DIVING BELOW ZERO GHG EMISSIONS: HOW THE ENERGY TRANSITION AND INDUSTRIAL TRANSFORMATION CAN DELIVER ON CLIMATE TARGETS, CIRCULARITY AND SOUND ECONOMICS.

NEGEM WORKSHOP AT EUBCE, BOLOGNA - ITALY, *JUNE 5TH 2023*

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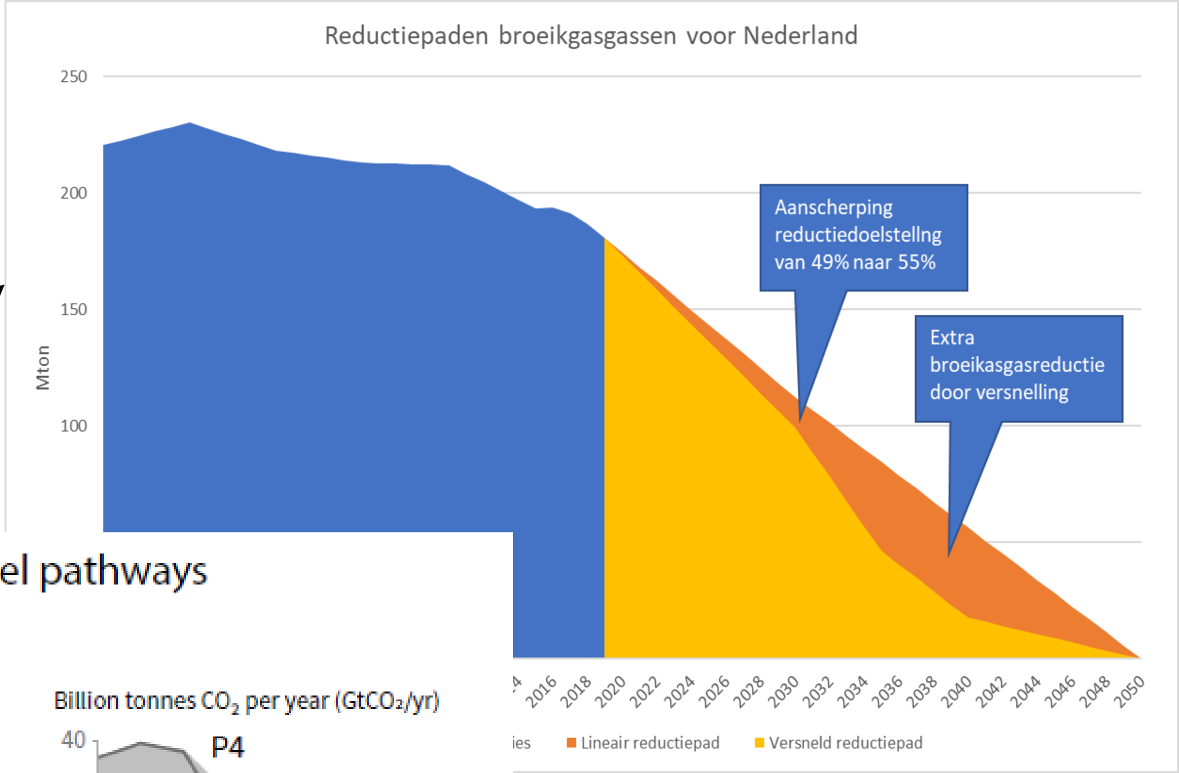
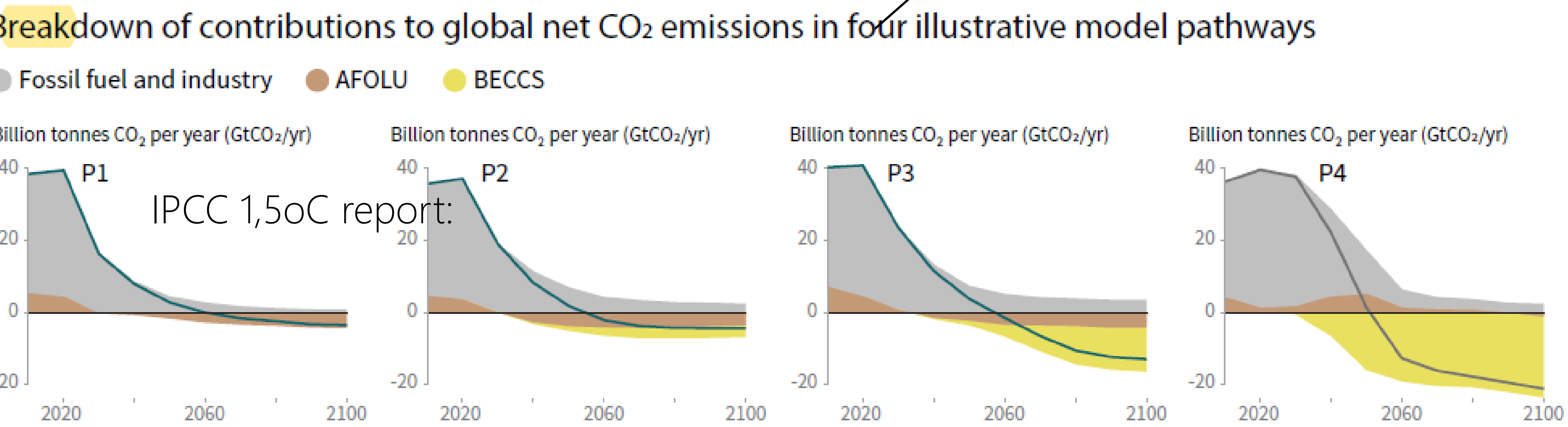
ACCELERATING THE ENERGY TRANSTION

Implications for the Netherlands:



IPCC 1,5oC report:



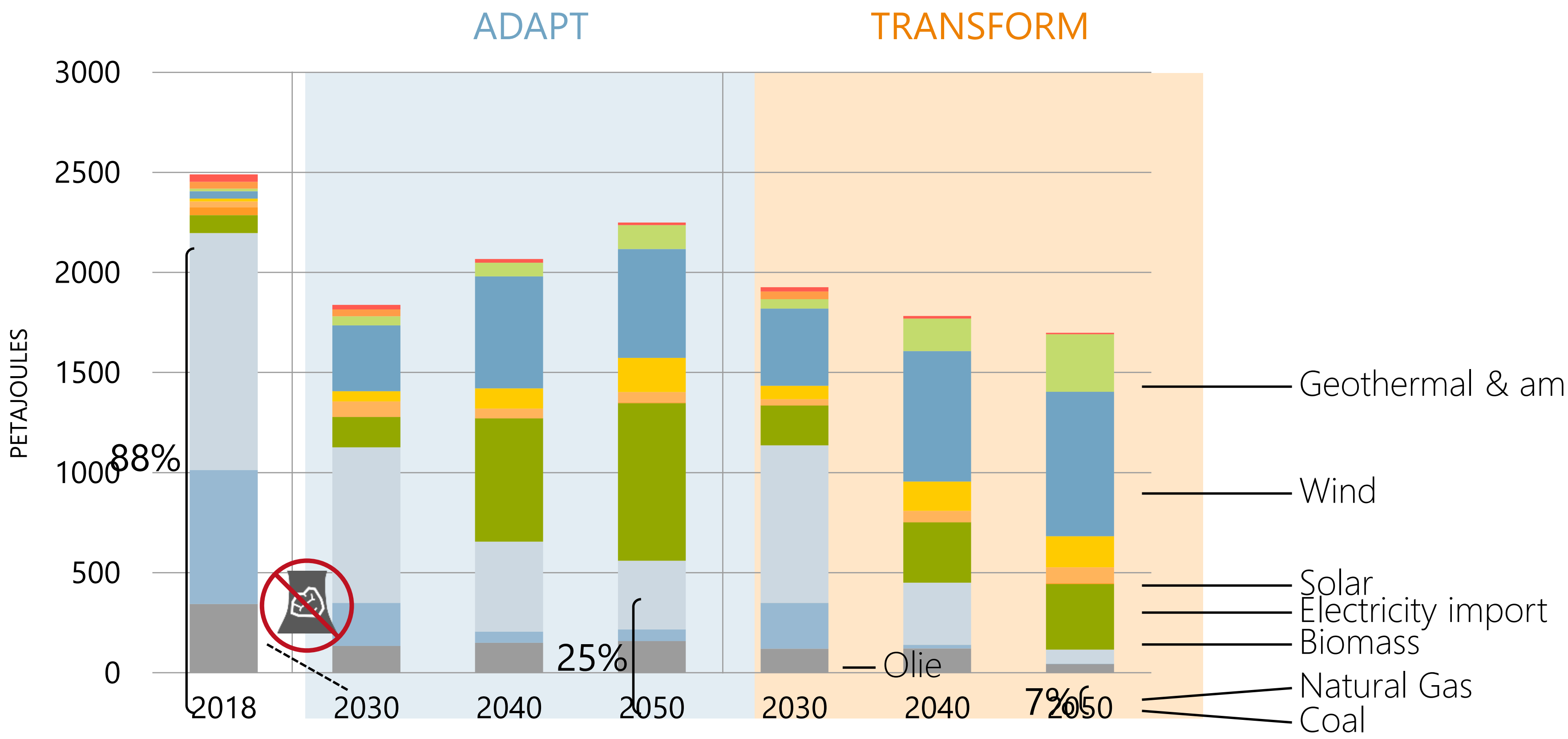
P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

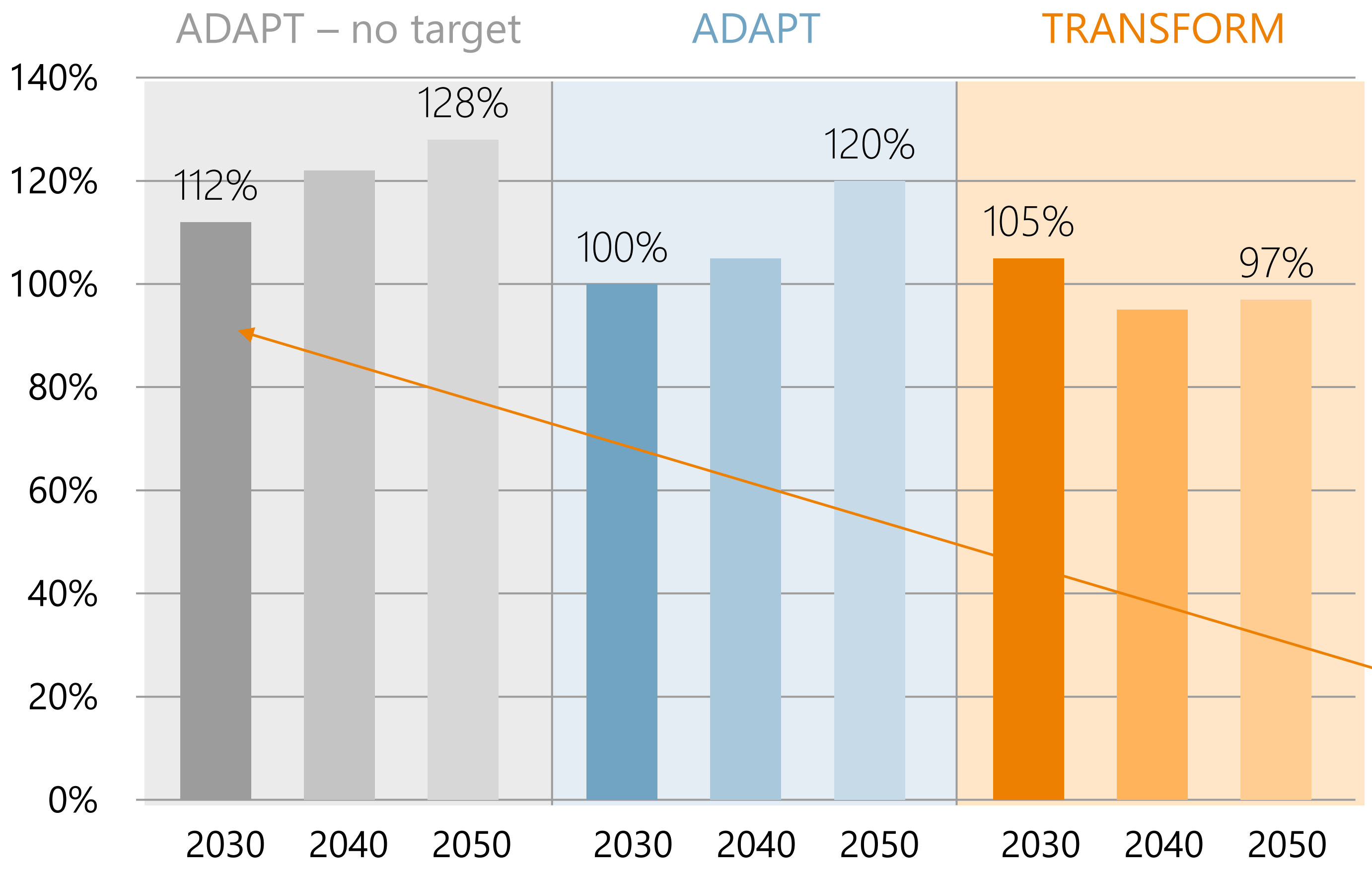
2 FUTURE ENERGY SCENARIO'S FOR THE NETHERLANDS; PRIMARY ENERGY SUPPLY MIX



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

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

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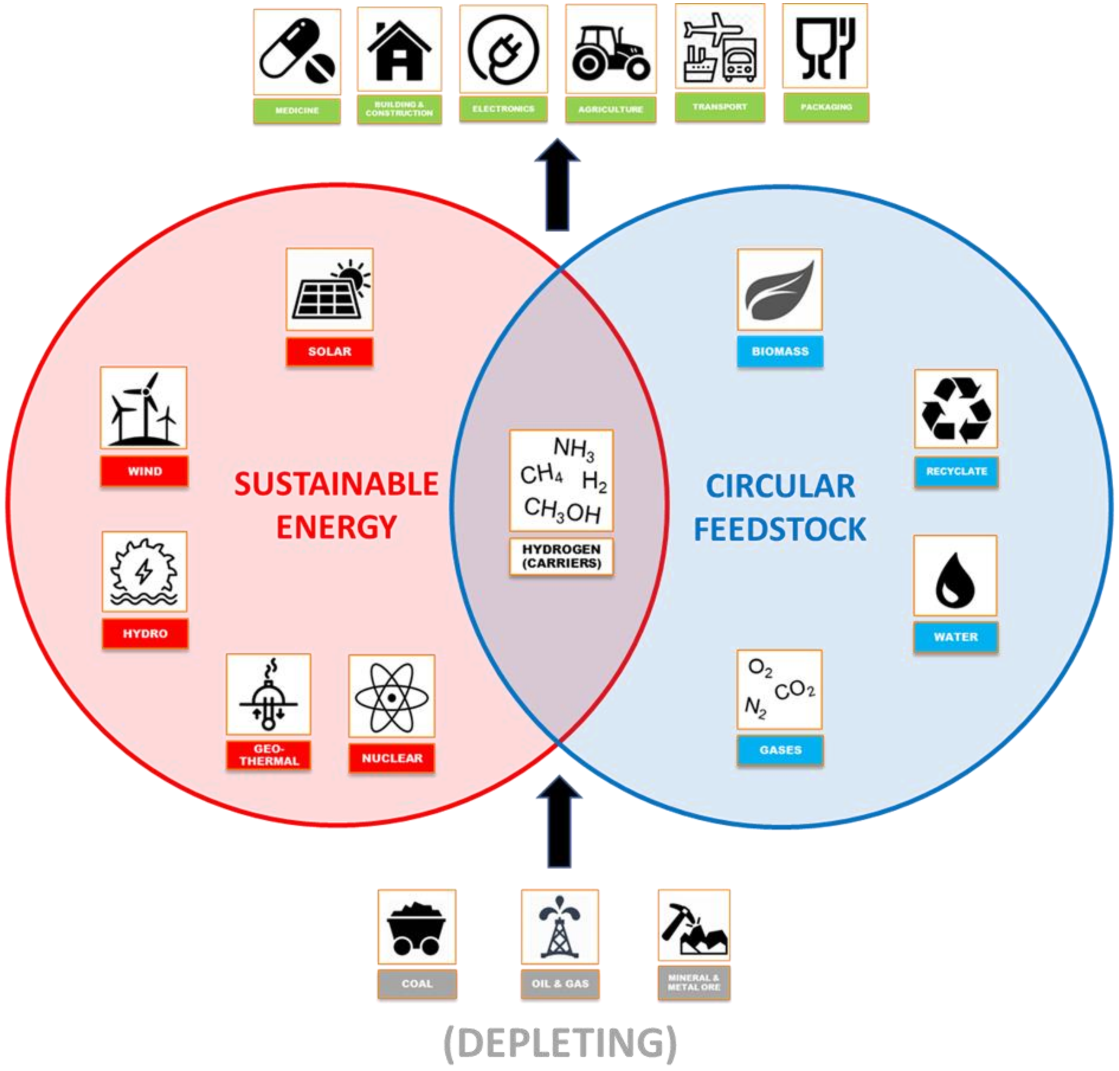
VISION – A FULLY SUSTAINABLE INDUSTRY
ENABLED BY DECARBONIZED ENERGY & RECARBONIZED FEEDSTOCK



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! Over roughly 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]

CIRCULARITY

WHY:

- 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
- Worldwide Industry partnership announced 1.5 billion euro initiative plastics recycling January 14, 2019

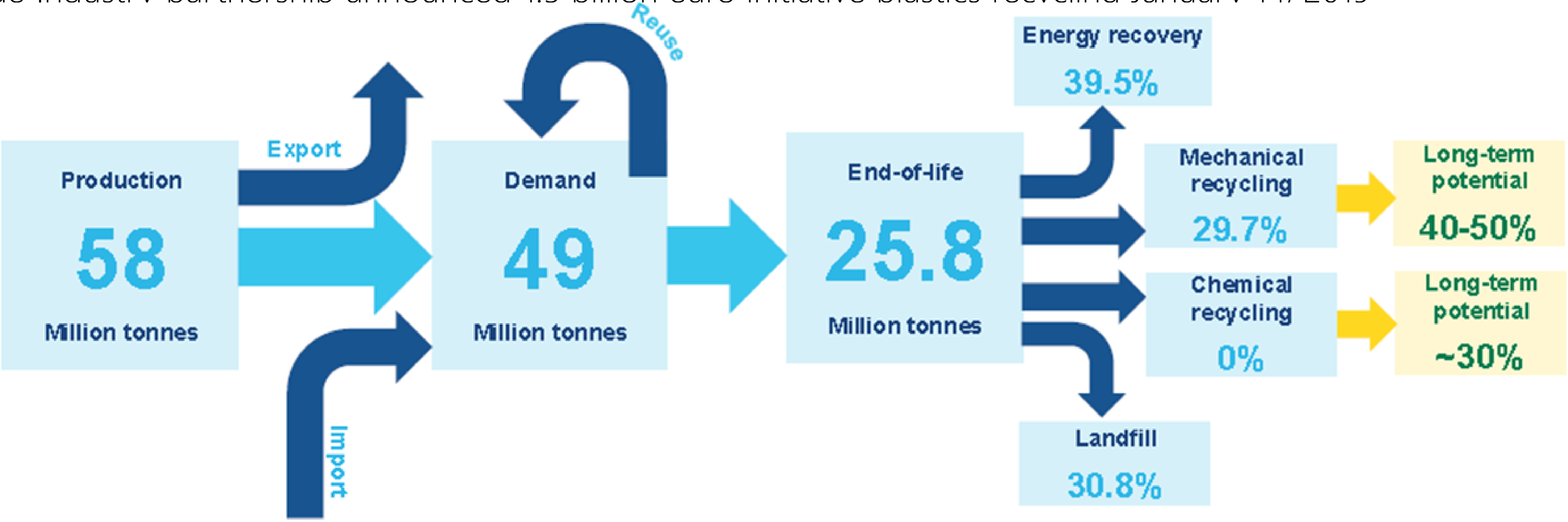


Figure 3-5 European plastics production, demand and waste treatment in 2015, including long-term potential. Team analysis based on Plastics Europe [15], Accenture [14].

ELECTRIFICATION:

Power to chemicals

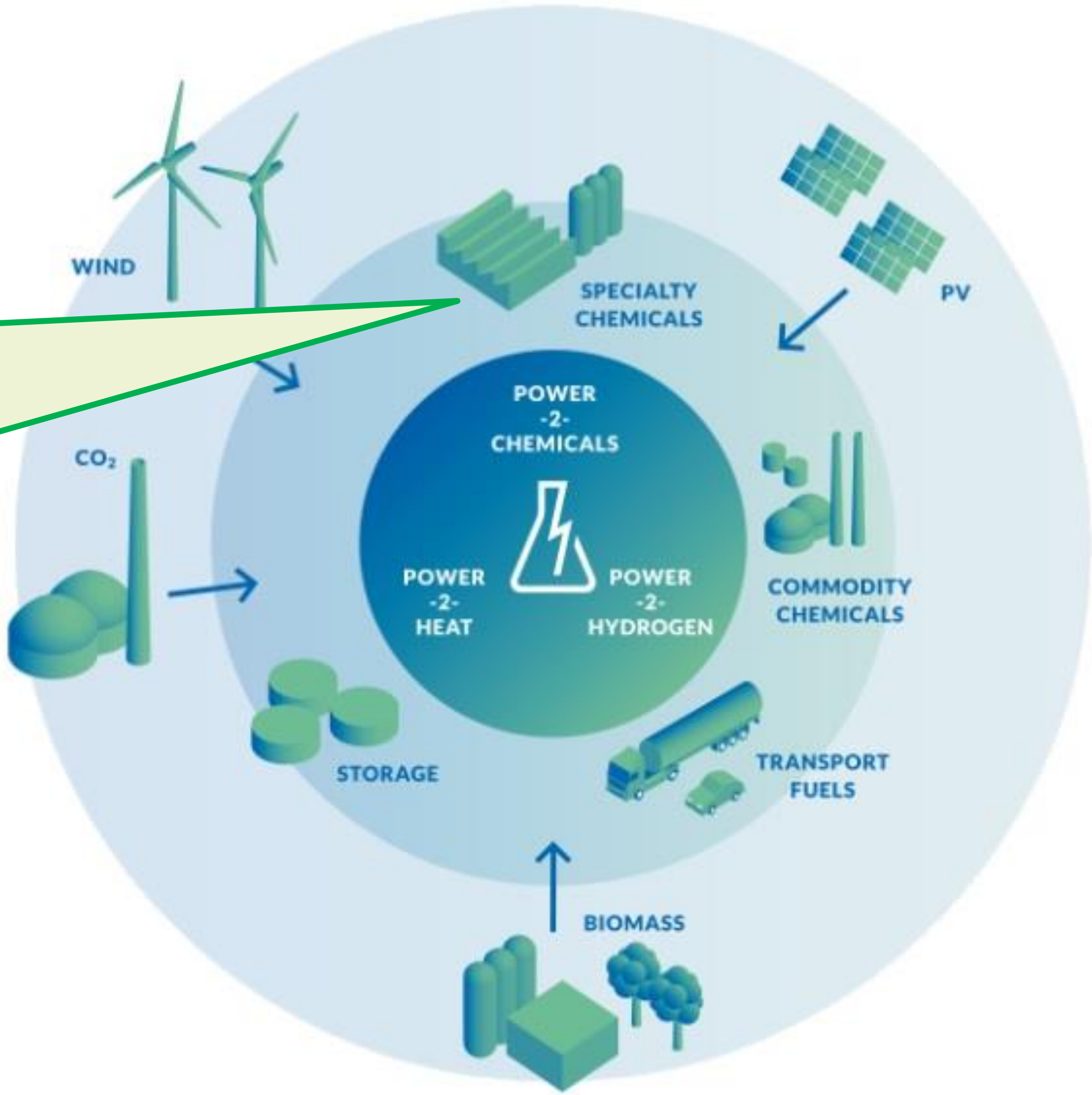
- Electro-organic synthesis
- CO_2 electro-reduction
- Electro-oxidation
- Electro-reduction

Electro-oxidation:

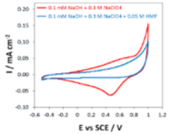
- ✓ Oxidation of furfural
- ✓ Oxidation of hydroxymethylfuran
- ✓ Oxidation of alcohols

Electro-reduction:

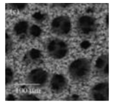
- ✓ Reduction of furfural
- ✓ Reduction of hydroxymethylfuran
- ✓ Reductive amination
- ✓ Reduction of oxygen



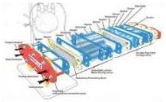
Key technical & scientific enablers:



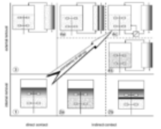
Electrochemistry



(3D structured) electro-catalysts



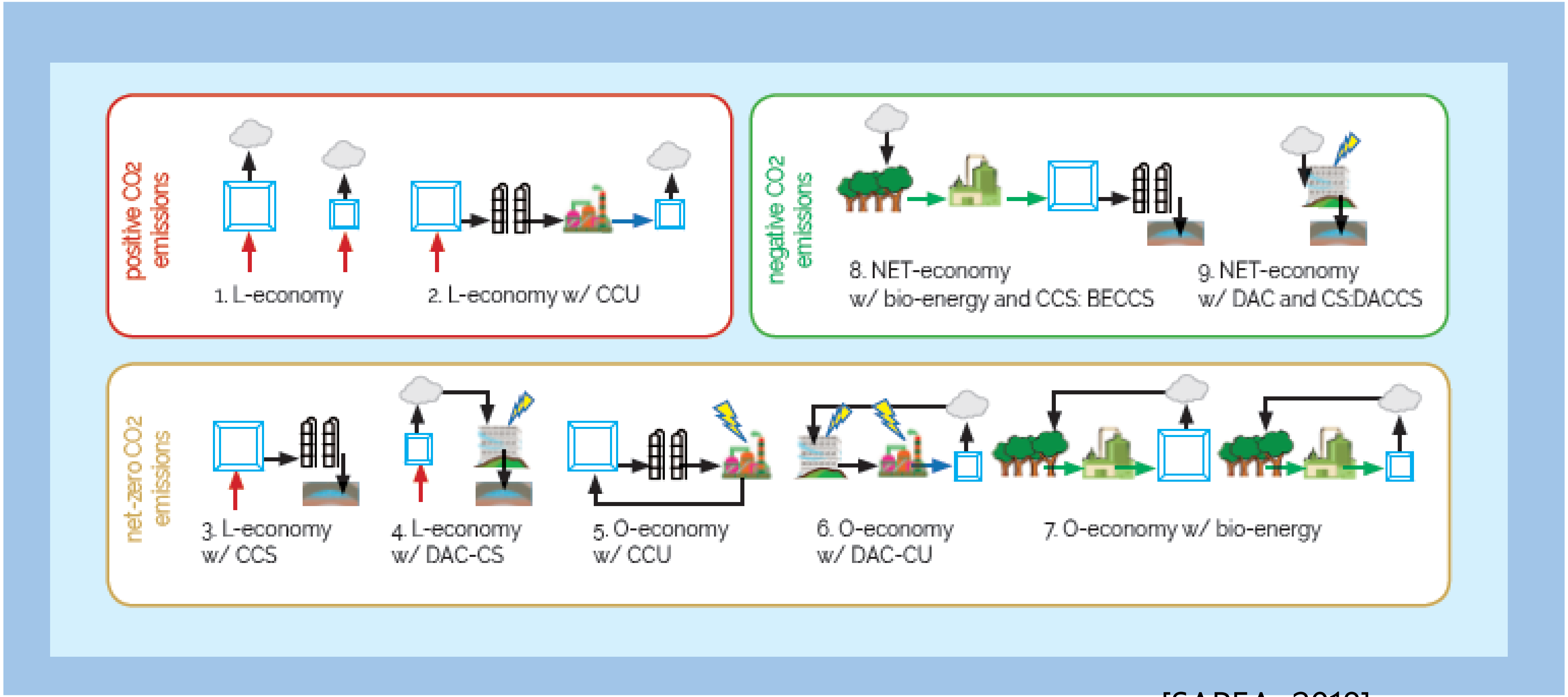
Reactor design



Downstream processing

Integrated design & Economics

BASIC CARBON BALANCES OF CCU WITH DIRECT AIR CAPTURE (DAC), BECCS AND COMBINATIONS OF BOTH.

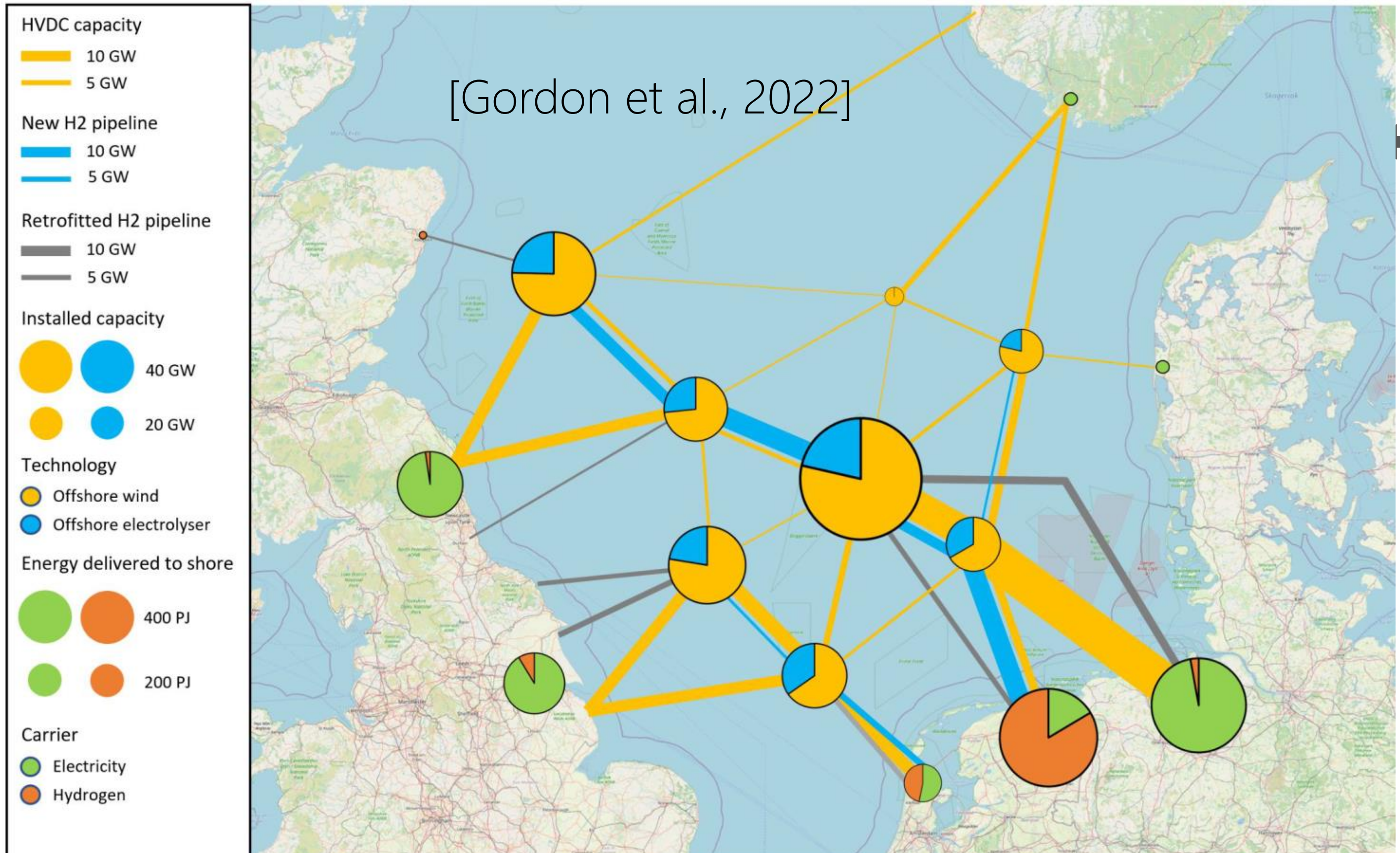


[SAPEA, 2018]

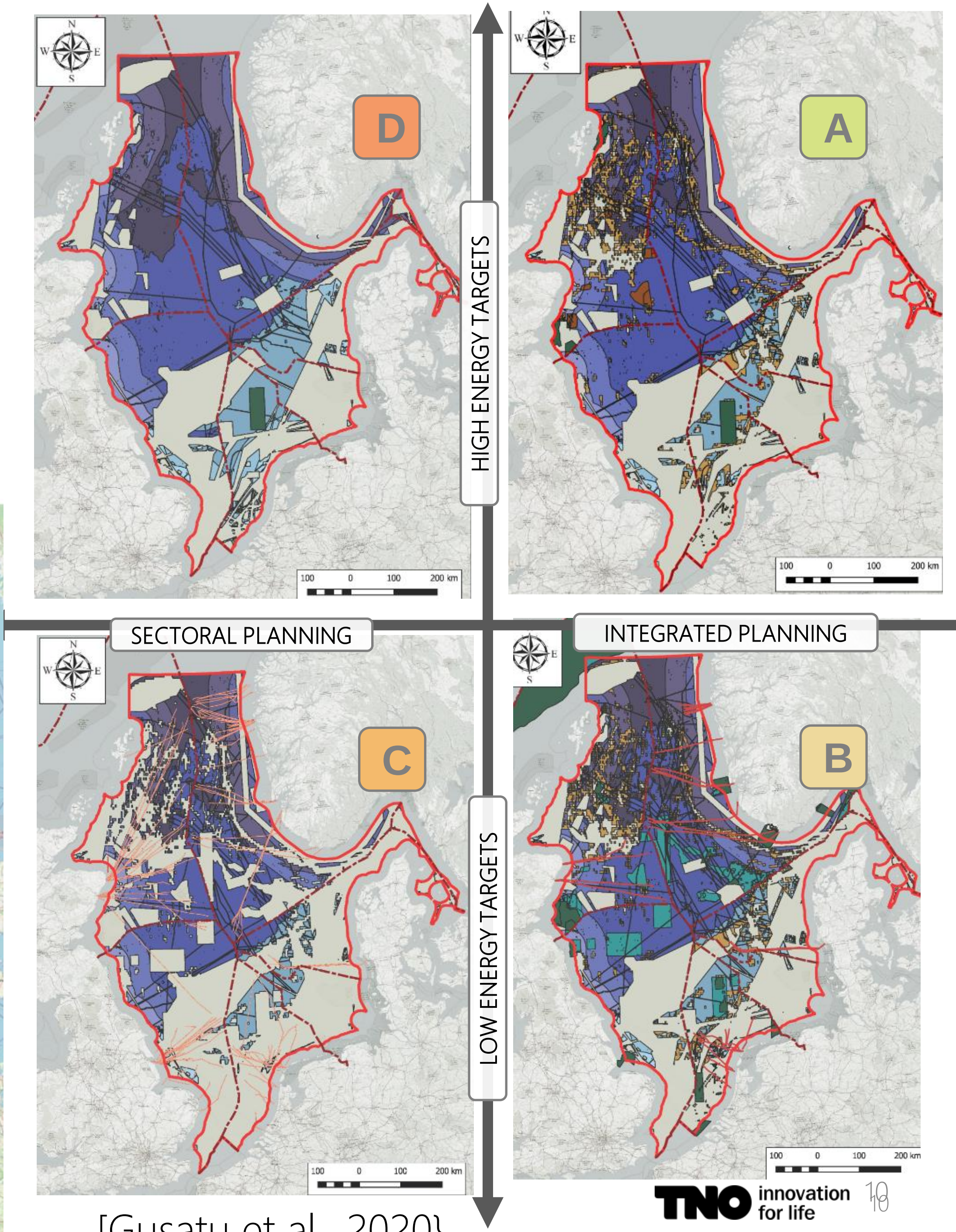
Major opportunities for future low carbon chemical industry

NORTH SEA REGION: BIGGEST LIVING ENERGY TRANSITION LABORATORY IN THE WORLD

source: Tennet



[Gordon et al., 2022]



[Gusatu et al., 2020}

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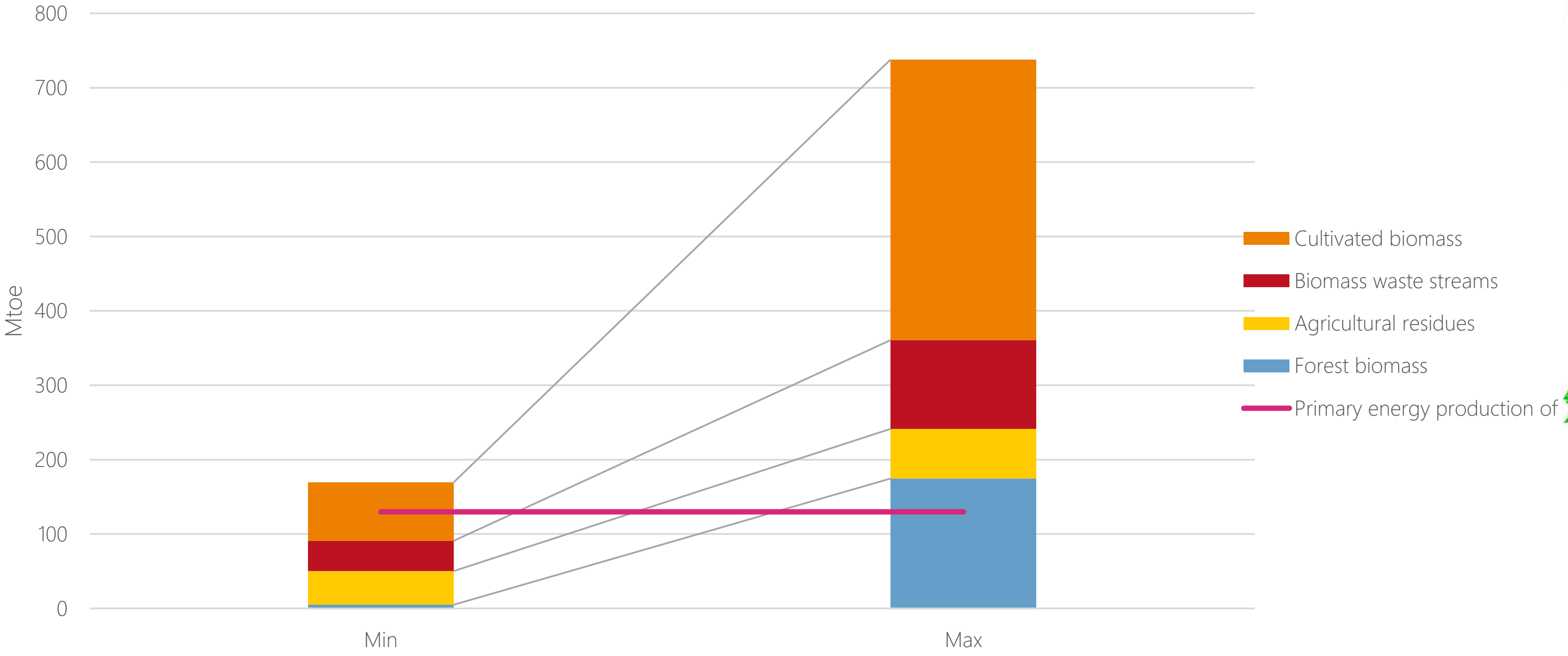
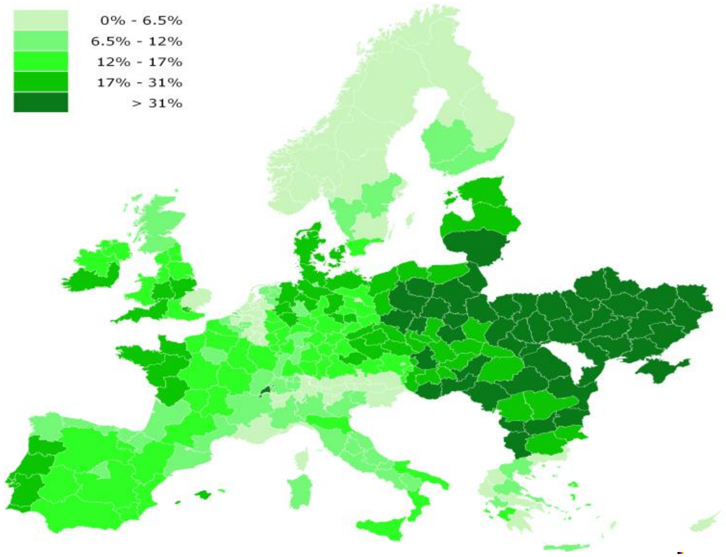
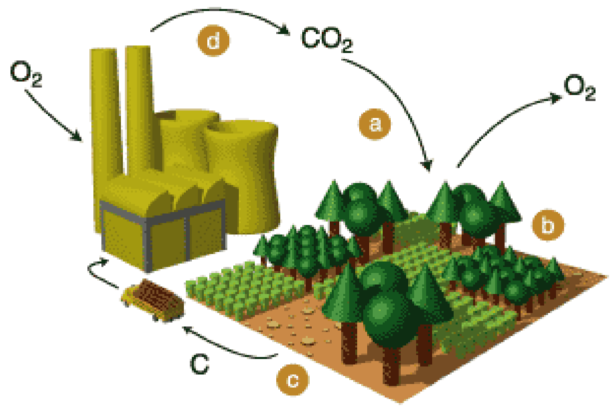
BIOMASS POTENTIALS EU28 IN 2050; 7-30 EJ COMPARED TO 68 EJ; TOTAL PRIMARY ENERGY USED TODAY

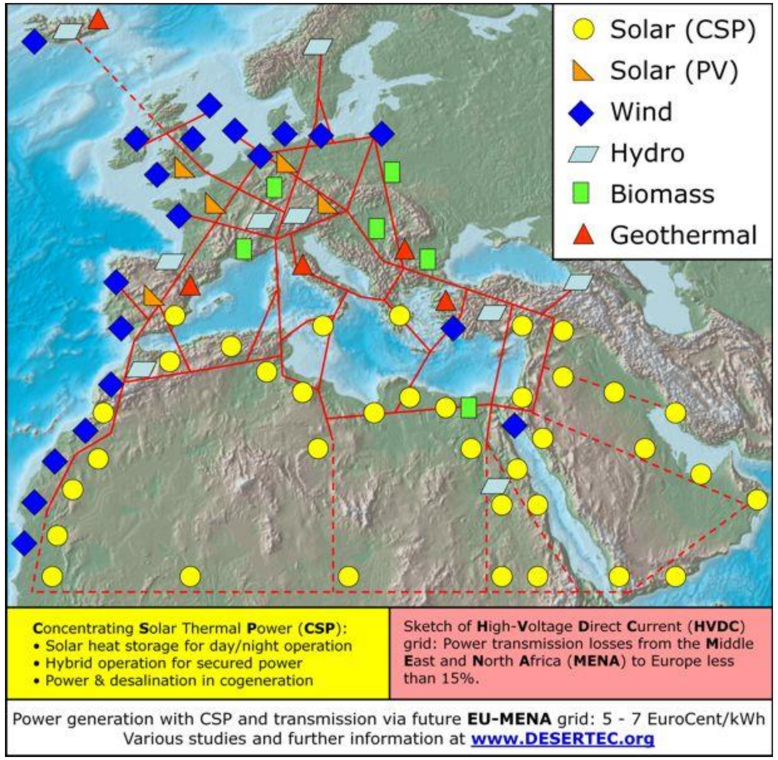






[Faaij, Energies, 2022]

FURTHER ENERGY SYSTEM INTEGRATION…



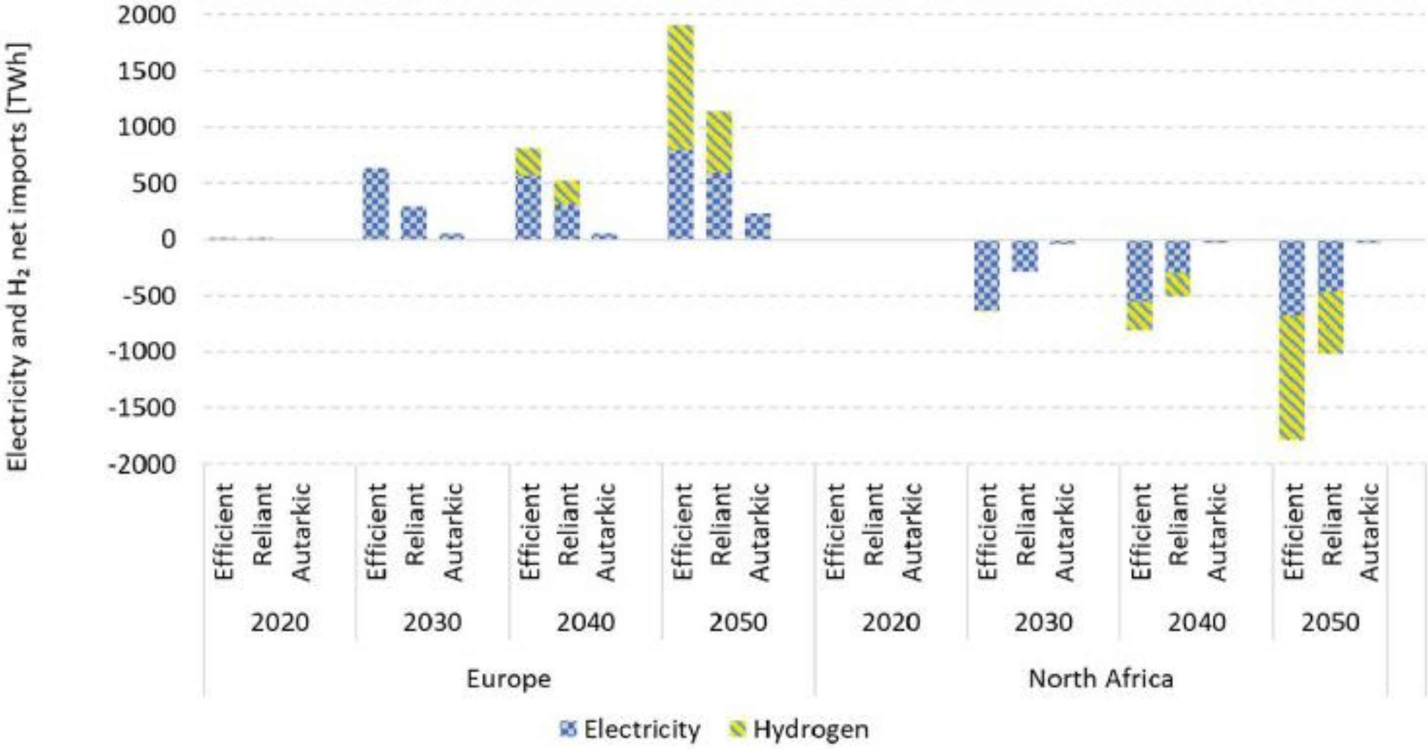
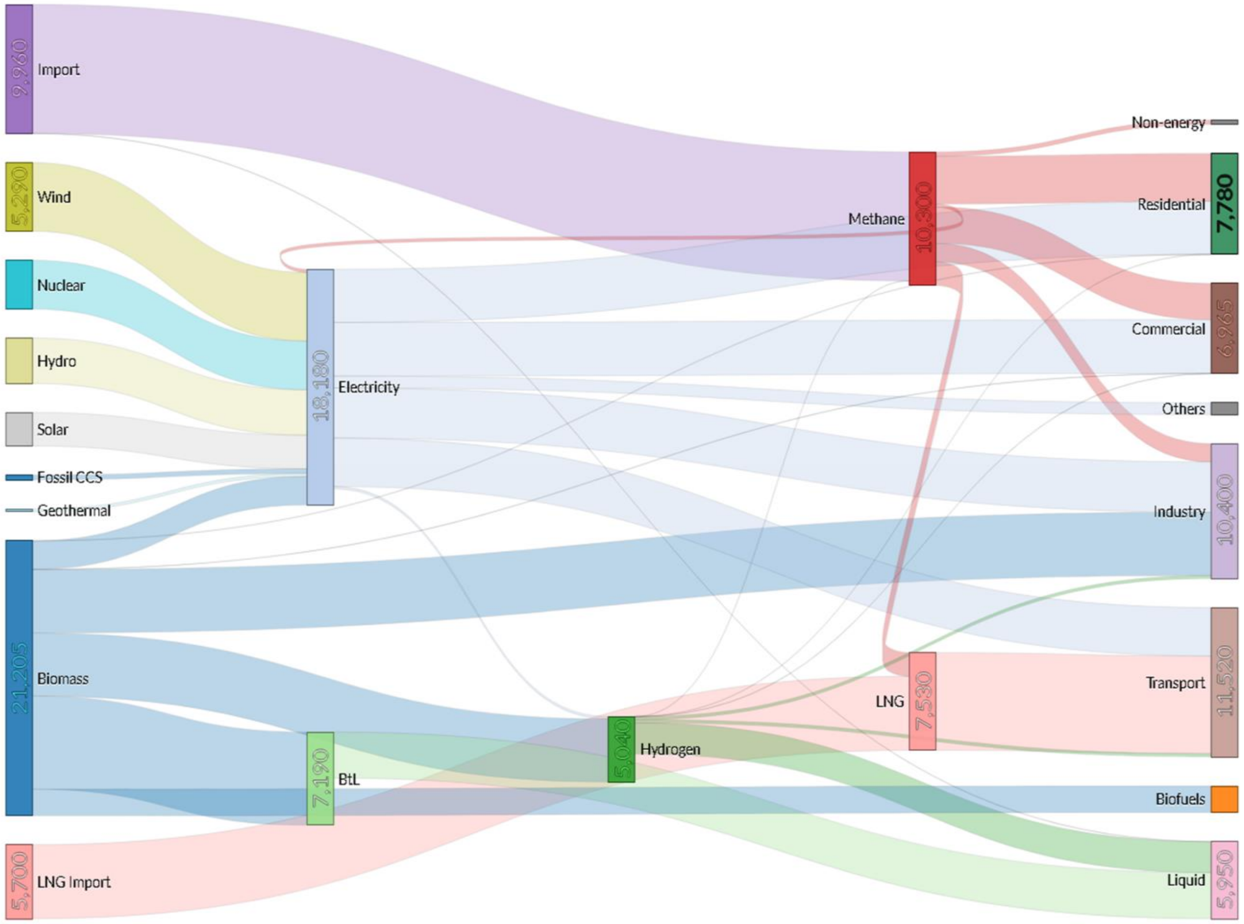


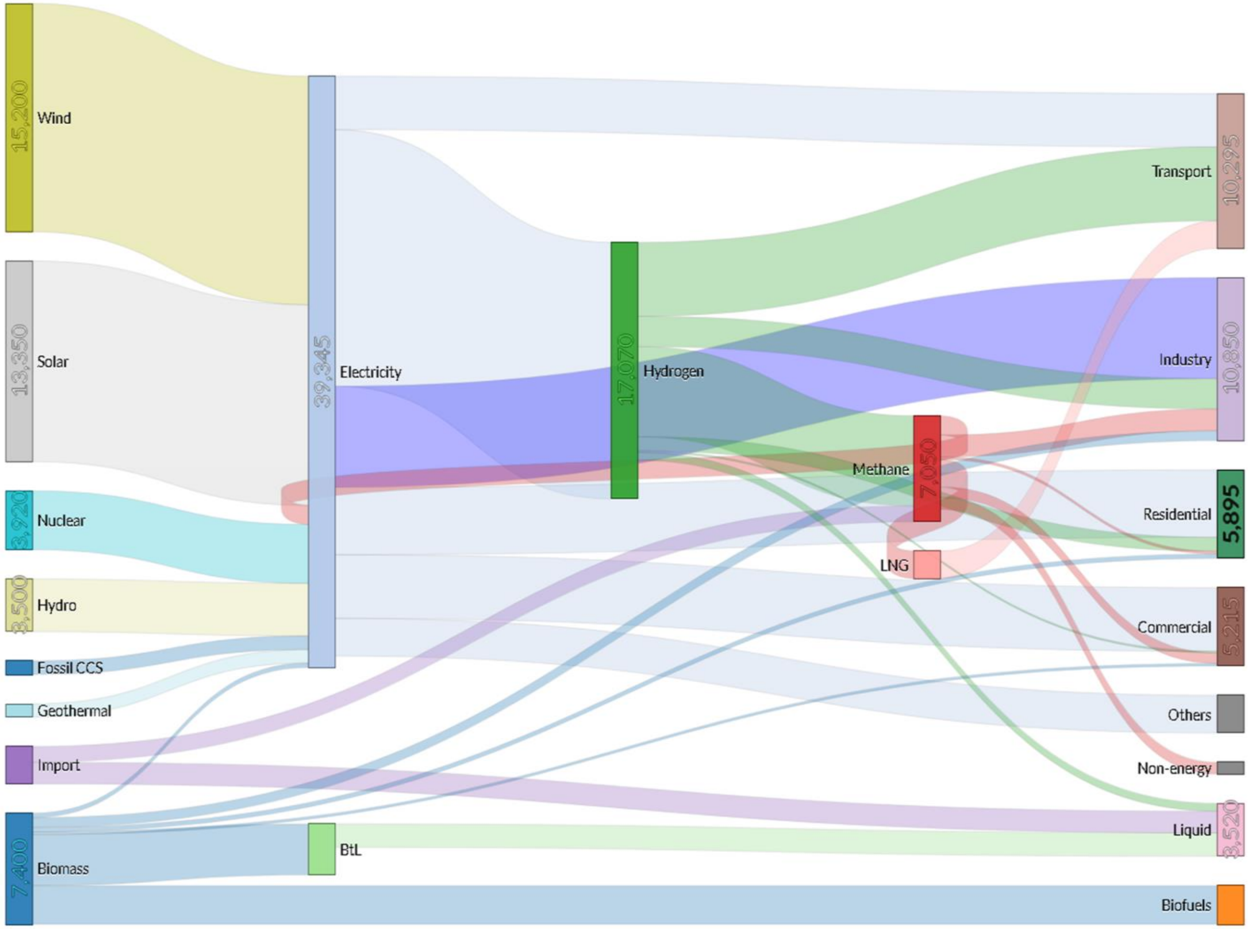
Fig. 4. Projections with TIAM-ECN for trade of electricity and hydrogen.

Zwaan et al, Energy Policy 2021, TIAM model

TWO DEEP GHG REDUCTION SCENARIO'S FOR THE EU IN 2050 (JRC-TIMES MODEL)



high biomass and CCS scenario



Max solar & wind scenario (+ no CCS, minimal Bio)

[Blanco et al., applied Energy 2018]

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Reference scenario:
Open optimisation by IESA-Opt

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Scenario description

This scenario assumes a BAU development of the energy system accordingly with existing national and European policies, with highly unconstrained potentials. The model optimizes for lowest combined system costs across all sectors toward 2050.

The only restriction is a linear CO_2 reduction goal, with 100% reduction in 2050.

Key Performance Indicators & Sectors

Below, you can find the key performance indicators for the CO_2 price in 2050, final electrification rate, renewable share, the energy cost and total hydrogen use.

For each sector, a specific technology pathway or combination of pathways is chosen. On the next slide you van find the sector effects of this scenario.

Sector nudges

Next, the system will be nudged towards the sector archetypes defined previously. This nudging is done by adding just one restriction to the model: in 2050 the sector **must** use the archetypical technology.

This restriction will cause system wide changes and sector specific changes.

System effects

100 %
CO2 emission reduction (compared to 1990 levels) at 2050

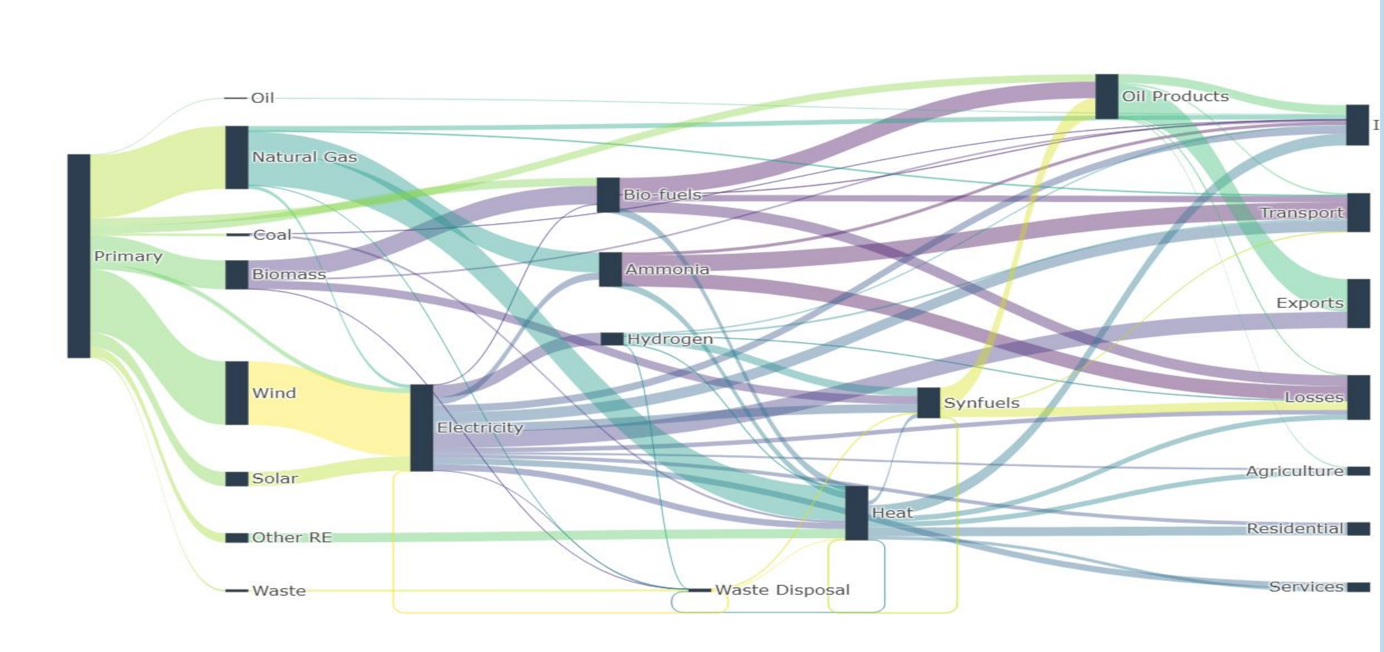
104.44 €/ton
ETS CO2 price at 2050

50.98 %
Final electrification rate at 2050

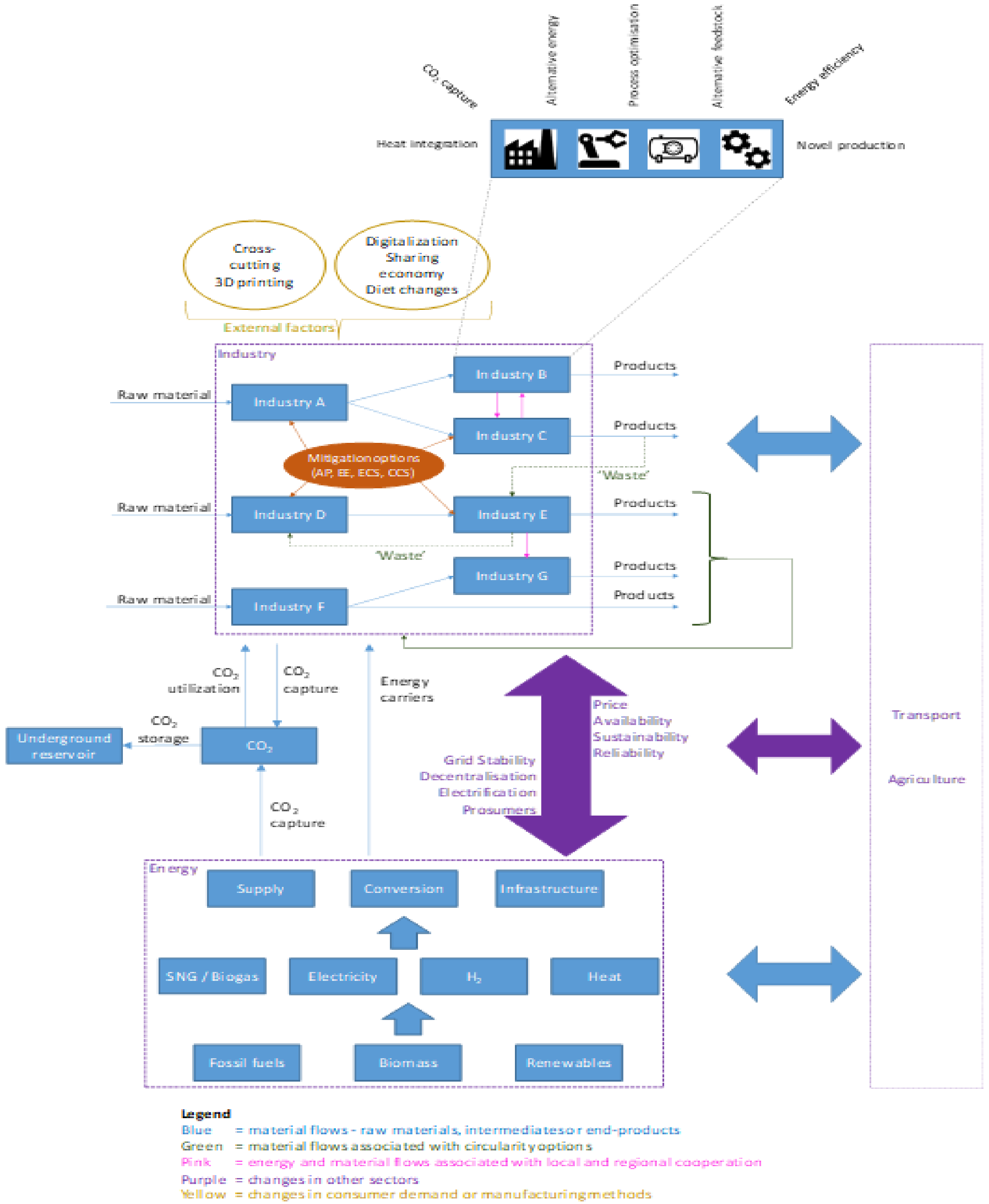
64.75 %
Renewables share of primary energy at 2050

32.51 €/MWh
Final energy cost at 2050

261.3 PJ
Hydrogen use at 2050



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



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)

Bio-based options

Steel
- Hisarna with biomass and CCUS

HVC
- Bio-plastics
- Bio-ethylene
- MTO*

Ammonia

Hydrocarbons
- Fermentation
- Hydro-pyrolysis
- Bio-syngas

CCUS-based options

Steel
- BFO + CCUS
- BFO +TGR+ CCUS
- Hisarna + CCUS

HVC
- Traditional steam crackers + CCUS

Ammonia
- Haber—Bosch with SMR and CCUS

Hydrocarbons
- Traditional refineries + CCUS

Electrification options

Steel
- LTWIN
- HTWIN

HVC
- Electrified steam crackers
- MTO*

Ammonia
- SSAS

Hydrocarbons
- Syngas from direct CO_2 electrolysis

Hydrogen-based options

Steel
- Direct reduction with H_2

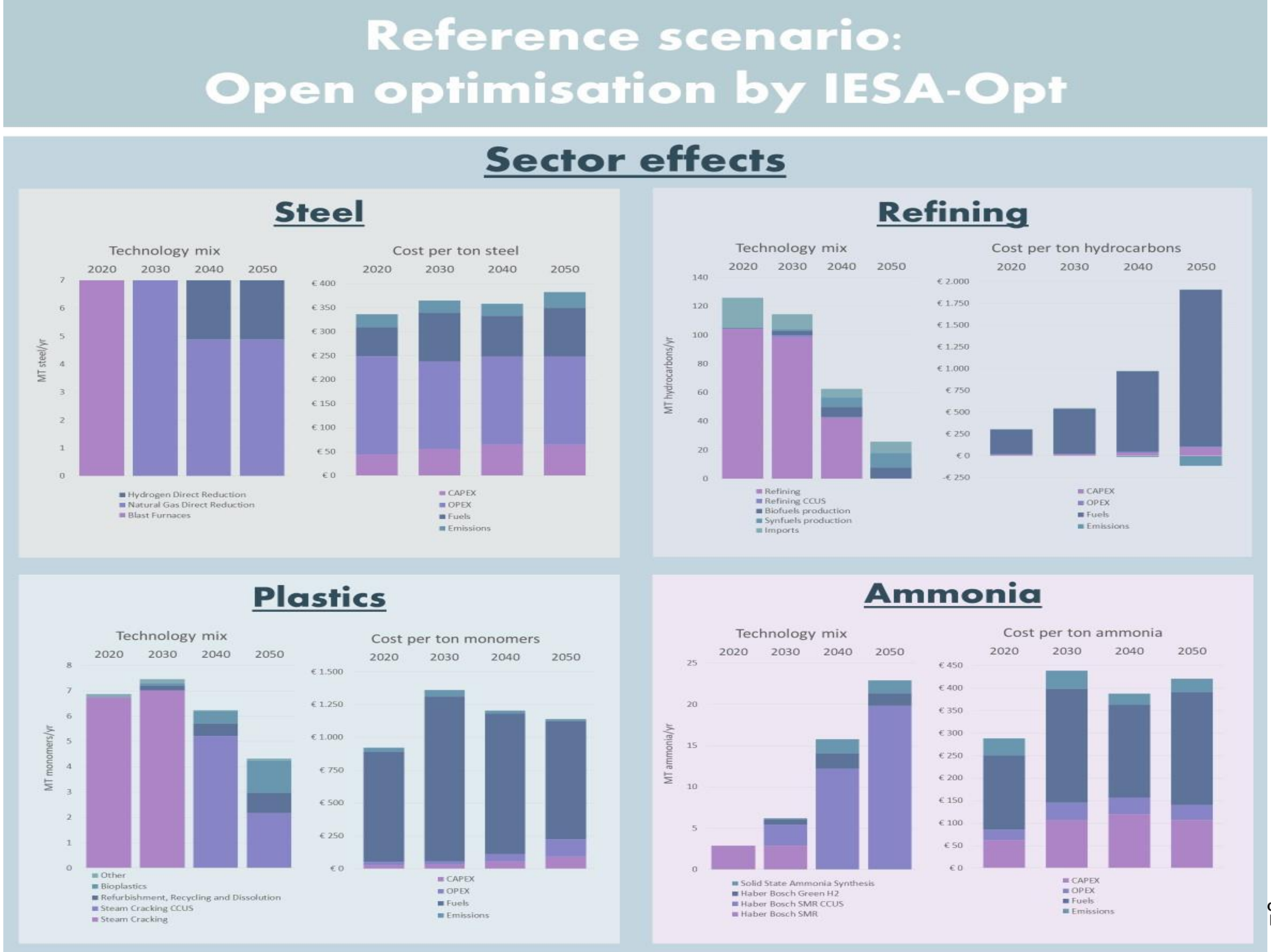
HVC
- Hydrogen steam crackers
- MTO

Ammonia
- Haber—Bosch with market H_2

Hydrocarbons
- Syngas RWGS
- Methanol from H_2 and CO_2

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

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



Virgin Monomer production

A SYSTEM TRANSTION THAT SHOULD ACCELERATE, WHAT DOES THAT IMPLY?

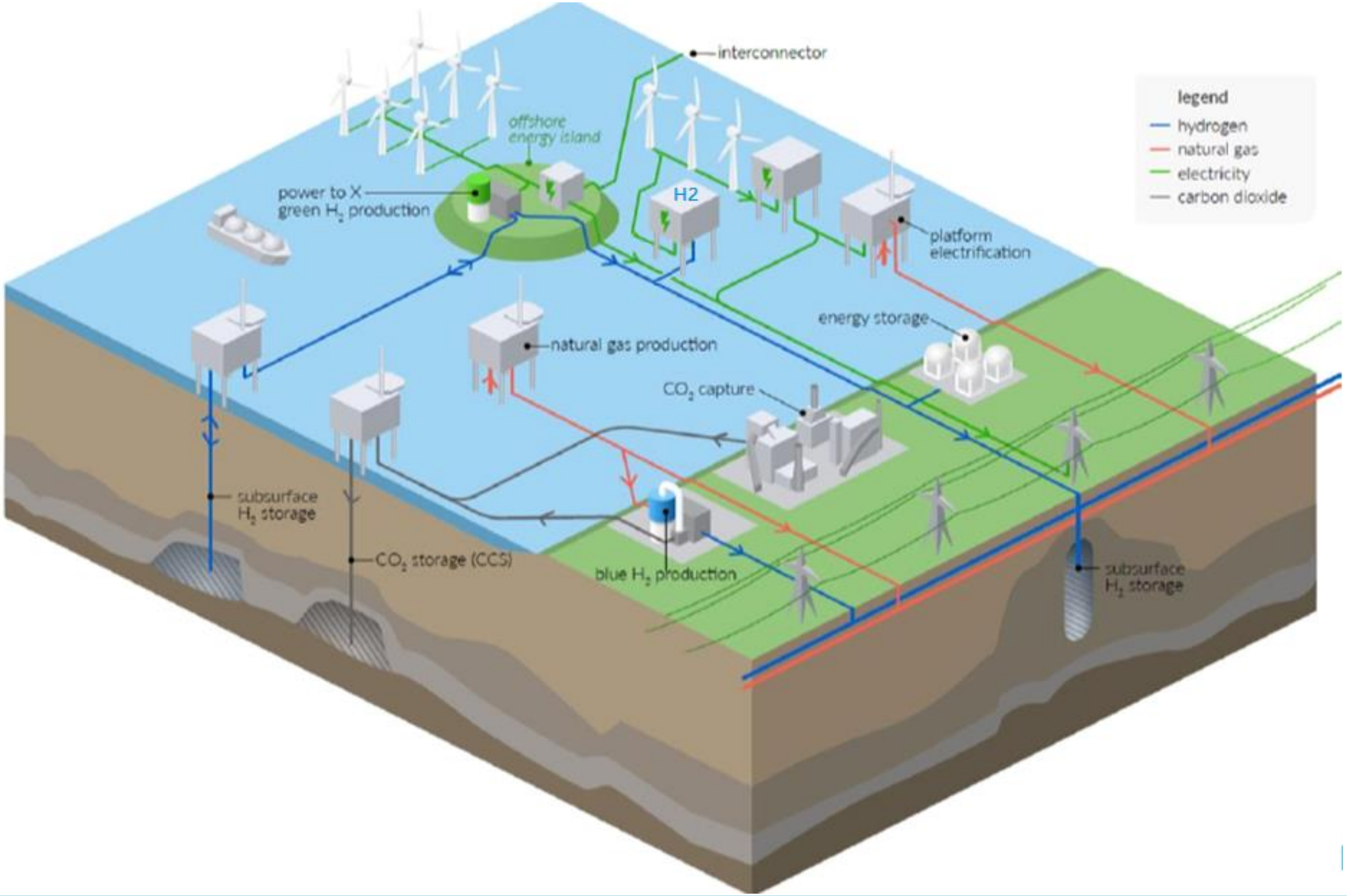
- **Speed of innovation**: the organisation of Research & Development, Demonstration + Deployment is currently insufficient to achieve the required results on time across the energy (and material) transition.
- Alignment between the **energy transition and achieving a (more) circular economy** is insufficient.
- Same is true for meeting **other important sustainability goals** for strong reduction of environmental impacts and contributing to (sustainable) economic development.
- **Implementation procedures** (planning, decision making, licensing, spatial planning, etc.) for large energy infrastructure projects, retrofitting the built environment, etc are way too slow. Role of different government bodies is crucial and requires strong improvement.
- The energy transition needs to be translated into very concrete and **interlinked trajectories** to 2050 next to meeting targets in 2030. Interlinked means also **proper timing and ''better'' (preferably ''perfect'') foresight.**
- The **information basis** underpinning the above can be much improved.

A SYSTEM TRANSTION THAT SHOULD ACCELERATE, WHAT DOES THAT IMPLY? (II)

- Ways of collaboration (e.g the actual deployment of **mission driven collaboration** between market, government and research) needs to be realized.
- **Finance** for the required investments and **RDDD** is still a bottleneck, including faster transfer from fossil to sustainable sectors and companies.
- Strengthening **international collaboration** is needed for acceleration, scaling up RDDDD and burden sharing.
- The same is true for **coordination and realization of the required energy infrastructure** (North Sea region, large scale import schemes of H2 and biobased products).
- The energy transition (and industrial transformation) is a combination of a **technical and social transition** and to be governed accordingly.
- Change the perspective on that the required efforts and changes in the economy from an experienced costs to society is seen as an **investment in sustainable growth**.

INTEGRATED ENERGY SYSTEM ON THE NORTH SEA
COORDINATED EFFORTS ON THE ENTIRE SYSTEM = KEY

North Sea Energy offshore system integration



- CO2 storage
- H2 production
- Electrification
- Energy storage
- Energy islands

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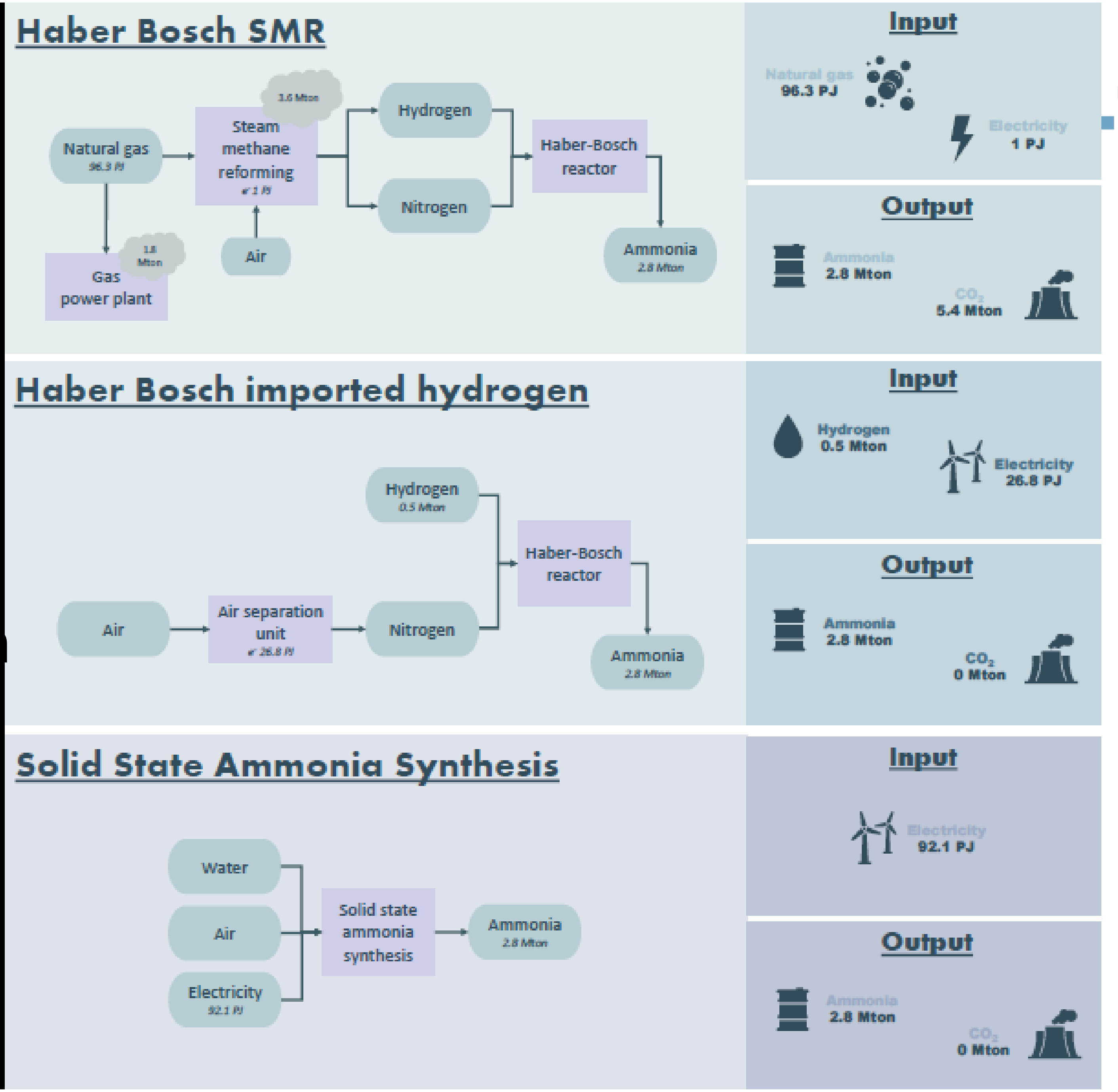
‘’Simple’ example: Different archetypes for “future low GHG Ammonia production



› WHY “*INDUSTRIAL TRANSFORMATION*”?

- The (heavy) industry and associated governments in the Antwerp-Rotterdam-Rhein-Ruhr (ARRRA) area will have to make far-reaching decisions in the coming years with regard to **investments** in new technologies, infrastructure and regional development in order to meet the climate goals of the Paris Agreement.
- Industry in the Netherlands is responsible for approximately **50% of energy consumption, emissions, and consumption of raw materials**. The Dutch ambition is also to achieve net zero or even negative emissions in 30 years. This will require significant investments and high-risk decisions.
- Due to large **uncertainties and interdependencies** in the cross-border area with regard to technology development, market demand development, sustainable raw materials and energy availability, energy infrastructure and transnational legislation and regulations, it is very difficult for companies and governments to make these decisions and balance costs and benefits of investments.