Potentieel van groene waterstof en impact op infrastructuur in de transitiepaden naar 'net zero emissions' ammoniakproductie.

'Stories don't stop at the border'

Pieter Lodewijks

PROJECT PARTNERS

DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e.V.

"Science and Industry in Dialogue"

- Primary industry sector in the energy transformation
- Future feedstocks for the chemical industry
- Sustainable processes
- Industrial symbiosis

vito — EnergyVille

"Vision on Technology for a better World"

- Research in cleantech and sustainable development
- Economic, technological and behavioural aspects of the current and future energy system
- Energy efficiency, renewable energy and flexibility

DVGW

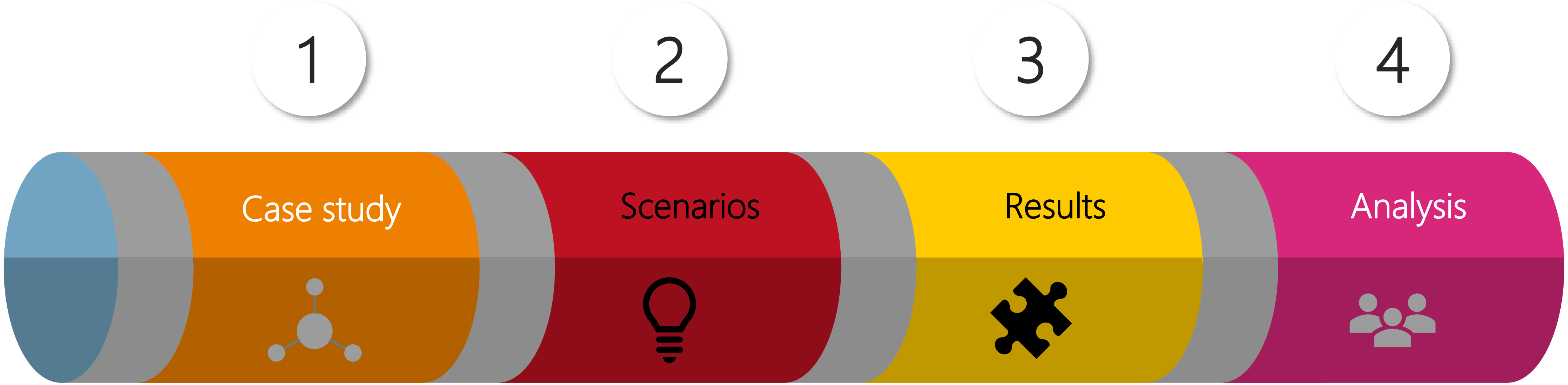
- Independent research facility in Karlsruhe, Germany
- Supports its member companies on their energy transition pathways with a focus on integrated gas infrastructure and gas technology
- Inspects and certifies gas appliances and is involved in national international standardization

TNO innovation for life

"We connect people and knowledge for innovation"

- Independent research organisation, VoltaChem program & Community
- Development of technology and knowledge
- Active in renewable feedstock, fuels, chemicals, CCUS and energy storage

OUR WORK ON INFRASTRUCTURE IN 4 STEPS



Selection of 3 ammonia production sites: BASF Antwerpen (BE), Chemelot Geleen (NL), Chempark Dormagen (DE)

Definition of decarbonization pathways, assumptions on natural gas, electricity and CO_2 prices, specific emissions of grid electricity

Calculation of economics, emissions and energy requirements of ammonia production for new pathways

Impact on local and (inter)national infrastructure

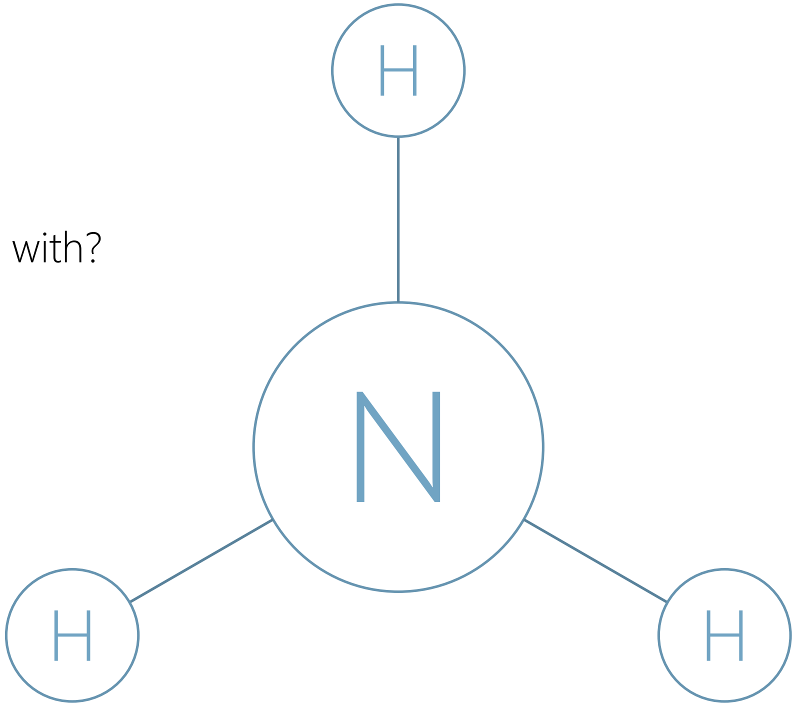
PRODUCTION IN ALL THREE COUNTRIES AND SUPPOSED EASE OF DECARBONIZATION MAKES AMMONIA WELL SUITED FOR A CASE STUDY

Ammonia

- Main chemical products
- Produced in all three countries
- Has a significant natural gas demand (0.5- 1.0 % of national natural gas consumption)
- Easy molecule to decarbonize

Main research questions

- What are the competitive decarbonization pathways?
- What are the implications for the infrastructure the industrial site needs to be supplied with?
- Which role can cross-border infrastructure play in the different scenarios?



THREE SITES IN A 185 KM RADIUS PRODUCE ~20% OF EUROPE'S AMMONIA USING REFORMING OF NATURAL GAS

BASF ANTWERP, BE

- Depreciated SMR plant
- Annual ammonia production ~600 kton/annum (2017)
- 38% of national natural gas non-energy use

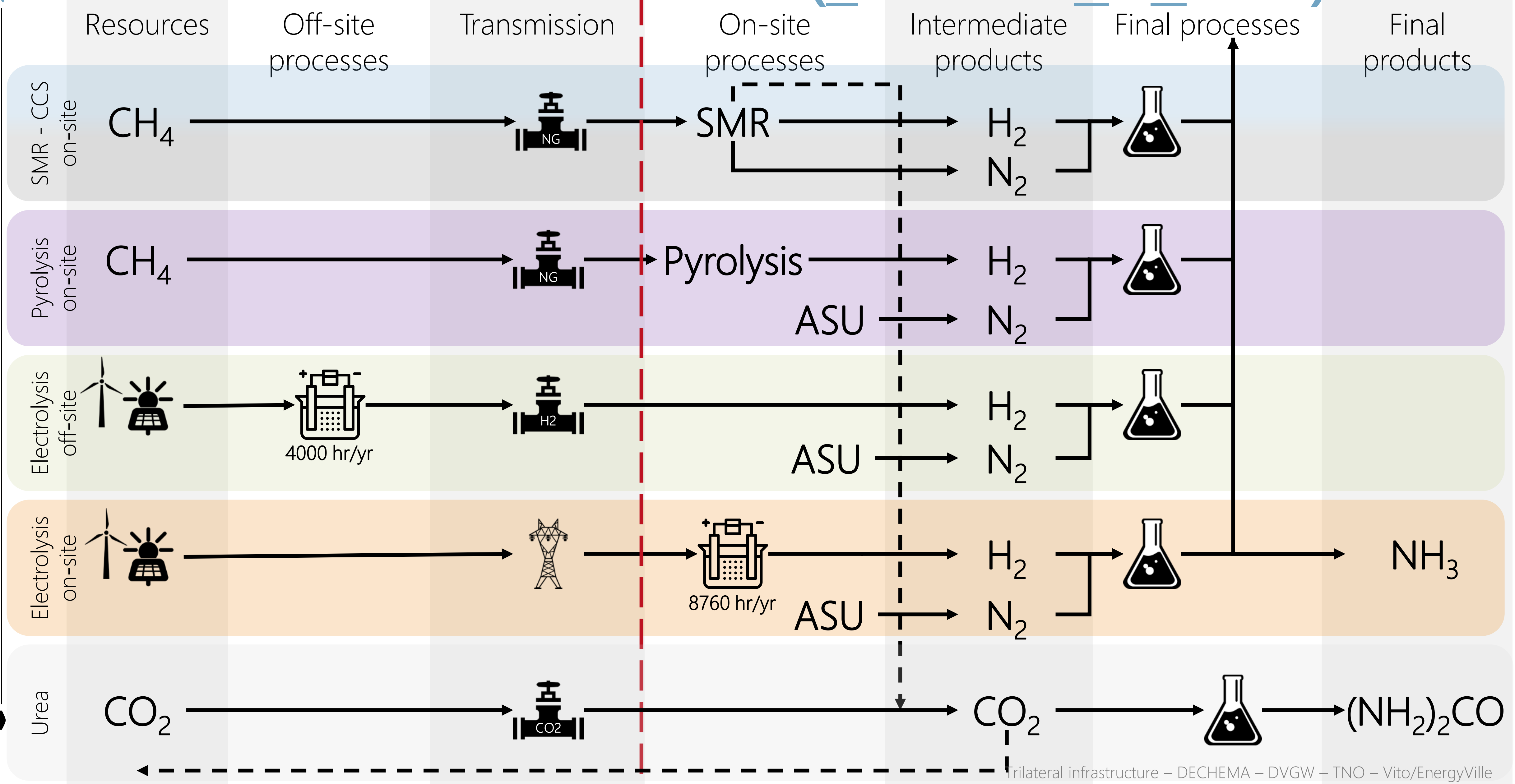
CHEMELOT SITE GELEEN, NL

- Depreciated SMR plant
- Annual ammonia production ~1100 kton/annum (2017)
- Annual urea production ~480 kton/annum (2017)
- 28% of national natural gas non-energy use

CHEMPARK DORMAGEN, DORMAGEN, DE

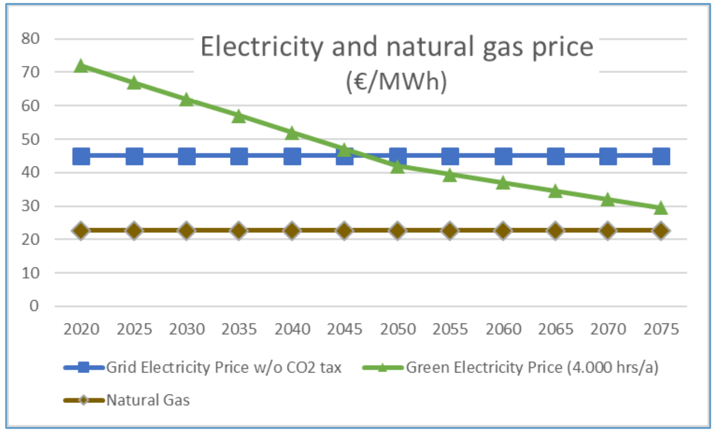
- Depreciated SMR plant
- Annual ammonia production ~285 kton/annum (2017)
- 6% of national natural gas non-energy use

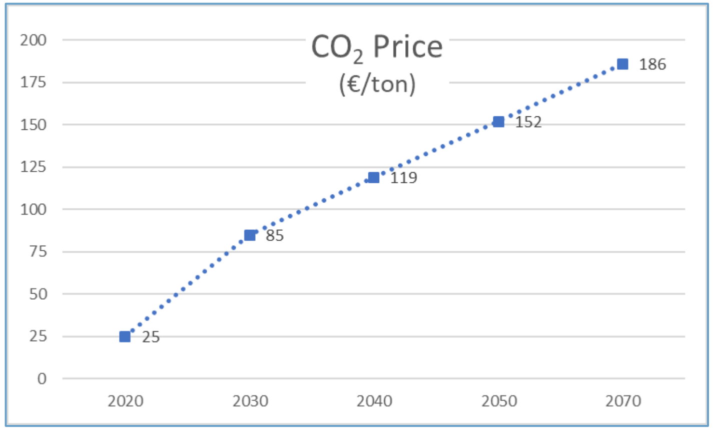
4 CARBON-NEUTRAL PATHWAY SCENARIOS EXIST FOR SMR BASED AMMONIA PRODUCTION (BUSINESS AS USUAL)

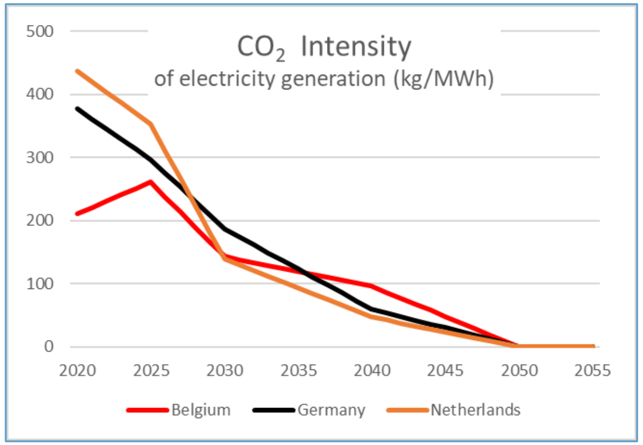


Trilateral infrastructure – DECHEMA – DVGW – TNO – Vito/EnergyVille

MODEL: EVOLUTION OF KEY DRIVERS & PROJECTION ASSUMPTIONS

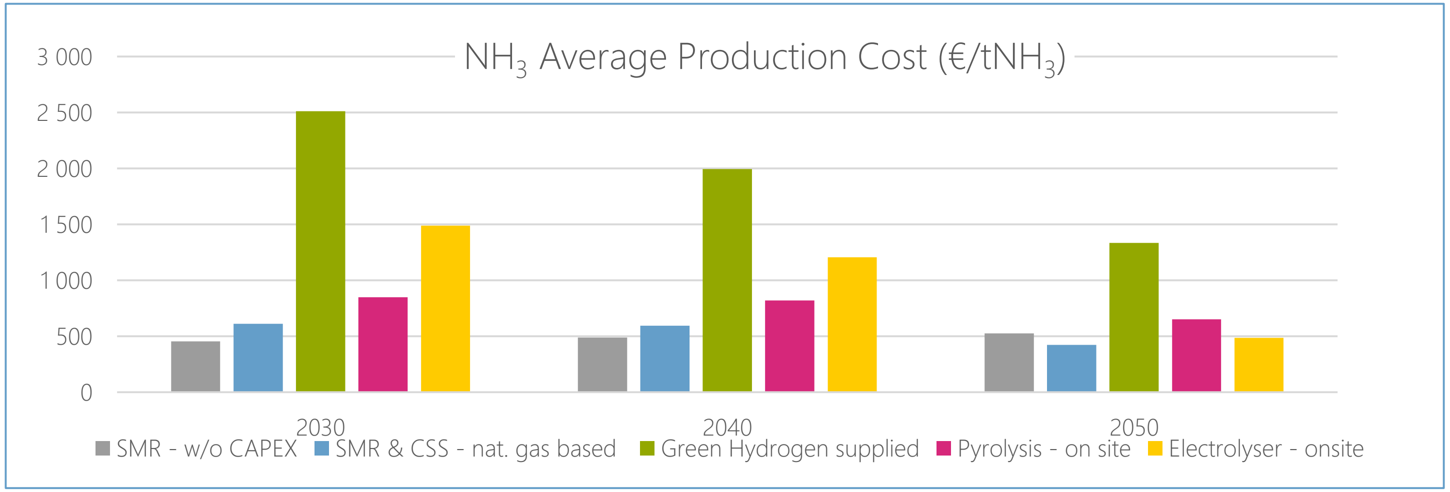






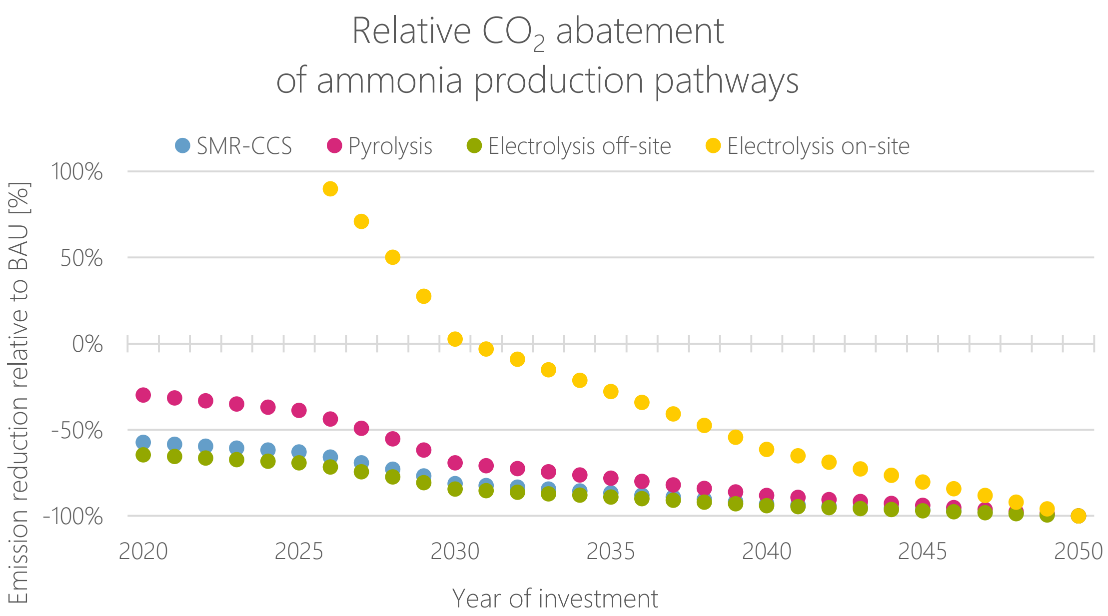
Improvements of installations:
CAPEX, OPEX, efficiency, …

SMR
Pyrolysis
ASU



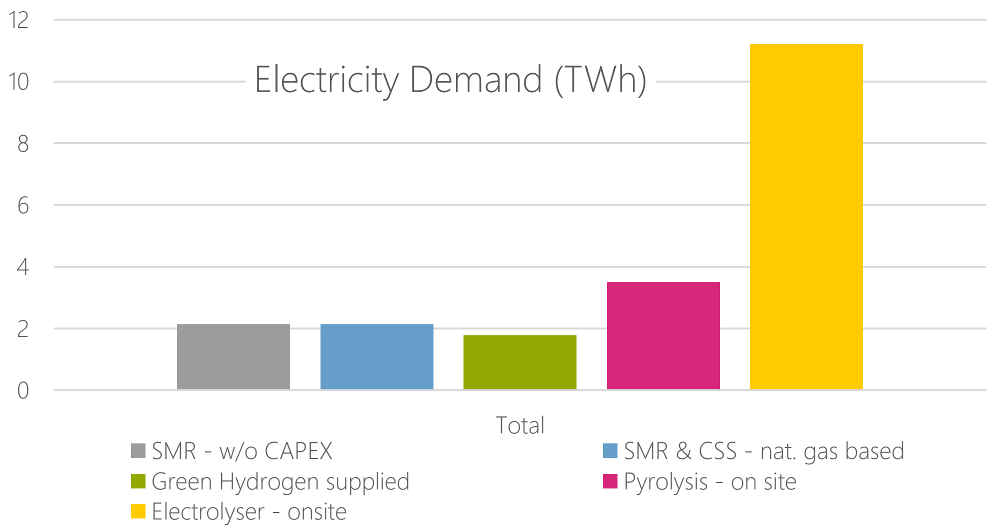
ALL PATHWAYS PROVIDE NET CARBON REDUCTION SOMEWHERE BETWEEN TODAY AND 2035 …

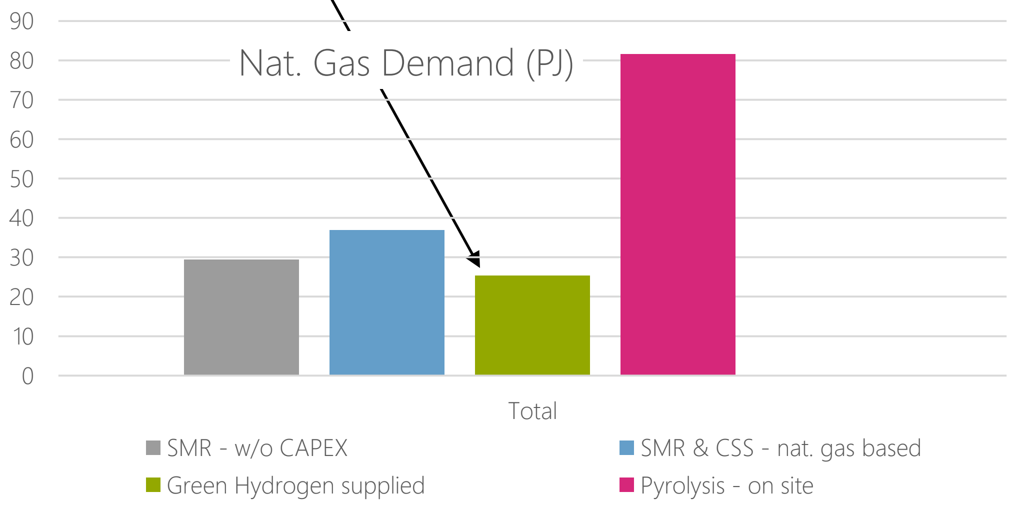
- … but for today's investment decisions only **SMR-CCS** is a technical feasible option considering a combination with step-by-step ramp-up of on-site electrolysis (PPA + grid electricity)
- **On-site electrolysis** becomes an option when CO_2-footprint of grid electricity drops below a certain value
- Once **methane pyrolysis** becomes commercially available it offers lower CO_2 abatement cost than SMR-CCS
- **Limitations** - please note: large uncertainties due to low TRL (pyrolysis) and unknown CO_2-storage costs (blue hydrogen)



IN TERMS OF ENERGY INFRASTRUCTURE CAPACITY, E.G. CHEMELOT SEEMS EQUIPPED FOR NO PATHWAY TODAY …

- **Impact on CO_2**
  - On-site **SMR-CCS** requires a CO_2 pipeline with a capacity of roughly 1.3 Mton/a
  - All other pathways lead to negative emissions and requires 0.35 Mton/a CO_2 transport to the site as feedstock for urea
- **Impact on energy carriers**
  - **Pyrolysis** requires increase of natural gas transport capacity up to 81 PJ/a (+6.4%** of Dutch national gas consumption)
  - **Electrolysis off-site** requires a hydrogen pipeline with a capacity of 185 kton/a (in scope of Gasunie's hydrogen backbone)
  - **Electrolysis on-site** would require a 11 TWh/a power connection (+20%** Dutch industrial electricity consumption)





**Based on CBS data obtained from www.energieinnederland.nl, accessed April 2020

OVERVIEW OF SITE-SPECIFIC ASPECTS

	Antwerp (BE)	Dormagen (DE)	Geleen (NL)	comments
Conventional	Existing Production	Existing Production	Existing Production	
SMR + CCS (blue H_2)	Harbor location advantageous for CO_2 export via shipping	CCS currently not possible in Germany	Offshore storage potential in empty gas fields	CO_2-infrastructure required -> repurposing NG pipelines
Green H_2 (pipeline or shipping)	Hydrogen pipeline but limited capacity; Harbor location with potential for direct H_2 terminal	Hydrogen pipeline but no connection to port	Natural gas pipelines could be converted to hydrogen	Existing hydrogen infrastructure not sufficient
Electrolysis on-site	Coastal location could lead to easy access to North Sea offshore wind park	Good grid connection (Power plant on-site, powered by natural gas)	Existing transmission network from coast to site, although far from shore	May be limited by grid capacity and large amount of green electricity (offshore?)
	6 TWh/a would require cross-border grid improvement		11 TWh/a would require grid improvement to site	
Pyrolysis of natural gas	Strong natural gas connection	Natural gas connection with 320 000 cubic meters per hour sufficient	Existing gas infrastructure insufficient	Continuous natural gas supply required

OVER TIME, CONDITIONS FOR AMMONIA SITES IN THE ARRRA REGION WILL BECOME INCREASINGLY SIMILAR

Observations

- Currently, BE, DE and NL differ in terms of energy markets and emission intensity of electricity, but expecting integrated energy markets in near-future NWE, these factors will become more uniform over time
- Political borders may remain, but “technical” and regulatory borders disappear
- Given the similarities and impact of transitions of chemical sites, a cross-border approach is highly recommended

Main pathway implications for the whole region (2050)

- SMR (BAU): = 2.7 Mton/a emissions, with a cumulative total of 105 Mton up to 2050
- SMR-CCS on-site: + 2.7 Mton/a CO_2 pipeline and storage infrastructure capacity
- Pyrolysis on-site: + 104 PJ/a natural gas supply, high uncertainty due to low TRL of technology
- Electrolysis off-site: + 4.3 GW of wind farm, electrolyser peak capacity and buffers for 350 kton/a green hydrogen
- Electrolysis on-site: + 16.5 TWh (1.9 GW) electricity demand, security of carbon free electricity supply in future

OPPORTUNITIES FOR NEXT STEPS

Objective	Question (s)
Dialogue and engagement	How do individual sites / infrastructure providers see the transition?
Identification of knowledge gaps	What requirements can be derived towards the infrastructural challenges?
Risk & uncertainty	Can security of supply be guaranteed in the transition and beyond?
Identification of no-regret options	Can best practices be derived and (international) guidelines for the transition be developed?
Market position vs. decarbonization targets	How to stay competitive during and beyond the transition while at the same time fulfilling political aims?
Cross-sectoral integration	How to rearrange and redefine the interactions of chemical sites, energy infrastructure, refineries, other industries?
System synergies	New business-models for services?

SUMMARY

Motivation

In this first exercise, ammonia production serves as an example to discuss possible routes to CO_2-neutrality and their impacts on connecting infrastructure

Process and infrastructure transition

4 alternative (sustainable) processes are analysed on a value-chain basis and compared on

- expected (global) costs per unit of product,
- CO_2 impact over time
- required capacities of energy/molecule infrastructures
- taking into account (repurposing of) existing assets and needs for new assets

For discussion

How can these type of exercises (also applied to other sector/products) be used as stepping stones to work towards a cross-border infrastructure (investment) plan? Which next steps should be taken?

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APPENDIX - LIMITATIONS AND UNCERTAINTIES

Limitations of approach

- Limitation on one product (ammonia): Results are not (fully) applicable for other products.
- Limitation on site location: Results are not necessarily applicable for other sites as results seem site-specific.
- Some technologies and processes currently lack technological maturity (e.g. methane pyrolysis) and/or social acceptance

Limitations in data availability

- Most data for chemical and industrial sites and (critical) infrastructure is not public domain data
- Use of aggregated data

Limitations in timeseries forecasting

- Timeseries forecasting strongly depends on political and regulatory actions that we currently witness to be subject to major changes (EU Green Deal, Paris agreement and their translations in national laws)
- Especially the effects and potential business models (and hence alternatives) that arise of high CO_2-prices are little known and controversially discussed in literature

APPENDIX - MAIN ASSUMPTIONS

[€/tonCO_2]	2020	2030	2040	2050	2070
CO_2 Price	25	85	119	152	186

- WEO 2019 Sustain. Dev. Scenario & extrapolations

[€/MWh]	2020	2030	2040	2050	2070
Grid Electricity Price w/o CO_2 tax	45	45	45	45	45
Green Electricity Price (4.000 hrs/a)	72	62	52	42	32
Natural Gas	22.7	22.7	22.7	22.7	22.7

- Eurostat
- TYNDP 2020 (National Trends Scenario)
- Vito/EnergyVille & extrapolations

Grid Elc CO_2 intensity		2020	2030	2040	2050	2070
Belgium	[kgCO_2/MWh]	266	181	122	0	0
Germany	[kgCO_2/MWh]	478	237	76	0	0
Netherlands	[kgCO_2/MWh]	555	176	60	0	0

- European Environment Agency
- TYNDP 2020 (National Trends Scenario)

Development electrolysis		2020	2030	2040	2050	2075
CAPEX	[€/kW]	1200	950	850	750	500
Efficiency	[%]	1	1	1	1	1
CAPEX	[€/tH_2]	7707	5695	4931	4215	2645
CAPEX	[€/tNH_3]	1369	1011	876	748	470
OPEX	[€/kW]	36	29	26	23	21
OPEX	[€/tH_2]	231	171	148	126	108
Lifetime	[h]	50000	60000	70000	80000	100000

- https://doi.org/10.1016/j.apenergy.2018.08.027
  *Potential of Power-to-Methane in the EU energy transition to a low carbon system using cost optimization (DVGW et al.)