, but capacity falls to 13% (32 TWh H₂ instead of 245 TWh CH₄).
- More decentralized storage for supply security of SMEs.

Alternative Energy/H₂ Carrier: Ammonia

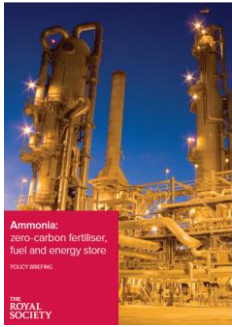
- NH₃ energy density is almost twice that of hydrogen (350 bar).
- Due to simpler tanks (9 bar at 25°C), energy density can rise up to four times.
- Less energy required for cooling (-35°C) and, alternatively, for compression (9 bar).
- Ammonia transport by ship or pipeline is cheaper than liquid hydrogen.

» The H₂ economy will be based not only on hydrogen but also on ammonia as an energy carrier.«



Motivation

Ammonia – Production, Shipping, Storage Infrastructure 2020



185 Mio. t ammonia per annum
in 2020 worldwide

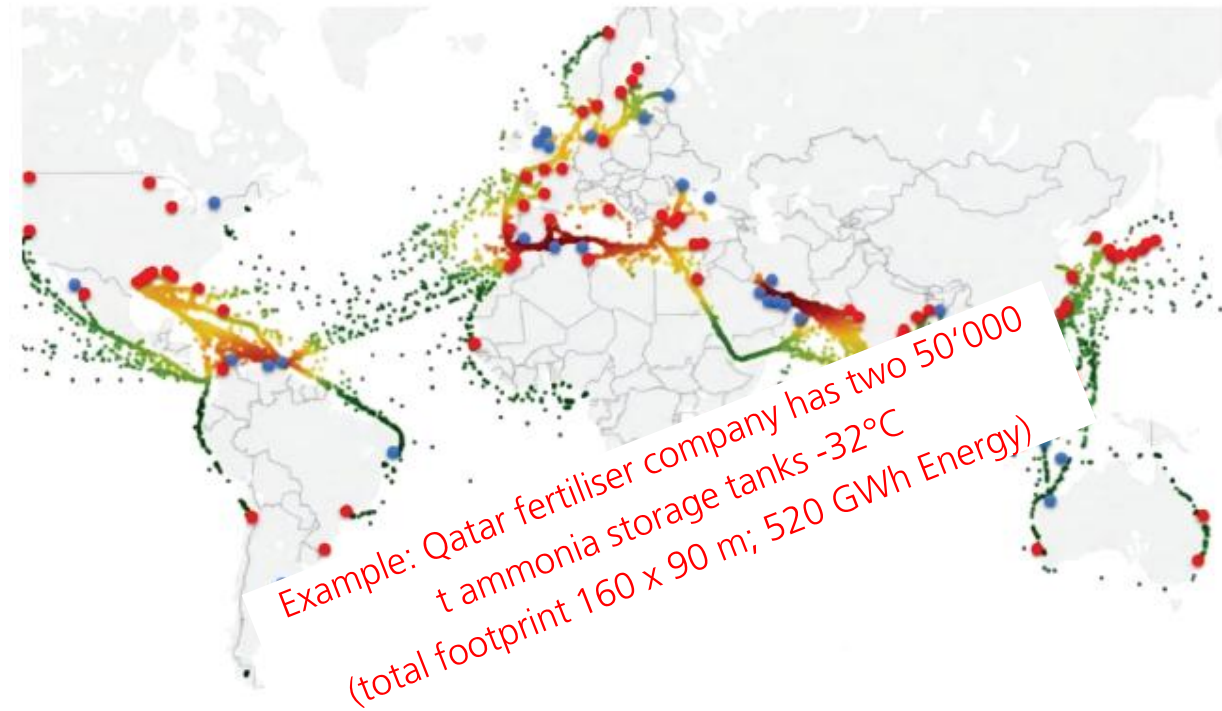


»Ammonia is already a global bulk commodity, and its transport and storage have been technologically solved.«

Ammonia shipping infrastructure, including a heat map of liquid ammonia carriers and existing ammonia port facilities (2017).

KEY

● Ammonia loading facilities ● Ammonia unloading port facilities



Ammonia – Future Role in a Decarbonized World

Industrial Perspective

Home | Magazine | 1.2023 "Gateway Hamburg"

Leinen los für grünen Wasserstoff

Düsseldorf, 27. Mai 2025



Der klimafreundliche Energie-Hub im Hamburger Hafen nimmt Fahrt auf. Die Arbeiten am Ammoniak-Importterminal haben begonnen und es gibt Abkommen mit immer mehr Lieferländern.

Uniper und thyssenkrupp Uhde bündeln Kräfte für Schlüsseltechnologie der globalen Wasserstoffwirtschaft

» The industry prepares for the ammonia economy.«

Brunsbüttel

Terminal für grünen Ammoniak geplant

[26.03.2025] RWE plant in Brunsbüttel den Bau eines Terminals für den Import von grünem Ammoniak, das einen wichtigen Beitrag zur deutschen Wasserstoffversorgung leisten soll. Das Projekt soll nicht nur die Dekarbonisierung der Industrie unterstützen, sondern auch den Standort langfristig auf eine vollständig grüne Energieversorgung vorbereiten.

hafen-hamburg.de | [Leinen los für grünen Wasserstoff](https://stadt-und-werk.de/?pdf=1&postid=78041)
stadt-und-werk.de/?pdf=1&postid=78041
[Brennstoffzellenanlage in Bruchsal liefert Strom und Wärme](https://hafen-hamburg.de/) | EnBW



01.02.2026 | Pressemitteilung

Unternehmen aus Saudi-Arabien und Deutschland unterzeichnen wegweisende Absichtserklärung zur Lieferung von Ammoniak >

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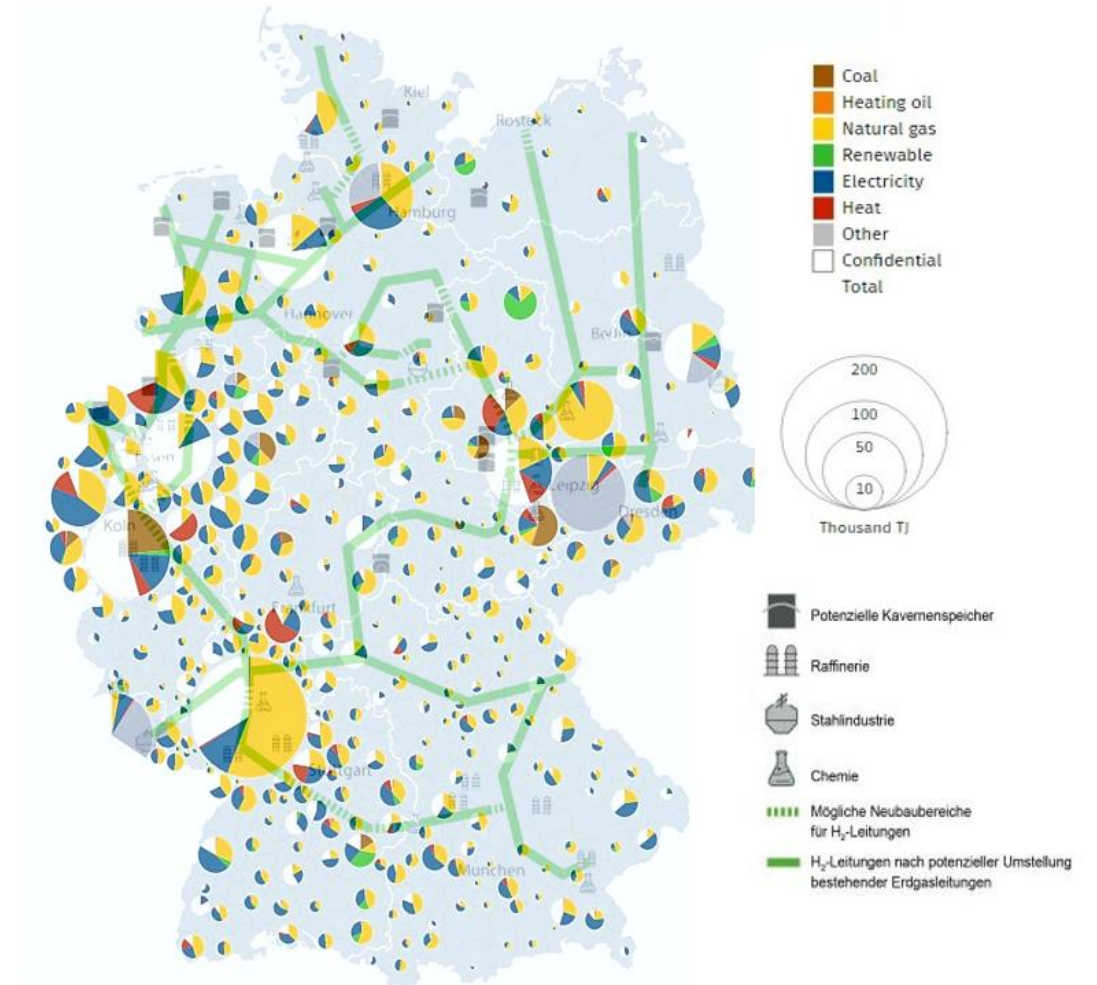
ENERGY DEMAND VERSUS FUTURE HYDROGEN SUPPLY

European Hydrogen Backbone

- Hydrogen supply will be available for heavy industry and the chemical industry
- Electrification will **not** work for all industries
- Large areas will **not** be connected to the hydrogen grid (central and southwest Germany)
- **Ammonia can also supply energy to areas located away from large hydrogen pipelines**

Take-away message:

NH_3 is THE H_2 economy energy carrier for medium-sized enterprises without their own pipeline connection, especially in southern and central Germany



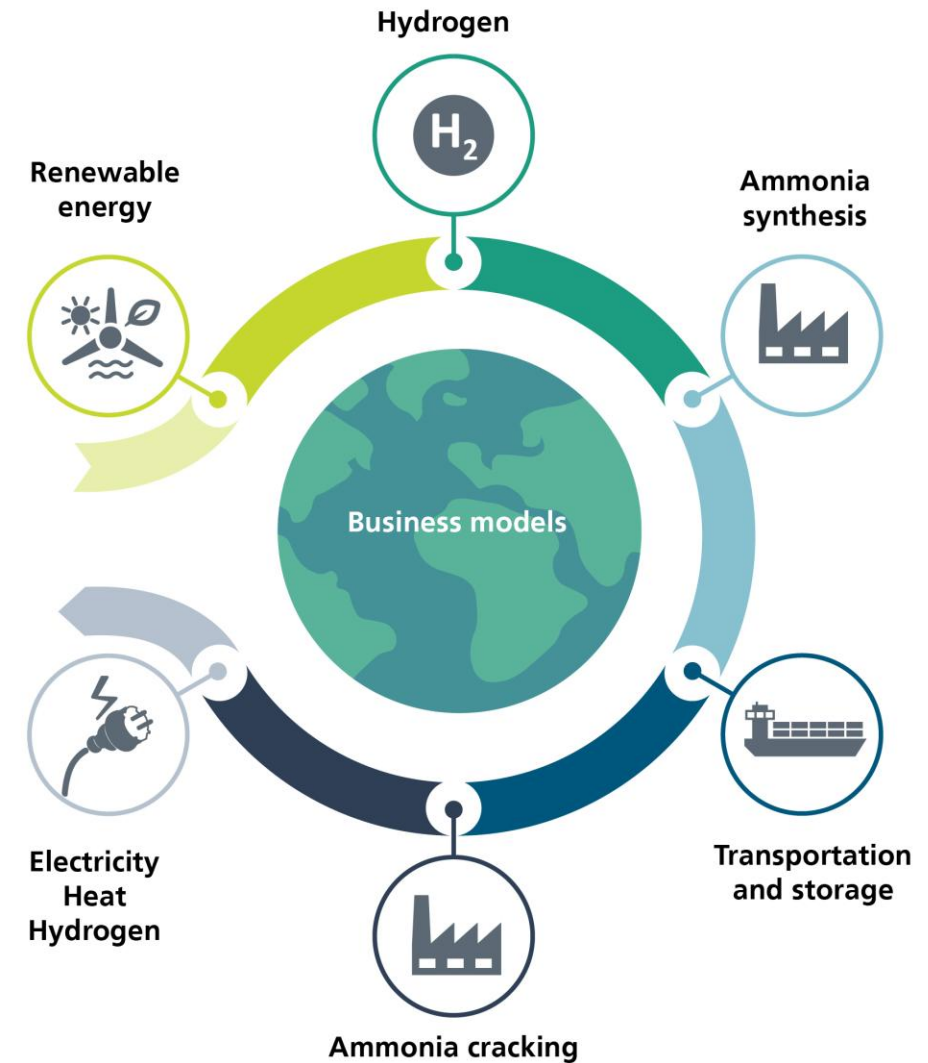
AmmonVektor Flagship Project – In a nutshell

Global Objectives

Development of decentralized NH₃ technologies for energy sovereignty in future H₂ economy

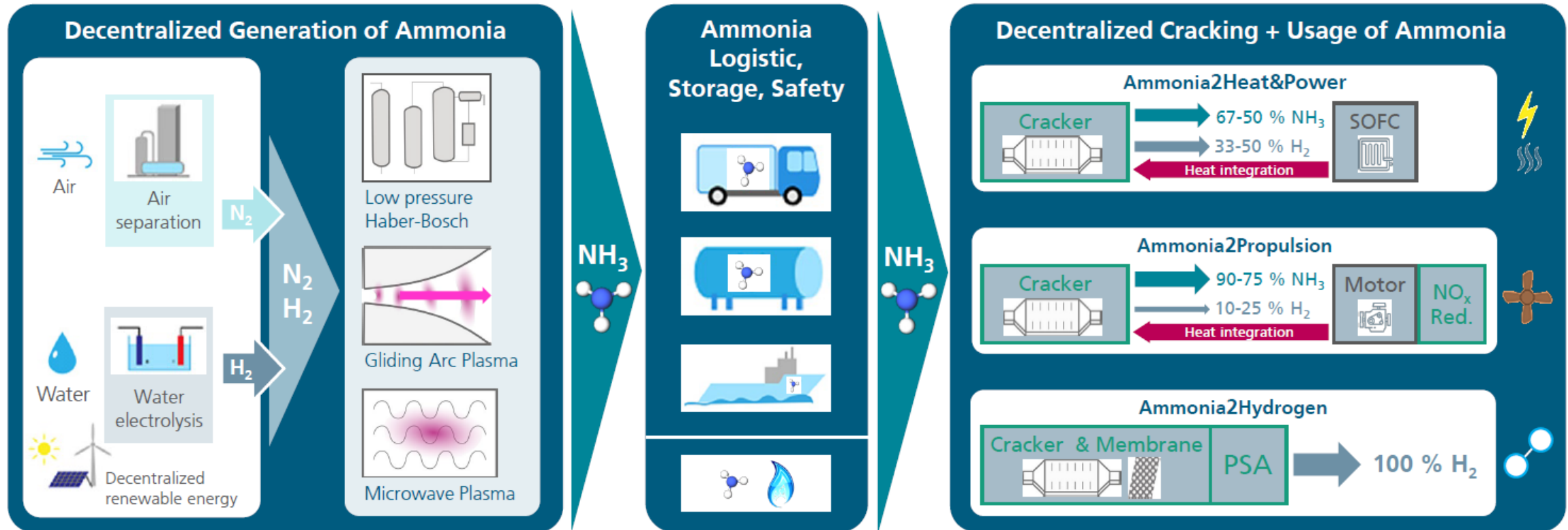
- Decentralized NH₃ synthesis
- Distribution and decentralized storage logistics for NH₃
- Decentralized NH₃ crackers
- Generation of H₂, electricity, heat, mechanical energy
- Decentralized business models

»Fraunhofer-Gesellschaft is pooling its expertise to supply leading technologies for the NH₃ market of tomorrow.«



AmmonVektor FLAGSHIP PROJECT – Structure

H₂ Economy through NH₃ Technology



TP5

Business models: Creating sustainable and resilient value chains

Simulation of a Hydrogen-Ammonia Integrated Network

Evaluation of the Potential of Ammonia as a Hydrogen Carrier in the Energy Distribution Supply Chain

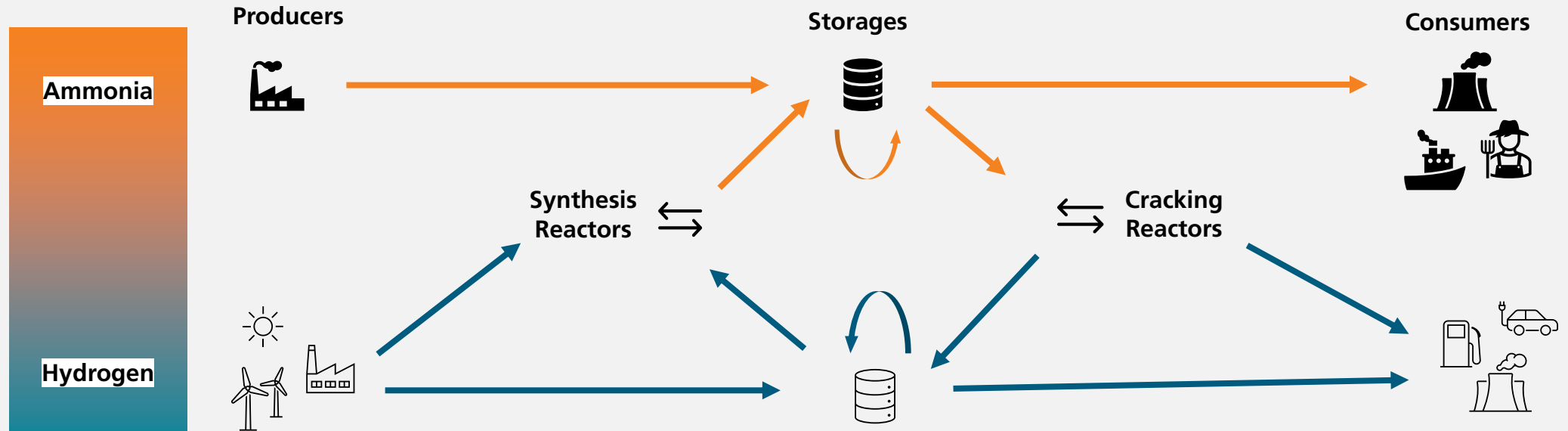


Features:

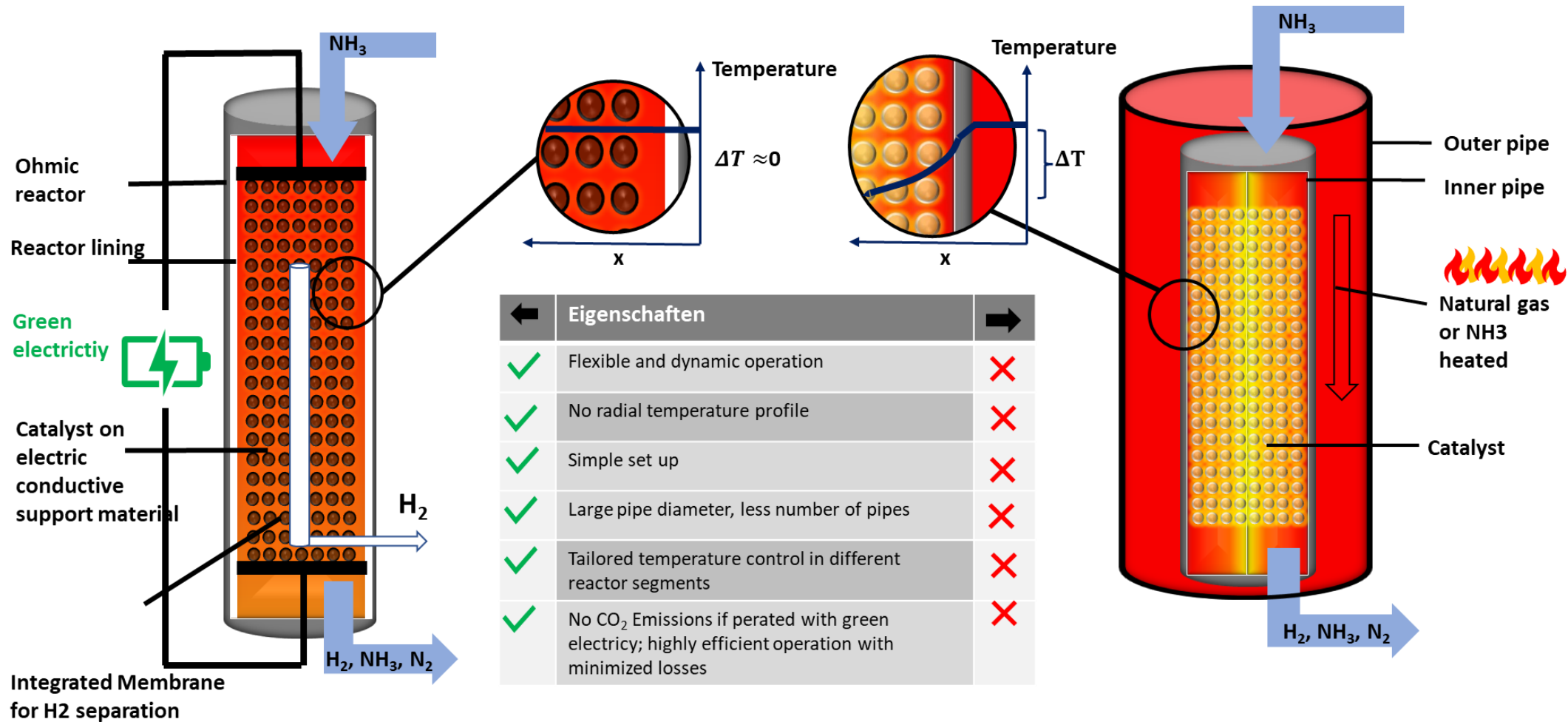
- ❑ Analysis based on a **flexible time horizon** and geographical considerations (regional, national, or global)
- ❑ **Incorporation of uncertainty** in future demand and cost development through various scenarios
- ❑ **Concentration on specific segments** of the supply chain possible (e.g., centralized vs. decentralized cracking)
- ❑ Optional **focus on specific consumer markets** (e.g., marine propulsion systems)

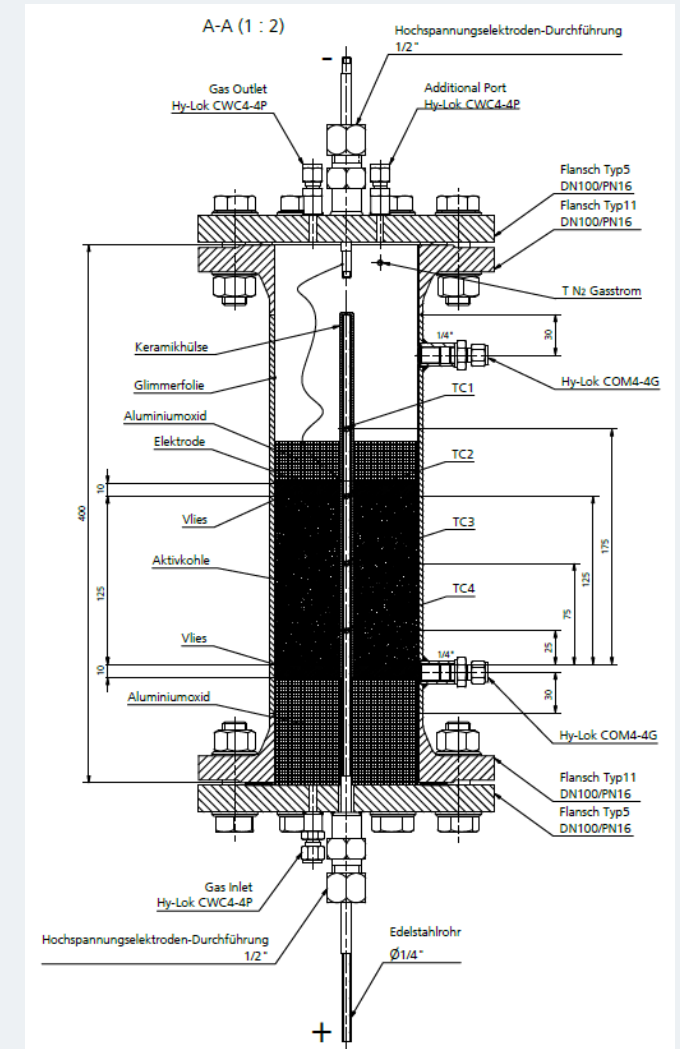
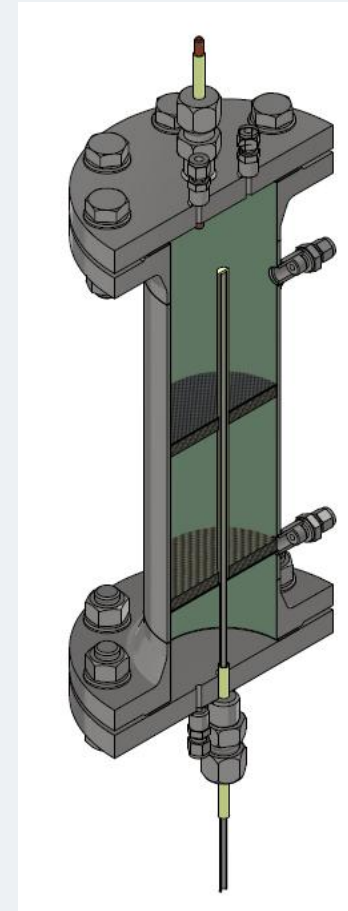


Underlying Network:



Ohmic Heating for Highly Efficient Ammonia Decomposition

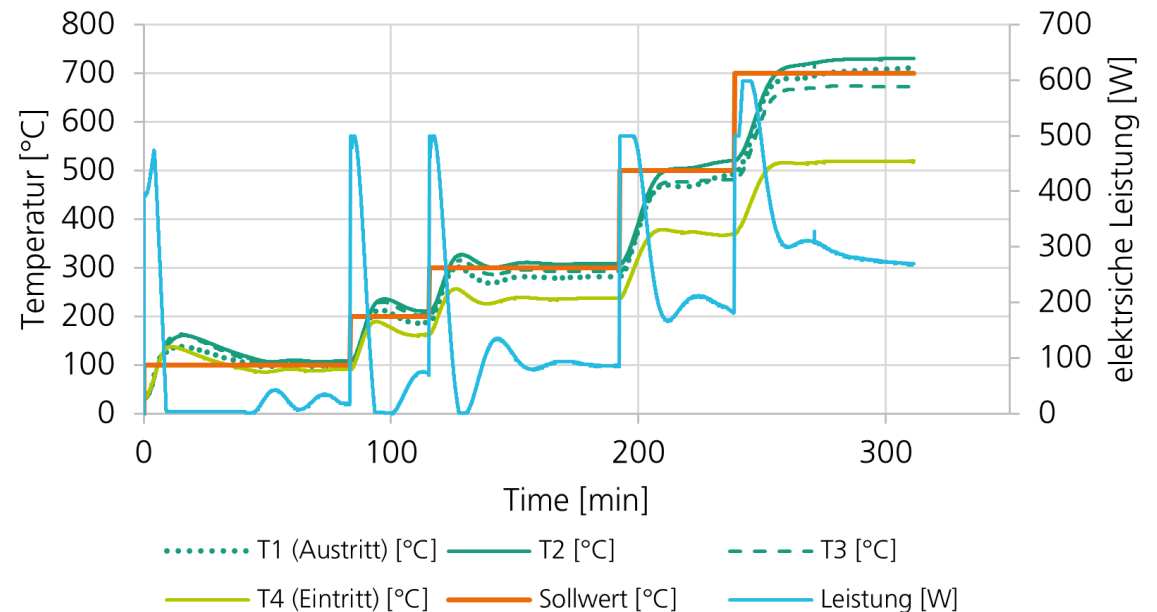




Reactor development – Ohmic heating

Conducting heating tests:

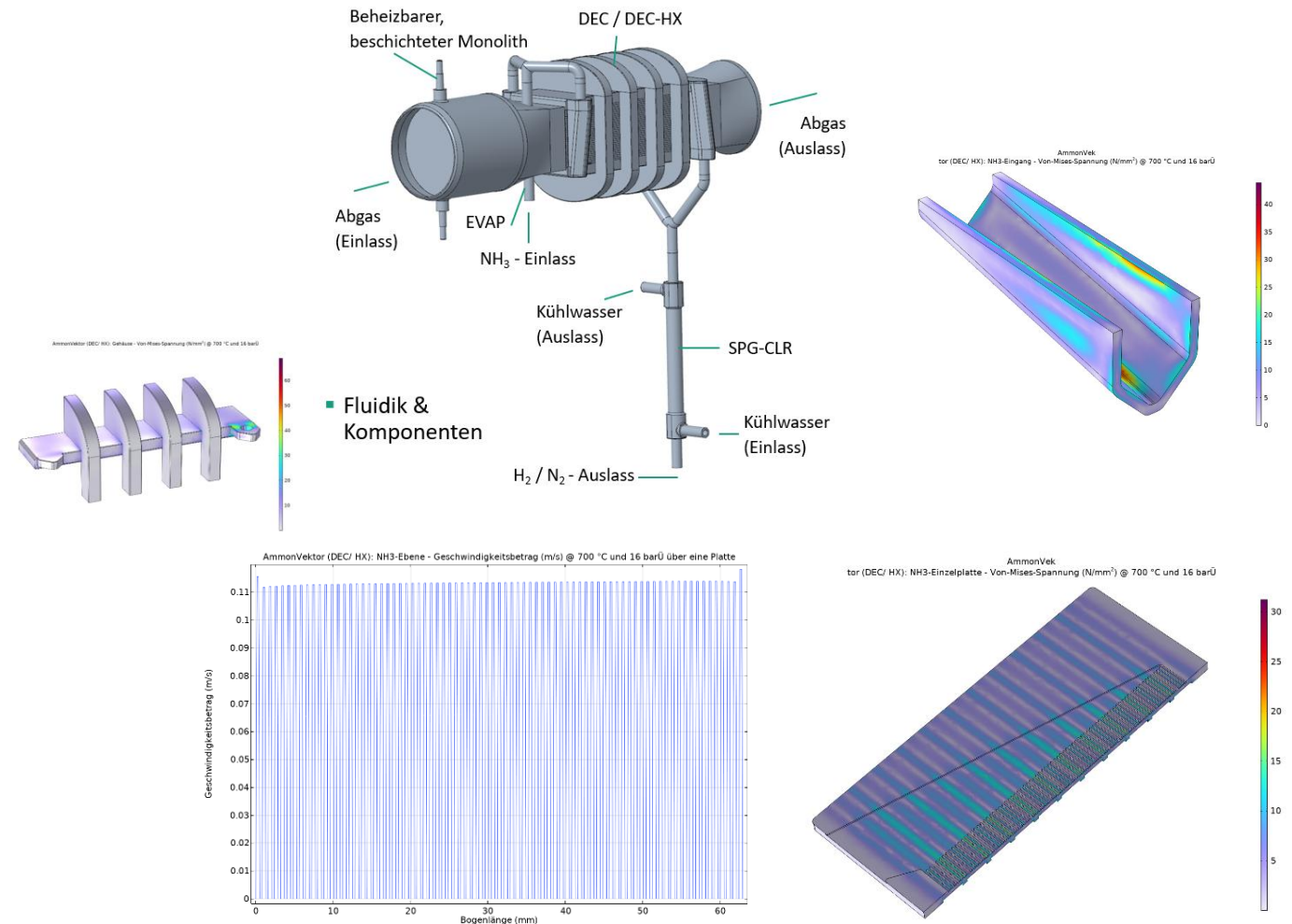
- A too high resistance of the fixed bed prevents the introduction of the power necessary for heating
 - Stepwise heating to 100, 200, 300, 500 and 700 °C
 - Limitation of electrical power
 - Up to 500 °C at 500 W
 - Up to 700 °C increased to 600 W
 - Control via the average of measuring points T1–T3
 - With increasing temperature, the fixed-bed temperature T4 at the inlet deviates from T1–T3
 - At the 700 °C setpoint, T1–T3 are within ± 25 °C around the setpoint, while T4 is only about 510 °C
- The power required at 700 °C is about 270 W.
Resistance of the fixed bed about 1.5 Ω (near the optimum of the power supply)
75 % of the catalyst filling have a well-controllable temperature and are comparatively isothermal.



Reaktorentwicklung – abgasbetriebener Crackreaktor

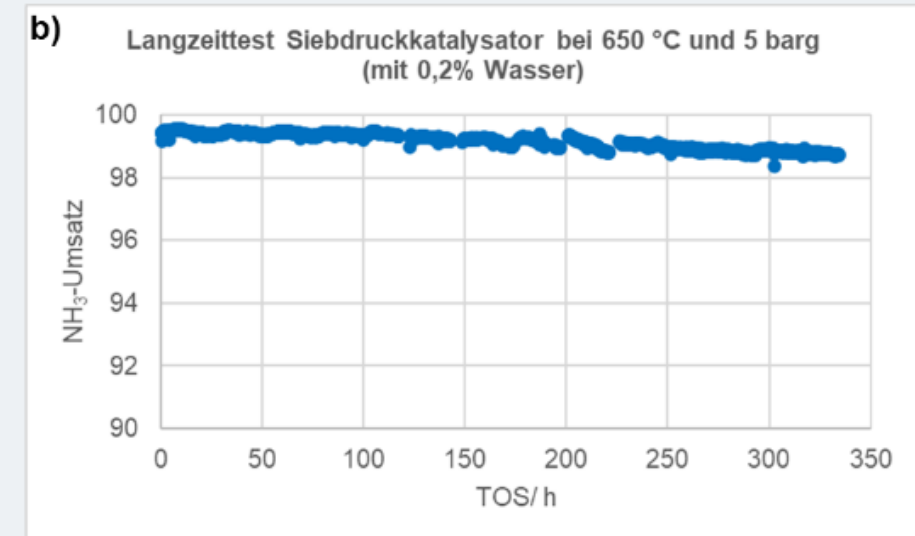
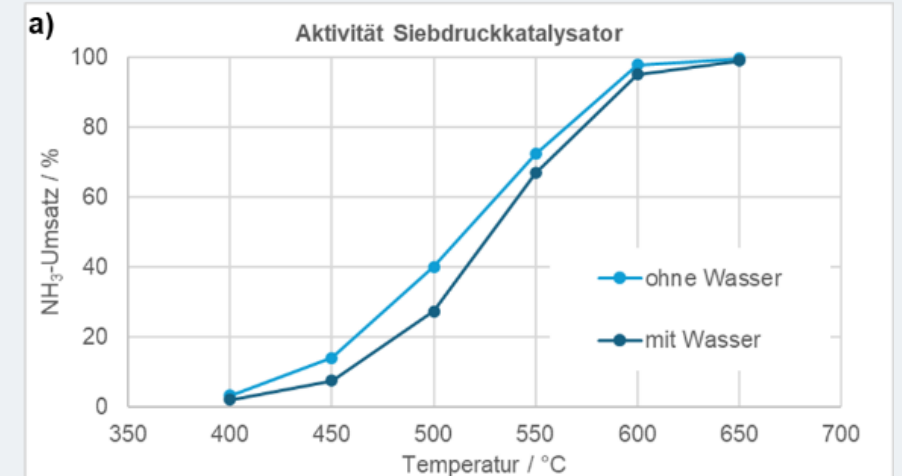
Design of the exhaust-gas-operated cracker reactor (DEC/DEC-HX) was finalized:

- Uniform distribution of ammonia over the channels of a plate
 - Simulation of the mechanical stability of the plates, the stack and the side connections
 - Internal processing started
 - Coating of the plates with catalyst
 - Stacking and welding of the reactor stack
- An electrically heated, catalyst-coated monolith integrated in the exhaust line before entry into the cracker reactor allows additional temperature control of the exhaust gas:
- During start-up
 - In part-load ranges



Ammonia cracking catalysts - Catalytic coating

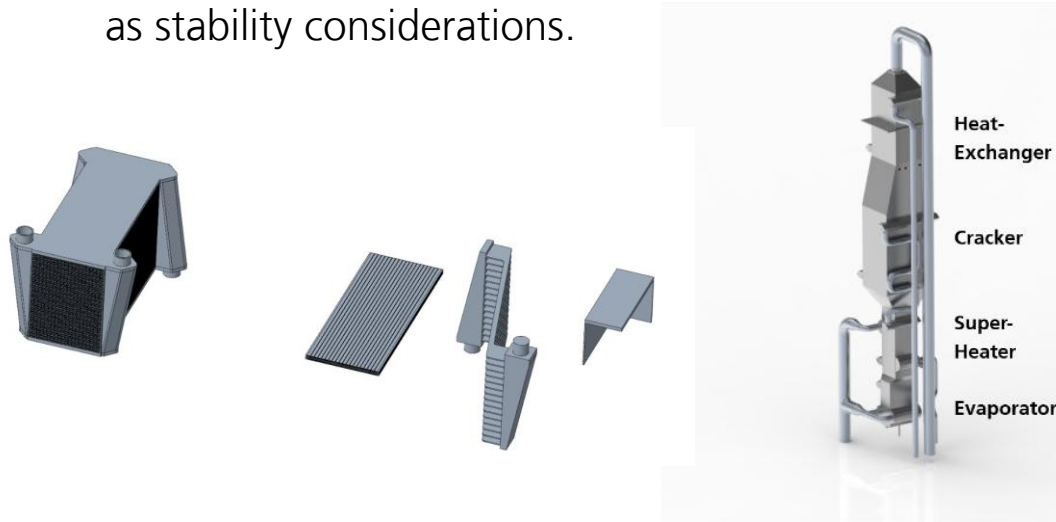
- Technical ammonia contains water (usually 0.2–0.5 %), therefore investigations were carried out in the presence of water.
- Activity measurements with addition of 0.2 % water (WHSV = 200 L g_{cat}⁻¹ h⁻¹) showed a negative influence of water.
- Long-term test at WHSV = 100 L g_{cat}⁻¹ h⁻¹: nearly stable over 300 hours.
- Therefore, further optimization of the catalyst formulation is ongoing.



Development and Testing of Demonstrators

Conversion of an existing ammonia cracking reactor to operation with PSA (IMM)

- Housing in pressure vessel
- Continuous operation with PSA 75 kg/d
 - Development of a plate heat exchanger reactor with a catalyst wall coating
 - Integration of the experimental data 2 using the process engineering simulation model and based on the parameterization of the CAD files into the reactor design
 - Finalization of the reactor development through (iterative) simulations regarding fluid and thermal distribution as well as stability considerations.



ICE thermodynamic test bench for single- and multi-cylinder engines

Combustion system development capabilities (Performance and Emissions)

Fluid supply und -conditioning

- Process air, oil, coolant
- Fuels (liquid or gaseous)
 - Petrol (DIN EN 228), Ethanol, Methanol, LPG (up to 500 bar), Diesel (DIN EN 590), (Ammonia from Q2/2026)
 - Methane, Hydrogen (up to 50 bar), ...

Emission analysis

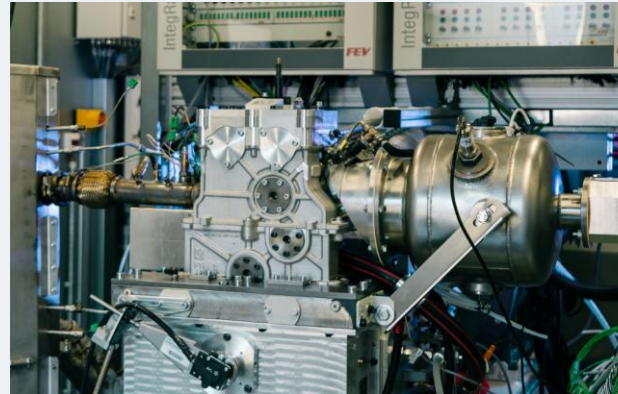
- CO, CO₂, NO/NOX, THC, O₂, CH₄,
- Particle amount, -size und -size distribution

Application Tools

- Freely programmable development engine control units (ECU) with cycle-based real-time control capability
- High-speed cameras, UV intensifiers and UV endoscopes are available for combustion visualization
- Rapid post-processing of measurement data based on ICT data Management Tool

Fraunhofer ICT single-cylinder research engine

- Scalable top (cylinder head) and bottom end (cylinder block/crank train) for customized project specifications
 - PtX demonstrators
 - Online wear measurements using radio nuclide technology – Cooperation with FhI-IWM



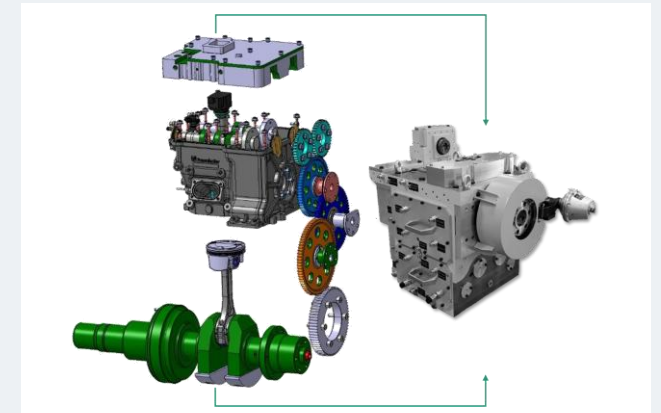
Test bench



Standard exhaust gas analyzer + fast gas analyzer (CLD, FID, NDIR), particle counter (>23nm), particle spectrometer (>5nm)



Optical measurement technology



Fraunhofer ICT single-cylinder research engine

Fraunhofer FLAGSHIP PROJECT »AmmonVektor«

- Concept revision of the combustion process demonstrator
- Metals containing Cu, such as plain bearings and liners, are of particular importance here (as are seals and other components in the fuel path)
- Analysis of exhaust gases
- Optimization of combustion process (H_2/NH_3)
- Coupling of cracker and engines

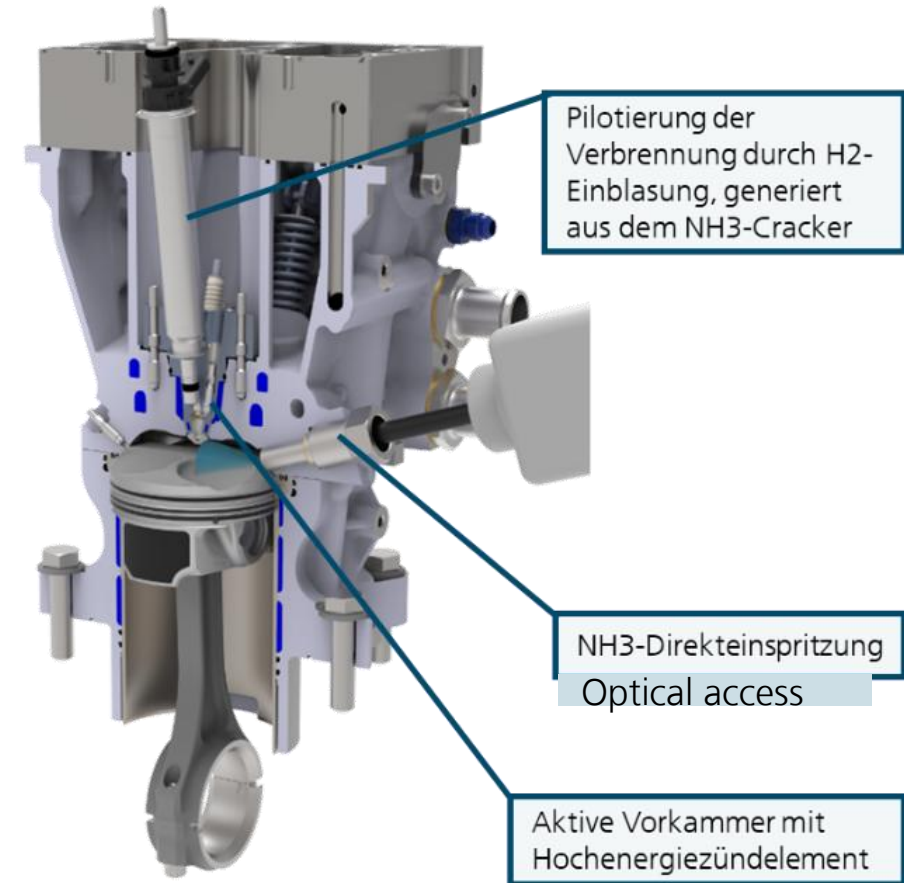
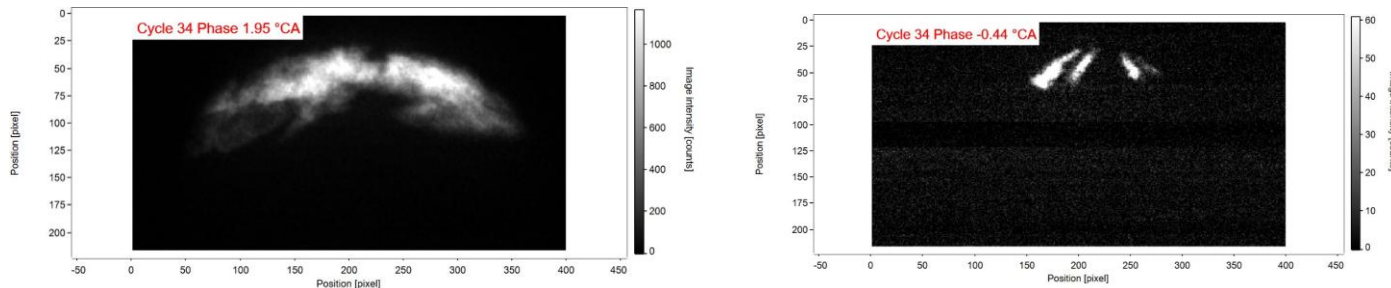


Abbildung: 3D-CAD Entwurf des NH_3 -Brennverfahrensdemonstrators

Applied Research for Clean Combustion

Carbon Capture

Utilization of **biogenic residues** and waste

Flue gas treatment & **emission reduction**

Combustion of solid fuels

- Grate furnaces in different designs 30, 100, 300, 440 kW
- Powder burner 100 kW
- *Oxycombustion grate furnace* (under construction)

Combustion of gaseous fuels

- Oxyfuel combustion for carbon capture
- CH_4 , H_2 , NH_3 burner (under construction)

Emission measurements

- Particulate matter (VDI 2066)
- Cascade impactor
- Mobile FTIR
- High-temperature camera
- ...

Gas cleaning and emission reduction

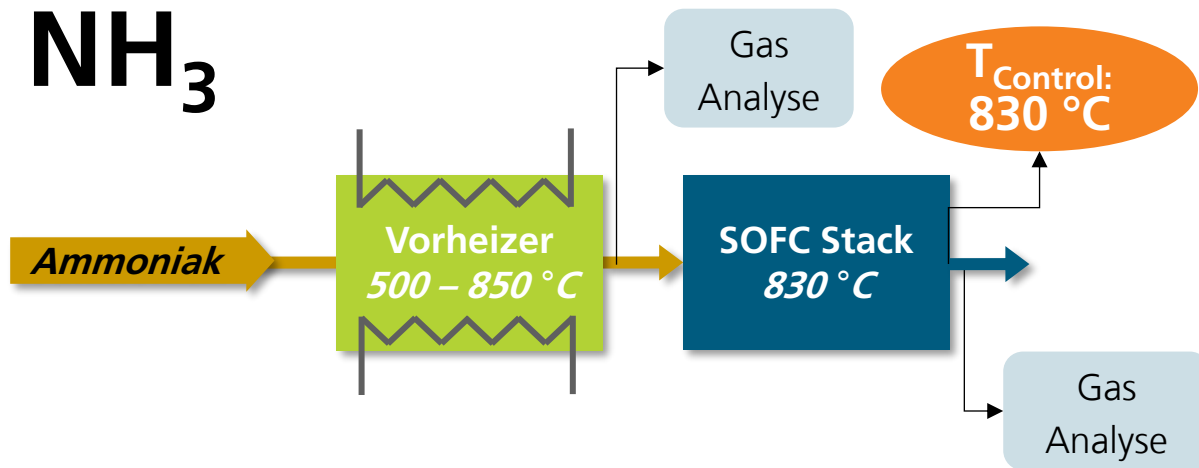
- Activated carbon
- Electrostatic precipitators
- Scrubber
- Catalytic emission reduction
- Reburning



NH₃-SOFC-Tests

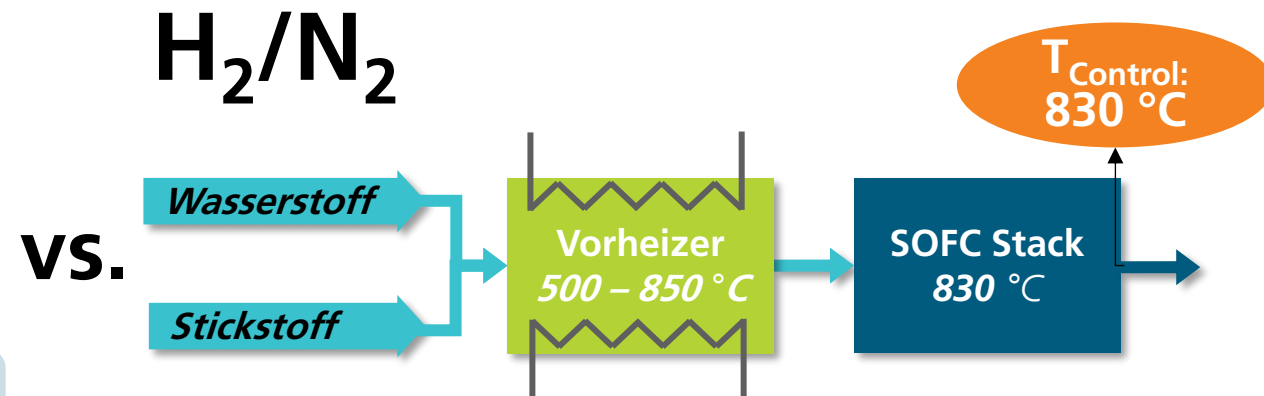
Comparison test with H₂/N₂ at the SOFC stack:

NH₃, T_{Stack,outlet} = 830 °C, 75 % FU, 1000 W
Variation of the NH₃ conversion rate via the preheater temperature
Gas analysis before and after the anode (SOFC stack)



H₂/N₂, T_{Stack,outlet} = 830 °C, 75 % FU, 1000 W

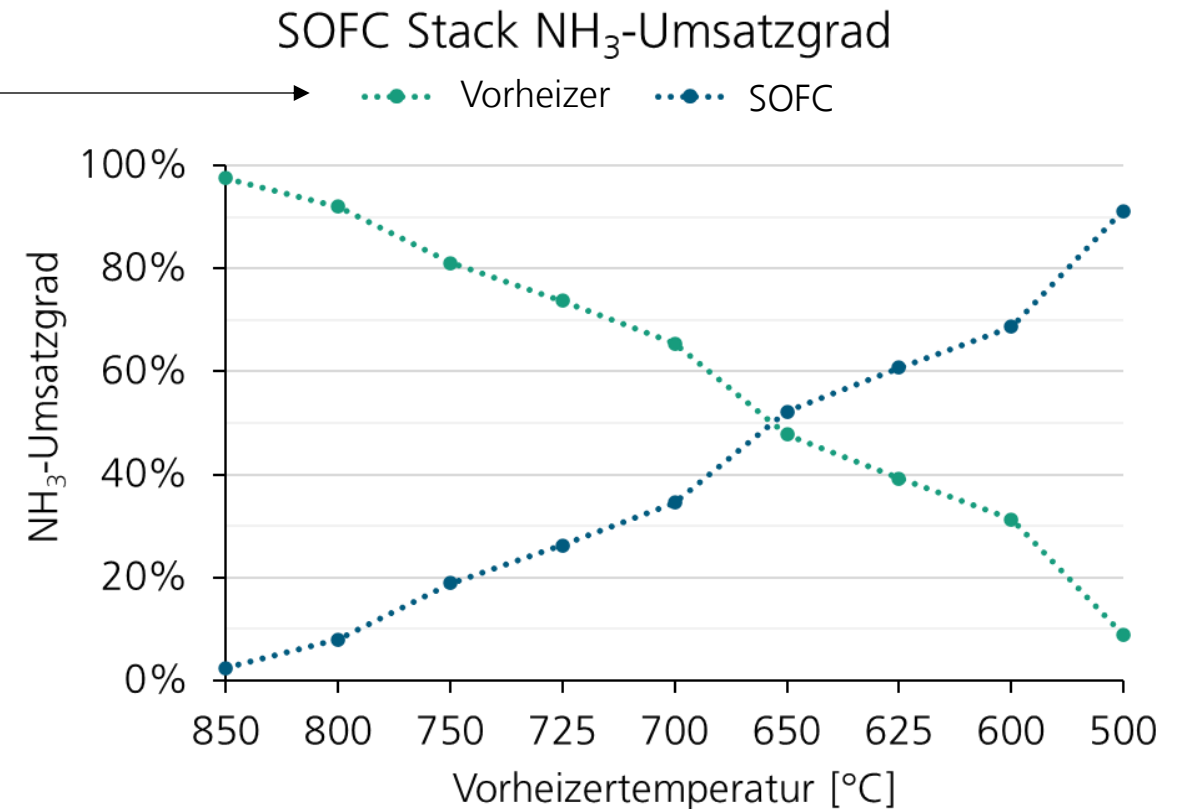
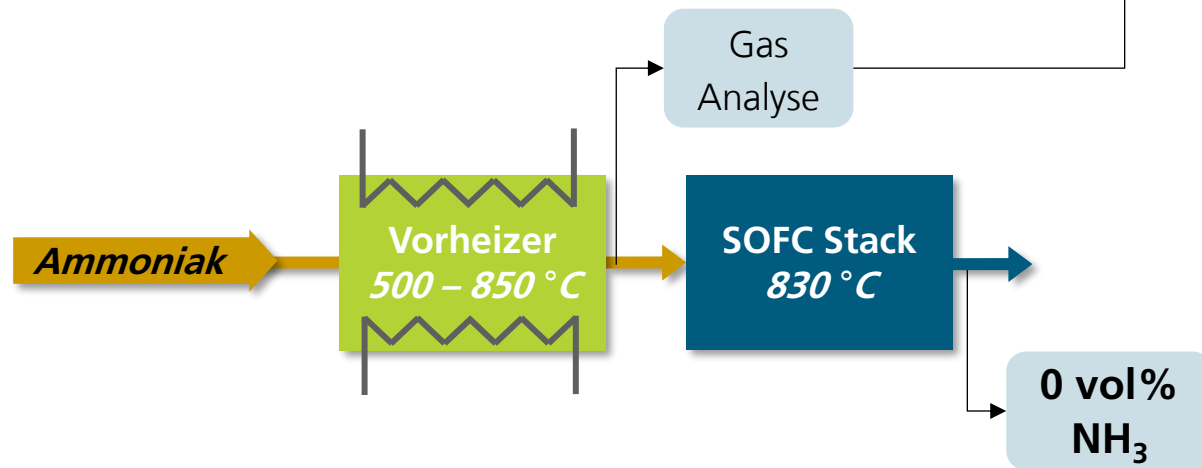
Variation of the preheater temperature
Dosage of the same fuel power into the SOFC stack
→ without endothermic cracking (75 % H₂, 25 % N₂)



NH₃-SOFC-Tests

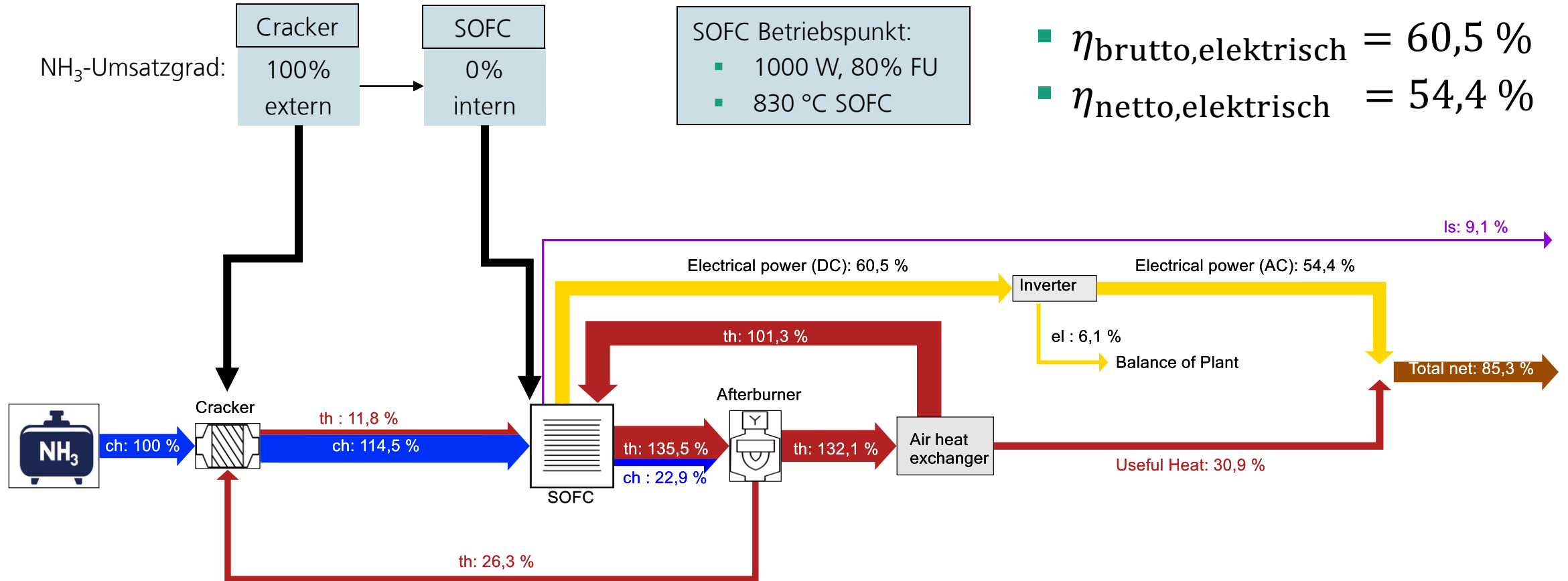
NH₃-SOFC-Tests:

- Fuel: NH₃, T_{Stack,outlet} = 830 °C, 75 % FU, 1000 W
- 0 vol.% NH₃ measured downstream of the anode
- Stable operation with up to 90 % uncracked ammonia reaching the SOFC



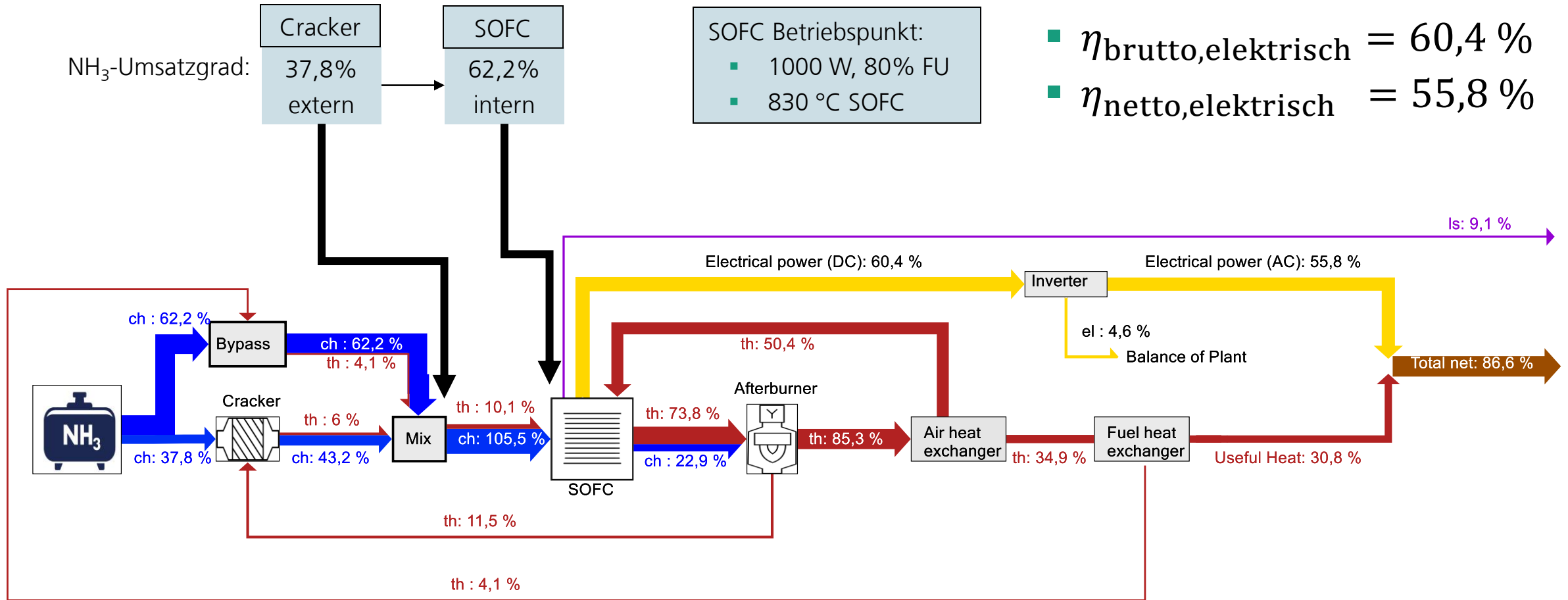
Analysis of System Operation

Process simulation: 100 % Cracking external



Analysis of System Operation

Process simulation: 62 % Cracking inside of the SOFC-Stack → blower power reduction

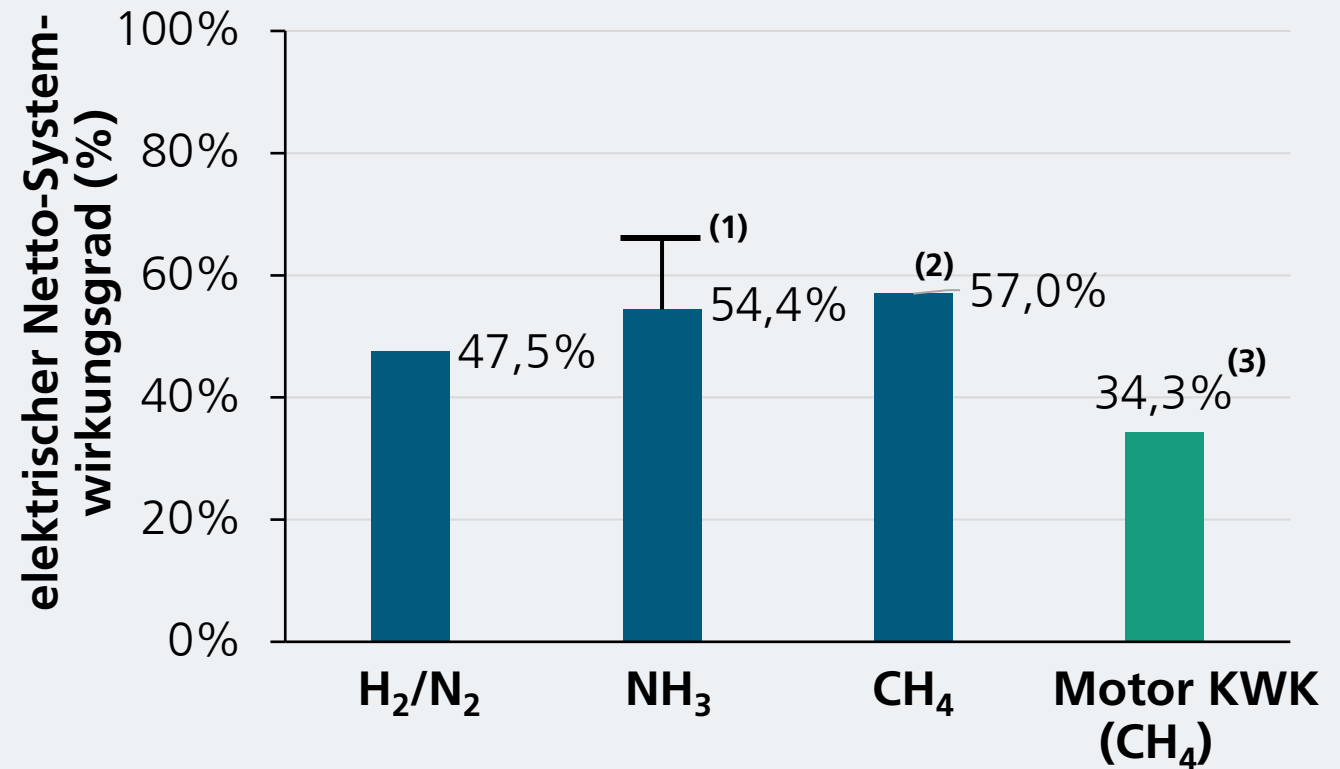


Analysis of System Operation

Comparison with other fuels

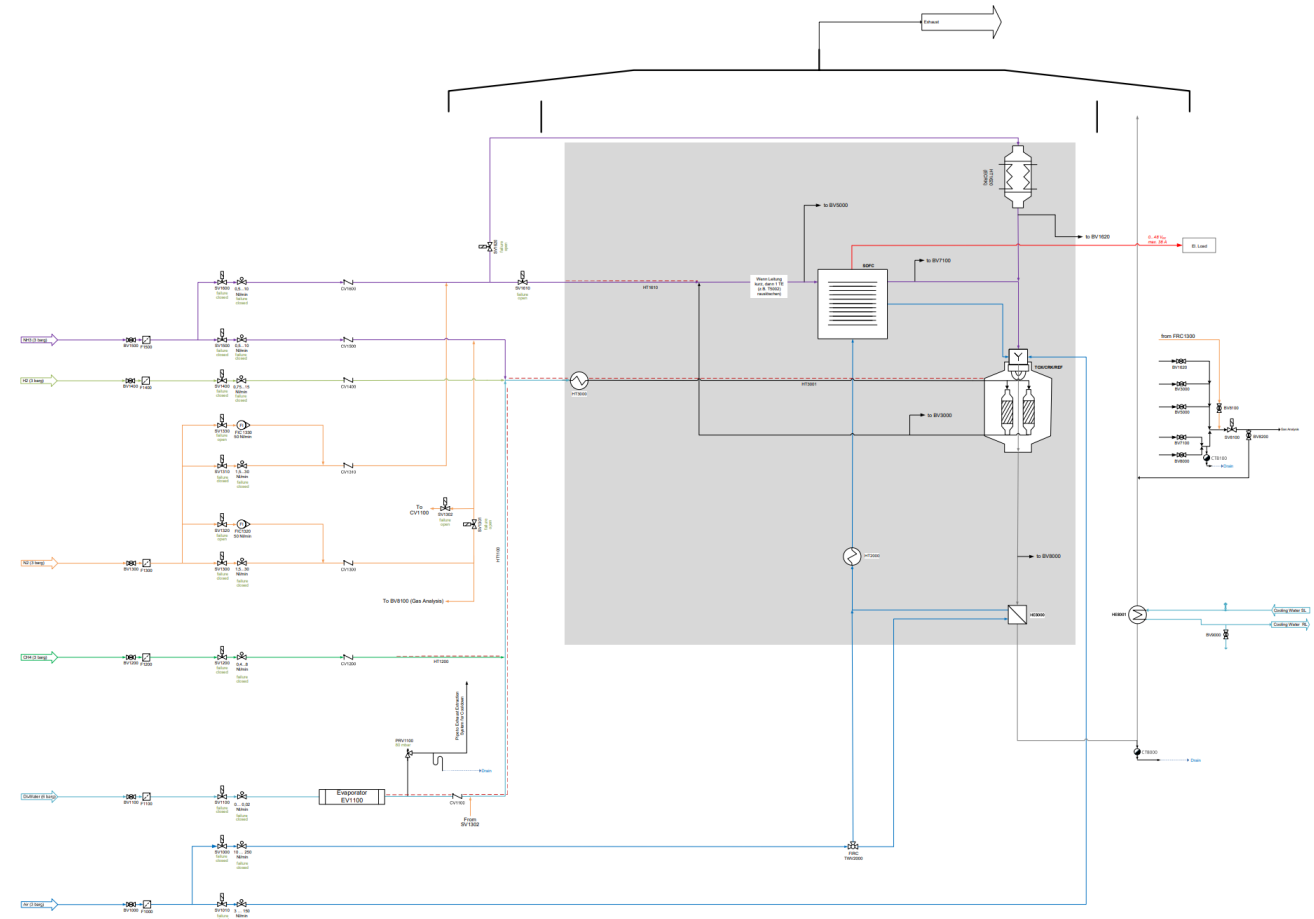
Comparison with other fuels

- NH_3 -SOFC operation enables high electrical net system efficiencies out of the box
- Already comparable with methane-based SOFC operation with anode gas recirculation (2)
- Increase of NH_3 electrical efficiency through further known system concepts (AOGR, cascading) (1)
- → Possibility to use NH_3 AND CH_4 in a multi-fuel SOFC system



Results

- Pre testig at IKTS
- Concept: Multi-Fuel Test Rig (NH₃ and CH₄)
- Design of the afterburner/reformer/cracker unit
- Demonstrator design: Scalable multi-fuel SOFC unit
- Implementation phase: Electrical planning, orders, assembly, commissioning
- Test phase: End of 2026

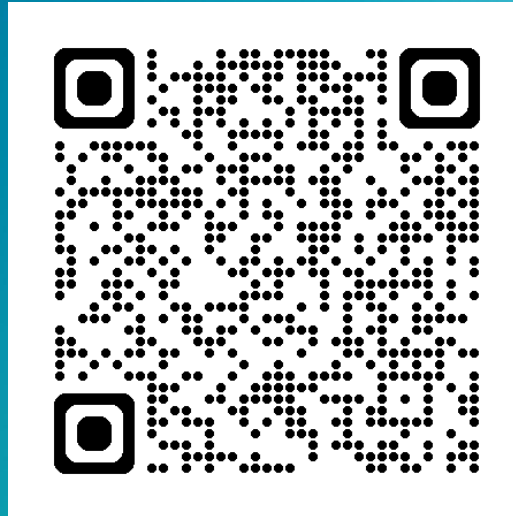


Prozessflussdiagramm des Multi-Fuel-Teststands

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