HOW INDUSTRIAL TRANSFORMATION AND NUCLEAR ENERGY SUPPLY AFFECT EACH OTHER.

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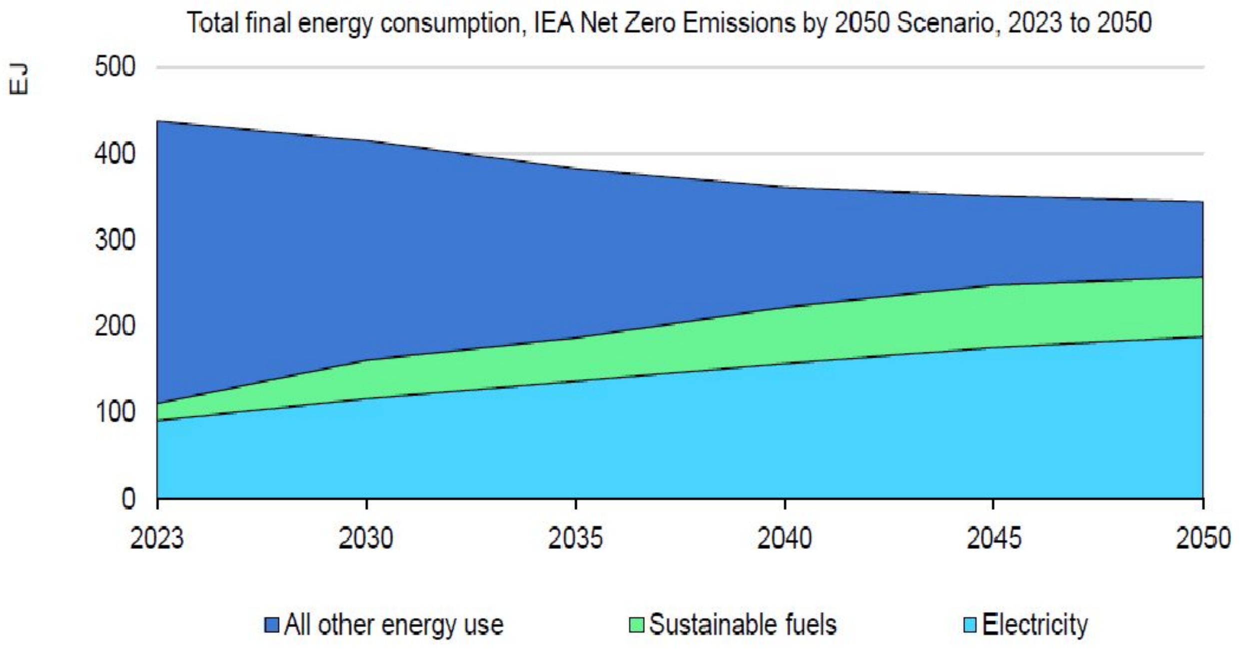
ENERGY TRANSITION IS NOW EVEN MORE FUNDAMENTAL!

- SECURITY OF SUPPLY
- RESILIENCE
- COMPETITIVENESS
- STRATEGIC AUTONOMY
- CLEANTECH AND INNOVATION CONTROLS
- CLIMATE AND ENVIRONMENT.
- INTERLINKED WITH COMPETITIVE INDUSTRY /CIRCULAR ECONOMY

MULTIDIMENSIONAL CHARACTER NOW MORE PROFOUND… & MORE URGENT.

Sustainable fuels play a key role along electrification and energy efficiency measures

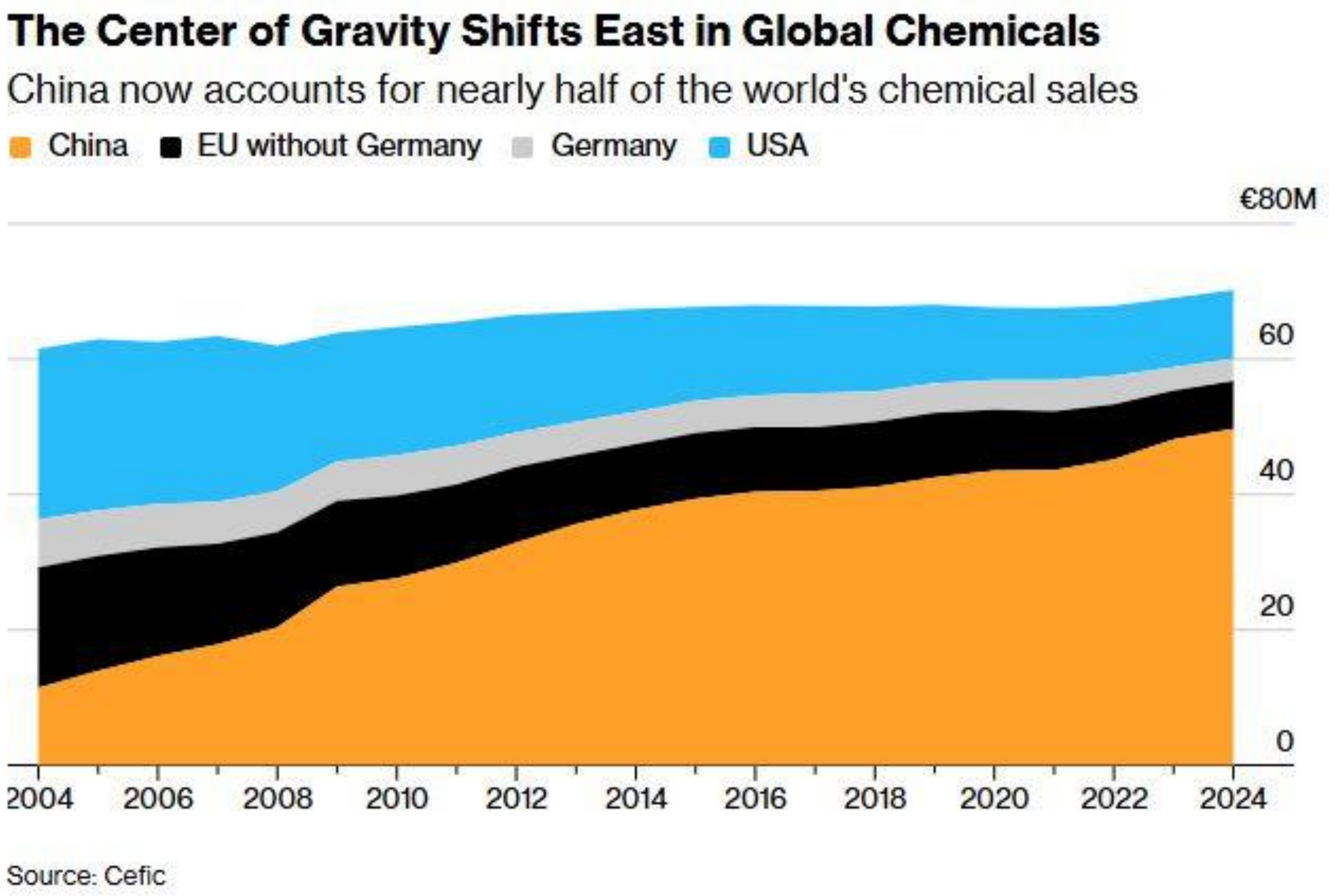


Source: IEA (2024) World Energy Outlook. Sustainable fuels includes modern bioenergy, low-emissions hydrogen and hydrogen-based fuels including low-emissions hydrogen used as a feedstock for non-energy purposes.

Sustainable fuels such as biofuels, hydrogen and hydrogen-based fuels provide 80 EJ of energy in 2050 in NZE, near equal to global electricity demand today. By 2050 they support one quarter of global energy consumption.

WHERE DOES EUROPEAN INDUSTRY GO?

…AND WHAT WILL BE THE AFFECT OF FUNDAMENTAL POLICY CHANGES IN EUROPE?…



And China also produces over half the worlds' steel…

EUROPE; STAND UP!

- **Draghi report**: Invest! Strategic independence!
- **Letta rapport**: Scale up!
- **Antwerpen declaration**: sustainable & competitive industry
- **Single market & competitiveness report**
- EC Climate Neutrality report: Future energy system is a systemic change
- EU industrial accelerator act…
  - **Lack of synergies between research and industry**
    - High energy prices
    - Lack of public investments in R&I/cleantech
    - Workforce reskilling
    - Strategic dependencies on third countries

NERA Netherlands Energy Research Alliance

AT THE SAME TIME, EUROPE (EU+UK+ NORWAY+SWITZERLAND):

- 2e economy globally in PPP (larger then US; in GDP larger then China; which will be old prior to being rich), the largest global trade block and market with the most prosperous economies.
- Includes 7 of the 10 most innovative economies worldwide
- Realising an absolute decoupling between economic growth and GHG emissions.

NERA Netherlands Energy Research Alliance

Global Innovation index, 2024:

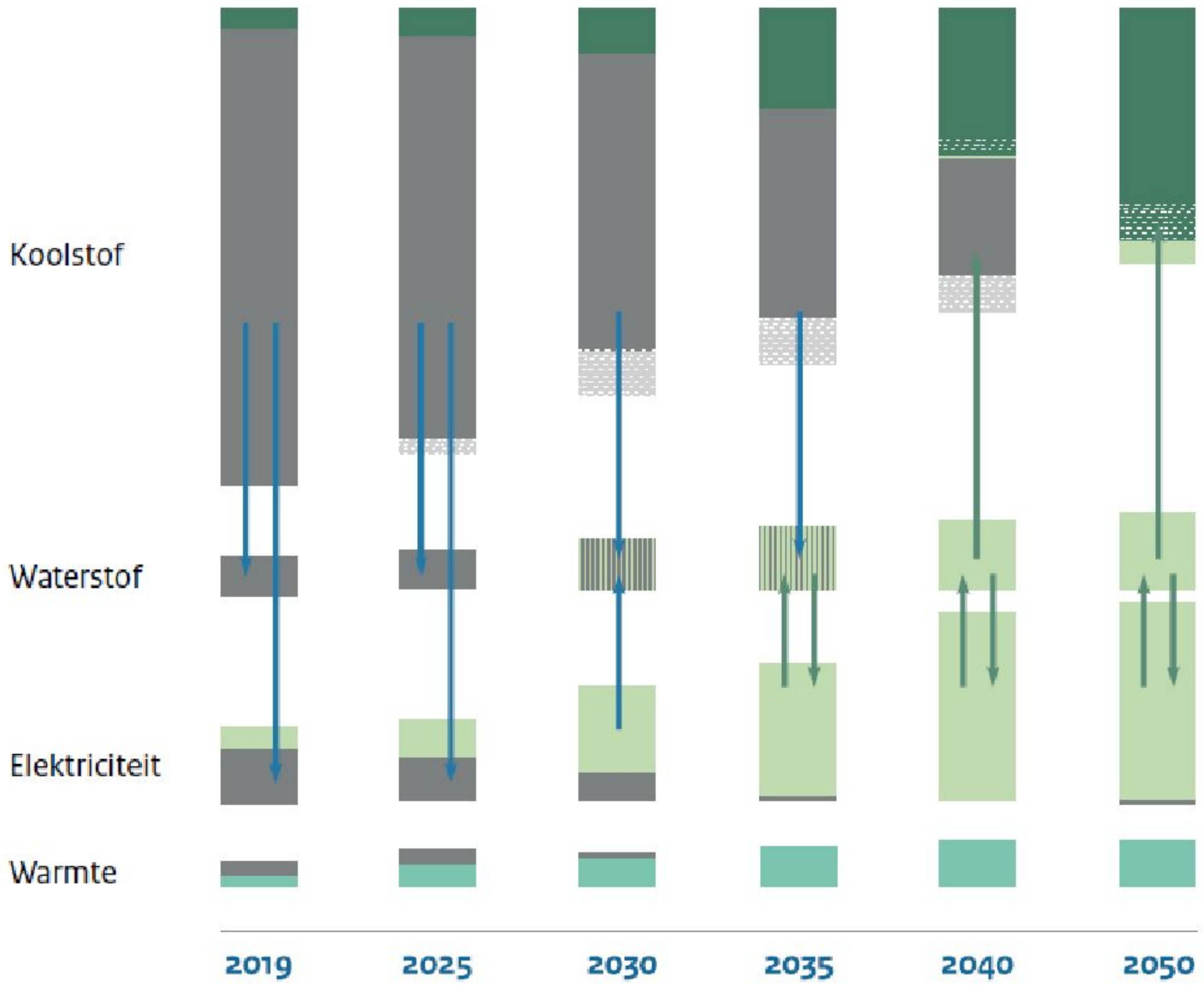
Most Innovative Countries in 2024

The following table includes all of the data we used
consecutive year, **Switzerland** was named the wor

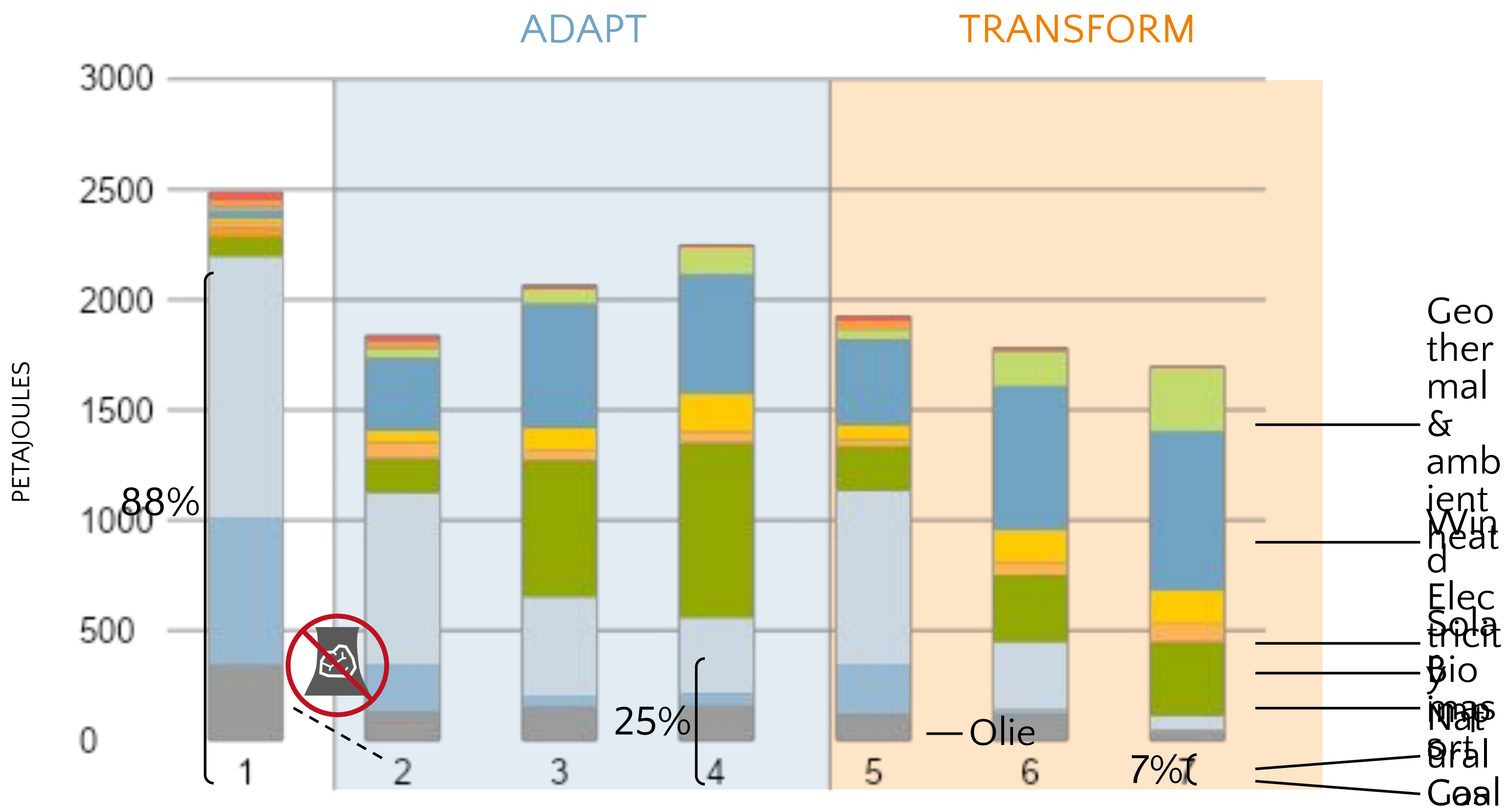
Rank	Name
1	Switzerland
2	Sweden
3	U.S.
4	Singapore
5	UK
6	South Korea
7	Finland
8	Netherlands
9	Germany
10	Denmark
11	China
12	France
13	Japan
14	Canada
15	Israel
16	Estonia
17	Austria
18	Hong Kong
19	Ireland
20	Luxembourg

Nationaal Plan Energiesysteem 2050 (1.0)

[EZK, 2023]



2 FUTURE ENERGY SCENARIO’S FOR THE NETHERLANDS; PRIMARY ENERGY SUPPLY MIX



- Excludes:
- Non-energetic use
- International aviation & shipping

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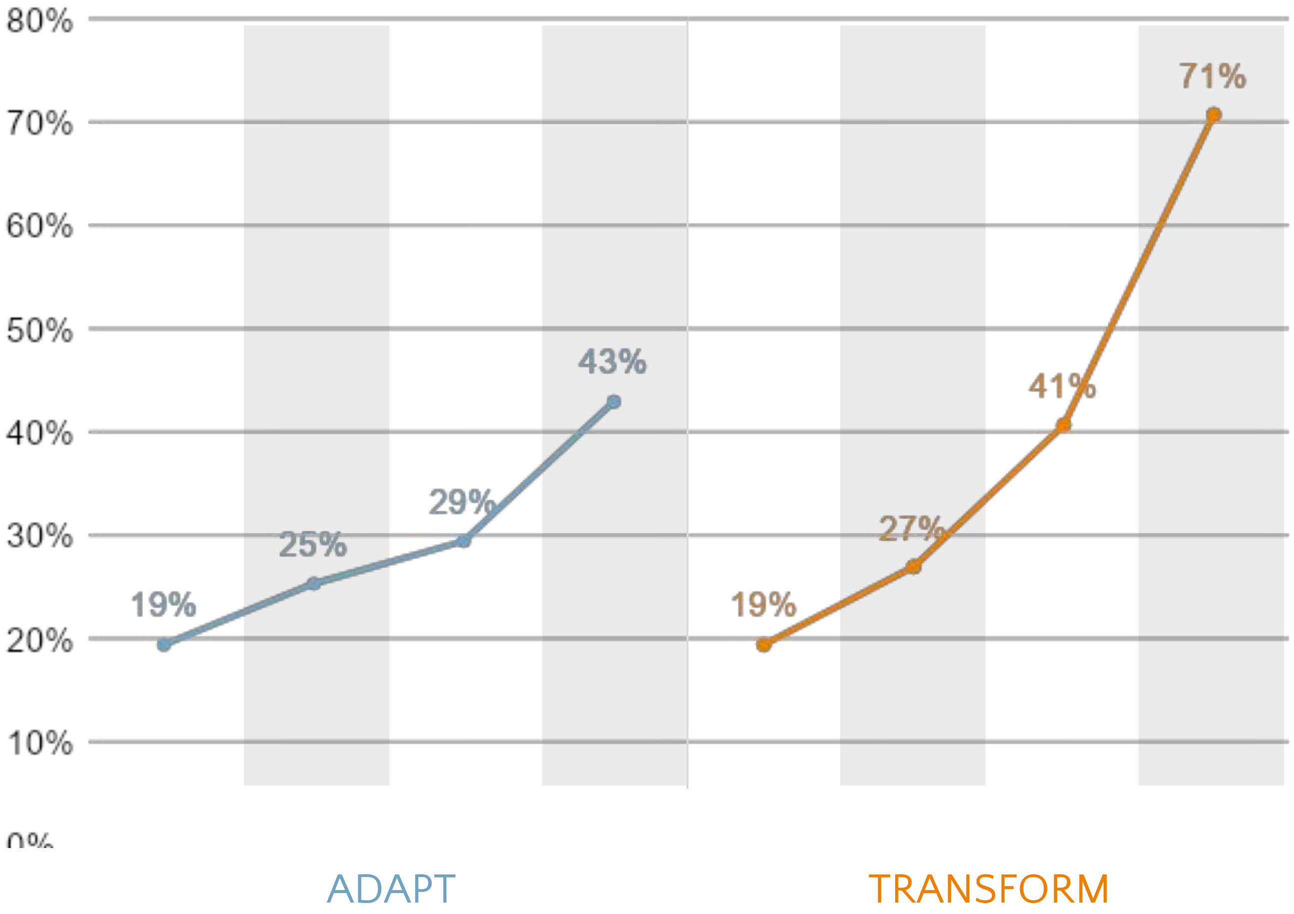
SHARE OF ELECTRICITY IN THE ENERGY SUPPLY

DOUBLING – TRIPLING COMPARED TO TODAY

Share electricity in total energy supply



Share low C electricity

	ADAPT	TRANSFORM
2018	19%	19%
2030	81%	76%
2040	97%	97%
2050	99%	99%

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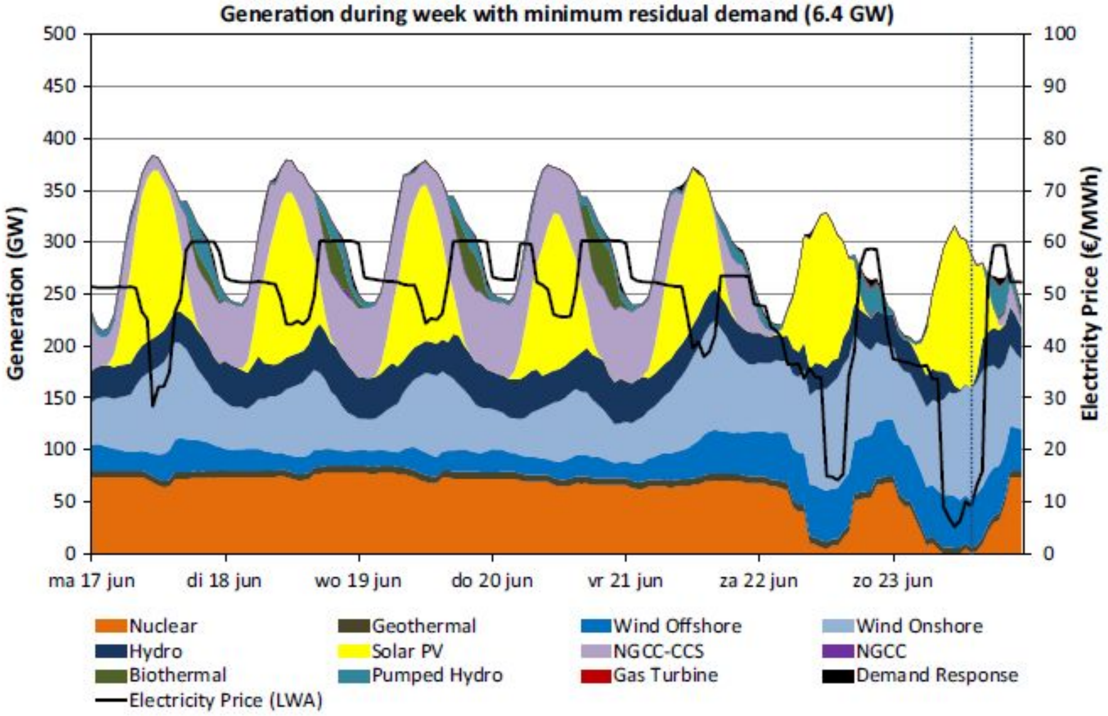
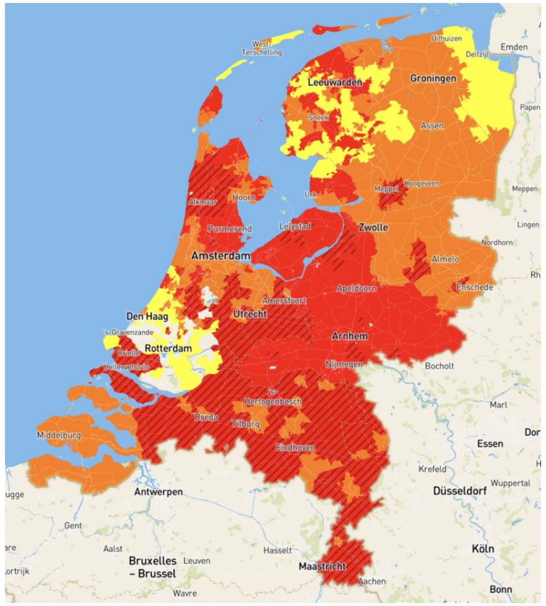
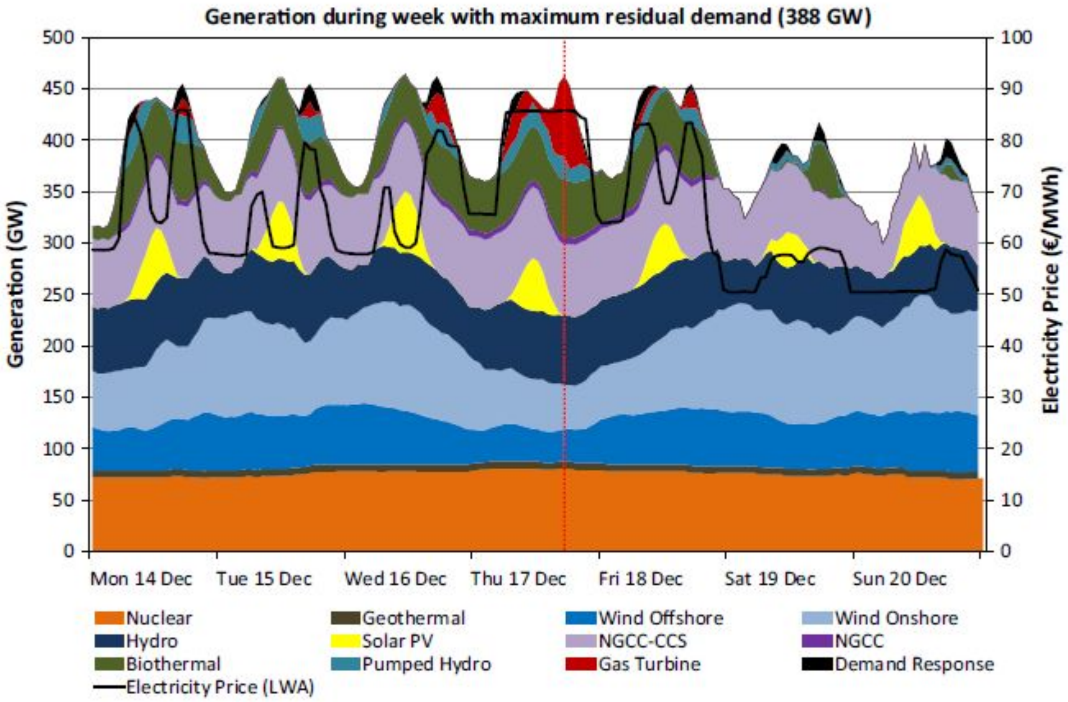


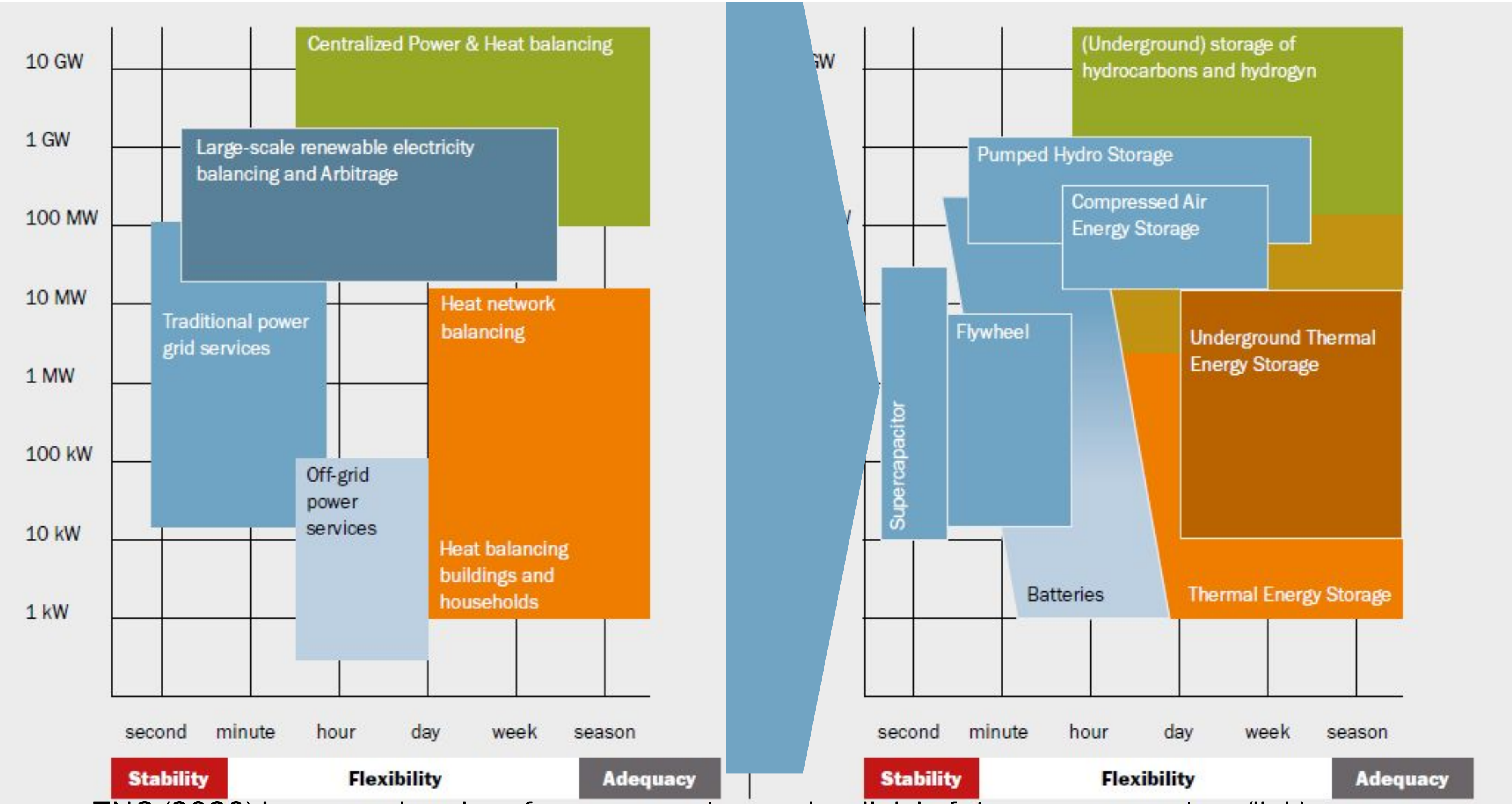
Electricity system simulations
NW Europe 2050 with 60% iRES
Weeks with maximum and
minimum
residual loads during the year.
[Brouwer et al., Applied Energy, 2016]



System implications !



AVAILABLE AND EMERGING ENERGY STORAGE, FLEXIBILITY AND SYSTEM INTEGRATION OPTIONS…



Source: TNO (2020) Large-scale subsurface energy storage: key link in future energy system (link)

- Parameters power (Watt) and relevant timescales for charging and discharging.
- Colour coding indicates in which infrastructure system the storage technology is implemented:
- Blue = electricity
- Green = gas
- Orange = heat

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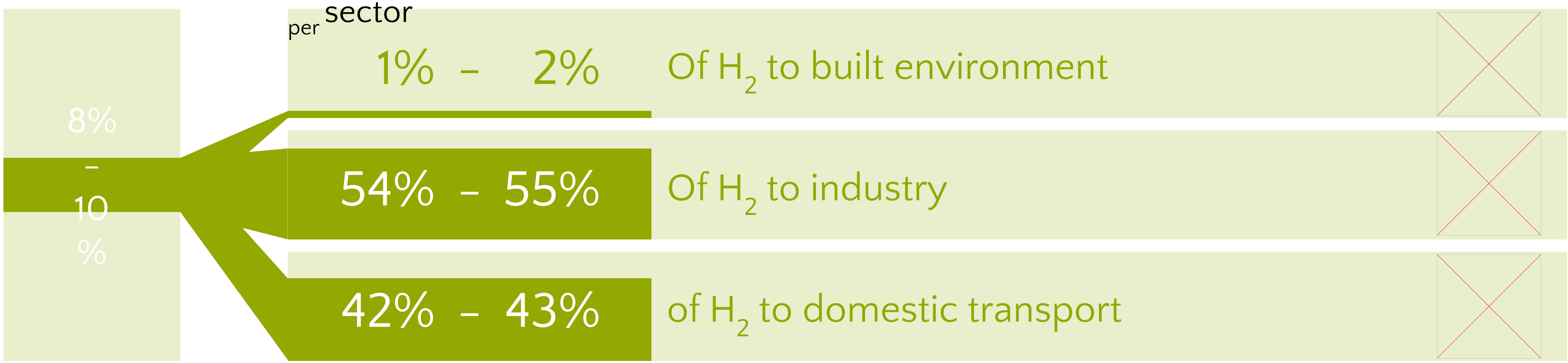
HYDROGEN RELATIVELY MODEST, BUT...

IMPORTANT ROLE IN THE ENERGY SYSTEM

TOTAL H_2
257/260 PJ

PERCENTAG
E H_2
per sector

Share hydrogen in the energy system
ADAPT 8% (257 PJ) en TRANSFORM 10% (260 PJ) in 2050

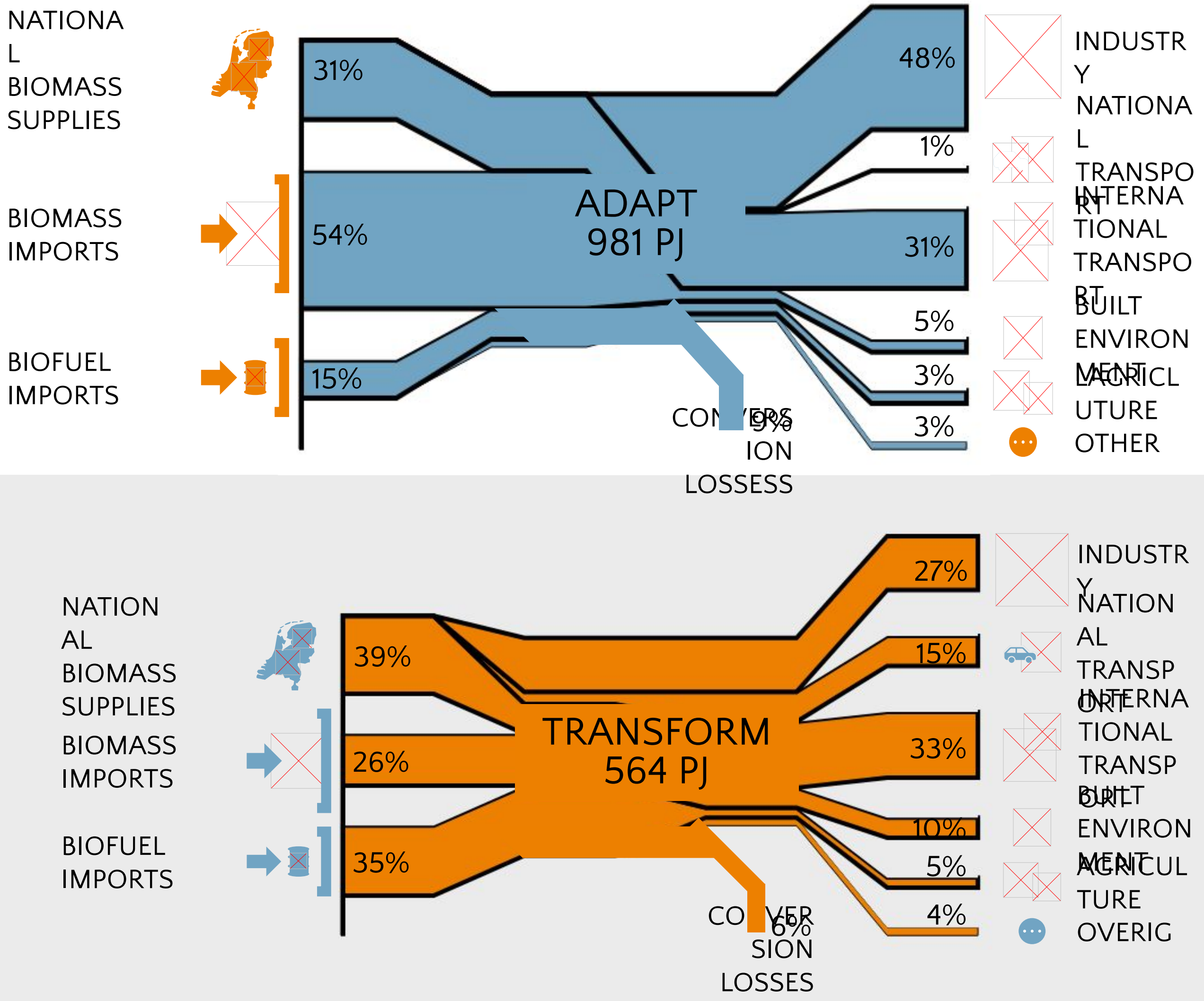


Production

ADAPT — Largely blue H_2, in 2050, also 25% green H_2

TRANSFORM — Only green H_2

BIOMASS ESPECIALLY USED IN: INDUSTRY & TRANSPORT



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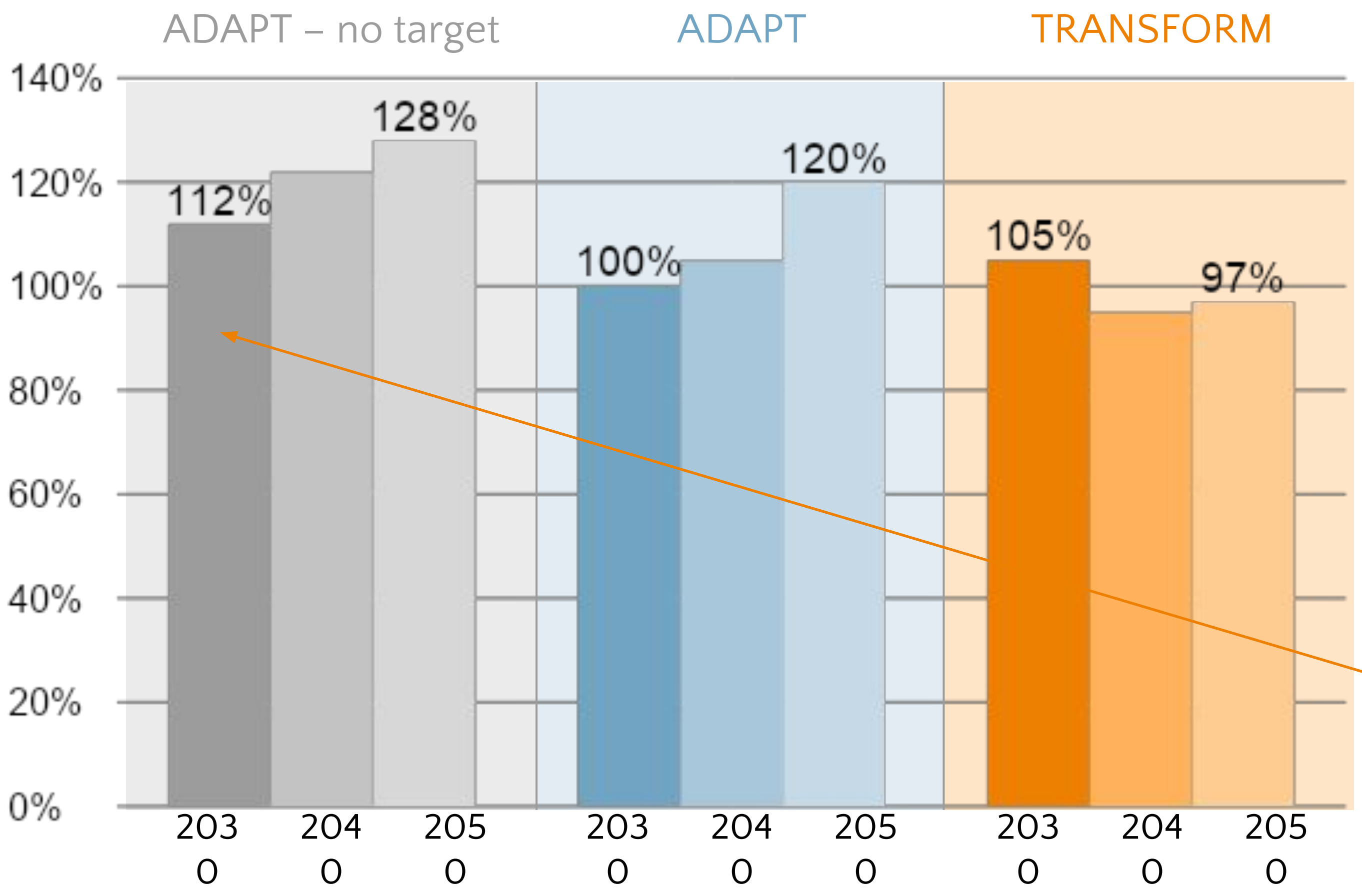
COSTS OF A SUSTAINABLE ENERGY SYSTEM

LOWER COMPARED TO A SCENARIO WITHOUT A GHG TARGET.

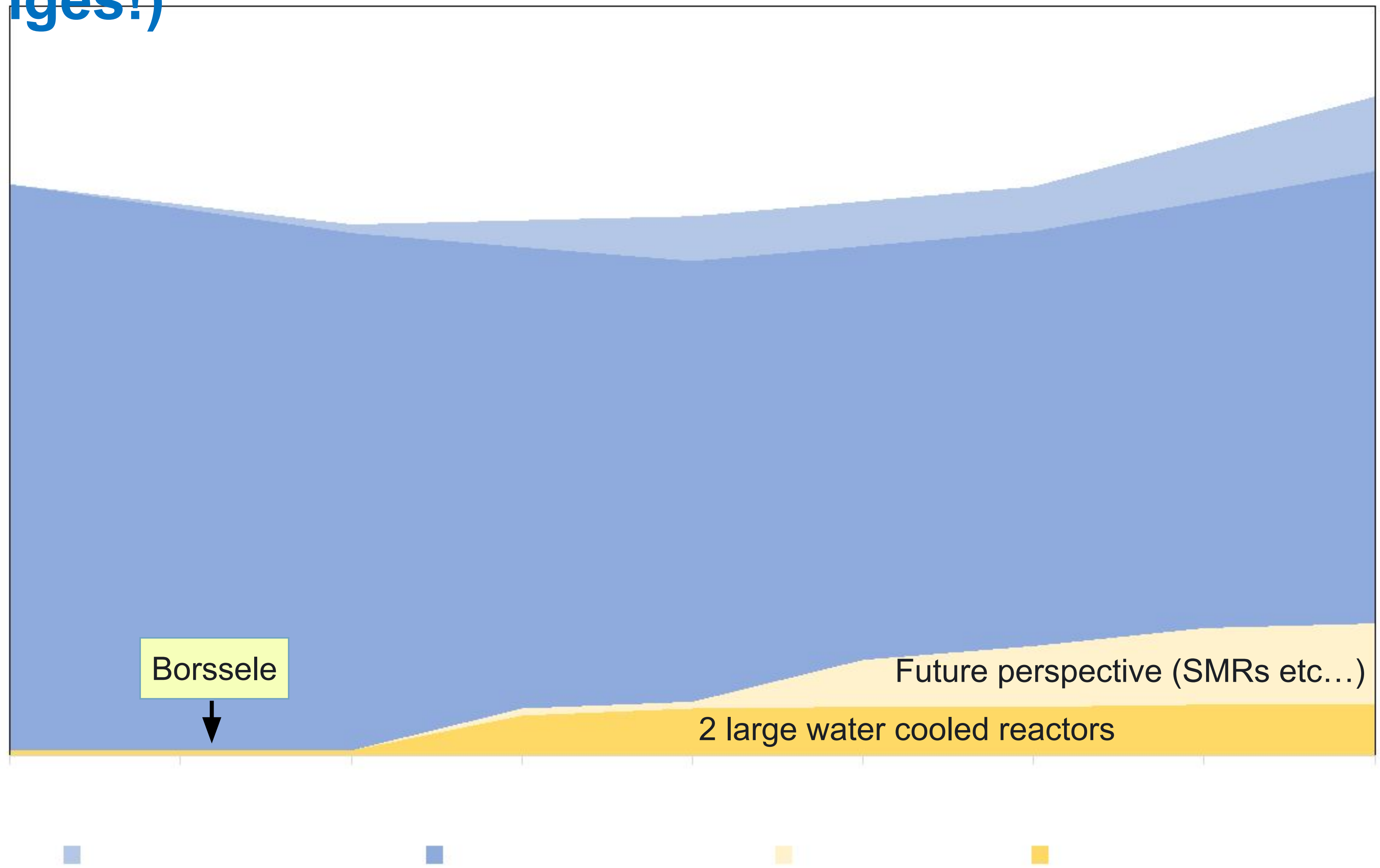


Preconditions:

- **All options (need to) contribute!**
- **Innovation (cost reduction)**
- **Optimal planning / deployment.**

This has about doubled with the Ukraine war resulting price levels for gas and oil

Potential nuclear energy in Dutch energy transition; Impacts on overall energy systems costs ~neutral (with ranges!)



INSTALLED NUCLEAR GENERATION CAPACITY (GW) RELATED TO VARIATION IN VRES CAPEX AND NUCLEAR CAPEX

VRES CAPEX	Nuclear gen III capacity [GWe] in 2050											
Highest	12.5	12.5	12.5	12.5	12.5	9.5	7.6	3.7	3.5	3.5	1.2	0.5
High	12.5	12.5	12.5	9.5	9.4	8.2	4.5	3.5	3.5	1.3	0.5	0.5
Mid	12.5	12	10.9	9.6	8.9	7.7	3.9	3.5	1.2	0.5	0.5	0.5
Low	12.5	12	10.9	9.8	8.8	7.7	4	2.1	0.5	0.5	0.5	0.5
Lowest	12.5	12	10.9	9.8	8.7	8	4	1.9	0.5	0.5	0.5	0.5
	4.5	**5**	**5.5**	**6**	**6.5**	**7**	**7.5**	**8**	**8.5**	**9**	**9.5**	**10**

Nuclear CAPEX [B€/GW]

Installed nuclear generation capacity with variations in the VRES capital costs against nuclear capital costs.

[Fattahi et al., Adv in Applied Energy, 2022]

ADVICE OF THE COUNCIL ON LIVING ENVIRONMENT AND INFRASTRUCTURE (RLI) PLEADS FOR THOROUGH ANALYSES AND POLICY

On the following dimensions:

- Energy security and reliability of the energy system
- Affordability
- Safety
- Sustainability
- Intergenerational justice

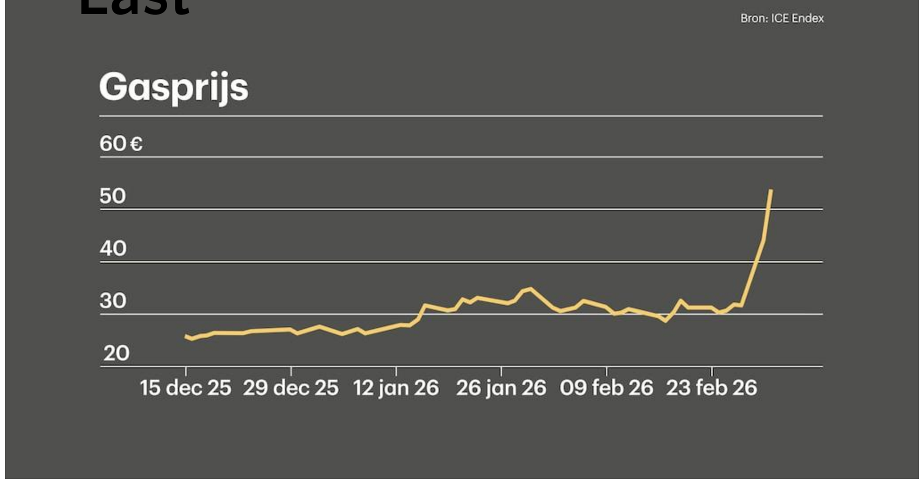
And the following key question whether nuclear energy is:

- –accelerating the energy transition or not? (realisation tim
- – going to be realized/implemented in such a way that the lower part of the cost range is achieved?
- – going to avoid conflicts (e.g. spatial) or increase them (issues on safety and storage of nuclear waste)

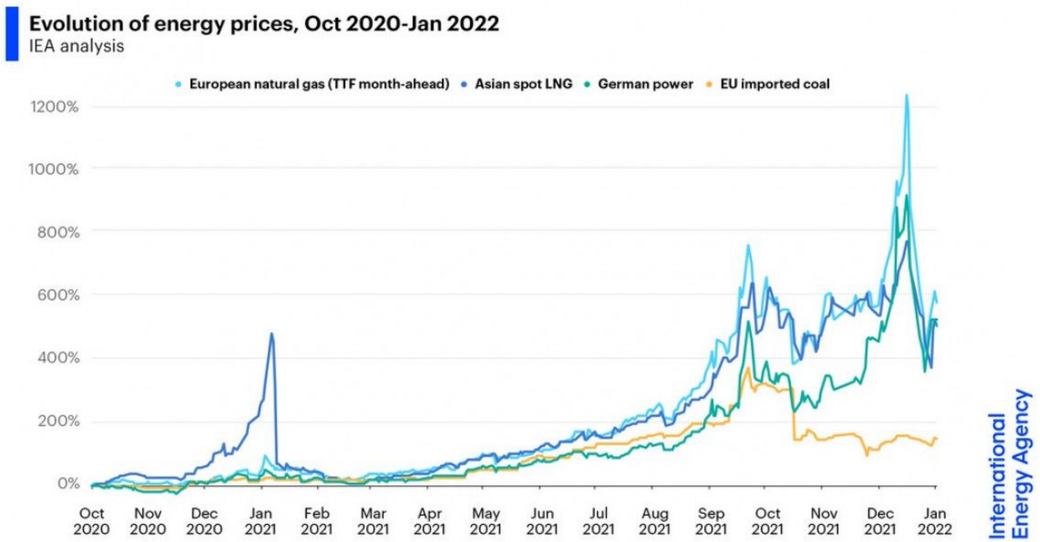
International dimensions affecting the energy transition & industrial transformation

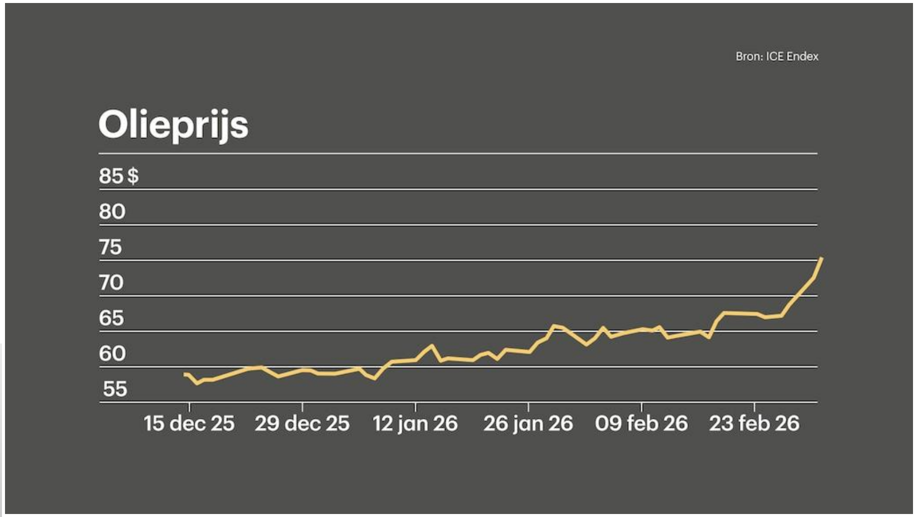
FOSSIEL = EXPENSIVE AND INSECURE. IMPORT BILL EU VOOR FOSSIL FUELS: ~ 0,5 – 1 TR EURO/JR.

2026: war Middle East



2022: Russian Invasion Ukraine:



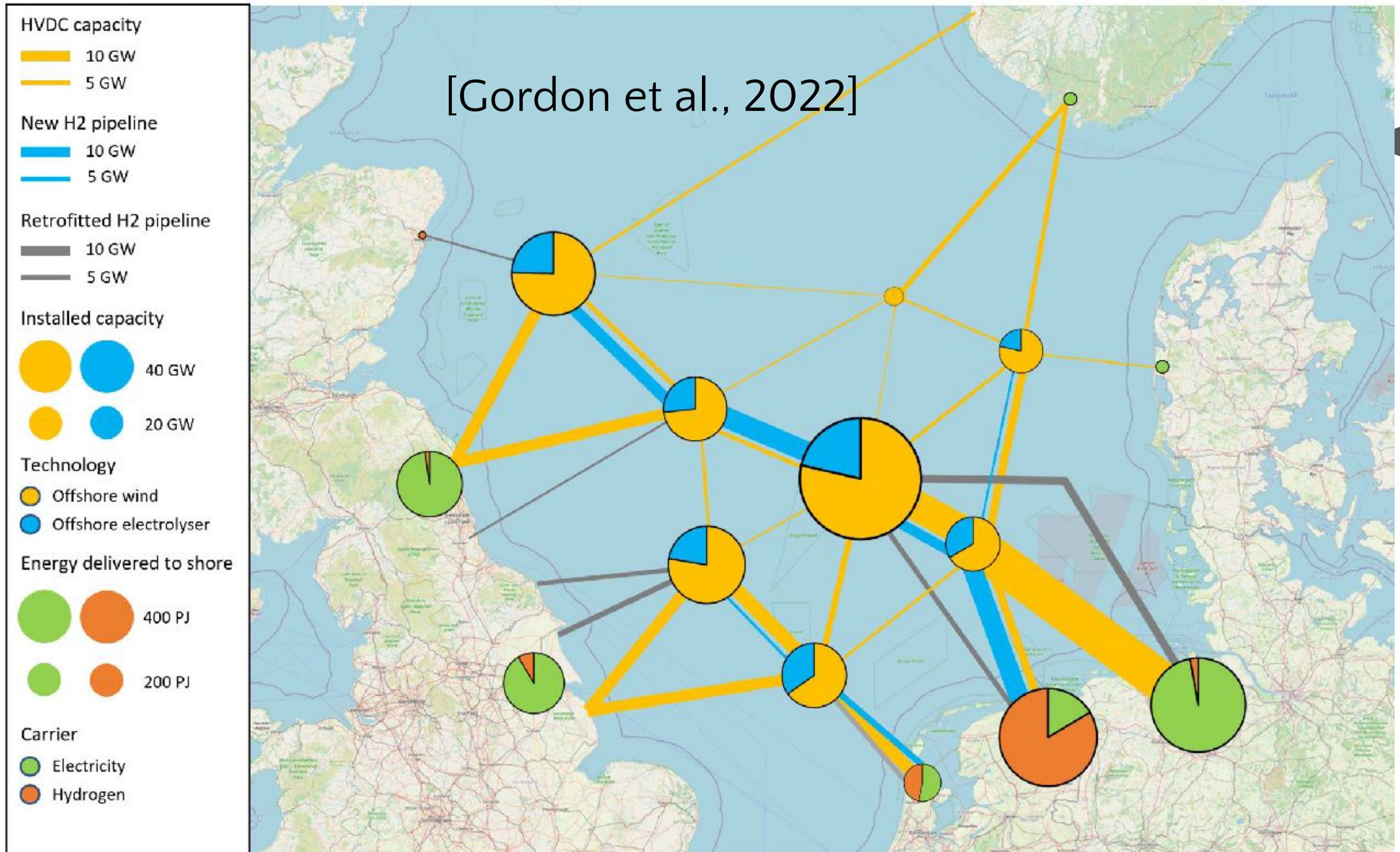


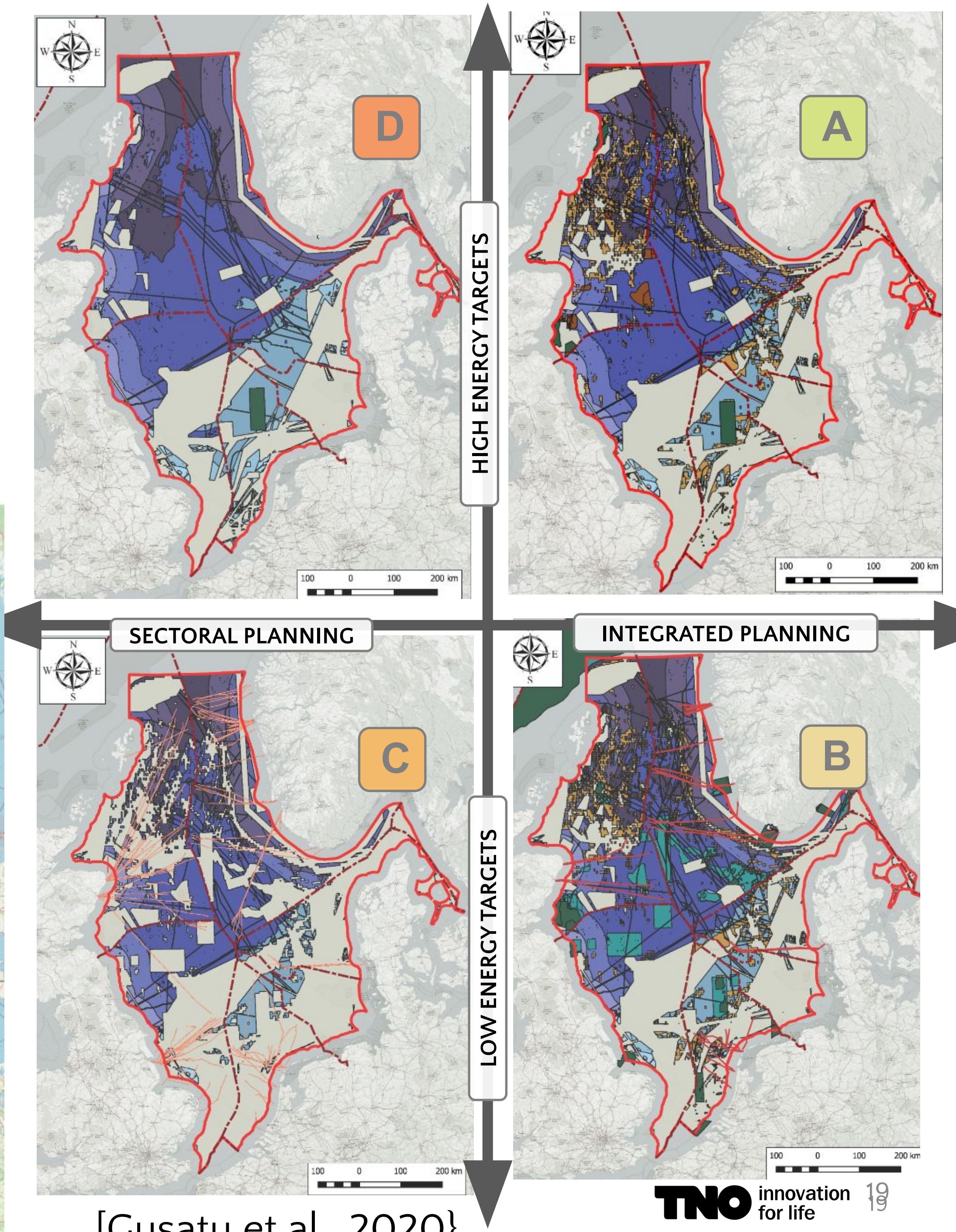
Op naar de volgende: 2028?

Trump dreigt met stop levering vloeibaar gas aan EU: 'Kom afspraken handelsakkoord na'

NORTH SEA REGION: TOWARDS 400 GW AND LARGE SCALE GREEN HYDROGEN SUPPLIES?

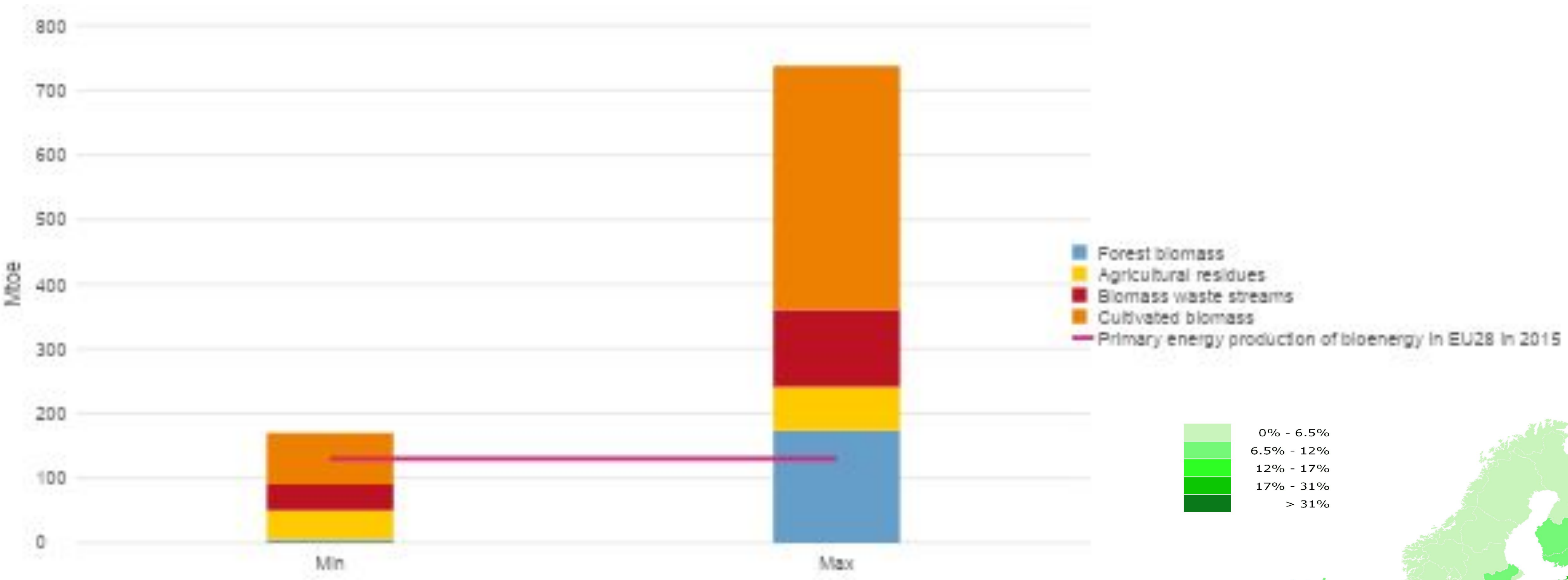
source: Tennet

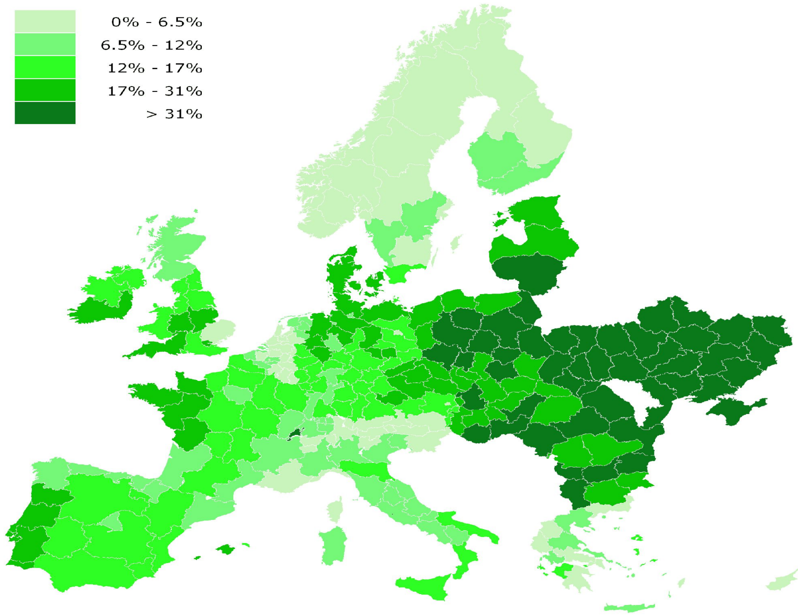




[Gusatu et al., 2020}

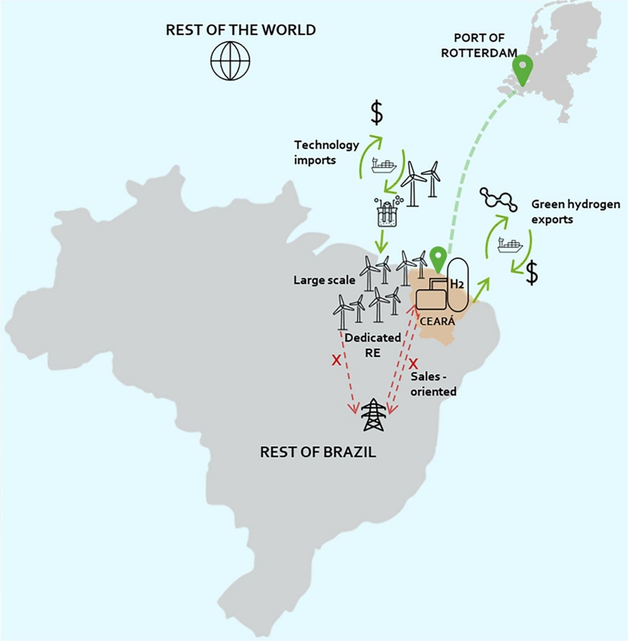
BIOMASS POTENTIALS EU28 IN 2050; 7–30 EJ COMPARED TO 68 EJ; TOTAL PRIMARY ENERGY USED TODAY

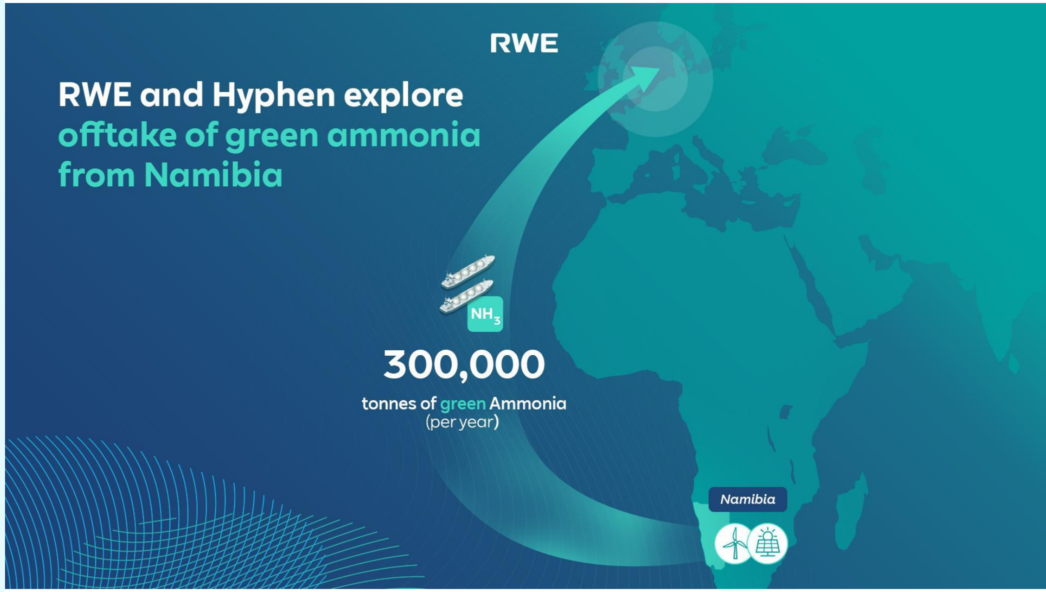


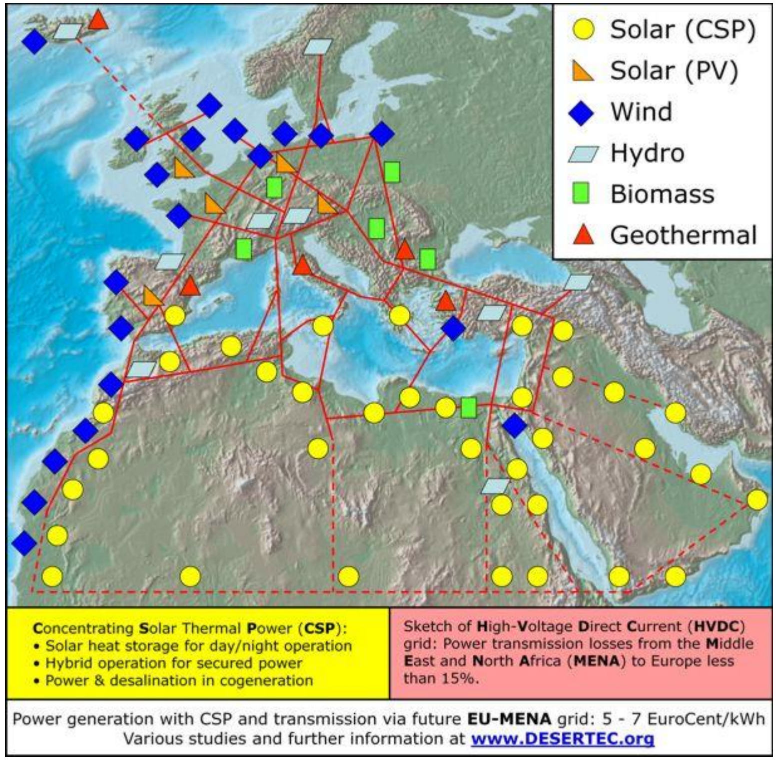


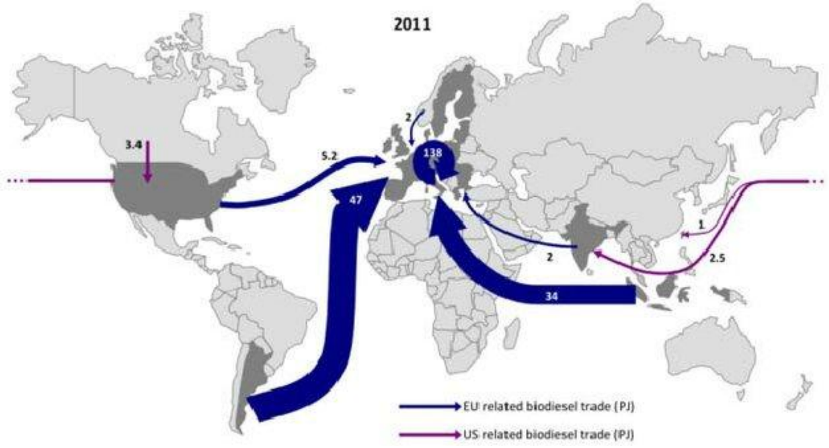
[Faaij, Energies. 2022]

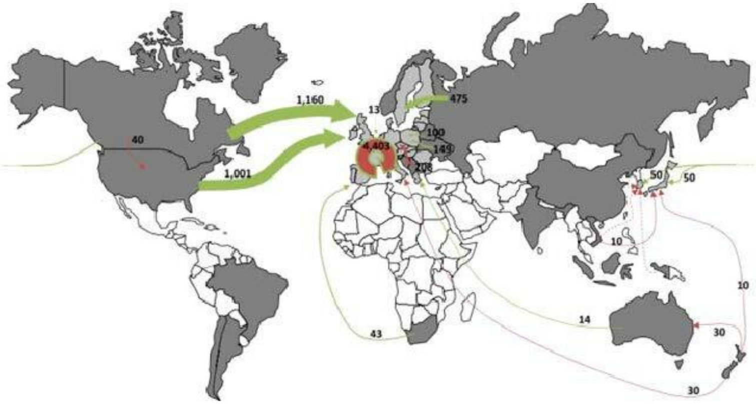
GLOBAL GREEN ENERGY MARKETS?









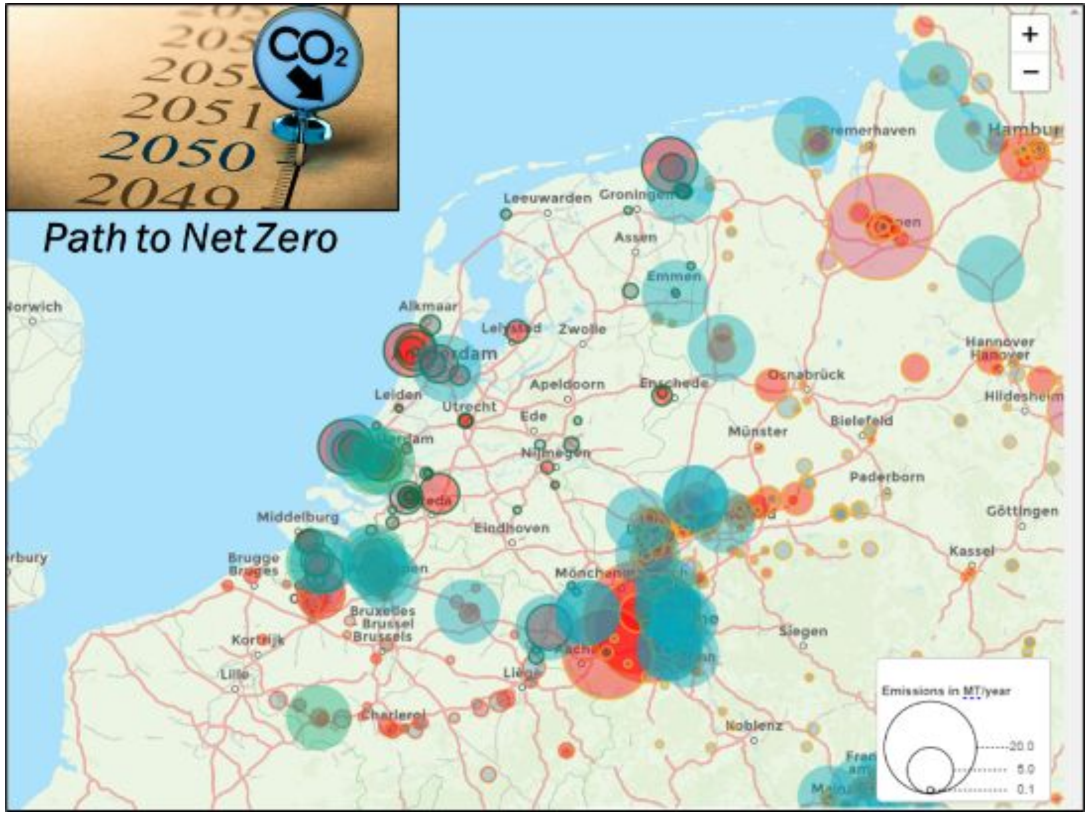


Global bioenergy trade; ethanol & wood pellets
Utrecht University, various publications

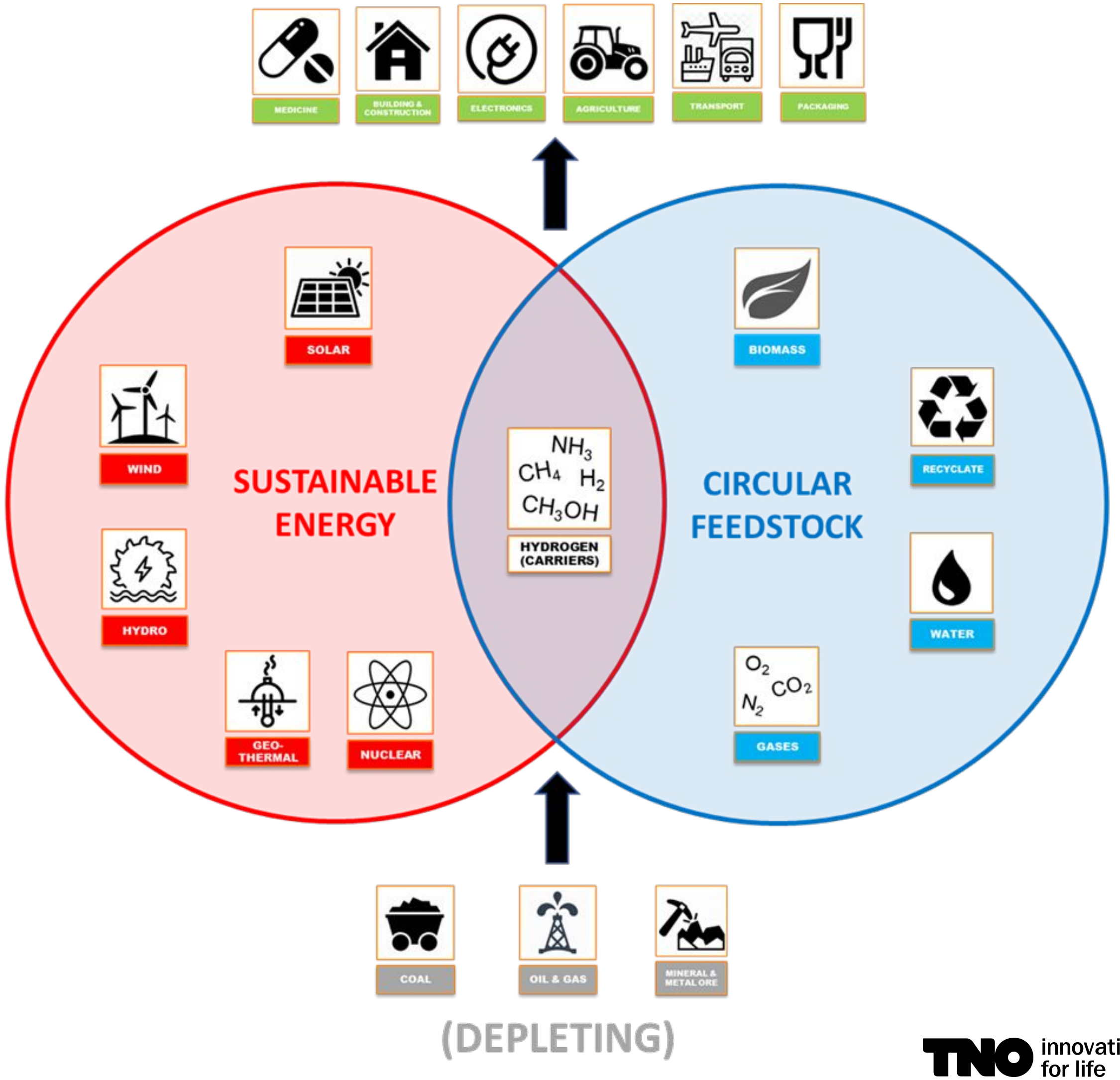
Industrial transformation (as part of the energy transition).

VISION – A FULLY SUSTAINABLE INDUSTRY

ENABLED BY DECARBONIZED ENERGY & RECARBONIZED FEEDSTOCK



ARRRA cluster ~50% of primary energy demand
And largeste chemical industry concentration worldwide.



INDUSTRIAL TRANSFORMATION □ ZERO CARBON FOOTPRINT DAUNTING COMPLEXITY

- **Industry ~50% of primary energy use.**
- **Many options:**
  - Energy efficiency improvement existing processes
  - New (inherently more efficient) processes
  - Renewable feedstock (biobased industry)
  - Renewable energy carriers (green power, green hydrogen)
  - Carbon Capture & Storage (with BECCS negative GHG emissions)
  - Recycling/re-use/circulair value chains
  - Shifts in markets and products.
- **All combined! < 3 decades; overall one investment cycle!!**
- **Factory level, regional level, structural changes in economy and energy system**

Figure 2 Location and size of the main industrial emission clusters.
1) Rotterdam - Moerdijk (16.9 Mt CO_2); 2) Noordzeekanaalgebied (12.0 Mt CO_2); 3) Zeeland - W-Brabant (7.9 Mt CO_2);
4) Chemelot (4.5 Mt CO_2); 5) Eemsdelta (0.7 Mt CO_2); 6) Emmen (0.5 Mt CO_2).[8,9]

EXAMPLE

- In 2015 world plastics production 335 Mta, only 2% of plastics closed loop recycling (Ellen McArthur)
- EU: in 2025 55% recycling rate set for plastics, 10 Mta plastics recycled to products (Circular Plastics Alliance) – in 2030 all plastics are recyclable and >50% is recycled
- Worl

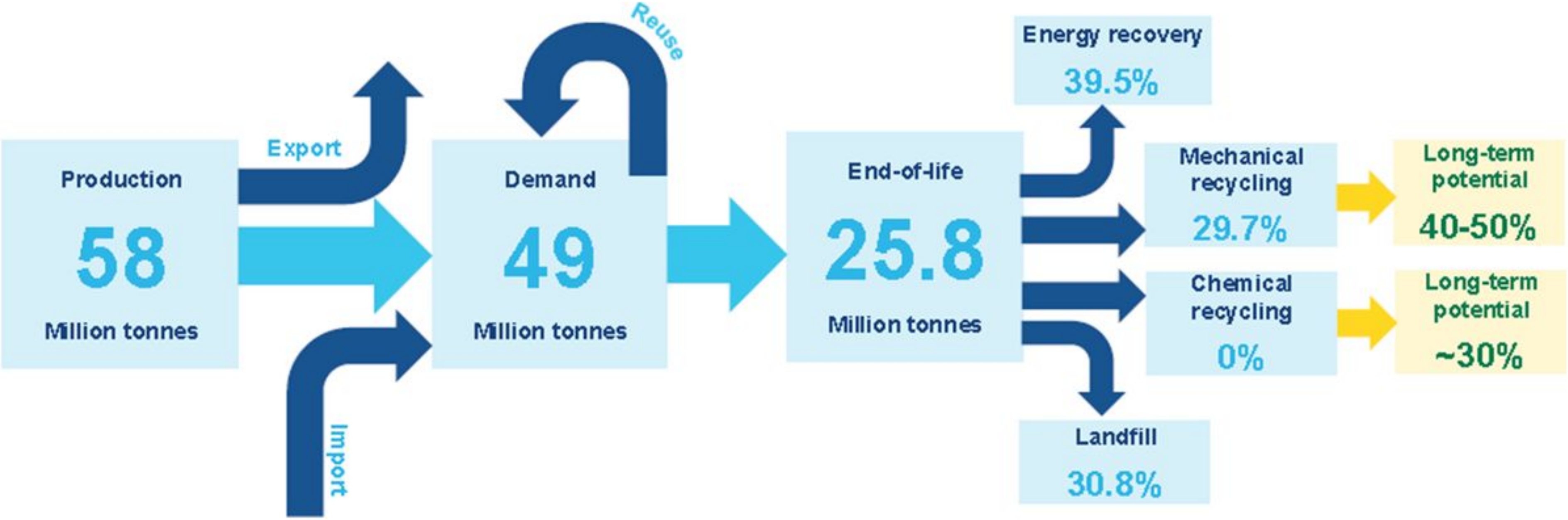


Figure 3-5 European plastics production, demand and waste treatment in 2015, including long-term potential. Team analysis based on Plastics Europe [15], Accenture [14].

ELECTRIFICATION: MAJOR FIELD OF INNOVATION

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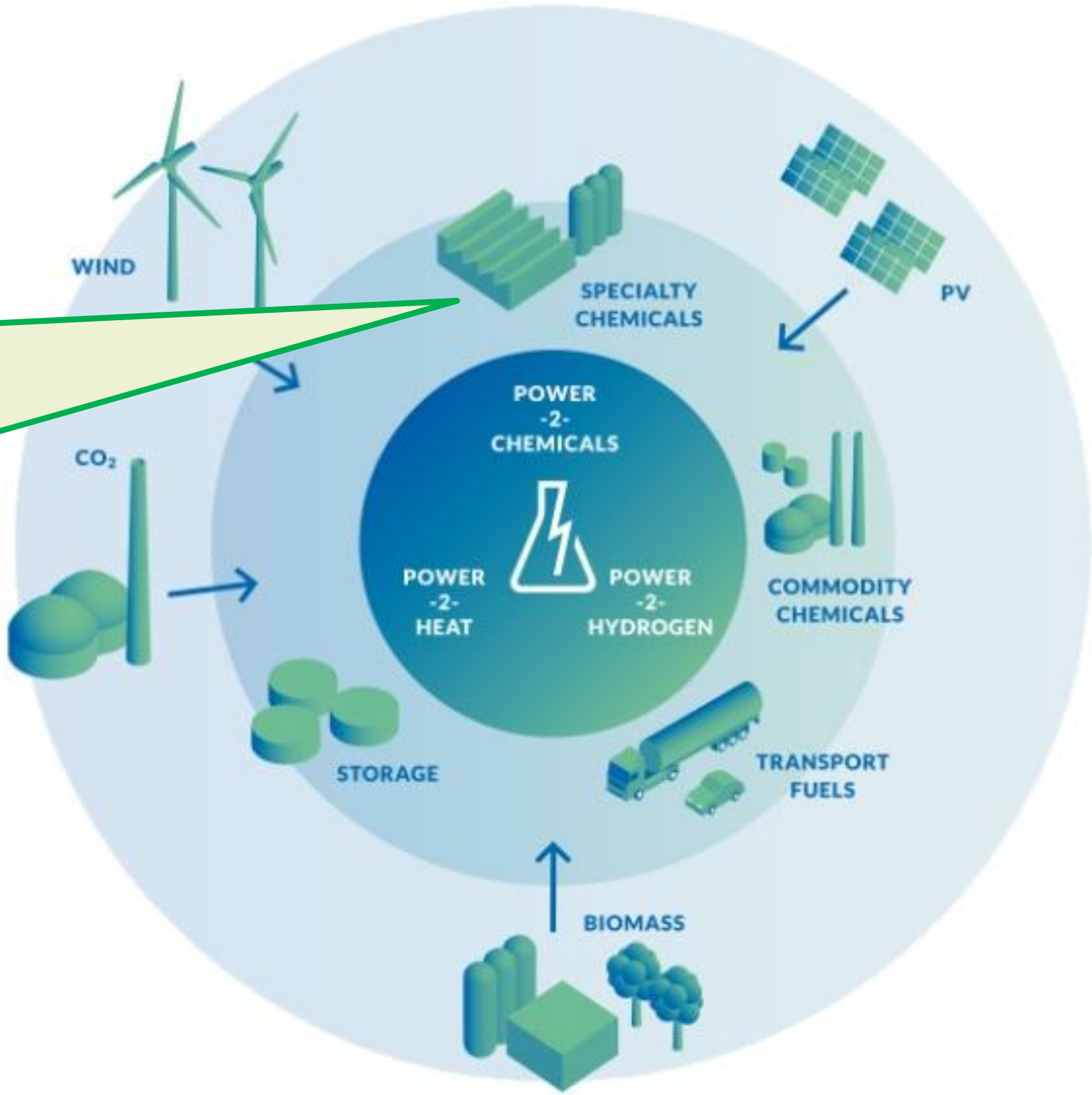
Power to chemicals

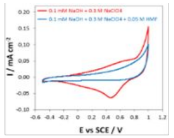
Electro-organic synthesis	CO_2 electro-reduction
Electro-oxidation	Electro-reduction



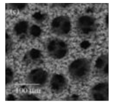
- ✔ Oxidation of furfural
- ✔ Oxidation of hydroxymethylfuran
- ✔ Oxidation of alcohols

- ✔ Reduction of furfural
- ✔ Reduction of hydroxymethylfuran
- ✔ Reductive amination
- ✔ Reduction of oxygen

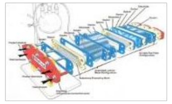
Key technical & scientific enablers:



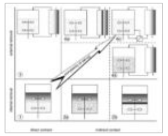
Electrochemistry



(3D structured) electro-catalysts

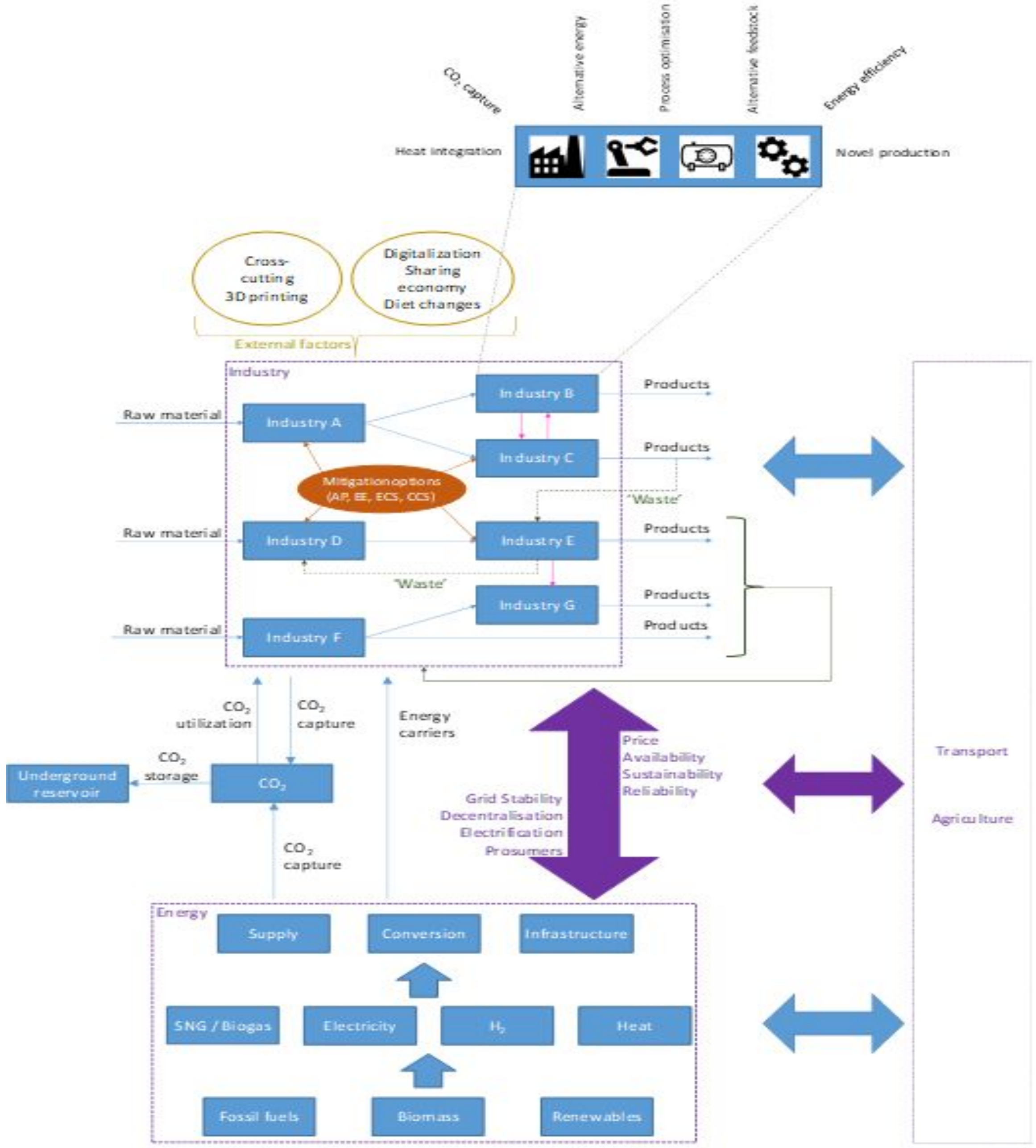


Reactor design



Downstream processing

Integrated design & Economics



Legend
Blue = material flows - raw materials, intermediates or end-products
Green = material flows associated with circularity options
Pink = energy and material flows associated with local and regional cooperation
Purple = changes in other sectors
Yellow = changes in consumer demand or manufacturing methods

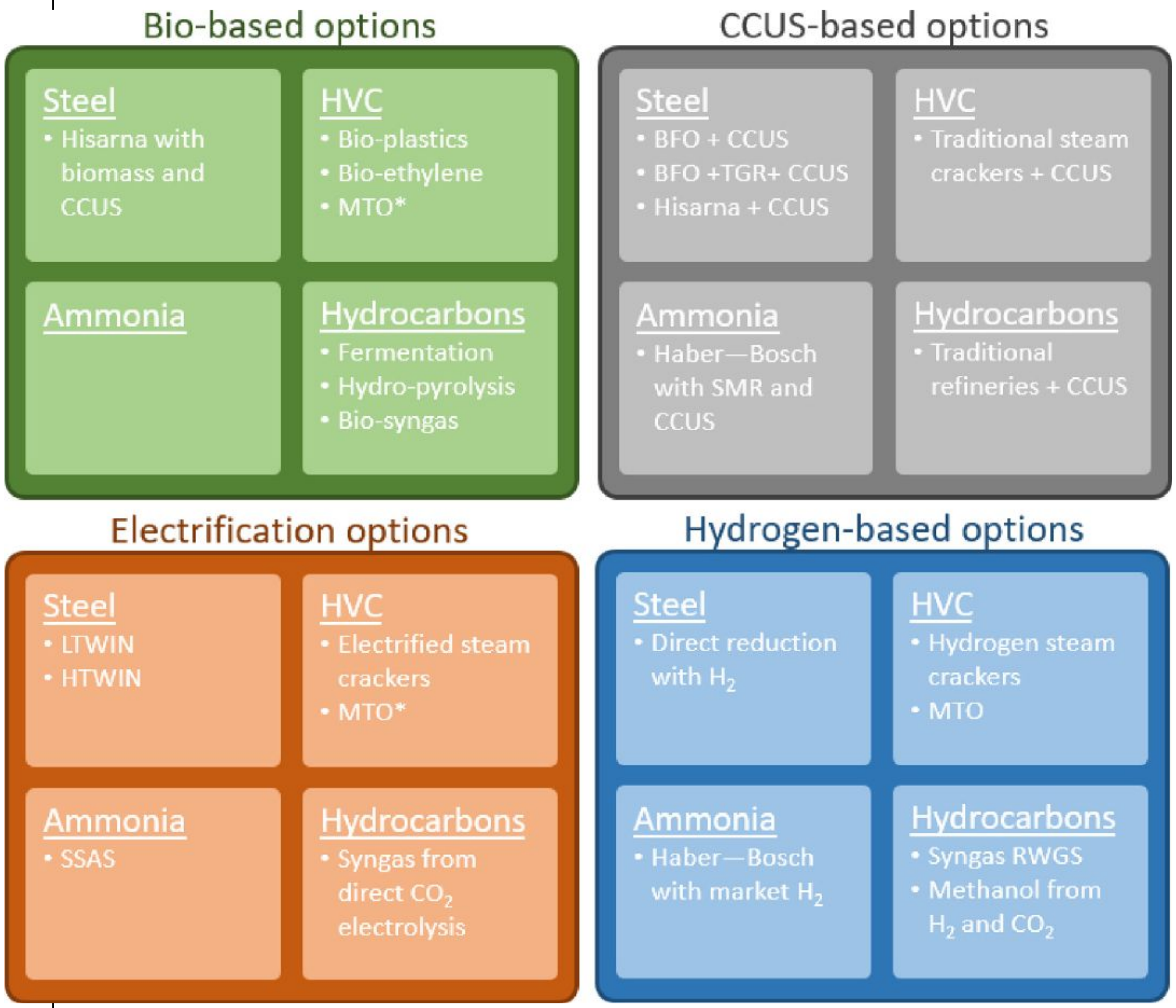
ALL THESE FACTORS MATTER, AND ARE INTERLINKED…

… MEETING THE 2050 TARGET ("0 GHG") REQUIRES MUCH MORE THEN THE CURRENT FOCUS ON 2030:

TRANSITION ENERGY SYSTEM, CIRCULAR ECONOMY AND NEW INDUSTRIAL PROCESSES TO BE COMBINED AND ARE INTERDEPENDENT.

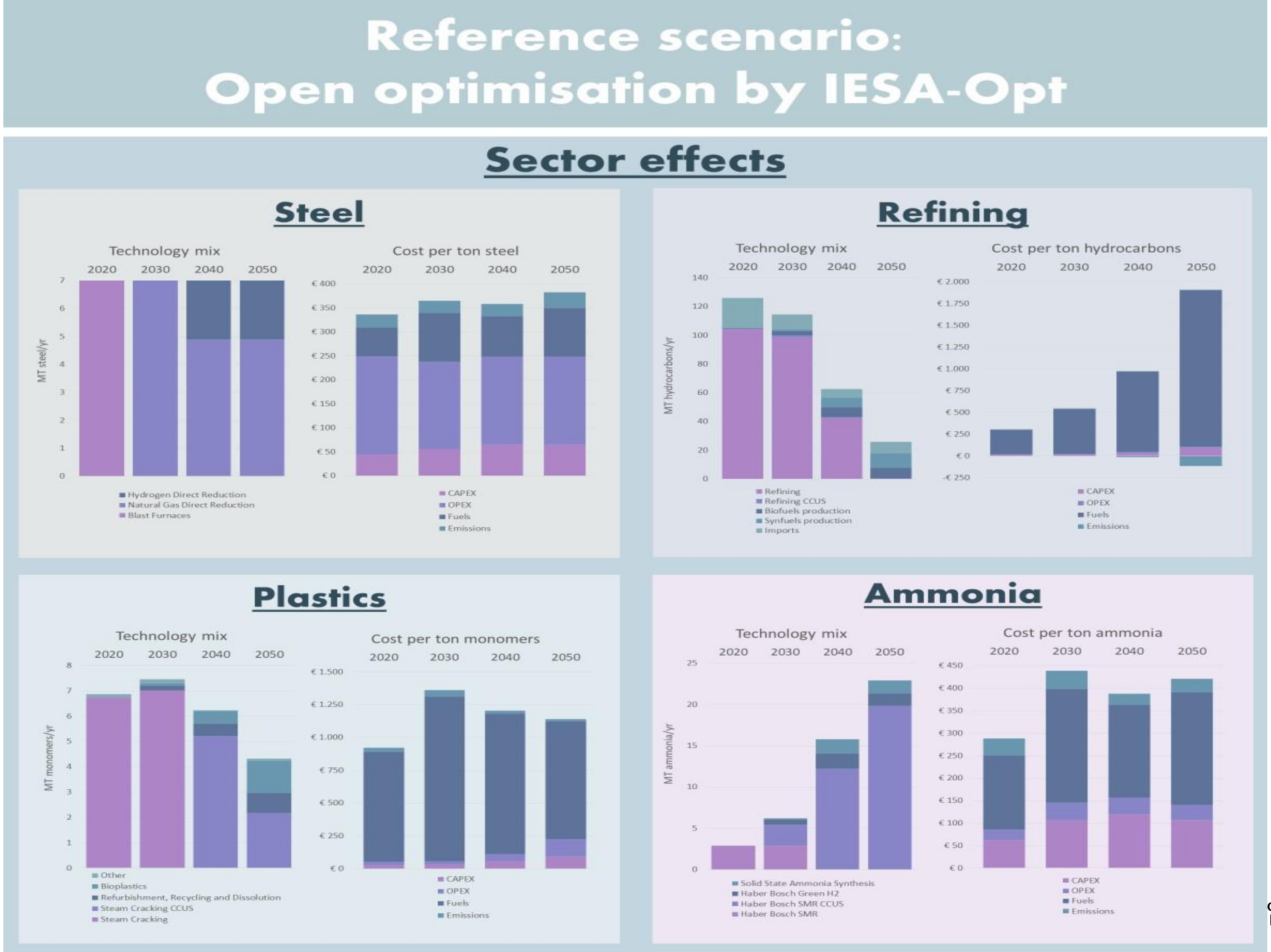
TECHNOLOGIES IN 4 MAIN CATEGORIES FOR INDUSTRIAL TRANSFORMATION

(WITHIN IESA-OPT MODEL FRAMEWORK)



[Sanchez et al., Advances in Applied Energy, 2022]

[Sanchez, Taminiau Faaij, advances in applied energy, 2022]



Virgin Monomer production

FINAL REMARKS

- **The role of nuclear energy in the energy transition** depends on:
  - The presence of the industrial production base (very wise to keep it!)
  - The role of circular production and use (impactful!)
  - The contribution of BBE, the North Sea Energy System and green carrier imports.
- **The role of nuclear energy for future industries** depends on:
  - The pathway to competitive and clean production and related technology portfolio and energy demand mix (e.g. heat demand)
- The speed of innovation on feasibility of delivering different energy carriers in industrial clusters
- **Overall:**
  - It is very wise to have and keep the nuclear options in the transition portfolio, but:
  - …the effectiveness (speed, costs) of innovation (especially SMR) in EU and NL

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2050: < 30 years; no time to waste!

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