THE HYDROGEN AND FUEL CELL CENTER

Ammonia as a Hydrogen Carrier for Decentralized Applications

Lena Engelmeier, Michael Steffen

Euregional H2 Business Event @ H2Hub Twente , 02.10.2025

ZBT

KEY FACTS

- Applied research and development: fuel cells, hydrogen and electrolyzer technology
- Focus on industry demand - Independent service provider and R&D partner
- GmbH/ltd. as daughter of University of Duisburg-Essen
- ~ 150 full time employees + ~30 student researchers
- Limited institutional funding by state of North-Rhine-Westphalia

UNIVERSITÄT DUISBURG ESSEN
Offen im Denken

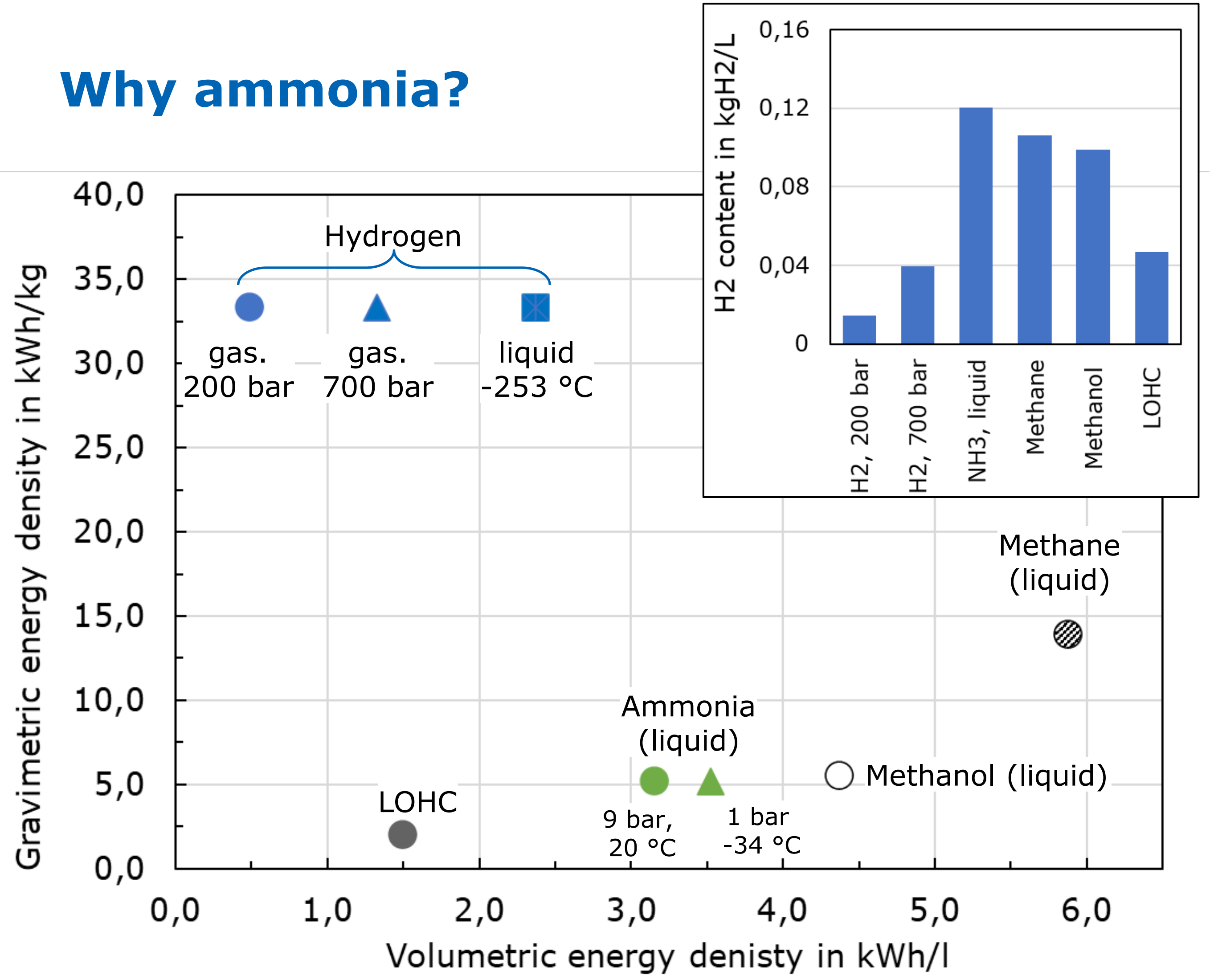
EUROPEAN UNION
Investing in our Future
European Regional Development Fund

Ministerium für Wirtschaft, Industrie, Klimaschutz und Energie des Landes Nordrhein-Westfalen

Ministerium für Kultur und Wissenschaft des Landes Nordrhein-Westfalen

JRF
MEMBER OF Johannes-Rau-Forschungsgemeinschaft

Why ammonia?



Due to transport, storage, and distribution, volumetric storage density with simple storage technology is crucial for the economic viability of energetic use!

- Hydrogen challenge: low density, costly transport
- Derivatives: Ammonia, Methanol, Methane

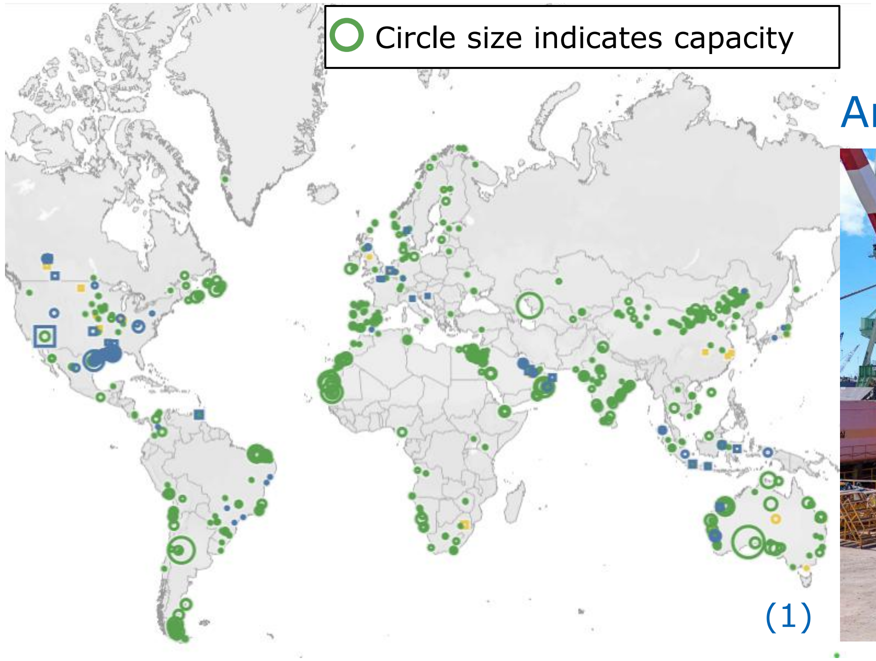
Ammonia advantages:

- Only carbon-free H_2 carrier
- GWP = 0
- High volumetric & gravimetric density
- Liquid at −33 °C or 9 bar → simple storage
- High heating value
- 2nd most produced chemical worldwide (>180 Mt/a; >18 Mt/a traded; >200 ports)
- Mature technology: production, storage, distribution, use
- 100+ years safe handling, despite toxicity
- Regulations & codes established

Weltenergierat, Ammoniak als Energieträger für die Energiewende, 2023

Ammonia infrastructure

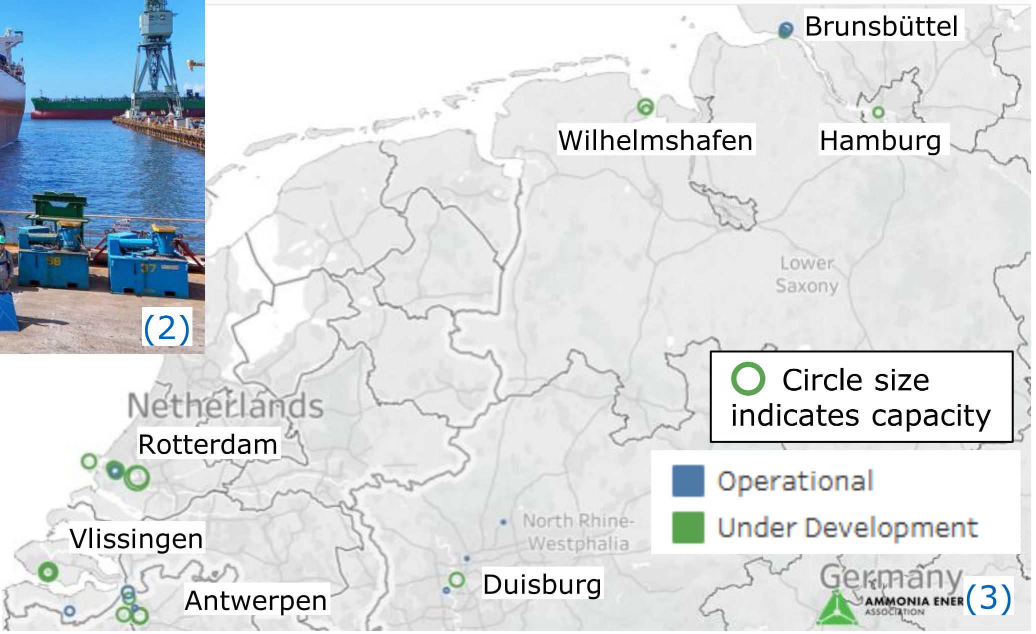
Production plants



Ammonia-Fueled Vessels

Ammonia terminals

- Ammonia terminal capacity expands worldwide
- planned NH_3-hubs in the ARRRA-region and North-Western Part of Germany



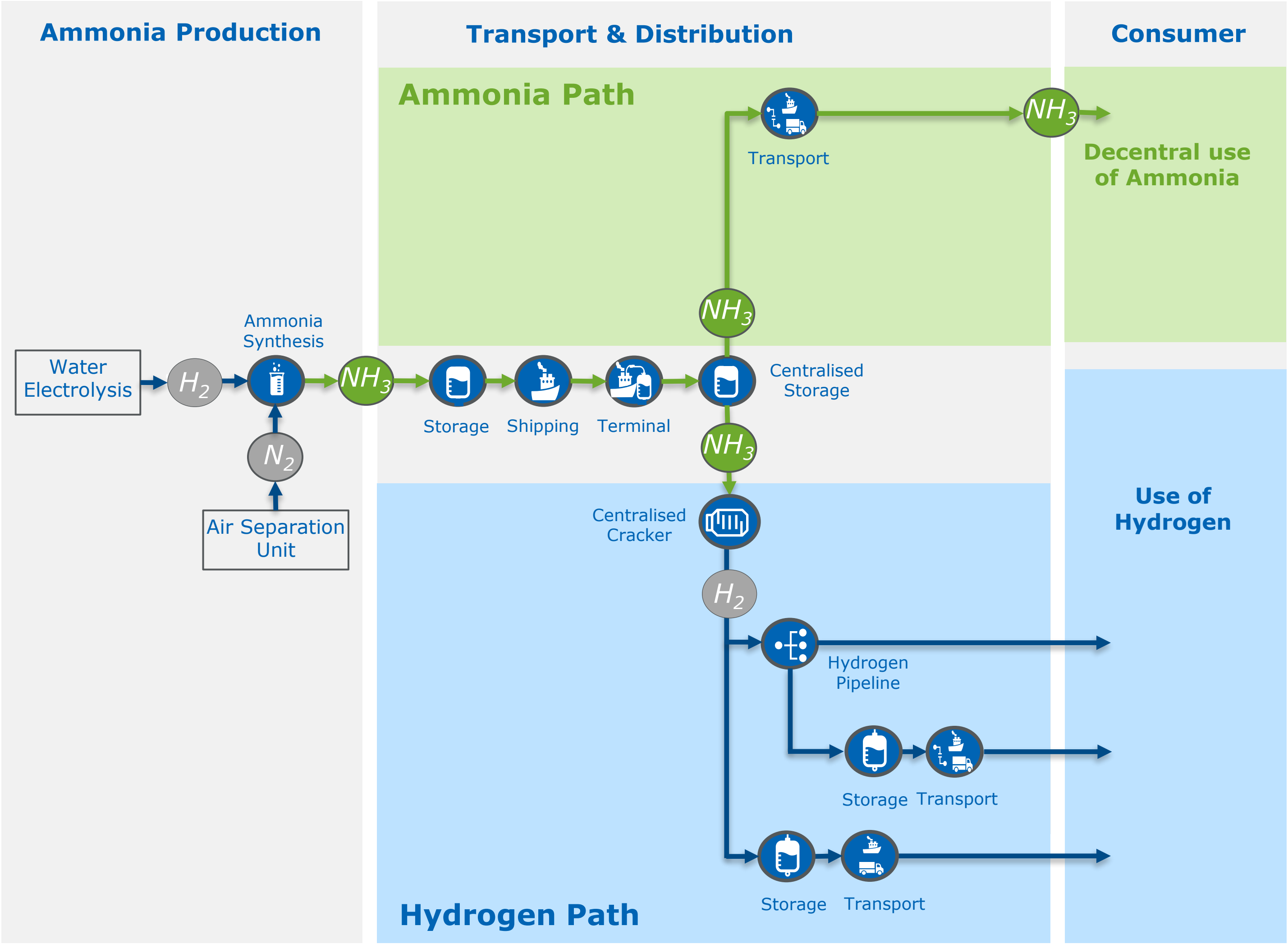
August 2025

- 478.8 million tons (Mt) of low-emission and transitional ammonia have been announced
- by 2030: 46.8 Mt could become operational

Ammonia infrastructure under development!

 (1) https://ammoniaenergy.org/lead/plants/, (2) https://ammoniaenergy.org/articles/exmar-launches-its-first-ammonia-fueled-vessel/, (3) https://ammoniaenergy.org/lead/infrastructure/

Ammonia Energy System



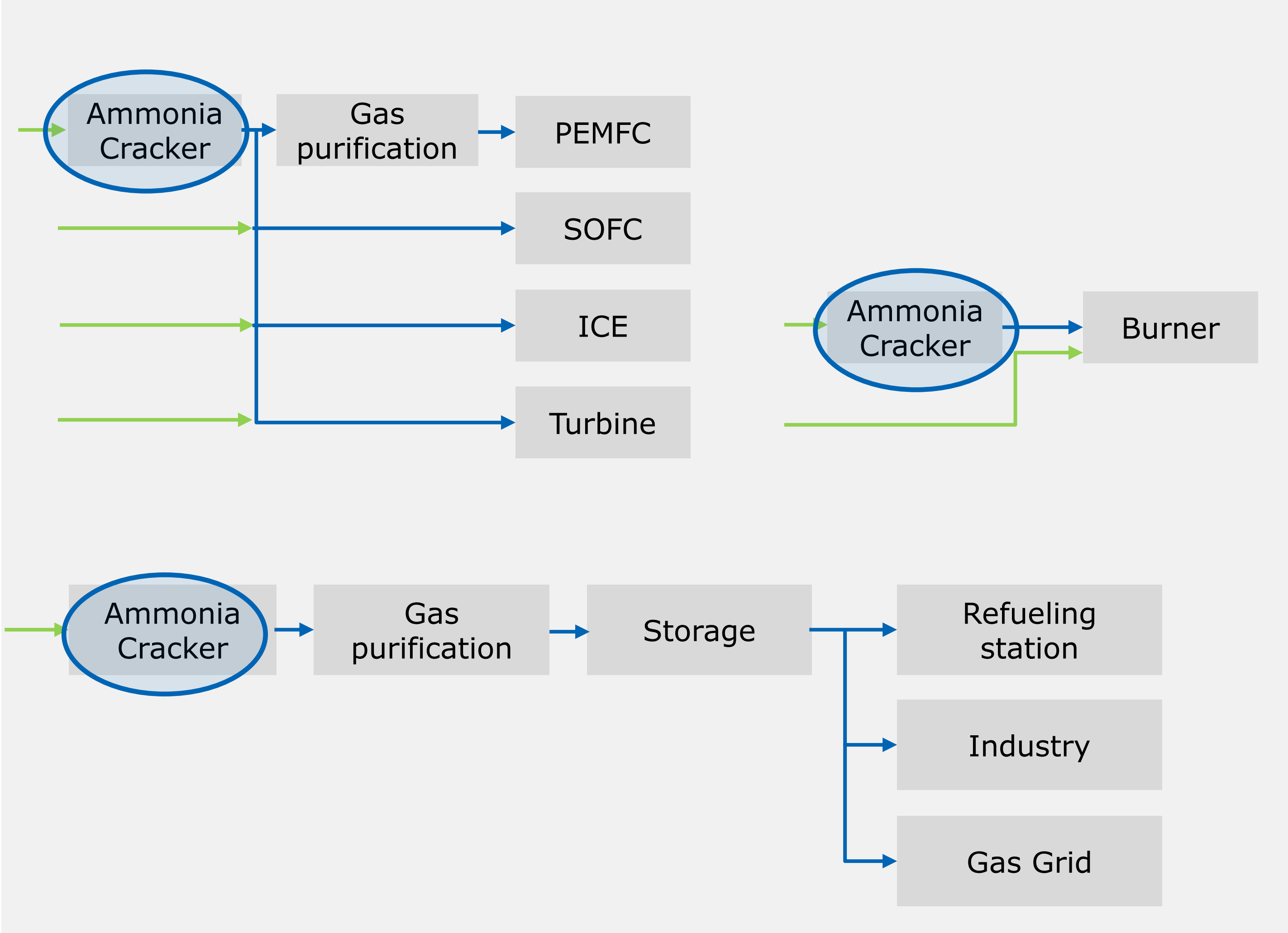
Decentral use of ammonia

- Ammonia for industry
  - chemical production (State-of-art)
  - steel production
  - process heat supply
- Ammonia for power generation
  - centralized power
  - decentralized power
  - CHP and backup power
- Ammonia for transport
  - ocean-going vessels, inland waterway vessels
  - trains
  - airplanes
  - construction and agricultural machines
- Ammonia for hydrogen fueling stations

➢ Ammonia shows high potential in future carbon free chemistry, transport and energy!

Figure adapted from: Westphal, H., Graul, H., Hoffmann, F., Klages, C., Kübler, M., Möhring, L., Völler, J. (2023): KOMMERZIELLE SCHNITT-STELLEN ALS HERAUSFORDE-RUNG FÜR DEN AUFBAU VON WASSERSTOFF-LIEFER-KETTEN. Policy Brief H2Global Stiftung 03/2023. H2GLOBAL STIFTUNG.

Usage of green ammonia in decentral applications

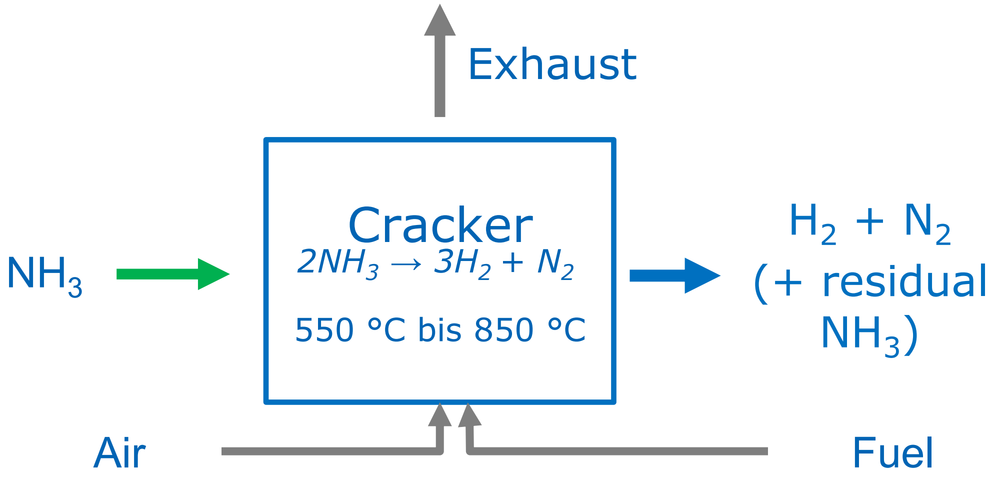


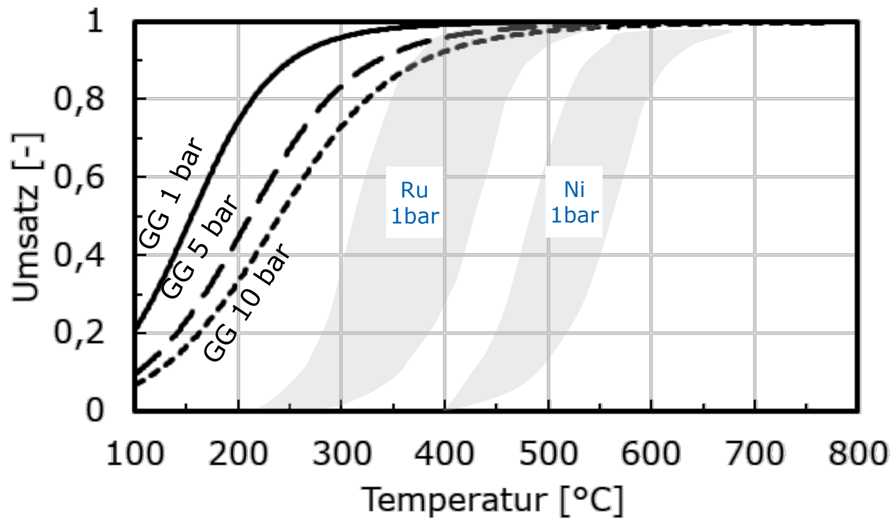
Decentral use of ammonia

- Ammonia for industry
  - chemical production (State-of-art)
  - steel production
  - process heat supply
- Ammonia for power generation
  - centralized power
  - decentralized power
  - CHP and backup power
- Ammonia for transport
  - ocean-going vessels, inland waterway vessels
  - trains
  - airplanes
  - construction and agricultural machines
- Ammonia for hydrogen fueling stations

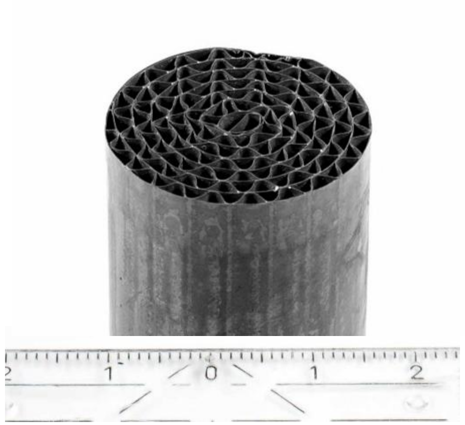
➢ Ammonia Cracker: Key component of the ammonia energy system.

Ammonia-Cracking: Functional Principle

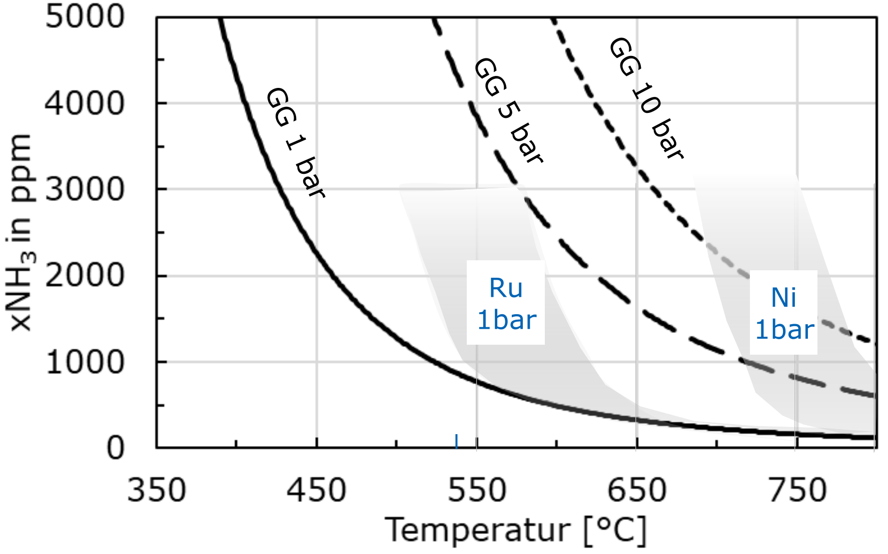




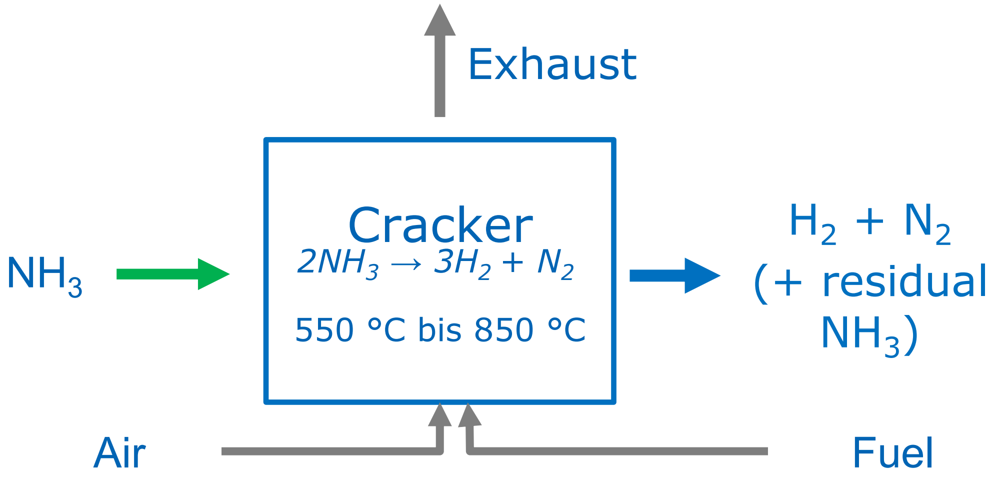
Photograph of bulk catalysts



Photograph of a honeycomb catalyst



Ammonia-Cracking: Functional Principle



Reactor with heat exchanger and integrated heat supply

Ammonia cracking plant

Decentralized and Small Scale Ammonia Cracking

- NH_3 crackers are a key component of the NH_3 energy system
- NH_3 crackers are not yet state-of-the-art and not commercially available

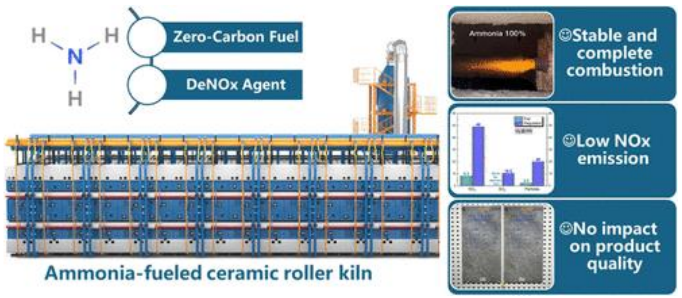
Main challenges in cracker development include:

- Development of novel catalysts
- Reactor design for efficient heat integration and transfer
- Identification and selection of suitable reactor materials
- Integration of appropriate purification processes

AMOGY
AMMONIGY
SUNBORNE SYSTEMS
H2 SITE Membrane reactors for H2 generation
AFC Energy
HYAMTEC
GenCell
KAPSOM
Starfire Energy
CSIRO
ZBT
KIER 한국에너지기술연구원
KIER KOREA INSTITUTE OF ENERGY RESEARCH
KIER
Fraunhofer

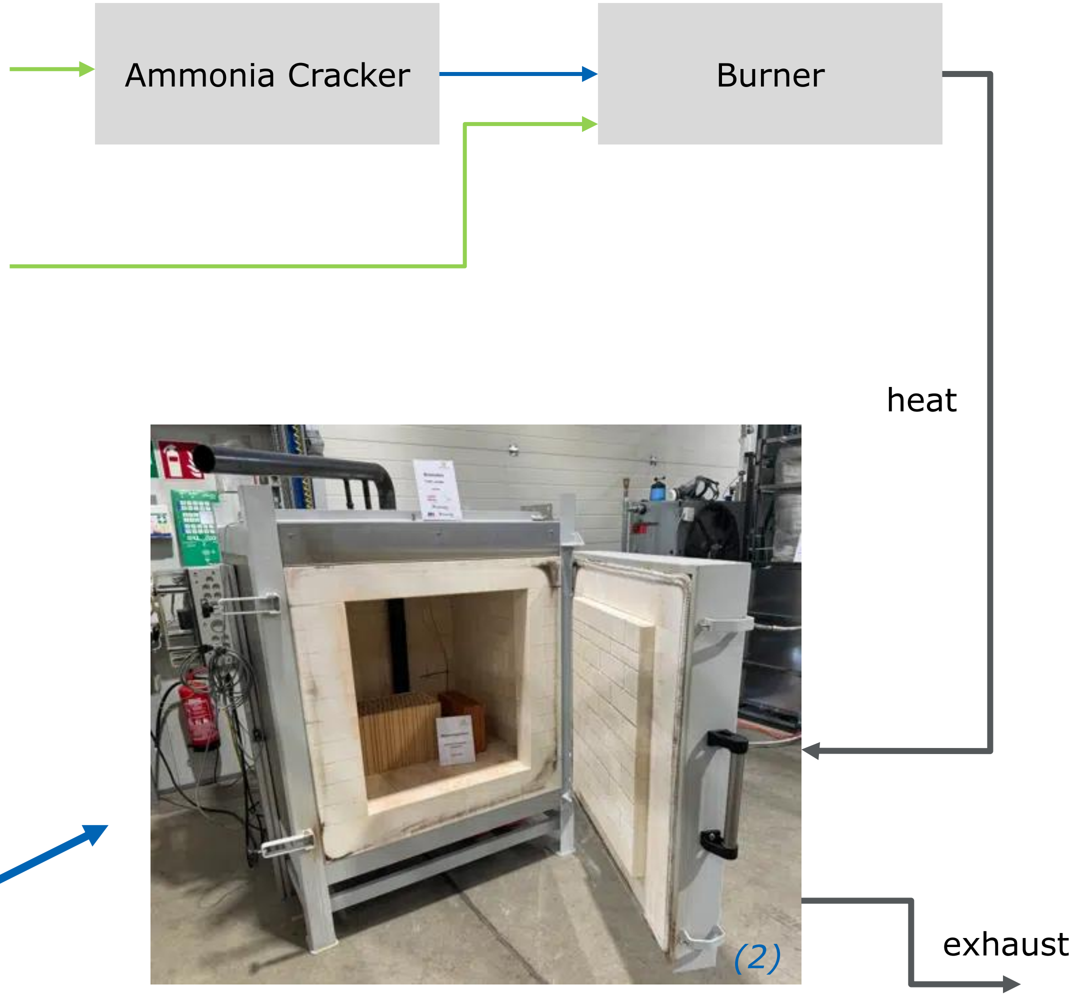
Ammonia for industry (process heat)

- glass production with pure Ammonia (*AGC*, Japan)
- cement clinker production with ammonia co-combustion (*Heidelberg Materials*, UK; *Mitsubishi UBE*, Japan)
- ceramic tile manufacturing with pure ammonia and ammonia/hydrogen (*Monalisa Group & Foshan Xianhu Laboratory*, China)



(1)

- **brick production** using ammonia, hydrogen, nitrogen (*Ammonigy*: Cracking tech provider, *Juwö Poroton*: leading German brick manufacturer, *Fraunhofer IMM*, *Fraunhofer ITWM* & *Industrie-Brenner-Systeme*: industrial burner manufacturer)



Pilot brick kiln, developed in "Green Cracked Gas" project *[2]*

(1) *Energy Fuels 2024, 38, 22593−22604* (2) https://www.zi-online.info/en/artikel/green-cracked-gas-as-firing-gas-for-clay-brick-production-decarbonization-with-ammonia-as-fuel-4254018.html

Ammonia for power generation

Gas turbines

- large-scale in development (USA, Japan, Korea)
- small scale at the stage of fundamental research

Table 4 (1)
Existing and in developing stage ammonia-powered gas turbines.

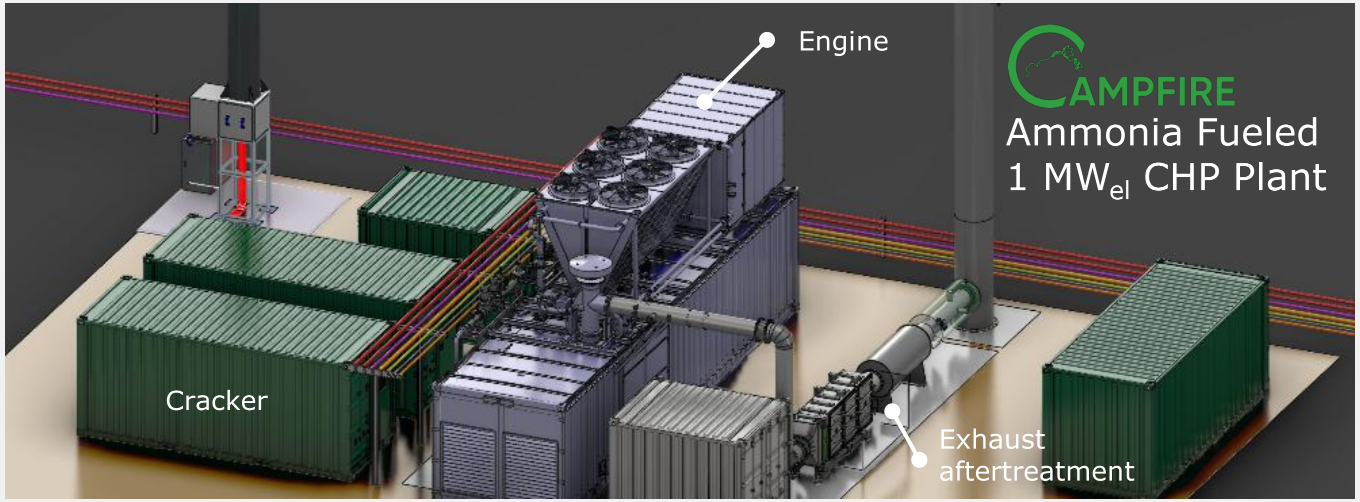
Manufacturer	Capacity	Operates on	Current status	Ref
Kawasaki Heavy Industries	1 MW	Pure ammonia or ammonia-natural gas blend	Developed & tested	[237]
Siemens	2 MW	Pure ammonia or ammonia-natural gas blend	Developed & tested	[238]
IHI	2 MW	Pure ammonia	Developed & tested	[239]
Turboden	15 MW	Ammonia-natural gas blend or pure ammonia	In operation	[240]
MAN Energy Solution	20 MW	Pure ammonia or ammonia-natural gas blend	Developing stage	[241]
Mitsubishi	40 MW	Pure ammonia	Developing stage	[242]
GE Vernova & IHI	–	Pure ammonia	Developing stage	[243]

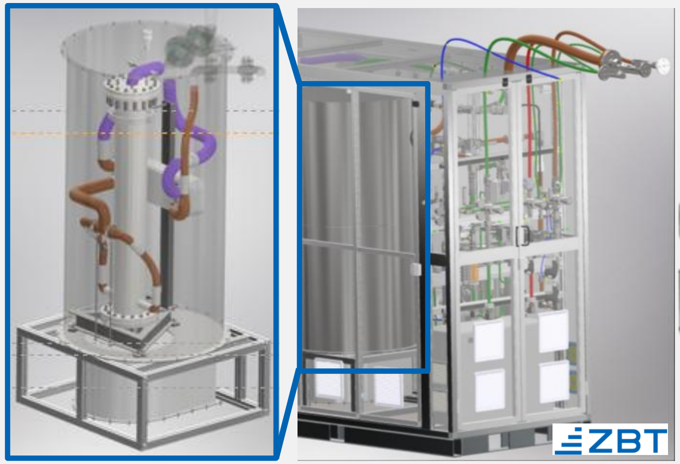
Fuel cells

- product development for AFC-technology by GenCell for off-grid power solution, currently in demo-phase
- R&D projects for SOFC-Technology mainly in Japan

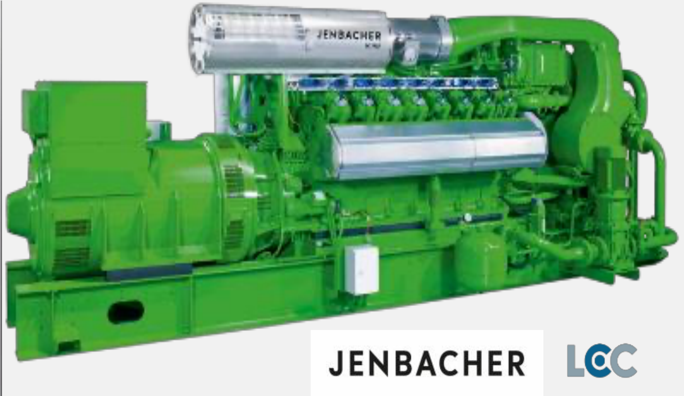
(2)

Engines





Cracking Plant 150 kW$_{H2}$

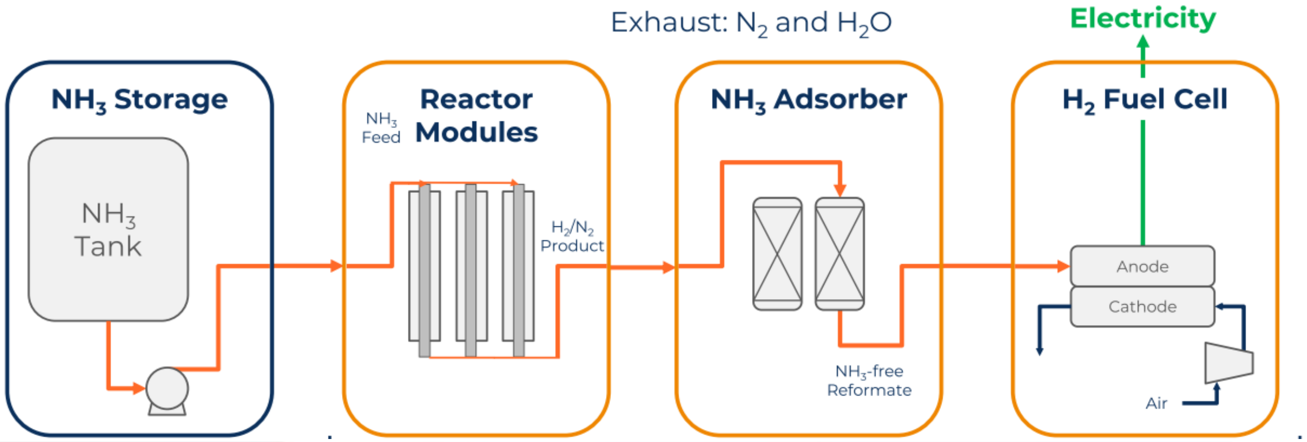


4-stroke gasengine, 1 MW$_{el}$

(1) Mohammed, Abubakar Gambo; Mansyur, Norfadilah; Hasini, Hasril; Elfeky, Karem Elsayed; Wang, Qiuwang; Ali, Mutari Hajara; Om, Nur Irmawati (2024): Review on the ammonia-blend as an alternative fuel for micro gas turbine power generation. In: *International Journal of Hydrogen Energy* 82, S. 428–447. DOI: 10.1016/j.ijhydene.2024.07.396. (2) https://www.gencellenergy.com/products/gencell-fox/

Ammonia for transport

- scalable Cracker-PEMFC-System
- powering a drone (5 kW), a tractor (100 kW), a truck (300 kW) and a tugboat (1000 kW)
- Terox ordered a 400 kW system installed in an 20 ft container to generate off-grid electricity to charge a battery bank which will in turn charge Terox's onsite fleet of electric construction vehicles

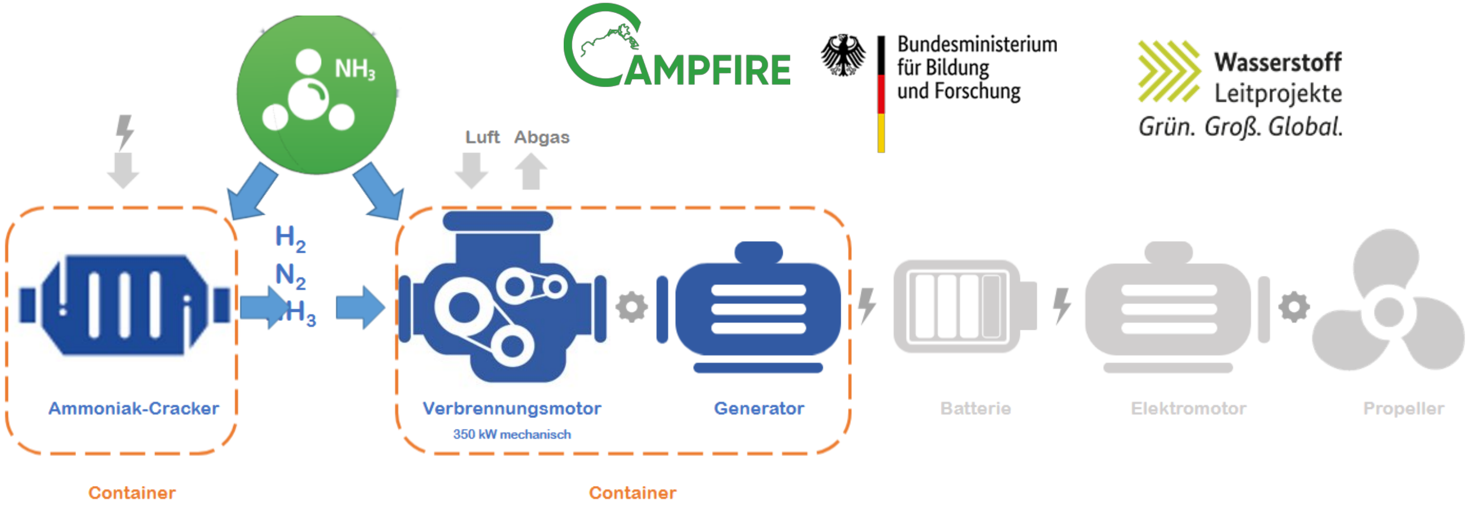


11 kg_{H2}/d ~ 2200 kg_{H2}/d

Woo, S. (2023): Ammonia-to-Power to decarbonize heavy industries. Ammonia Energy APAC 2023, 16.08.2023. Online verfügbar unter https://ammoniaenergy.org/presentations/ammonia-to-power-to-decarbonize-heavy-industries/, zuletzt geprüft am 10.05.2024.
Seonghoon Woo (2021): Ammonia – a renewable fuel for zero emission mobility. Ammonia Energy Conference, 09.11.2021.
Trym Sjoberg (AMOGY) (2024): Ammonia – a renewable fuel for carbon-free power, Juni 2024.

ZBT

Ammonia for transport



CAMPFIRE
Bundesministerium für Bildung und Forschung
Wasserstoff Leitprojekte
Grün. Groß. Global.

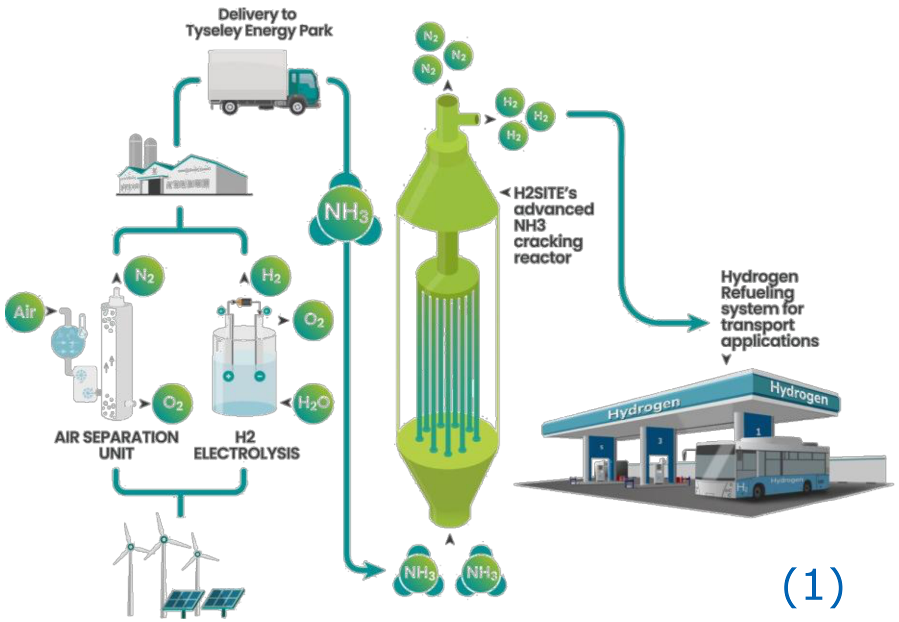
Propulsion system for inland waterway vessels

- basic engine: Liebherr A966 (4 stroke engine)
- development and construction of an 150 kW cracker system (~ 110 kg_{H2}/d) with development of EU conformity
- complete setup is planned to be commissioned end 2025

ZBT INP KIT FVTR Universität Rostock Traditio et Innovatio LIEBHERR GasKraft Engineering

Prehn, S.; Mohr, H.: „Ammoniak-betriebenes Cracker-Motor-Antriebssystem für Binnenschiffe – Projektübersicht und Status“ In: Sustainable Shipping Conference No. 6 23.04.2024 . Bremen
Braun, Annalena; Gierenz, Niklas; Braun, Samuel; Kubach, Heiko; Bernhardt, Sören; Prehn, Sascha et al. (2024): Aspects of Ammonia as Green Fuel for Propulsion Systems of Inland Water Vessels. In: Energy Tech, Artikel 2301648. DOI: 10.1002/ente.202301648.

Ammonia for hydrogen fueling stations



(1)

H2Site (Spain)

- Project: Ammogen
- Fuel cell grade hydrogen
- Capacity: 200 kg_{H2}/day
- Location: Tysley Energy Park (Birmingham, UK)
- announcement of 2000 hours of testing, producing more than 5 tons of hydrogen in 01/2025

(2)

Hyamtec (UK)

- Containerised, portable, cracking module
- Fuel cell grade hydrogen
- Capacity: 500 kg/day hydrogen output
- Status: market launch announced for 2026
- <9.5 kWh/kg_{H2} *1


Die Tankstelle, die sich ihren Wasserstoff aus Ammoniak selbst erzeugt

19.12.2023 · Von Henrik Bork · 3 min Lesedauer ·

Es ist keine gewöhnliche Tankstelle, die da gerade in Nanning in Betrieb genommen worden ist. Es ist Chinas erste kommerzielle Ammoniak-zu-Wasserstoff-Anlage mit angeschlossener Wasserstoff-Tankstelle.

Wasserstofftankstellen sieht man zunehmend in der heutigen Verkehrsinfrastruktur. In China gibt es jetzt die erste kommerzielle Ammoniak-zu-Wasserstoff-Anlage mit angeschlossener Wasserstoff-Tankstelle.
(Bild: Marc Elias - stock.adobe.com)

Chinas Petroleum-Riese Sinopec, der sich ein grünes Energieunternehmen zu wandeln versucht, hat Chinas erste kommerzielle Ammoniak-zu-Wasserstoff-Anlage mit angeschlossener Wasserstoff-Tankstelle am 8. Dezember im Südwesten der Volksrepublik eröffnet. Noch läuft der Testbetrieb, doch schon bald werden hier bis zu 40 LKW pro Tag mit

Guangxi Petroleum Nanning Zhenxing Energy Refueling Station (China)

(1) https://ammogen.co.uk/ (2) https://ammoniaenergy.org/articles/ammonia-cracking-in-the-uk-afc-energy-and-industrial-chemicals-group-announce-new-joint-venture/

Perspective and chances

- Ammonia is the only carbon free fuel and hydrogen carrier
- Ammonia can be used directly or via large scale cracking for hydrogen applications
- Ammonia has the potential to accelerate the energy transition
- Strong increase in green ammonia imports to northwest Europe and centralized ammonia crackers planned
- Demonstrations exist for decentral applications – technologies not yet state of the art
- Strong development potential for industry and cross-border research cooperation
- Politics need to strongly support R&D in ammonia technologies

Comprehensive ammonia news: https://www.ammoniaenergy.org/

THE HYDROGEN AND FUEL CELL CENTER

ZBT

Thank you for your attention!

Zentrum für BrennstoffzellenTechnik GmbH
Carl-Benz-Straße 201 / D-47057 Duisburg

Lena Engelmeier
l.engelmeier@zbt.de

WWW.ZBT.DE

Supported by:

Bundesministerium für Bildung und Forschung

Wasserstoff Leitprojekte Grün. Groß. Global.

wir! Wandel durch Innovation in der Region

KIEM PROJECT - GREEN METHANOL FROM PV

Leo Polak
Associate lector at HAN Research Center Balanced Energy Systems

Euregional H2 Business Event, H2Hub Twente, 2 October 2025

HAN_UNIVERSITY OF APPLIED SCIENCES

Volta Energy

ALLES OVER WATERSTOF

HAN SCHOOL OF ENGINEERING & AUTOMOTIVE (AEA)

- Research Center Balanced Energy Systems (BES)
  - Flexible Energy Solution; Engineering Hydrogen Systems
- Research Center Automotive Research (AR)
  - Green mobility; Smart Mobility

HAN hydrogen and mobility lab
Cleantech Park Arnhem (IPKW)
Part of Connectr Innovation lab

HAN_UNIVERSITY
OF APPLIED SCIENCES

Volta Energy

HAN_UNIVERSITY OF APPLIED SCIENCES · Volta Energy · ALLES OVER WATERSTOF

- **Hybrid generators with PV and battery**
- **Construction, infrastructure, festivals**
- **400 units**
- **Reduce CO2: from HVO 100 to green fuels**
- **Reduce NOx: use fuel cells**

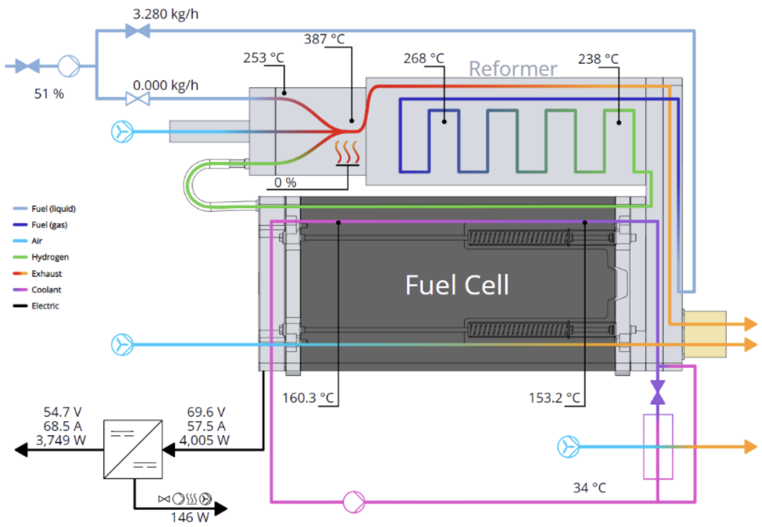
Volta 15 hydrogen and methanol

Hydrogen:

- ATEX zones
- Long permit process
- Poor volumetric energy density
- Complex transport logistics

Methanol:

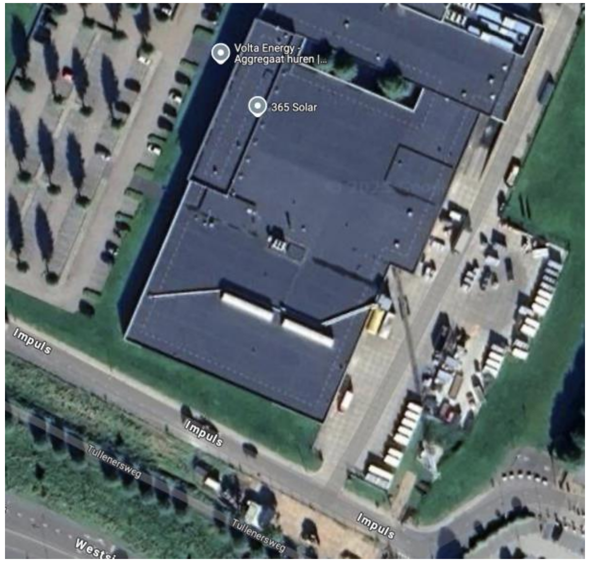
- No ATEX zone
- High energy density
- Easy transport and logistics



Why not produce methanol ourself?

- **Green methanol bought from the US**
- **Not very “green molecules”**

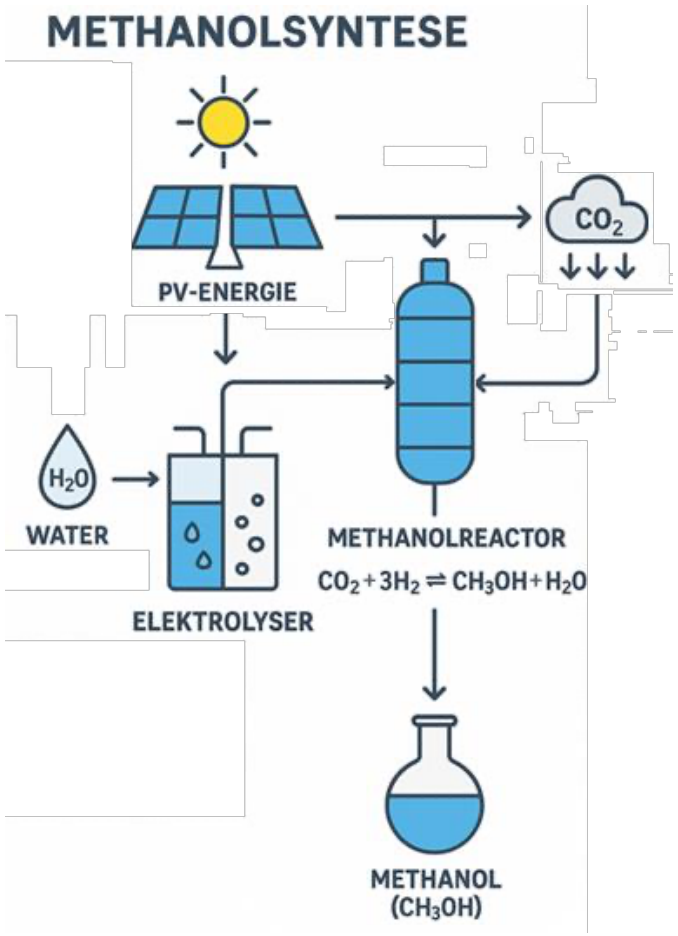
- **Growing fleet in Duiven**
- **Average 90% occupancy rate**
- **100 kWp PV unused on parking**
- **Will grow to 1 MWp unused on parking**



KIEM PROJECT: GREEN METHANOL FROM PV

- Techno-economical feasibility study of producing methanol from surplus PV-energy
- Consortium: Volta + HAN + Alles over Waterstof
- Multidisciplinary student team project (S6)

  - Estimate the techno-economic feasibility of production of e-methanol by Volta
  - Build a methanol test reactor



HAN_UNIVERSITY OF APPLIED SCIENCES
Volta Energy
ALLES OVER WATERSTOF

METHANOL TEST REACTOR BASIC PFD

A.A. Kiss et al. / Chemical Engineering Journal 284 (2016) 260–269

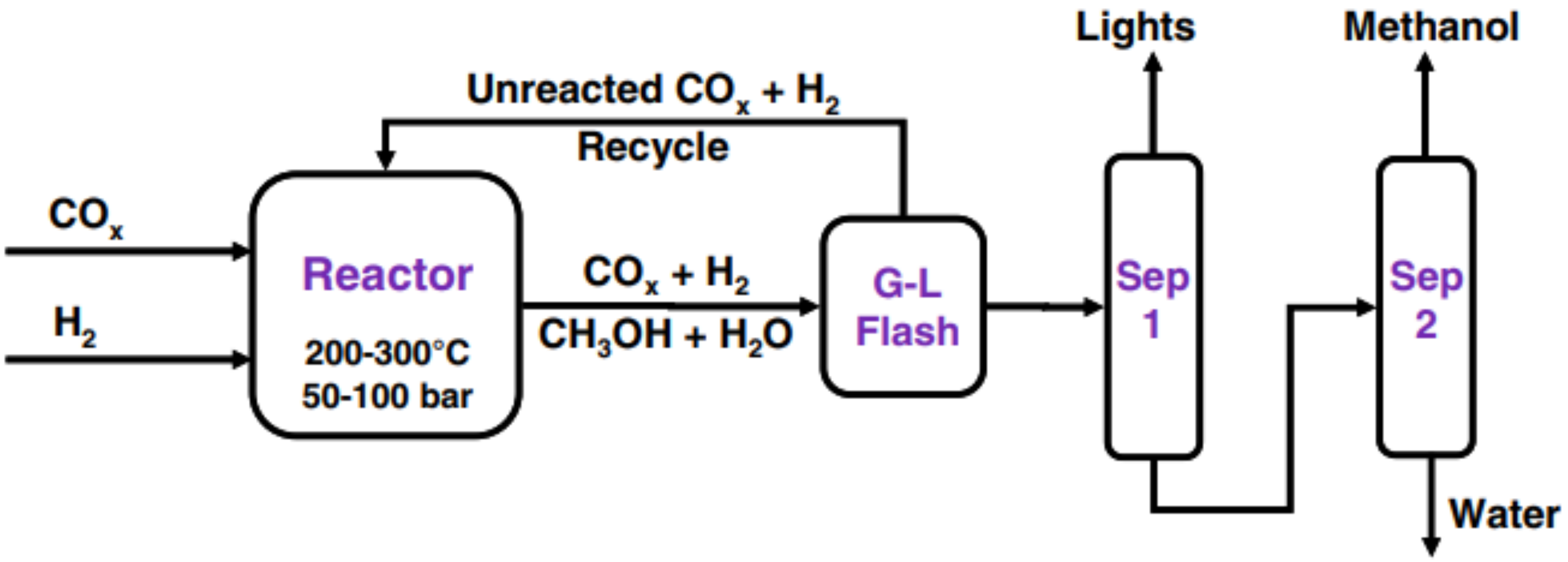
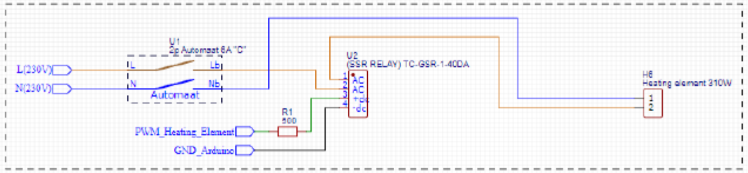


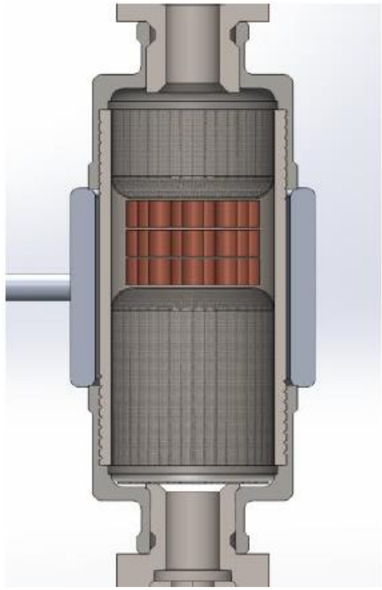
Fig. 7. Generic processing scheme for methanol synthesis from syngas or by CO_2 hydrogenation.

METHANOL TEST REACTOR – DESIGN

- Based on concept of Daniel van Laakke*
- Natural convection for circulation and cooling
- Built from off the shelf parts
- Strength and heat calculations
- Startup and shutdown procedures
- HAZOP



In: $CO_2(g) + 3H_2(g)$ at 50 bar

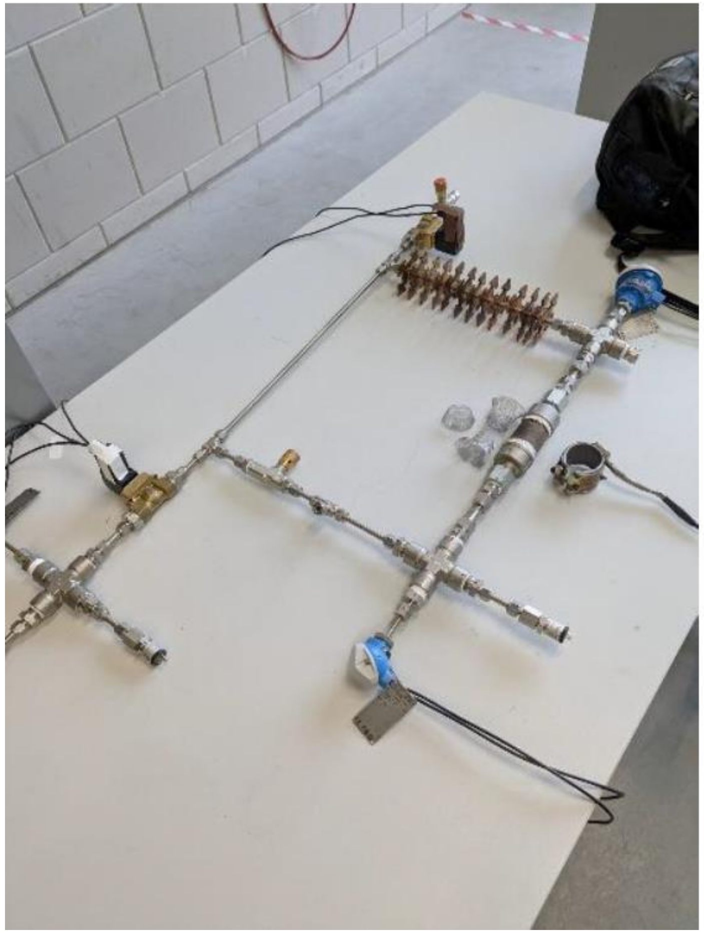


* van Laake, D. (2019). Development and characterization of a small scale methanol synthesis reactor based on natural convection. Master thesis.

METHANOL TEST REACTOR – REALIZATION

- System built
- Measurement and control tested, including heating to 250^{o}C
- Leakage from reactor connections
- Temperature variations are a challenge

Reactor with catalyst pallets sandwiched between two shaped pieces of mesh



Reactor loop with radiator fins and measurement and control assembled

Leak tests

TECHNO-ECONOMIC ANALYSIS

- Levelized cost of MeOH calculation:

$$\mathrm{LCoMeOH} = \frac{\mathrm{CAPEX_{an}} + \mathrm{OPEX}}{\dot{m}_{\mathrm{MeOH}}}$$

- Using scaled CAPEX from existing plant and

$$C_2 = C_1 \cdot \left(\frac{Q_2}{Q_1}\right)^{0.6}$$

- PEM electrolyser - Methanol plant in Denmark: [i]

- OPEX: Electricity, water, CO2, maintenance and labor
- Maintenance includes replacement of all components and materials

CAPEX schaal berekening		
Schaal voordeel factor	0,6	factor
Initiele productie Q1	42.000.000	Kilogram
Initiele aanschaf C1	150.000.000	euro

financiële gegevens		
Tijd operationeel per jaar	330	dagen
Elektriciteitsprijs	€ 0,100	euro/kWh
CO2 prijs per kg	€ 0,10	euro per kg
Kraanwater prijs	€ 0,00122	euro per liter
Arbeidskosten	€ 40.000	euro/plant
Onderhoudsfactor	6%	procent
Levensduur instalatie	20	Jaar
Rente voet	10%	procent

i https://www.reuters.com/sustainability/climate-energy/worlds-first-commercial-scale-e-methanol-plant-opens-denmark-2025-05-13/

TECHNO-ECONOMIC ANALYSIS – PLANT SIZING

- PV available now 100 kWp, in the future 1000 kWp
- Solar energy yield in the Netherlands ≈ 0,88 MWh/kWp/year
- Assume 330/365 of available PV energy is used for MeOH (330 operational days a year)

- Batteries can buffer energy of 1 day
- Maximum energy on 1 day ≈ average daily yield * 4 [ii]
- Plant is scaled such that it can convert this energy to MeOH on the same day

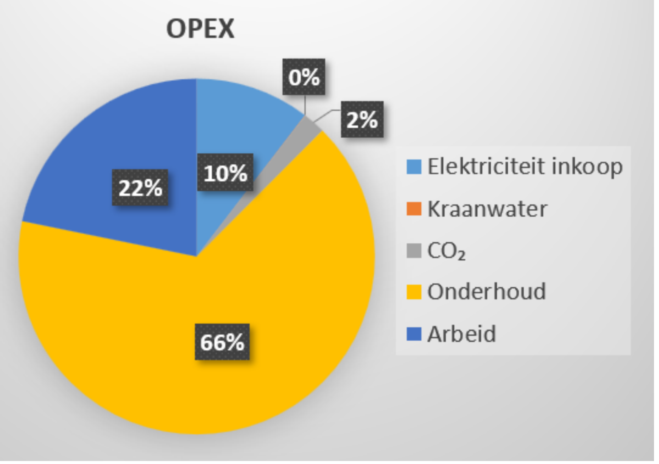
- Without energy from the grid plant utilization is very low
- Max energy from grid = 3 * PV energy yield * 330/365
- Investigate use of grid energy from 0% to 100% of maximum amount

ii https://www.zonnig.nl/kennisbank/hoeveel-kwh-levert-een-zonnepaneel-per-dag/

TECHNO-ECONOMIC ANALYSIS – RESULTS

- PV power = 100 kWp
- Grid use = 100%

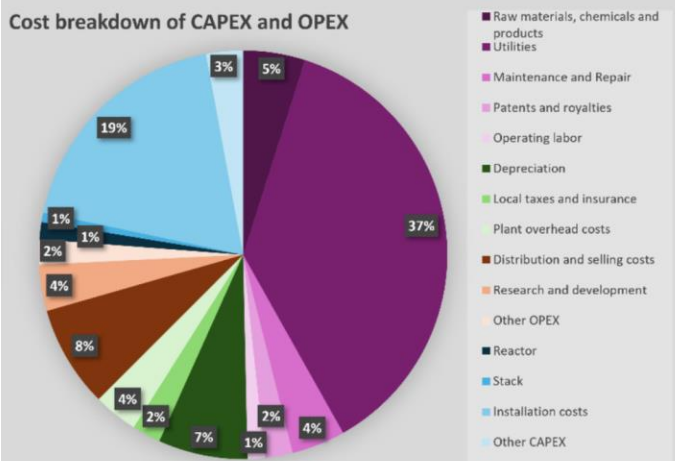
➢MeOH production = 31,742 kg/year
➢Required grid capacity = 40 kW
➢CAPEX = 2,009,670 €
➢Annualized CAPEX = 236,055 €/year
➢OPEX = 188,897 €/year
➢LCoMeOH = 13.39 € /kg



- "Green MeOH" price = 1,20 eur/kg mix
- Green MeOH willingness to pay ≈ 1,50 eur/kg

➢e-MeOH at this sizing too expensive

- Recent TEA publication by Saxion: [iii]
- Different case, with free CO2
- MeOH production = 11,492,250 kg/year
- LCoMeOH = 4,06 € /kg

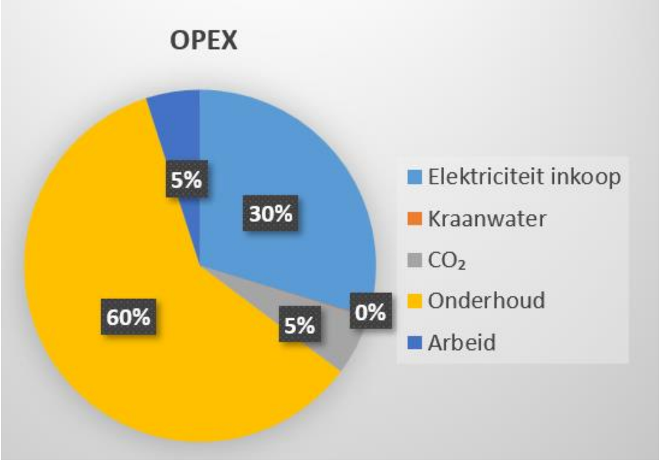


iii Gelten, H., et al. R. (2026). *Fuel*, *405*, 136528.

TECHNO-ECONOMIC ANALYSIS – RESULTS

- PV power = 1000 kWp
- Grid use = 100%

➢MeOH production = 317,423 kg/year
➢Required grid capacity = 402 kW
➢CAPEX = 8,000,639 €
➢Annualized CAPEX = 939,752 €/year
➢OPEX = 803,211 €/year
➢LCoMeOH = 5.49 € /kg

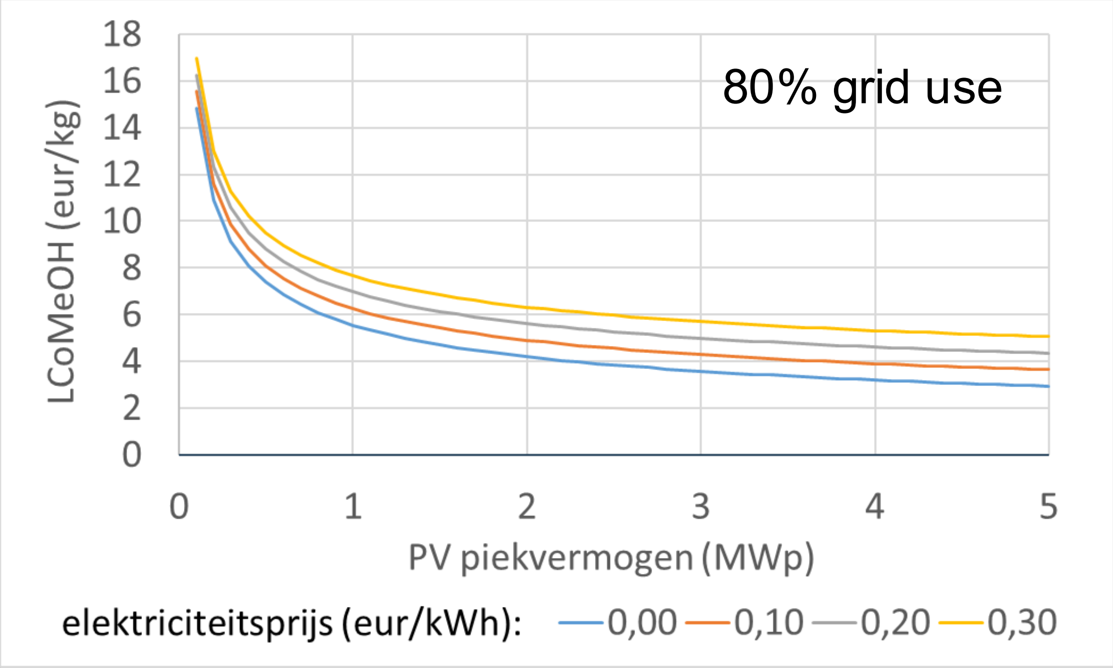


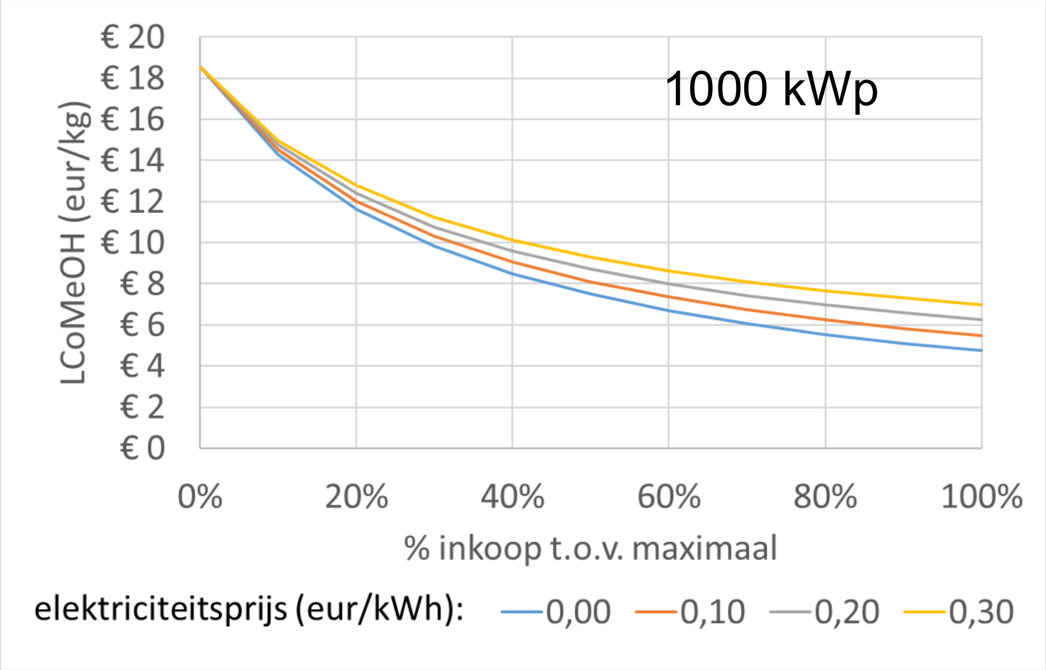
- PV power = 1000 kWp
- Grid use = 80%

➢MeOH production = 269,810 kg/year
➢Required grid capacity = Smaller
➢CAPEX = 8,000,639 €
➢Annualized CAPEX = 939,752 €/year
➢OPEX = 748,801 eur/year
➢LCoMeOH = 6.26 eur/kg

➢Better, but still expensive

TECHNO-ECONOMIC ANALYSIS – PARAMETER VARIATION





- 2000 kWp, 80% grid use and 0,10 euro/kWh leads to LCoMeOH = 4,91 eur/kg
- Price decreases further for even larger systems, but case of Volta is limited in scale
- Future technological improvements can bring price further down
- Subsidies can help reach feasibility now

CONCLUSIONS – OPEN QUESTIONS – DISCUSSION

- Reactor built, issues with leakage → Modification of in progress, to be tested this month
- It is possible to build a reactor system from off the shelf components
- Future testing of performance, process conditions, catalysts, degradation…?

- LCoMeOH too high costs for small systems, goes down for larger systems
- Within range of customer willingness to pay?
- Does the required scale fit in the case of Volta?

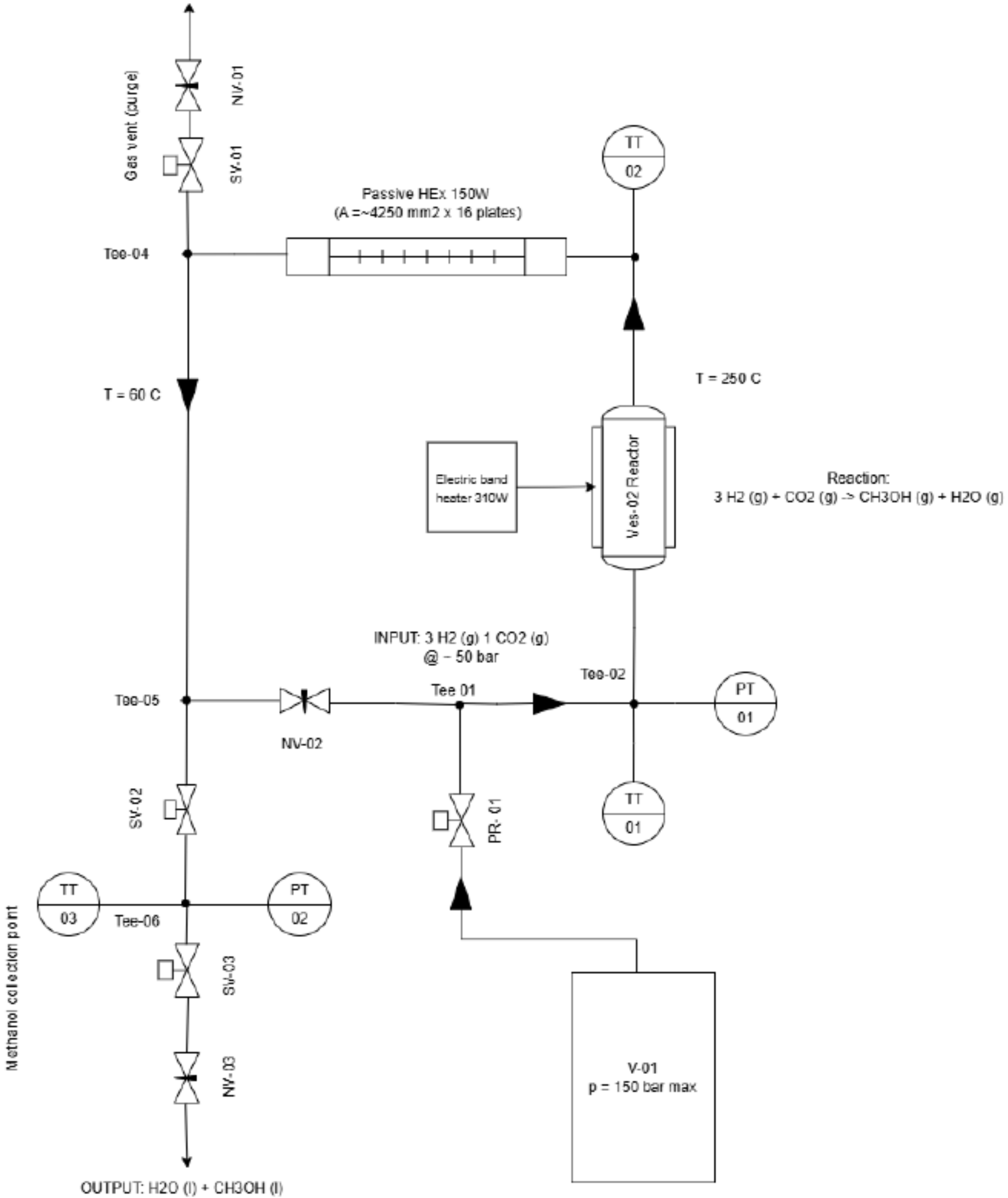
- Can we expect future technological improvements to lead to lower prices? When?
- Can we find a subsidy to build an R&D setup or demonstrator at Volta

KIEM PROJECT - GREEN METHANOL FROM PV

Project team:
HAN: Christiaan Boudri, Ruben Bruins, Leon Bunthof, Leo Polak (leo.polak@han.nl)
Volta Energy: Jeroen Clement, Roel Bleumer
Alles over Waterstof: Frank Mietes

Student team:
TBK: Job Bulten, Roel Wanschers
ELT: Gregory Gleim, Simon Melchers
WTB: Simar Bilici, Bart Gerritsen, Mahbub Fahim
HAN supervisor: Willem Kwak

METHANOL TES
REACTOR P&ID



HAN_UNIVERSITY
OF APPLIED SCIENCES

Energietoevoer gegevens			
PV piekvermogen	2000	kWp	
Percentage elektriciteit inkoop t.o.v. maximaal	80%	procent	
PV opbrengstfactor	0,88	MWh/jaar/kWp	
PV ratio maximale /gemiddelde dagopbrengst*	4		
Elektrolyser en reactor gegevens			
Verhouding waterstof in methanol	0,188	kg per kg methanol	
Energie verbruik PEM elektrolyser	52,0	kWh/kg H2	
Verhouding CO2 in methanol	1,374	kg per kg methanol	0,75
Kraanwater verbruik per kg waterstof	12	liter	
% bruikbaar water RO	75%	procent	
Energieverbruik waterzuivering	0,003	kWh/liter	
Heating_scaled = 157781,36 W	0,11	kWh/kg	
Cooling_scaled = 195933,6 W	0,13	kWh/kg	
financiële gegevens			
Tijd operationeel per jaar	330	dagen	
Elektriciteitsprijs	€ 0,100	euro/kWh	
CO2 prijs per kg	€ 0,10	euro per kg	
Kraanwater prijs	€ 0,00122	euro per liter	
Arbeidskosten	€ 40.000	euro/plant	
Onderhoudsfactor	6%	procent	
Levensduur instalatie	20	Jaar	
Rente voet	10%	procent	
CAPEX subsidie	€ -	euro	
OPEX subsidie	€ -	euro/kg methanol	

CAPEX schaal berekening		
Schaal voordeel factor	0,6	factor
Initiele productie Q1	42.000.000	Kilogram
Initiele aanschaf C1	150.000.000	euro

Output energie en massa		
Beschikbare PV energie	1.760	MWh/jaar
Maximale PV energie per dag (batterijen kunnen 1 dag bufferen)	19,29	MWh/dag
Elektriciteit inkoop om altijd volle capactieit te draaien	4.774	MWh/jaar
energie verbruik methanol productie per kg	10,0	kWh/kg

Output energie en massa		
methanol productie bij altijd volle capaciteit	634.846	kg/jaar
Netaansluiting om een dag volle capaciteit te draaien op het net	804	kW
Maximaal benodigde dagproductie waterstof	362	kg/dag
Elektrolyser vermogen benodigd	784	kW
Werkelijke elektriciteit inkoop	3.819	MWh/jaar
Werkelijke methanol productie	539.619	kg/jaar

Output financieel		
CAPEX totale plant	€ 12.126.701	euro
CAPEX afschrijving per jaar	€ 1.424.398	euro/jaar
OPEX totaal	€ 1.225.127	euro/jaar
CAPEX per kg methanol	€ 2,64	eur/kg
OPEX per kg methanol	€ 2,27	eur/kg
LCoMeOH	€ 4,91	eur/kg

Barriers and opportunities with GREEN MOLECULES

Hans Gelten & Zuzi Kurt

2nd Euregional H_2 Business Event
@ H_2Hub Twente

Power-to-Methanol: deep dive into techno-economic and environmental aspects

- The **impasse** between the supply of (truly green) hydrogen versus the still unclear demand from industry / companies and its huge impact on the speed of the energy transition.

- The **scope** of this research is:

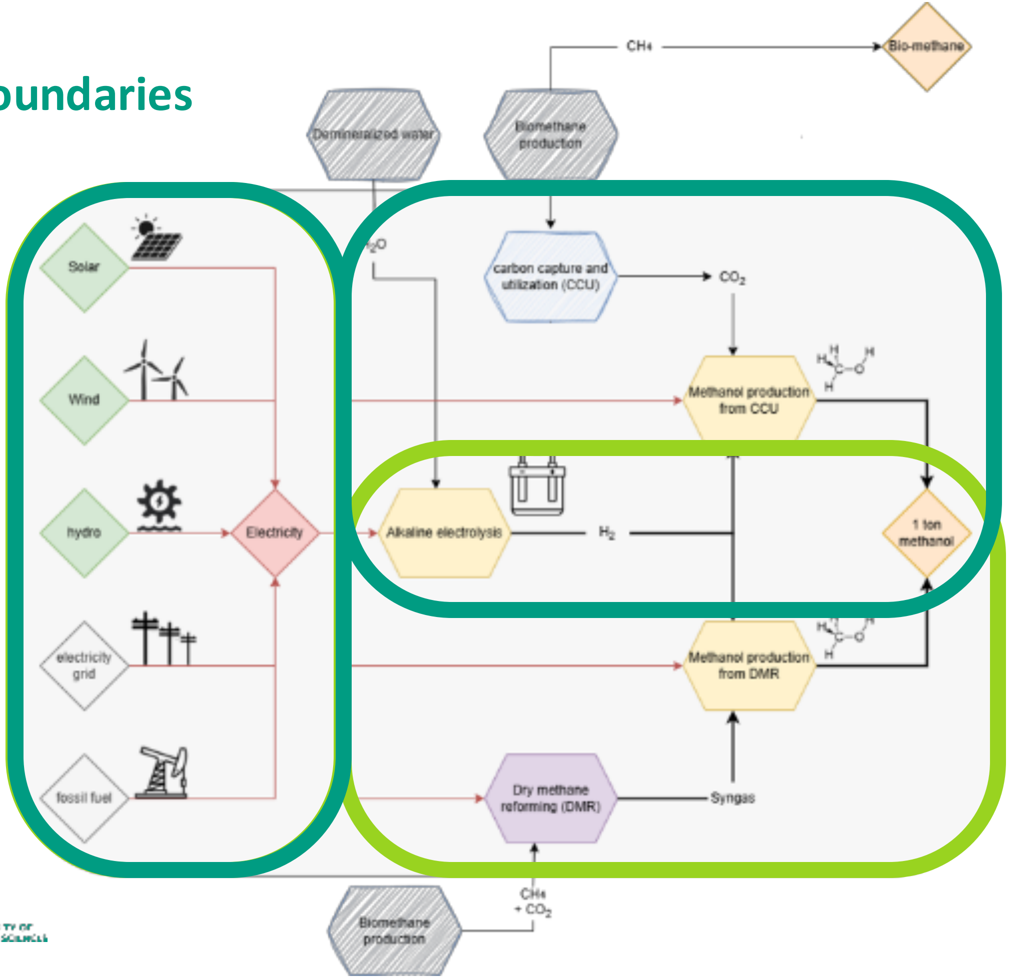
  How can hydrogen and C-based chemicals be produced as much as possible from circular and biogenic waste streams?

- Moderate, decentralised scale (~10.5 ton MeOH/year)

Twence

- Twence is located in Zenderen, near Almelo and is a large scale fermentation plant, converting organic waste (like manure) into biogas.
- Upgrading the biogas to green gas for the grid, results in CO_2 capture and liquifying with a capacity of 12.500 kg/h.
- Valorising CO_2 by producing green methanol → Techno-Economic Analysis of different scenarios

Boundaries



Process 1: Methanol from CCU

Water electrolysis & CO_2 hydro-genation to methanol

Process 2: Methanol from DMR

Dry methane reforming & syngas conversion to methanol

Methodologies: TEA and LCA

- A **Techno-Economic Analysis** combines mass and energy balances with economic factors (capital and operating costs) to estimate the Levelized Cost of product (LCoX)

- A **Life Cycle Analyses** assesses the environmental impacts of a process — from cradle (raw material extraction) to gate (produced product).

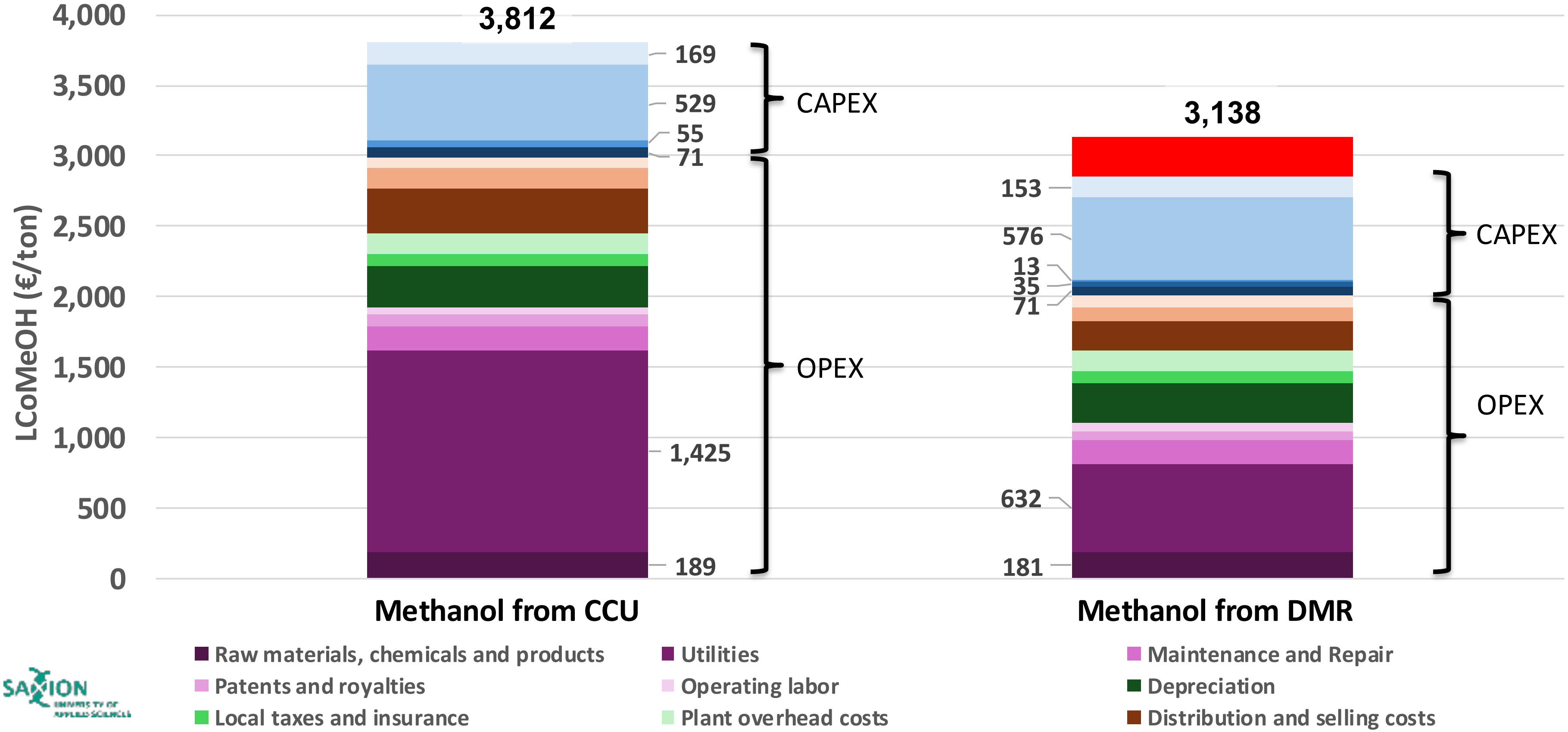
Ref: *H. Gelten et al, Power-to-methanol: Techno-economic analysis of a regional, decentral case-study, Fuel, 405 (2026), p. 136528*

Ref: *R. Turton, J. Shaeiwitz, D. Bhattacharyya, en W. Whiting, Analysis, synthesis and design of chemical processes, Fifth edition. Pearson, 2018.*

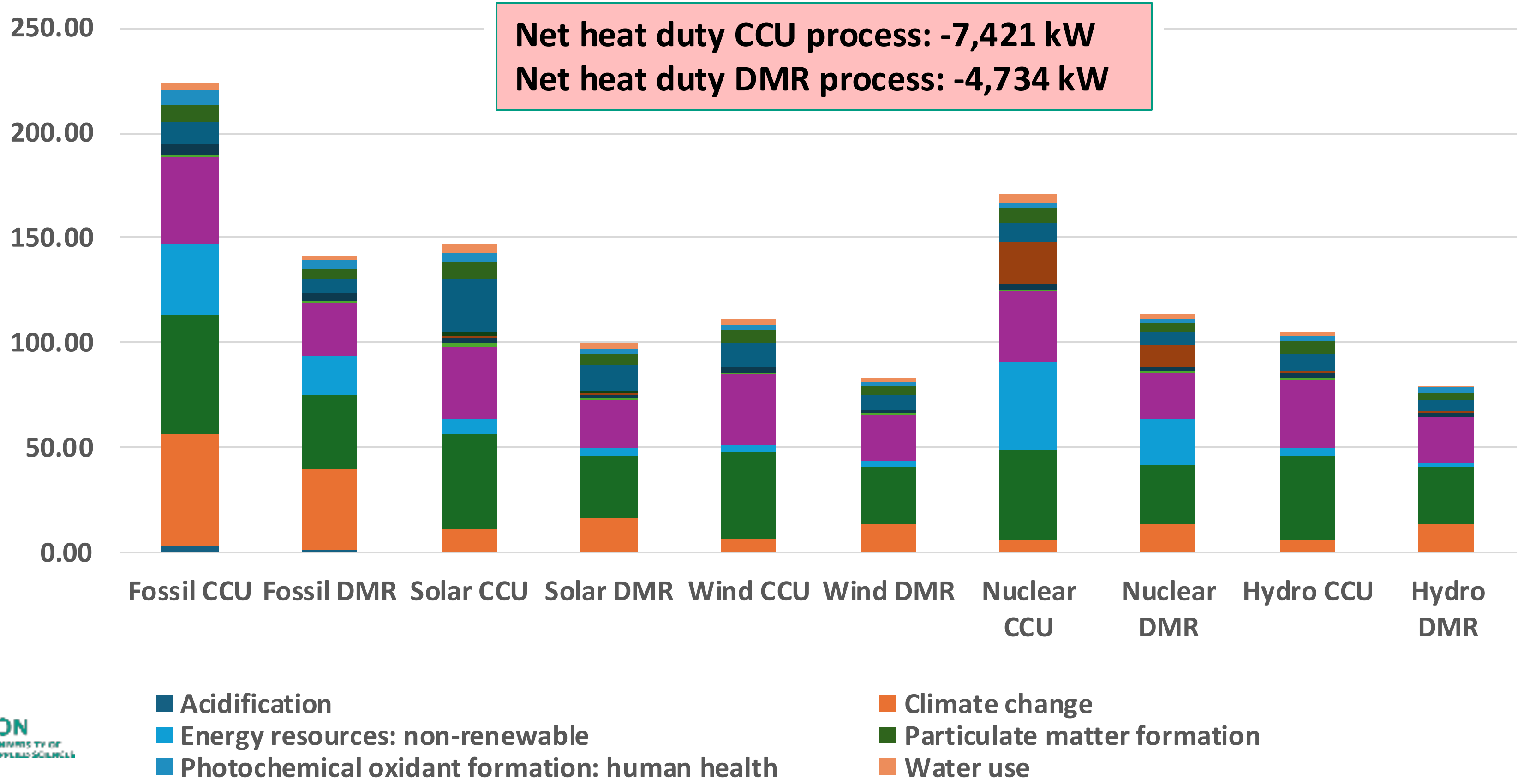
Ref: *S. Sala et al, Global normalisation factors for the Environmental Footprint and Life Cycle Assessment, EUR (28984), Publications Office of the European Union, Luxembourg, 2017*

Ref: *S. Sala, Development of a weighting approach for the Environmental Footprint, Publications Office of the European Union, Luxembourg, 2018.*

Results: Techno-Economic Analysis – Methanol from CCU and DMR compared



Results: Life Cycle Analysis – Methanol from CCU and DMR compared



Conclusion

- **From the TEA:** both processes result in high LCoMeOH, making the processes economical not viable. **From the LCA:** Methanol from DMR results in all cases in lower environmental impact then Methanol from CCU, due to the lower net heat duty (-4,734 kW vs -7,421 kW).

- Dry methane reforming followed by methanol synthesis results in the lowest LCoMeOH (3,138 €/ton) and with using wind power the least environmental impact.

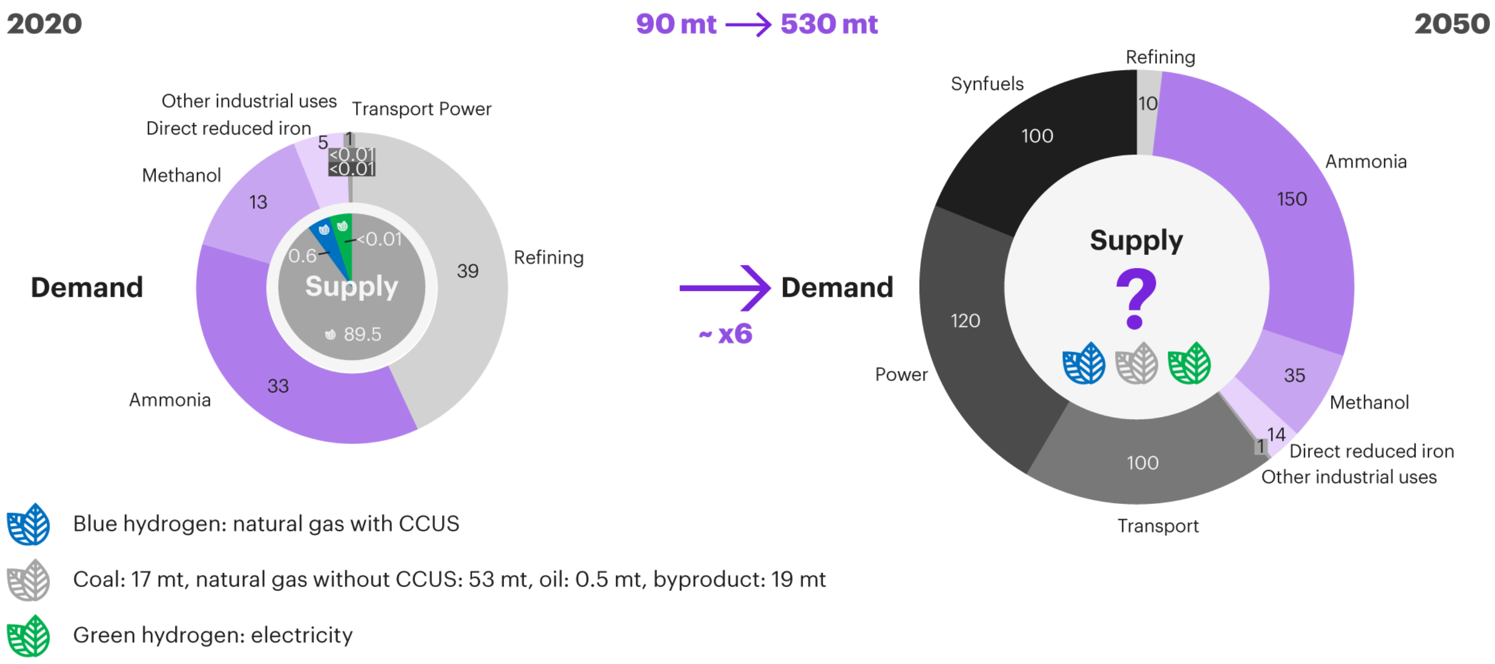
- **Main issues:** very high LCoH (~13 €/kg) and high levels of ecotoxicity and eutrophication

- But now: Why should we still put **much further effort** into Power-to-X and Green Molecules???

Figure 2

Today's supply of green hydrogen is negligible, but pledges to lower emissions necessitate its rapid expansion

Anticipated development of hydrogen supply and demand



Note: CCUS is carbon capture, utilization, and storage; mt is metric tons.

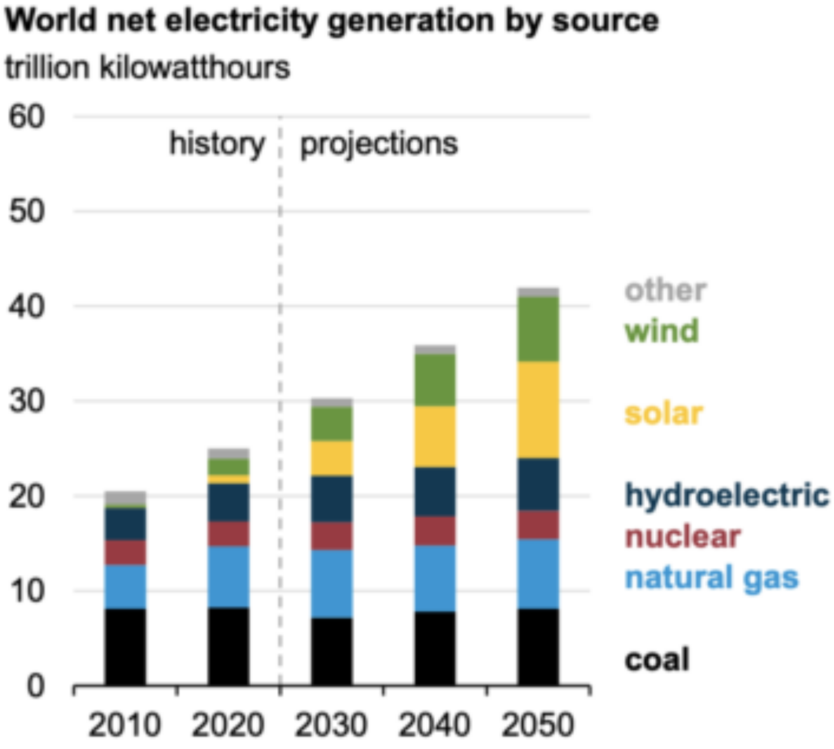
Source: Kearney analysis

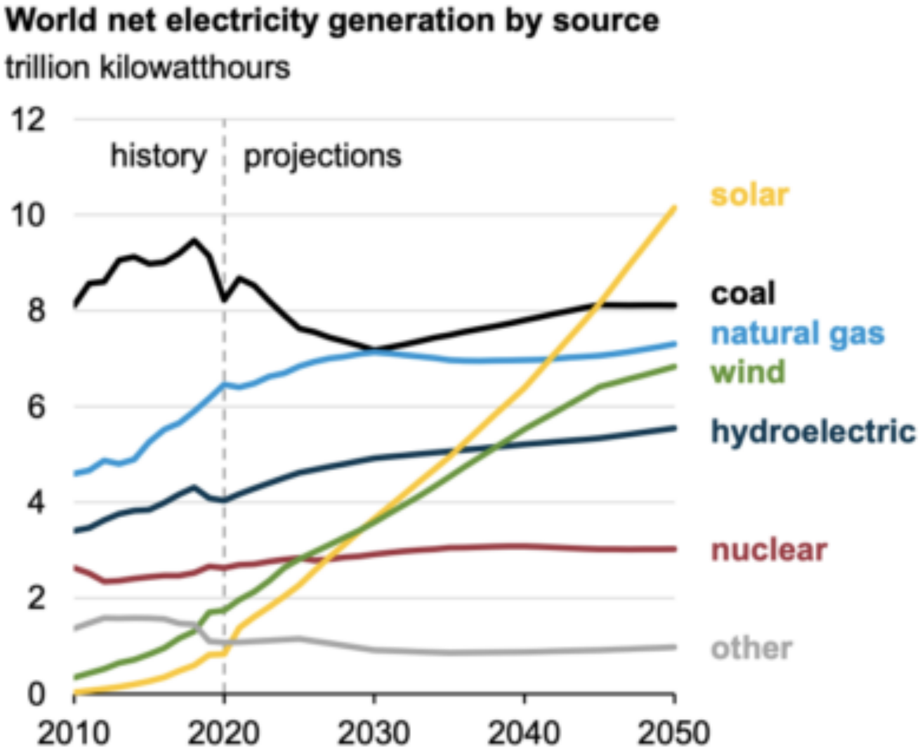
WHAT ABOUT BIO HYDROGEN OR OTHER ALTERNATIVES?

©AdobeStock (from left to right) scharfsinn86/AA+W

Renewable hydrogen is produced through the process of electrolysis, using renewable electricity to split water into hydrogen and oxygen and is therefore a ‘renewable fuel of non-biological origin’ (RFNBO).

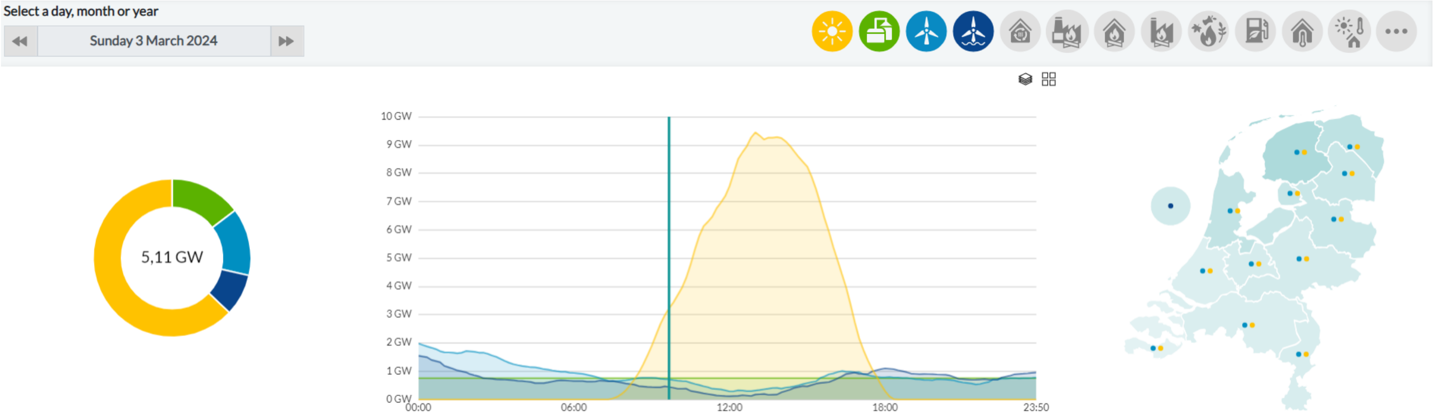
World net electricity generation by source

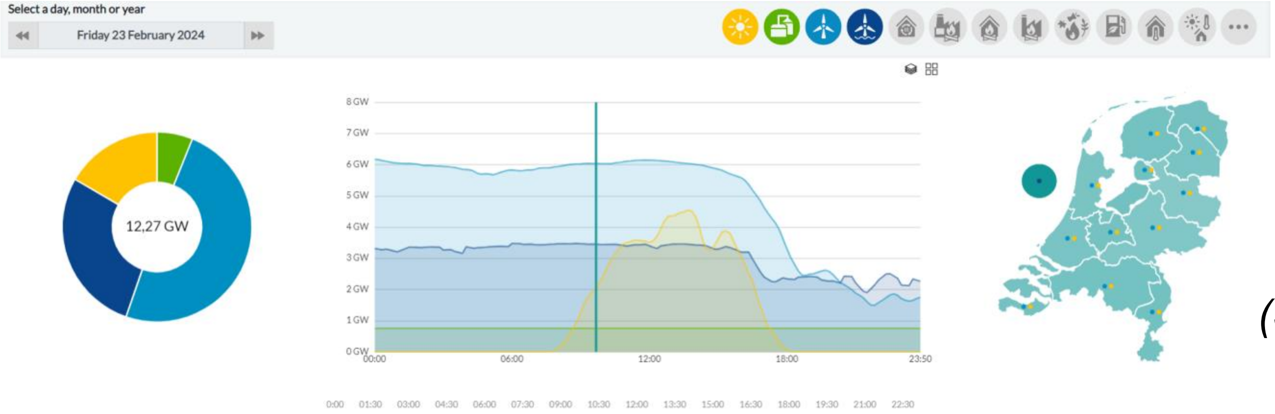




(Source: Institute for Energy Research)

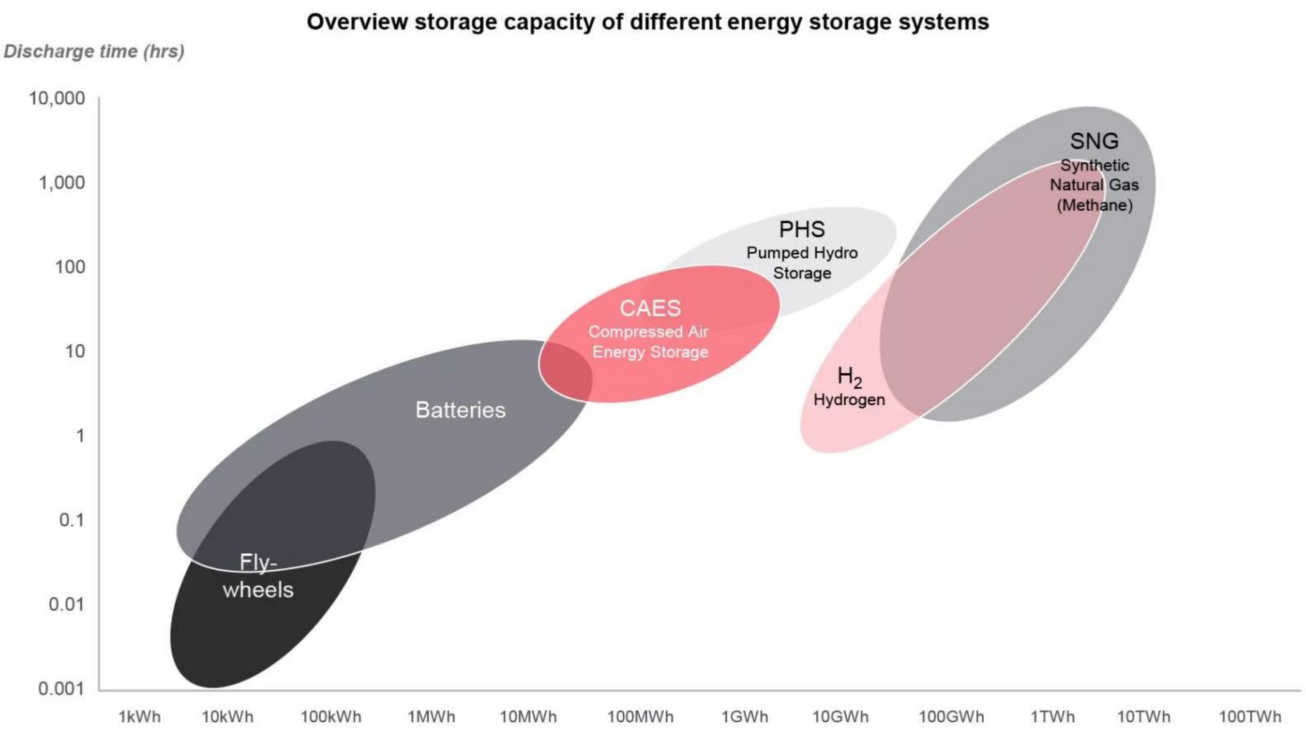
Fluctuations in production.....





(Source: www.opwek.nl)

Goal 1: Intermittency: how to coop with it?



Source: REN21

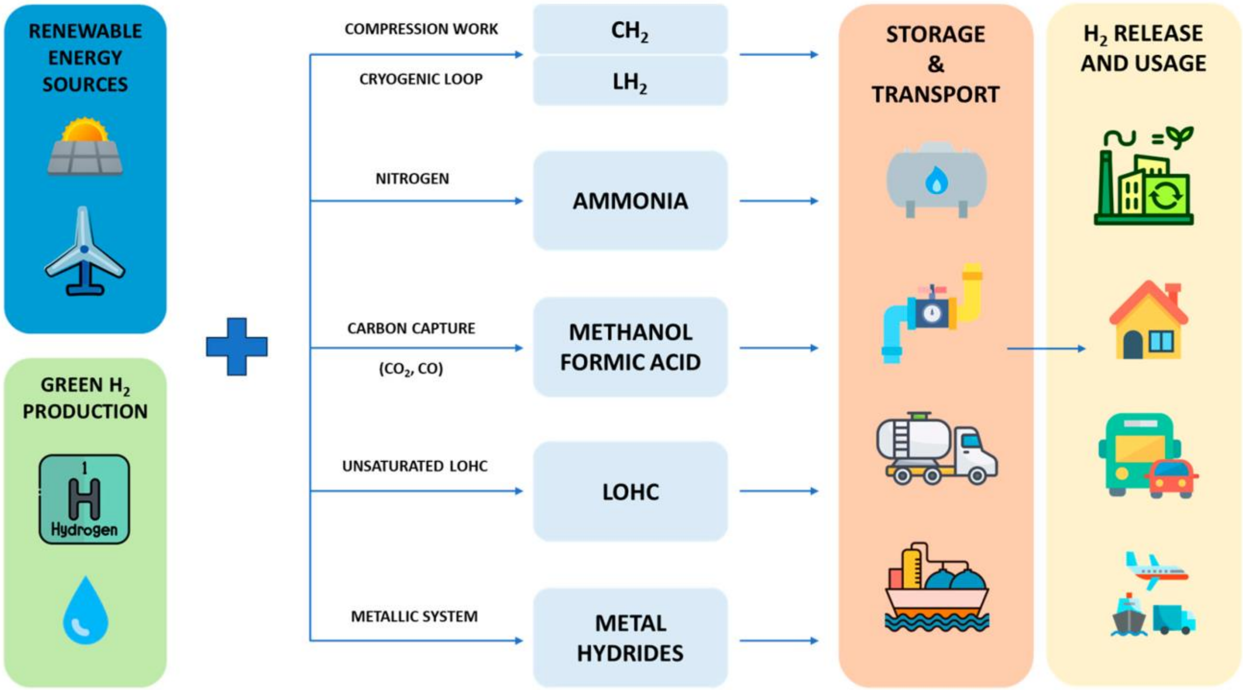
Source: Monetizing energy Storage – Oliver Schmidt 2023

Green Molecules Collective

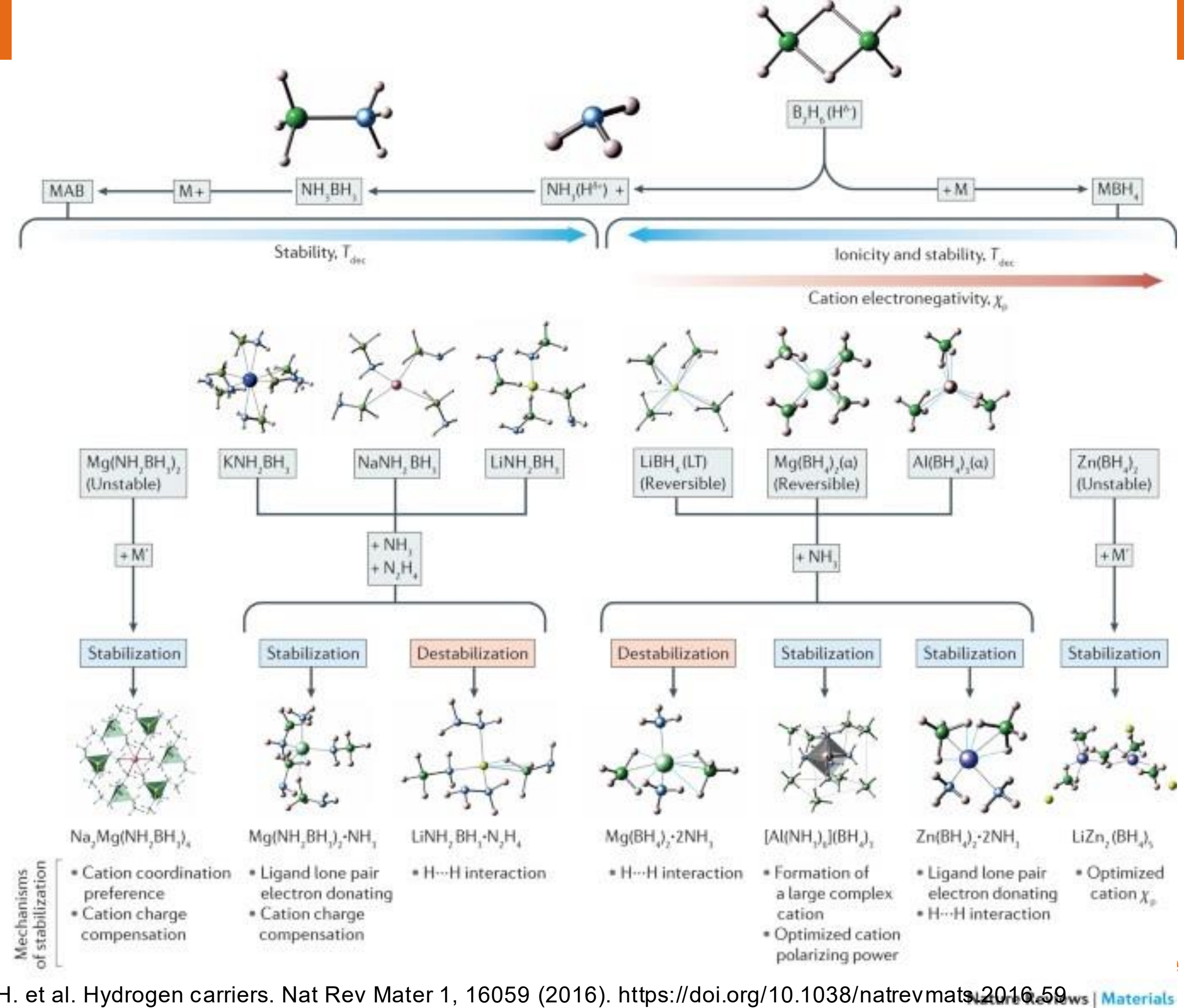
Green Molecules Collective (GMC) is a dynamic network that stimulates innovation and collaboration in the Netherlands in the field of green molecules, such as renewable methane and syngas. Its mission is to accelerate the energy and raw materials transition by optimally utilizing these valuable building blocks.

Lauched June 2025. Visit the website and connect! https://www.greenmoleculescollective.nl/

Alternative energy carrying molecules



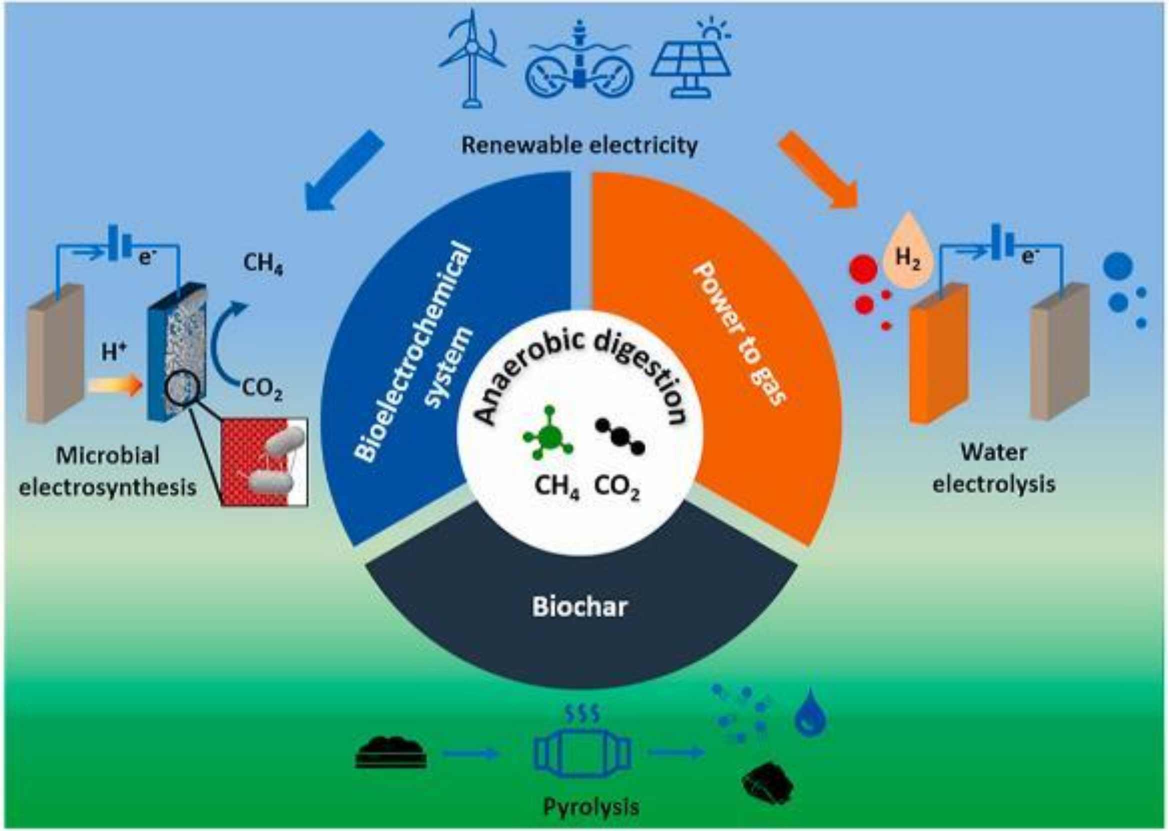
Reference: Energies 2023, 16(16), 6035; https://doi.org/10.3390/en16166035



the world.

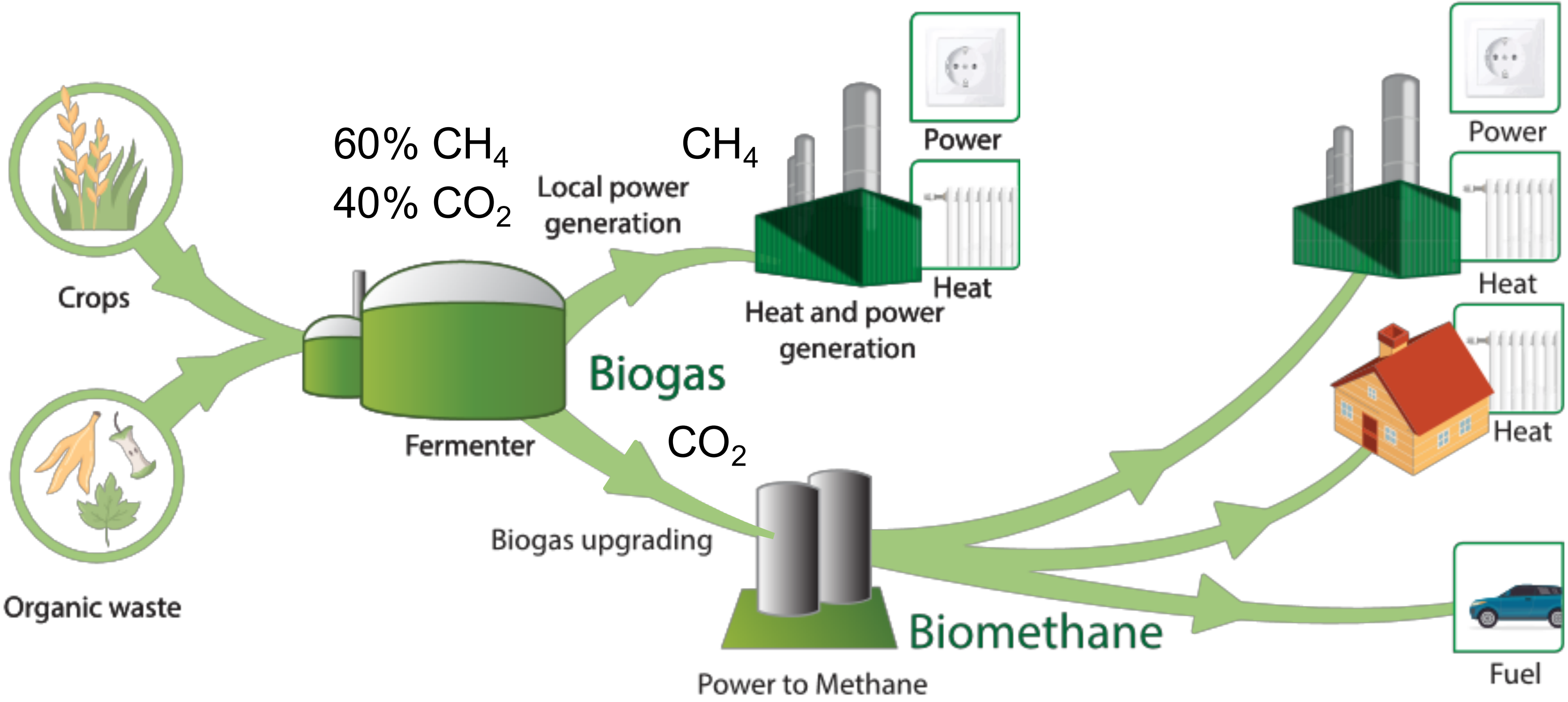
He, T., Pachfule, P., Wu, H. et al. Hydrogen carriers. Nat Rev Mater 1, 16059 (2016). https://doi.org/10.1038/natrevmats.2016.59

Goal 2: Integration of different processes and technologies



Reference: Lin, R., O'Shea, R., Deng, C., Wu, B., & Murphy, J. D. (2021). A perspective on the efficacy of green gas production via integration of technologies in novel cascading circular bio-systems. *Renewable and Sustainable Energy Reviews*, *150*, 111427.

Making more / more efficient green gas



$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

Challenges

- Packing materials for biofilm

Siporax

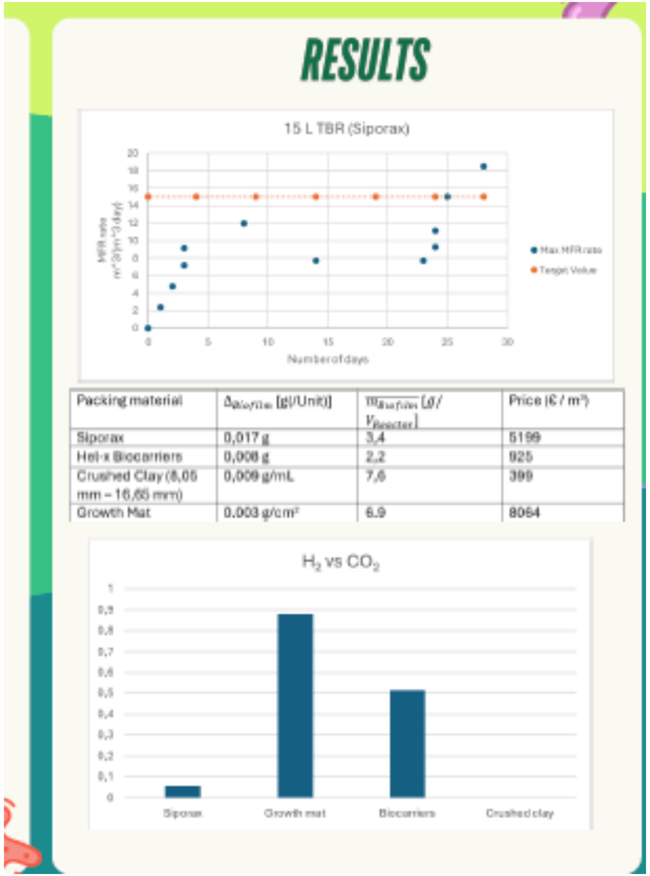
Growth mat

Clay

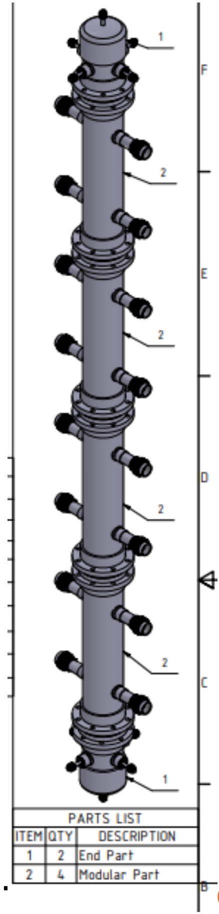
Hel-x-Biocarriers

Packing material	$\Delta_{Biofilm}$ [g(/Unit)]	$\overline{m}_{Biofilm}$ [$\bar{g}$/ $V_{Reactor}$]	Price (€ / m^3)
Siporax	0,017 g	3,4	5199
Hel-x Biocarriers	0,008 g	2,2	925
Crushed Clay (8,05 mm – 16,65 mm)	0,009 g/mL	7,6	399
Growth Mat	0,003 g/cm^2	6,9	8064

The 15-litre TBR worked after a shut-off period of a couple of months (Siporax).
The quick revival shows the system's robust character.
A Methane Formation Rate (MFR) of 18.5 was reached after 28 days.
The packing tested in the smaller reactors showed that the Crushed clay performed the best: most biofilm formed, and no Hydrogen was left after the reaction and that for the lowest price.

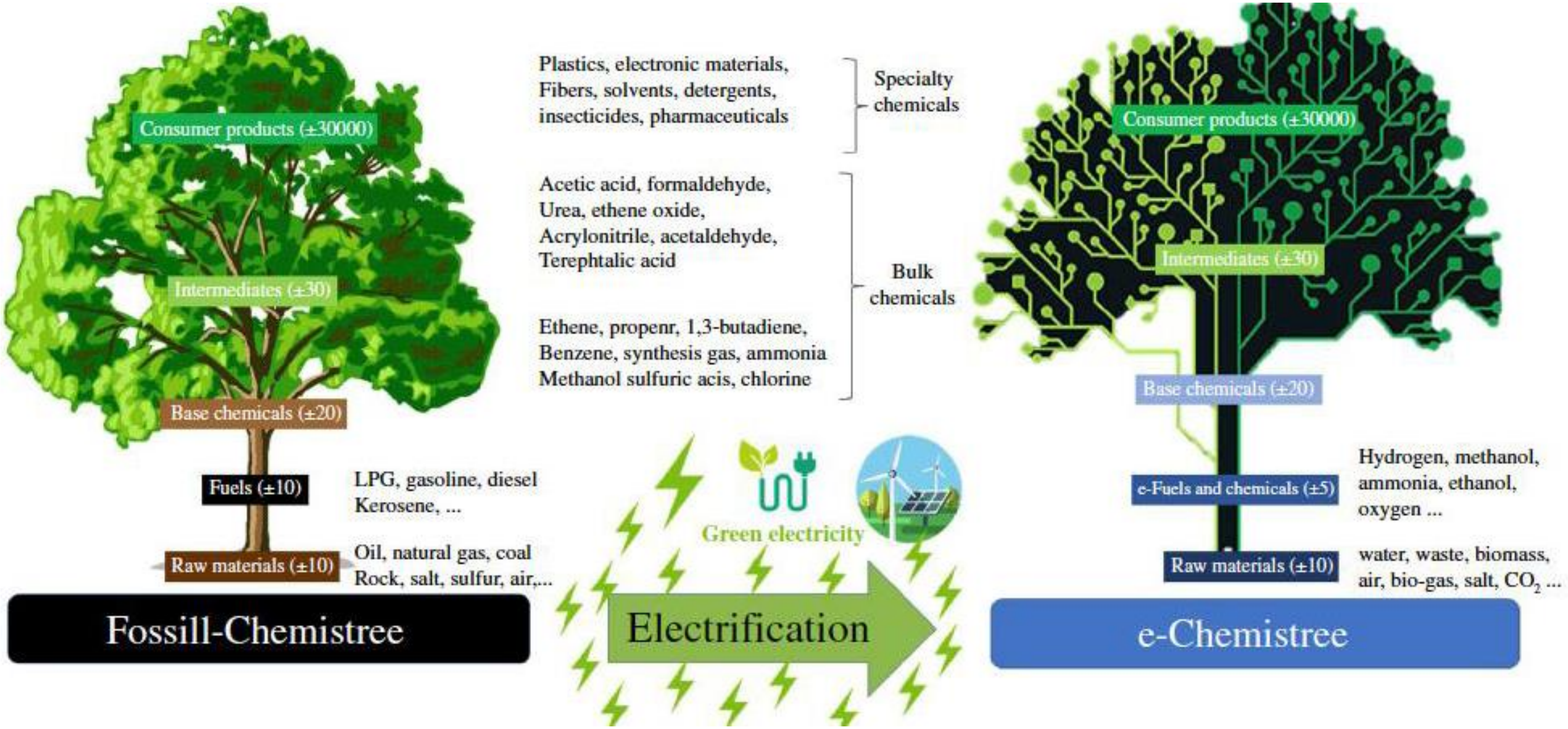


<90% methane content in the gas



share your e the world.

Goal 3: New processes, smart paths to produce green molecules



Source: GVNL-HyCARB

ENTRANCE
CENTRE OF EXPERTISE ENERGY

REMO-lab

- Upscaling facility for Renewable Molecules
- Combining Biochemical and Physical-Chemical processes
- REMO-lab is an open innovation test center in the energy testing ground
- Focuses on developing knowledge and technology for the production of green molecules
- Green molecules for :
  - Energy Transition
  - Circular Economy

THANK YOU!

Zuzi Kurt: z.g.kurt@pl.hanze.nl
Hans Gelten: j.a.p.gelten@saxion.nl

Bio-fuels + e-fuels

Fuel type / Applicability	Fossil Fuels	Bio Fuels	Synthetic Fuels
	Fuel product		
Drop-in (No modification needed)	• Kerosene • Diesel • Gasoline • Heavy Fuel Oil (HFO)	• Biokerosene • Biodiesel	• E-kerosene • E-diesel • E-gasoline
Non-drop-in (Modification to engine and infrastructure needed)	• Hydrogen • LNG / CNG • Methanol • Ammonia	• Hydrogen • Bio-LNG / Bio-CNG • Bio-methanol • Bio-ammonia • Ethanol	• Hydrogen • E-LNG / E-CNG • E-methanol • E-Ammonia • Direct power usage

(Source: DHL.com)