THE ROLE OF CC(U)S IN THE ENERGY TRANSITION AND INDUSTRIAL TRANSFORMATION; SHORT AND LONG TERM IMPLICATIONS..

CARBON STORAGE DIALOGUES 12 OCTOBER 2023, ROTTERDAM

ANDRÉ FAAIJ

DIRECTOR OF SCIENCE, TNO ENERGY & MATERIALS TRANSITION

DISTINGUISHED PROFESSOR ENERGY SYSTEM ANALYSIS, UTRECHT UNIVERSITY & UNIVERSITY OF GRONINGEN

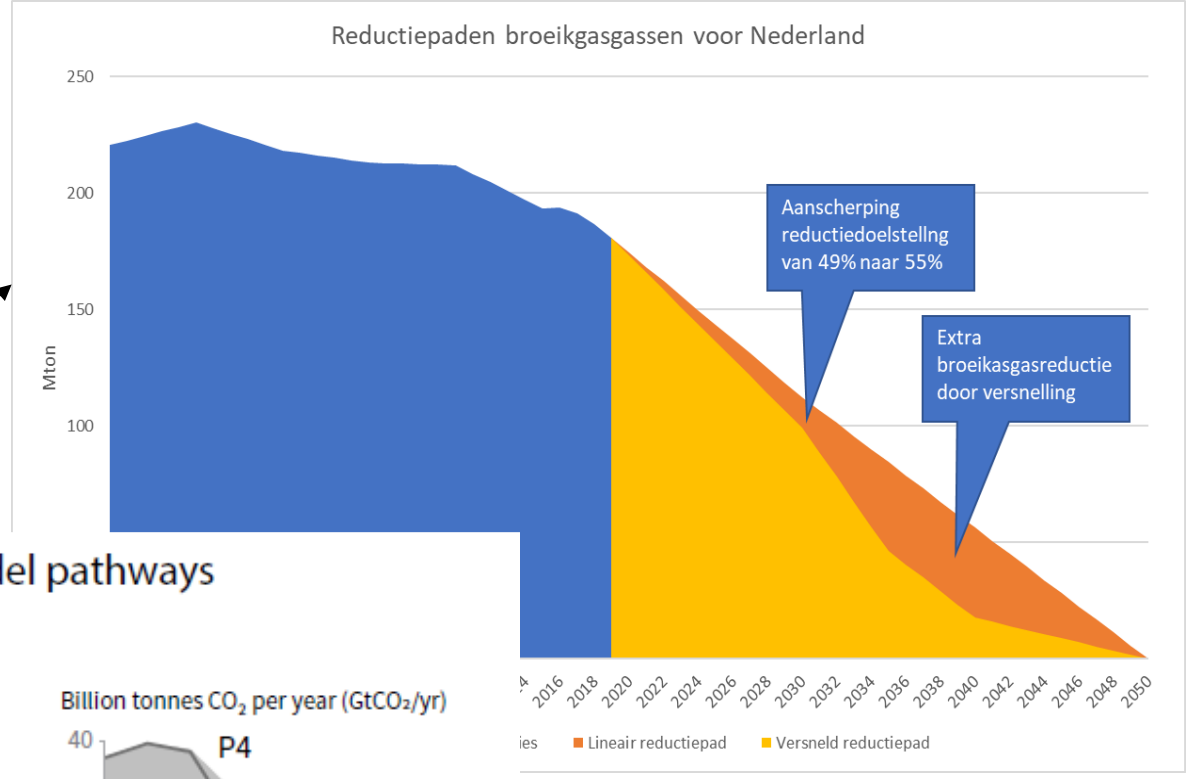
TNO innovation for life

Universiteit Utrecht

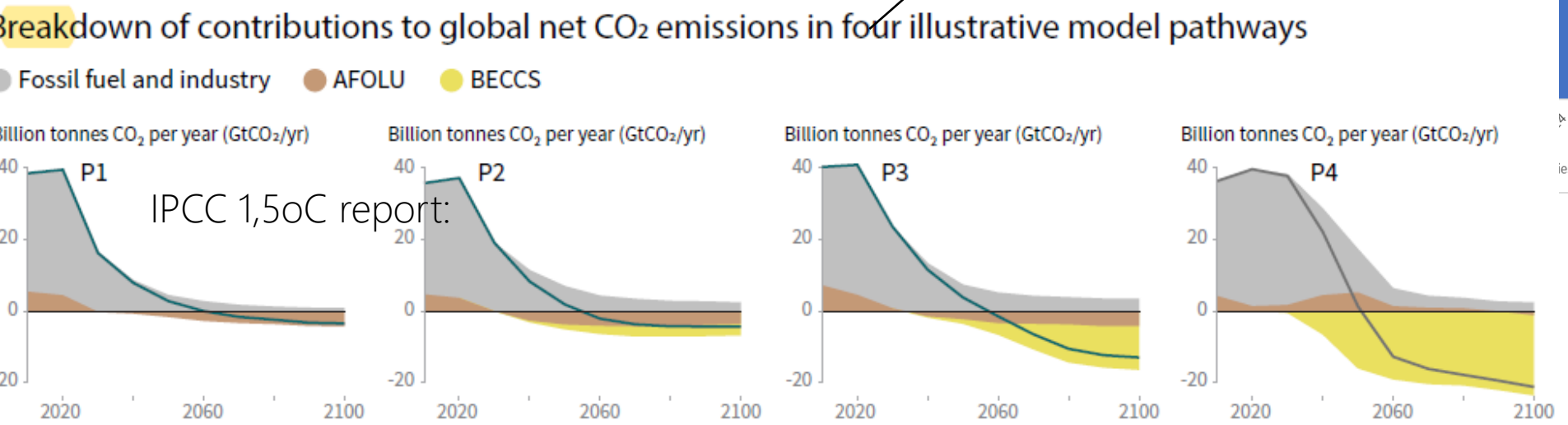
rijksuniversiteit groningen

ACCELERATING THE ENERGY TRANSTION

Implications for the Netherlands:



IPCC 1,5oC report:



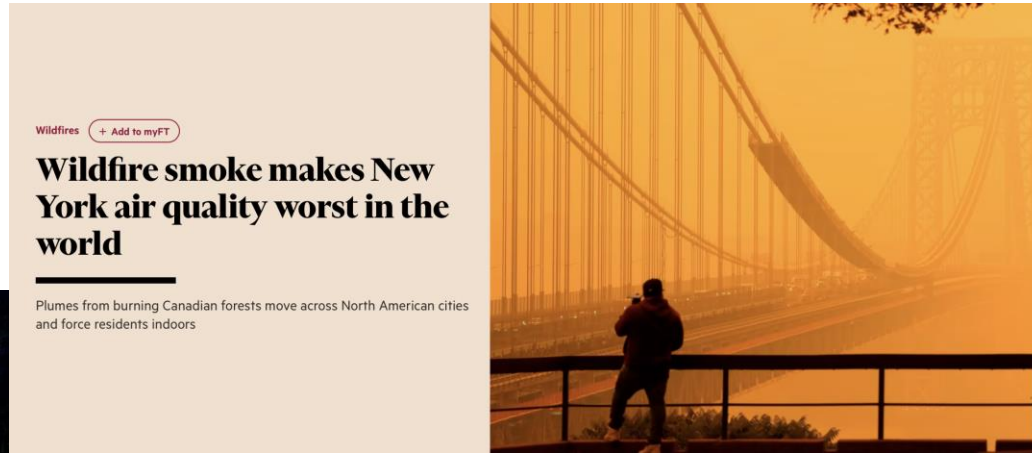
P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither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

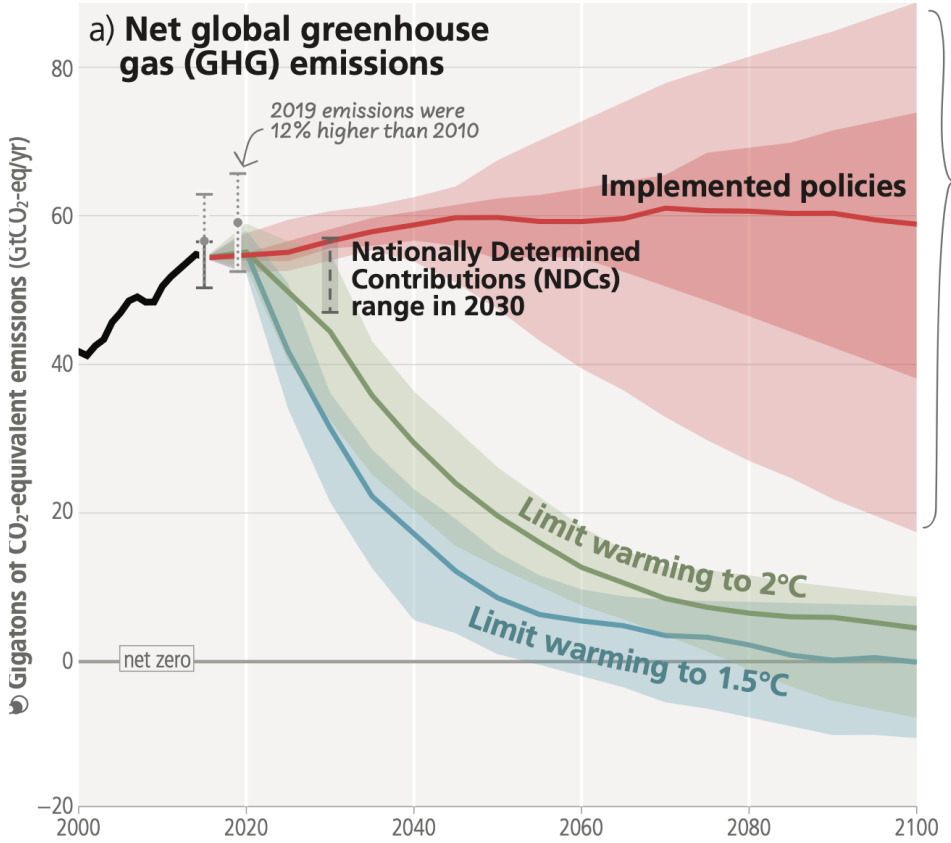
P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal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

CLIMATE WARMING

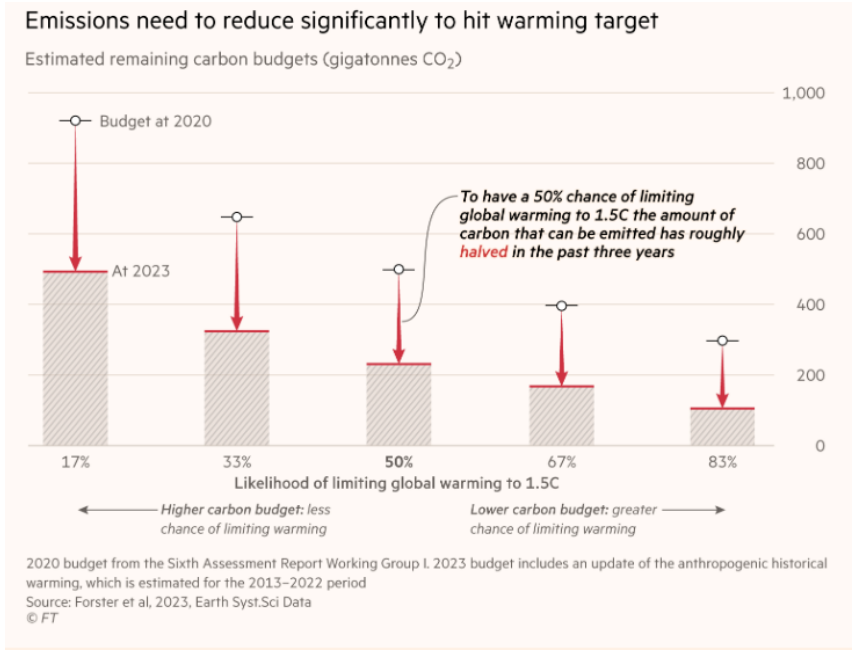




Implemented policies result in projected emissions that lead to warming of 3.2°C, with a range of 2.2°C to 3.5°C (medium confidence)

Key

- Implemented policies (median, with percentiles 25-75% and 5-95%)
- Limit warming to 2°C (>67%)
- Limit warming to 1.5°C (>50%) with no or limited overshoot
- Past emissions (2000–2015)
- Model range for 2015 emissions
- Past GHG emissions and uncertainty for 2015 and 2019 (dot indicates the median)



SCENARIO'S FOR THE DUTCH ENERGY SYSTEM IN 2050

ADAPT

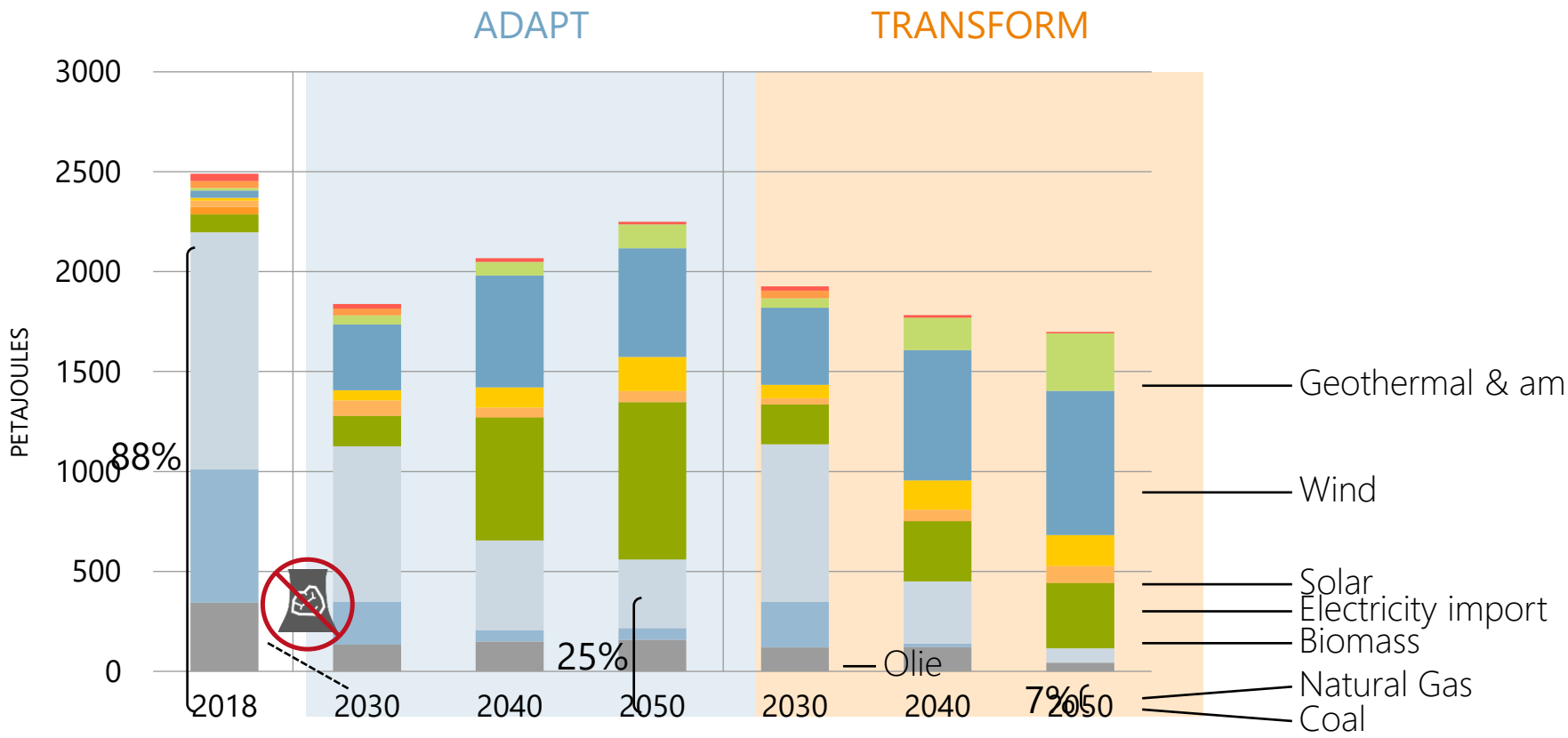
- Maintain prosperity
- Industrial structure (largely) unchanged
- Government leads
- Adapted energie system
- Fossil fuels in combinatinon with CCS allowed.
- Large scale import of biomass/bioenergye allowed

TRANSFORM

- Strong environmental awareness: reduction in consumption
- Innovative EU and Netherlands
- Initiatives of citizens and market players.
- Transformation of the energy system and industry
- No CO_2-storage
- Limited use of biomass.

Demography | Economic growth | Commodity-prices | Climate targets

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

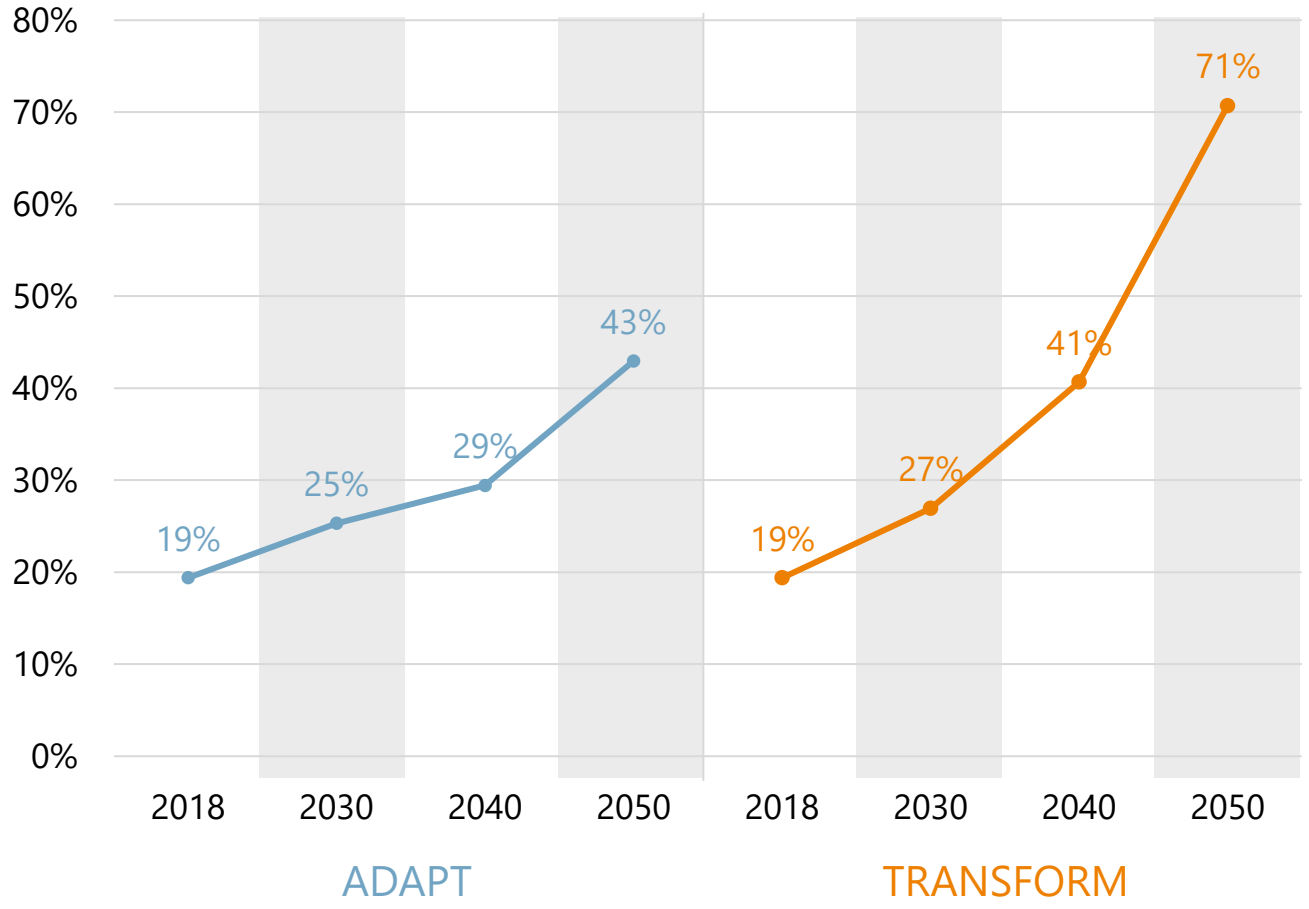


- Excludes:
- Non-energetic use
- International aviation & shipping

SHARE OF ELECTRICITY IN THE ENERGY SUPPLY

DOUBLING – TRIPLING COMPARED TO TODAY

Share electricity in total energy supply



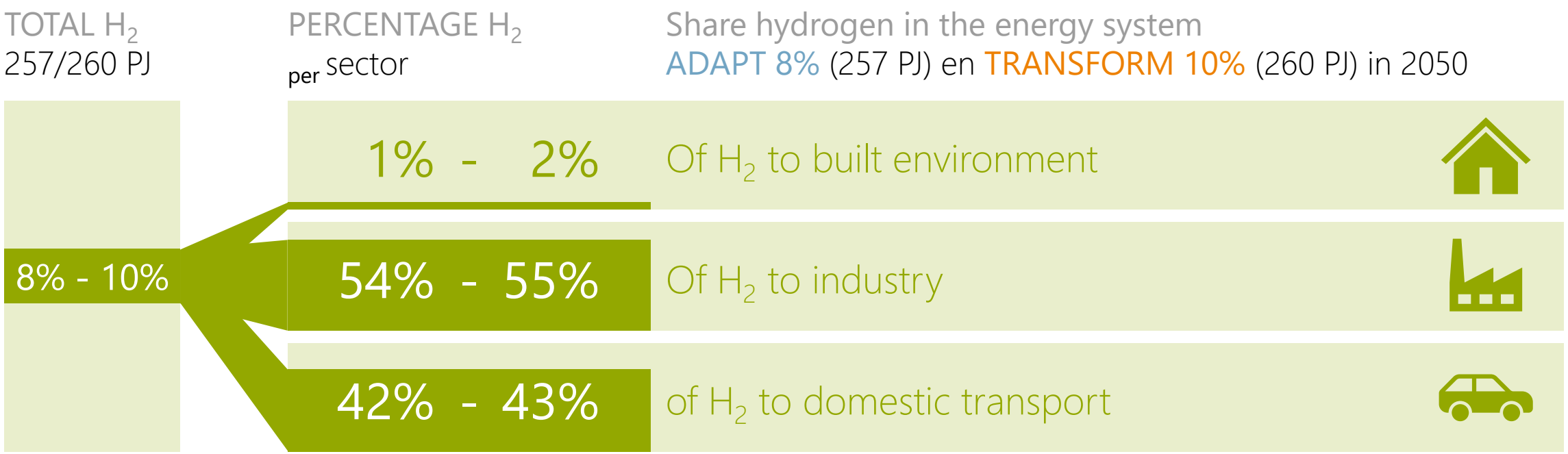
Share low C electricity

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

TNO innovation for life

HYDROGEN RELATIVELY MODEST, BUT…

IMPORTANT ROLE IN THE ENERGY SYSTEM

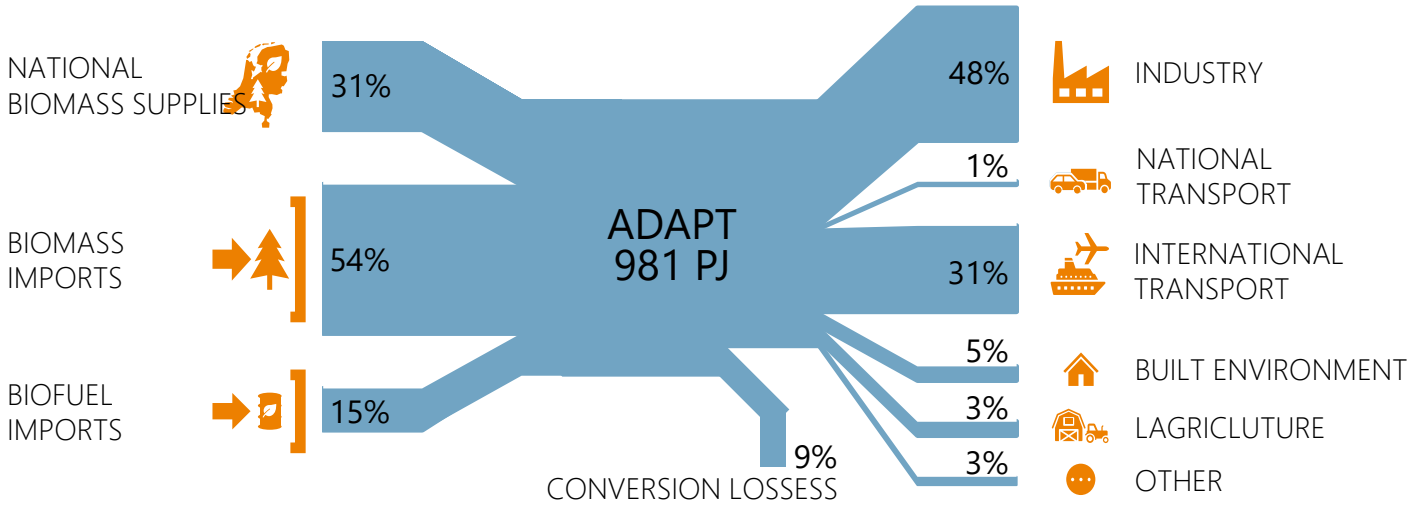


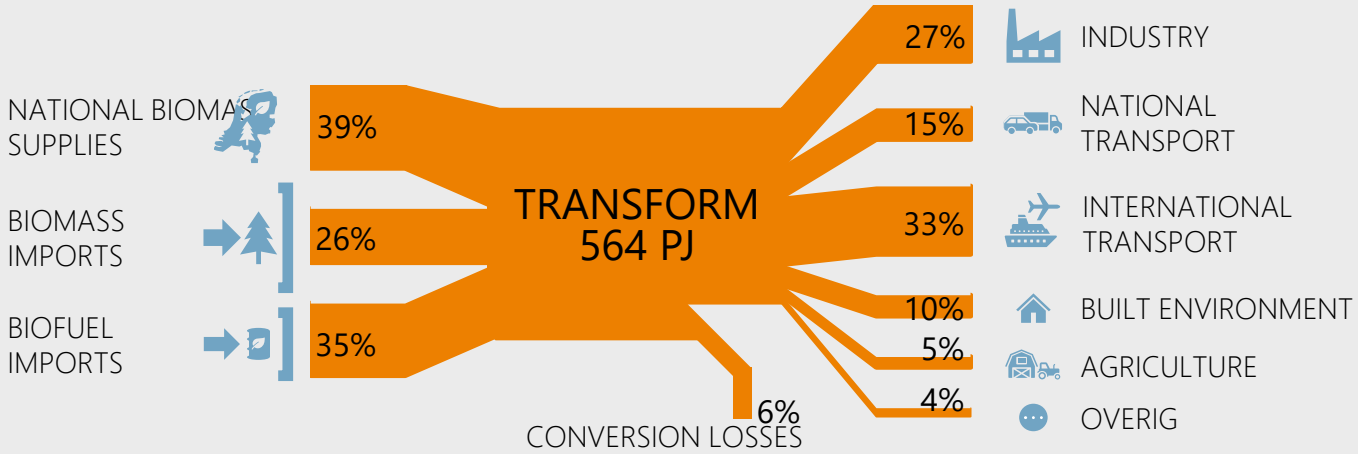
Production

ADAPT	Largely blue H_2, in 2050, also 25% green H_2
TRANSFORM	Only green H_2

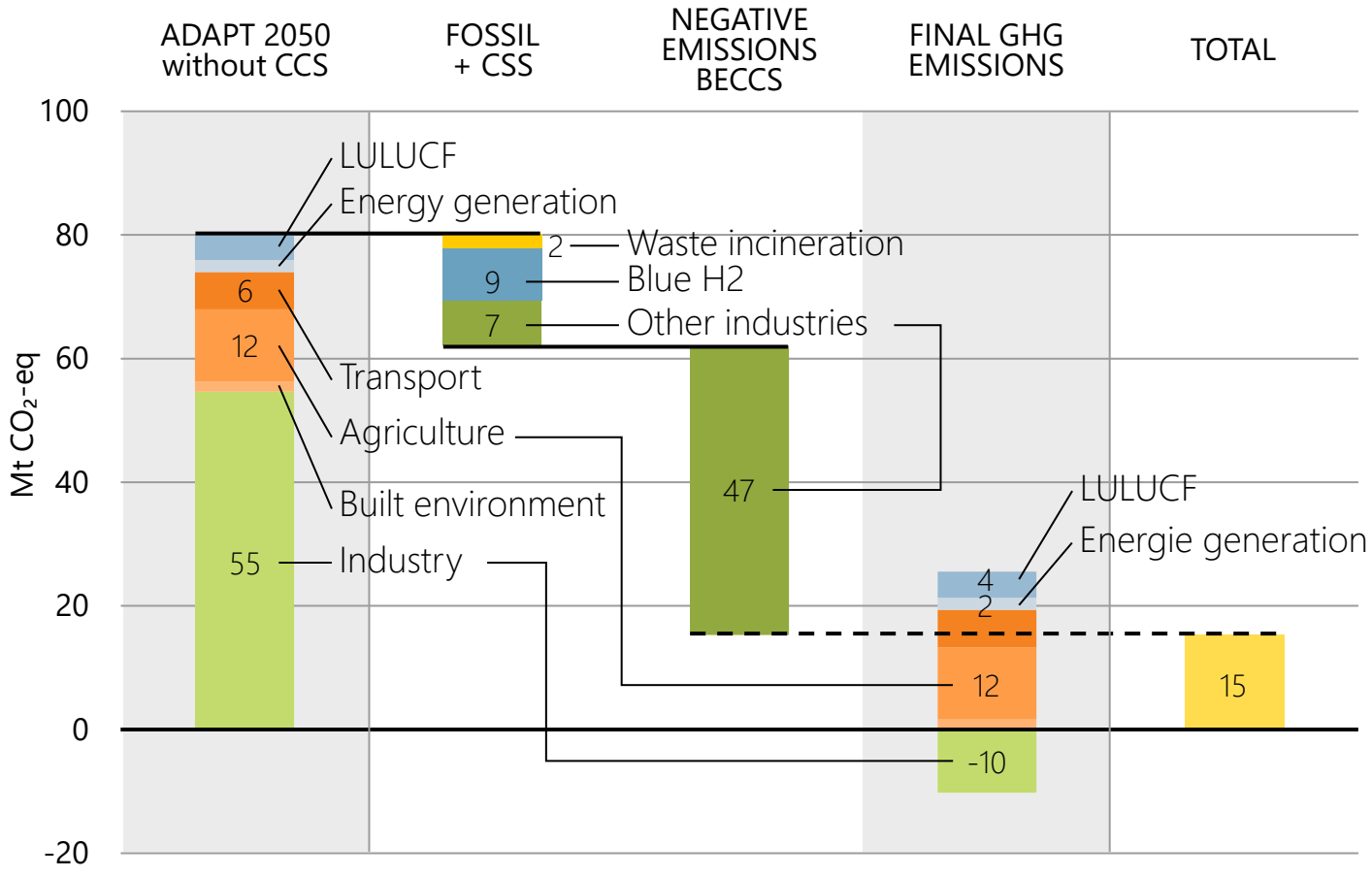
TNO innovation for life

BIOMASS ESPECIALLY USED IN: INDUSTRY & TRANSPORT





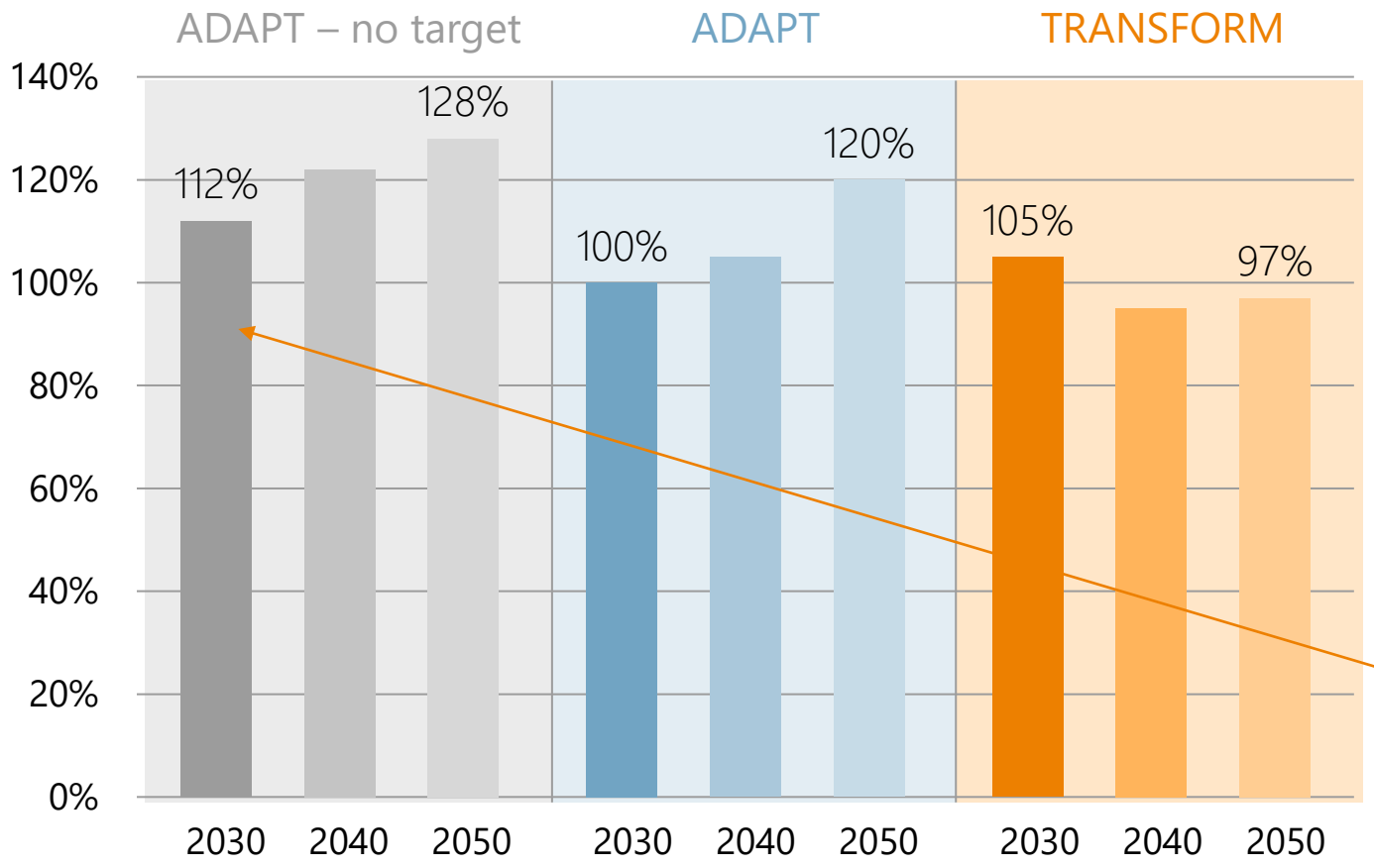
CO2 CAPTURE AND STORAGE
IN THE ADAPT-SCENARIO IN 2050



- 2030: 6,2 Mton
- 2040: 19 Mton
- 2050: 50 Mton

COSTS OF A SUSTAINABLE ENERGY SYSTEM

LOWER COMPARED TO A SCENARIO WITHOUT A GHG TARGET.



<u>Preconditions:</u>

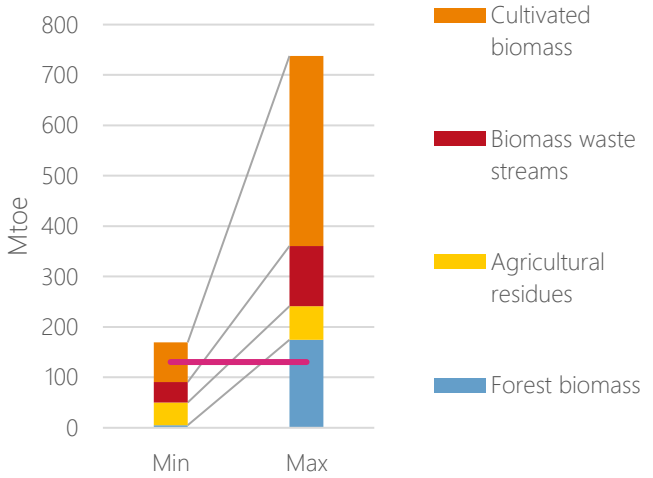
- All options (need to) contribute!
- Innovation (cost reduction)
- Optimal planning / deployment.

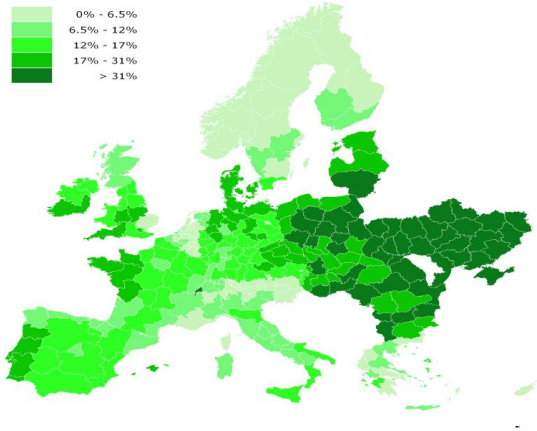
This has about doubled with the Ukraine war resulting price levels for gas and oil

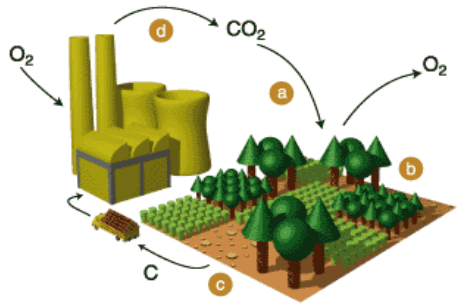
SUSTAINABLE BIOMASS SUPPLIES CAN INCREASE CONSIDERABLY IN SYNERGY WITH:

- Adaptation to climate change (vegetation covers are key!)
- Improving agricultural (and livestock) management reduces land use, environmental impacts and increases resilience.
- Reduction of food losses across value chains and alternative protein sources
- Land type – crop combinations, land zoning and land use patterns can to a large extent be steered towards co-benefits.
- Regeneration of idle, marginal or degraded lands gives ecological benefits; soil restoration, water retention, carbon storage, increased biodiversity.
- Good forest management improves resilience and productivity.
- Possible surprises from aquatic biomass (progress micro-algue and macro-algue/seaweed).

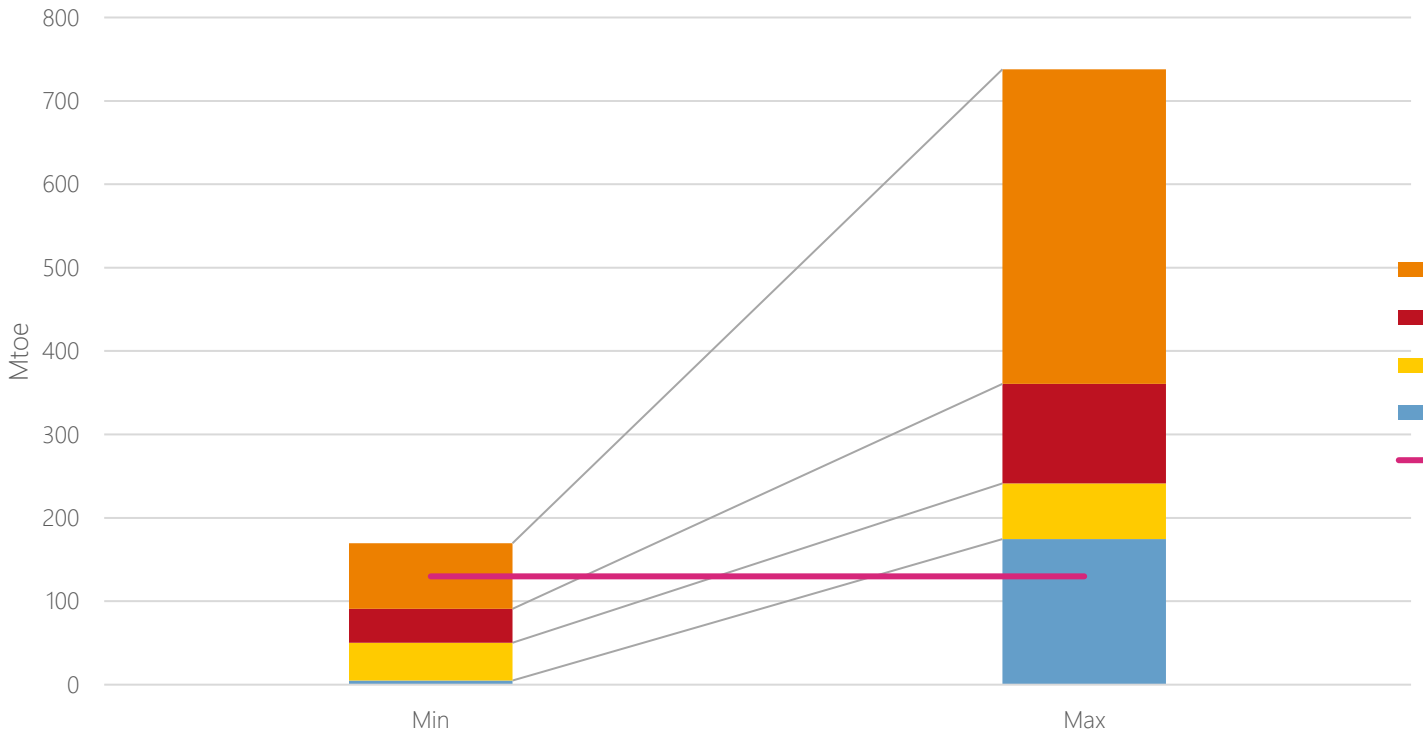
MANY, ALSO RECENT, STUDIES IGNORE PARTS OR A MULTITUDE OF THESE FACTORS!

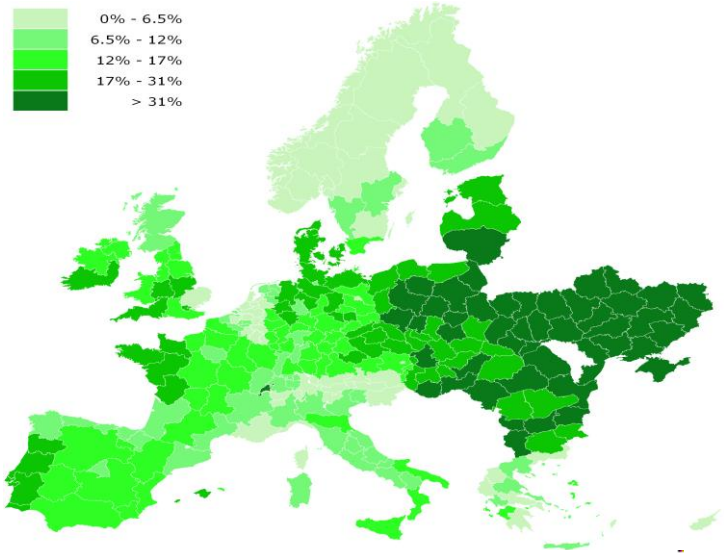


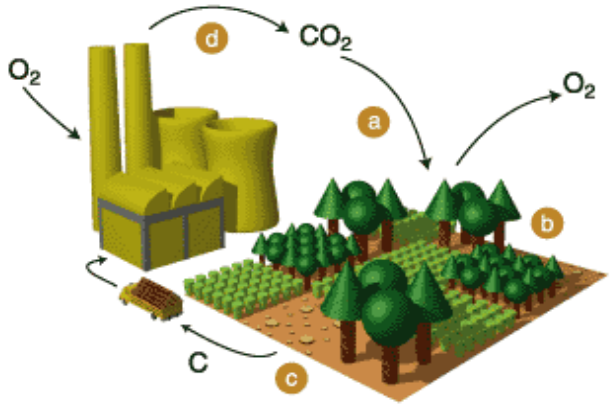




BIOMASS POTENTIALS EU28 IN 2050; 7-30 EJ COMPARED TO 68 EJ; TOTAL PRIMARY ENERGY USED TODAY

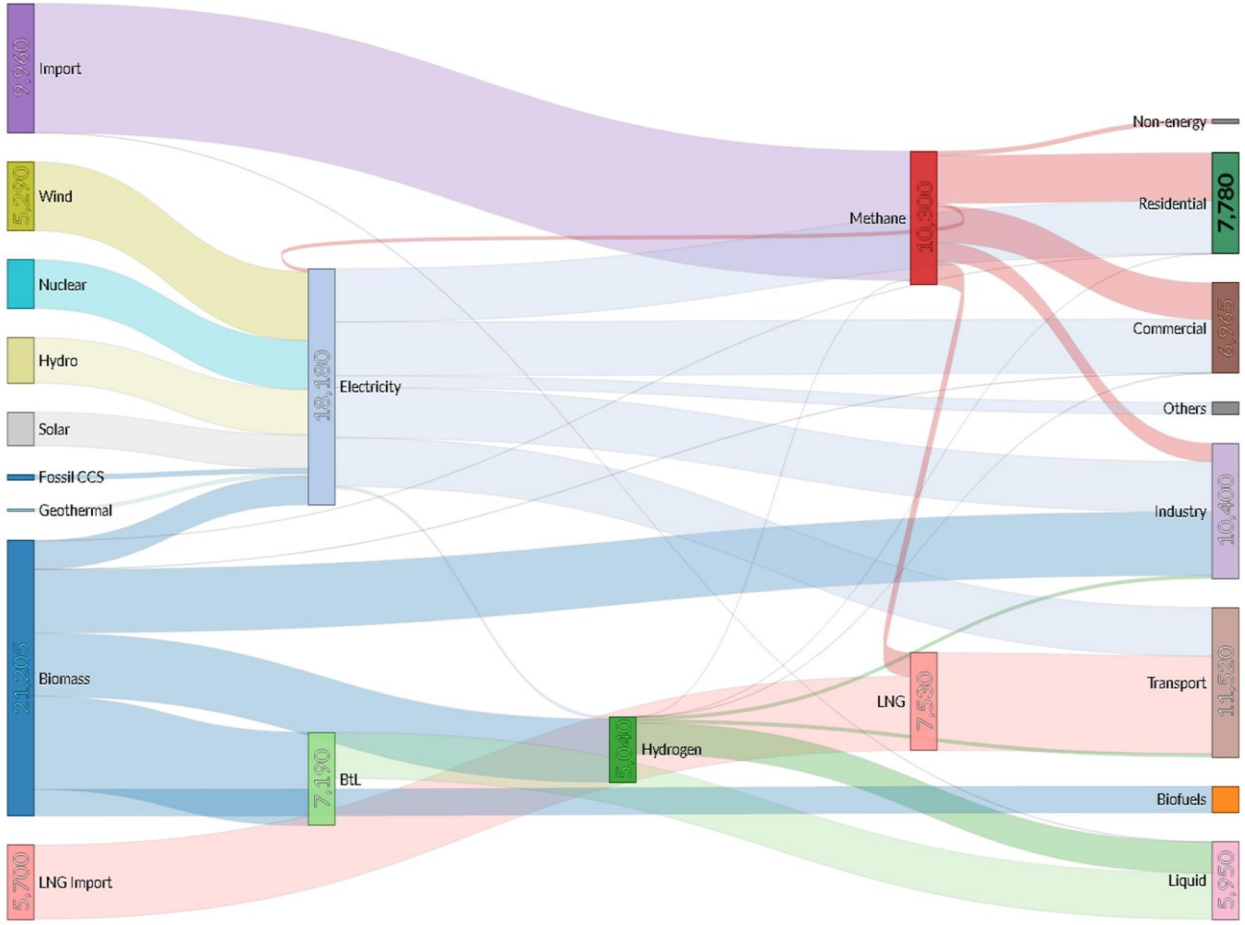




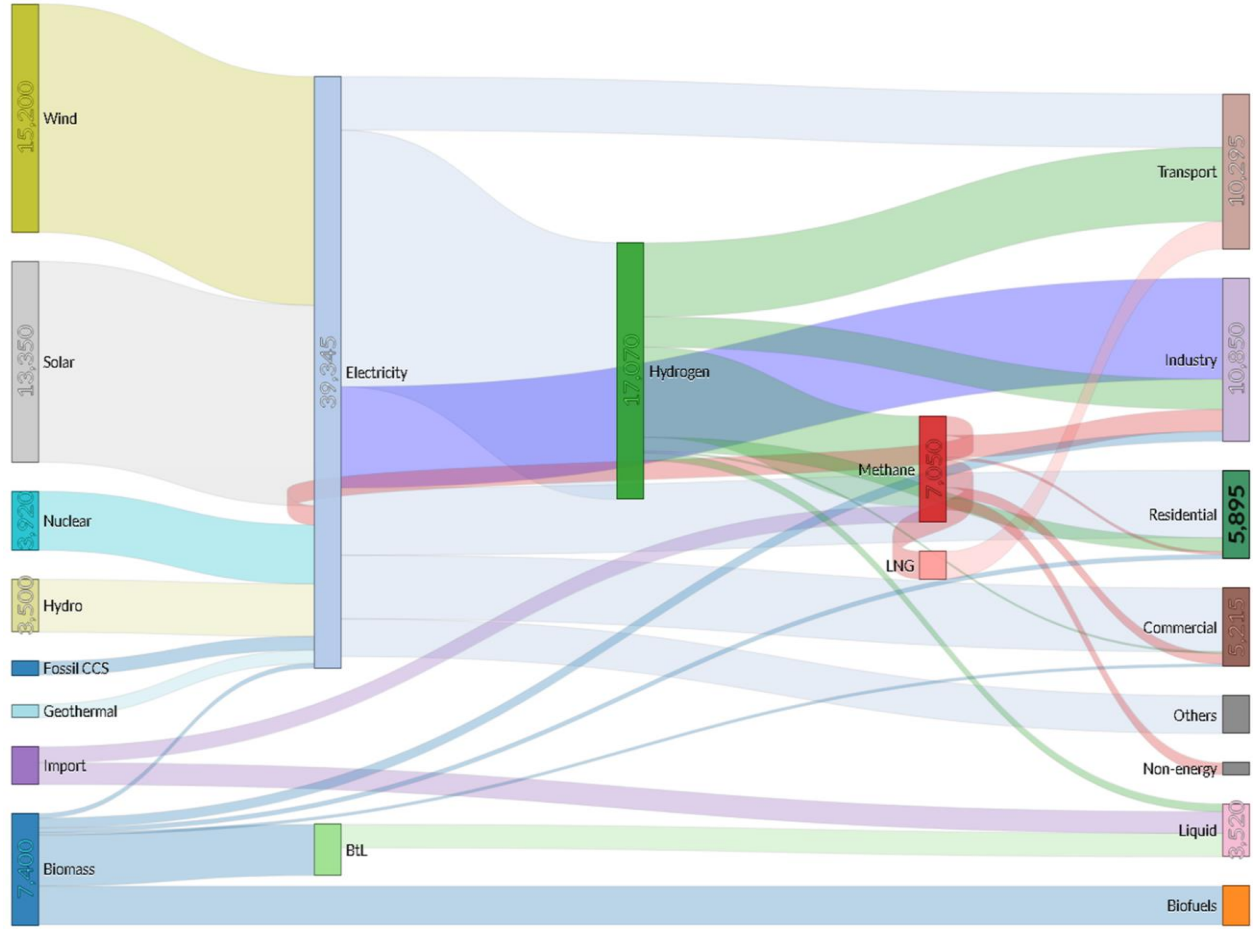


[Faaij, Energies. 2022]

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



high biomass and CCS scenario



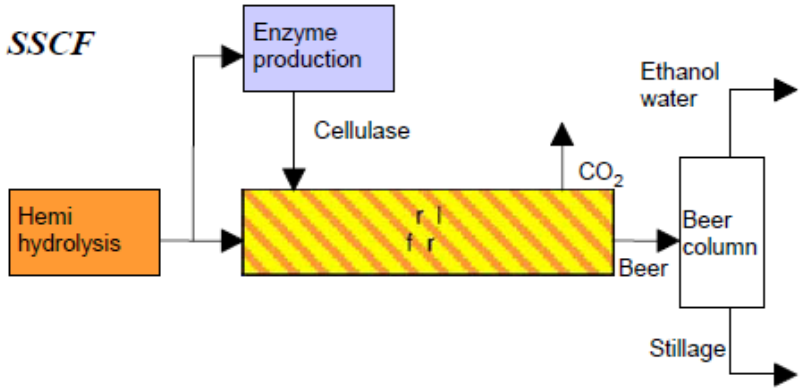
Max solar & wind scenario (+ no CCS, minimal Bio)

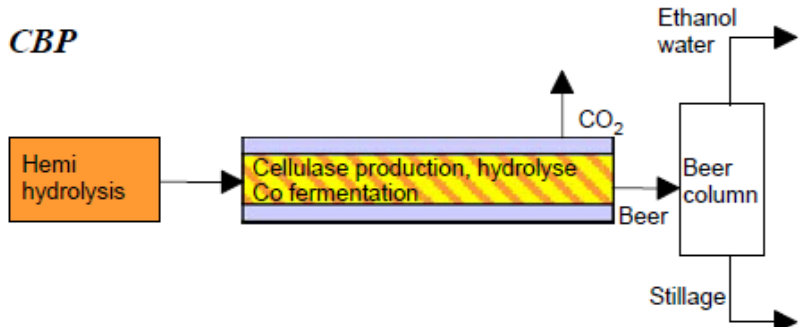
[Blanco et al., applied Energy 2018]

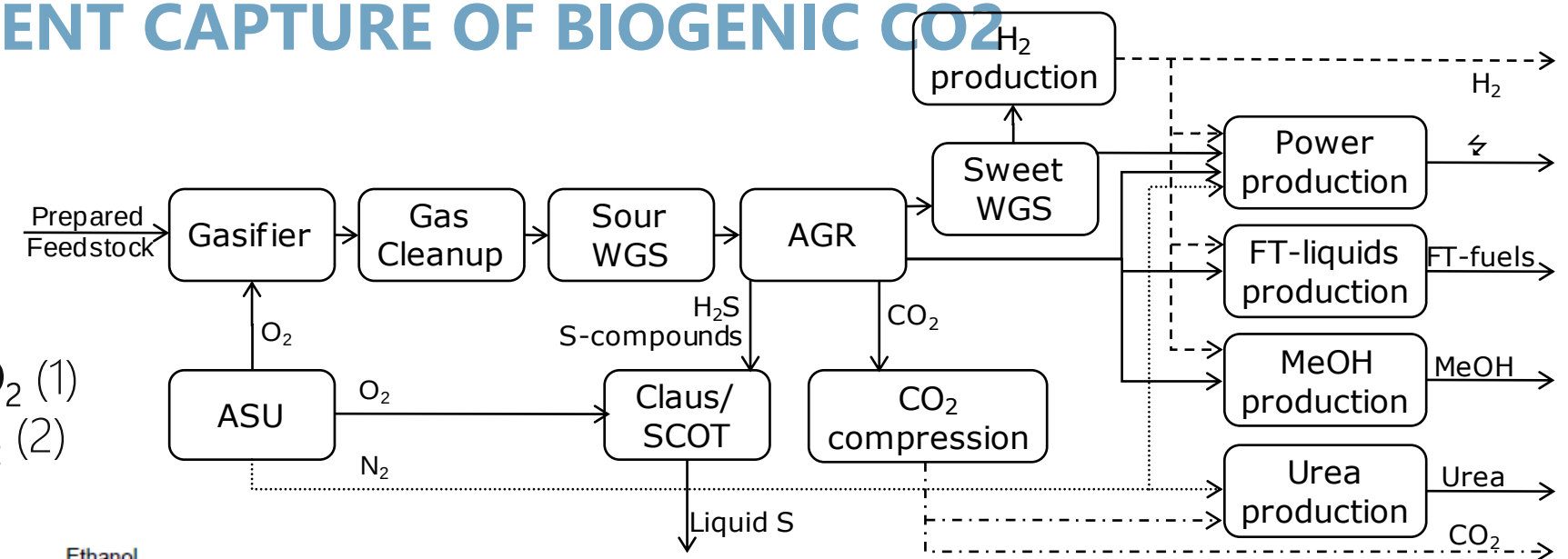
ADVANCED BIOMASS CONVERSION ALLOWS FOR EFFICIENT CAPTURE OF BIOGENIC CO2

$3C_5H_{10}O_5 \rightarrow 5C_2H_5OH + 5CO_2$ (1)

$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$ (2)







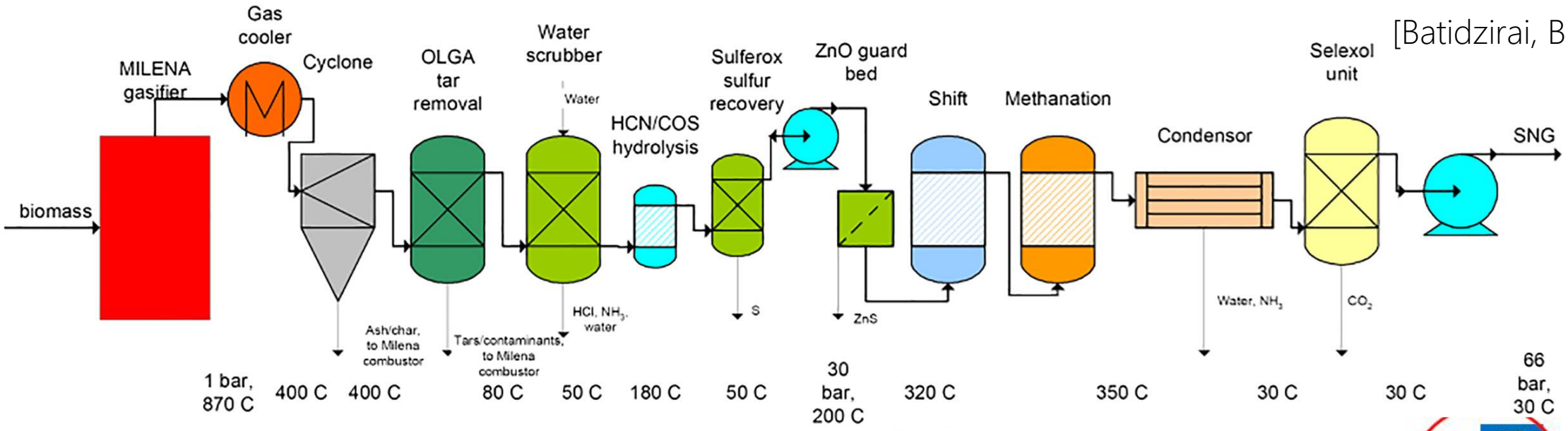
Gasification platforms with CO2 removal as part of syngas production

Meerman et al., RSER, 2012]

Hydrolysis & fermentation platforms with inherent production of pure CO2.

Hamelinck et al., Biomass & bioenergy, 2005

[Batidzirai, BioFPR, 2018]

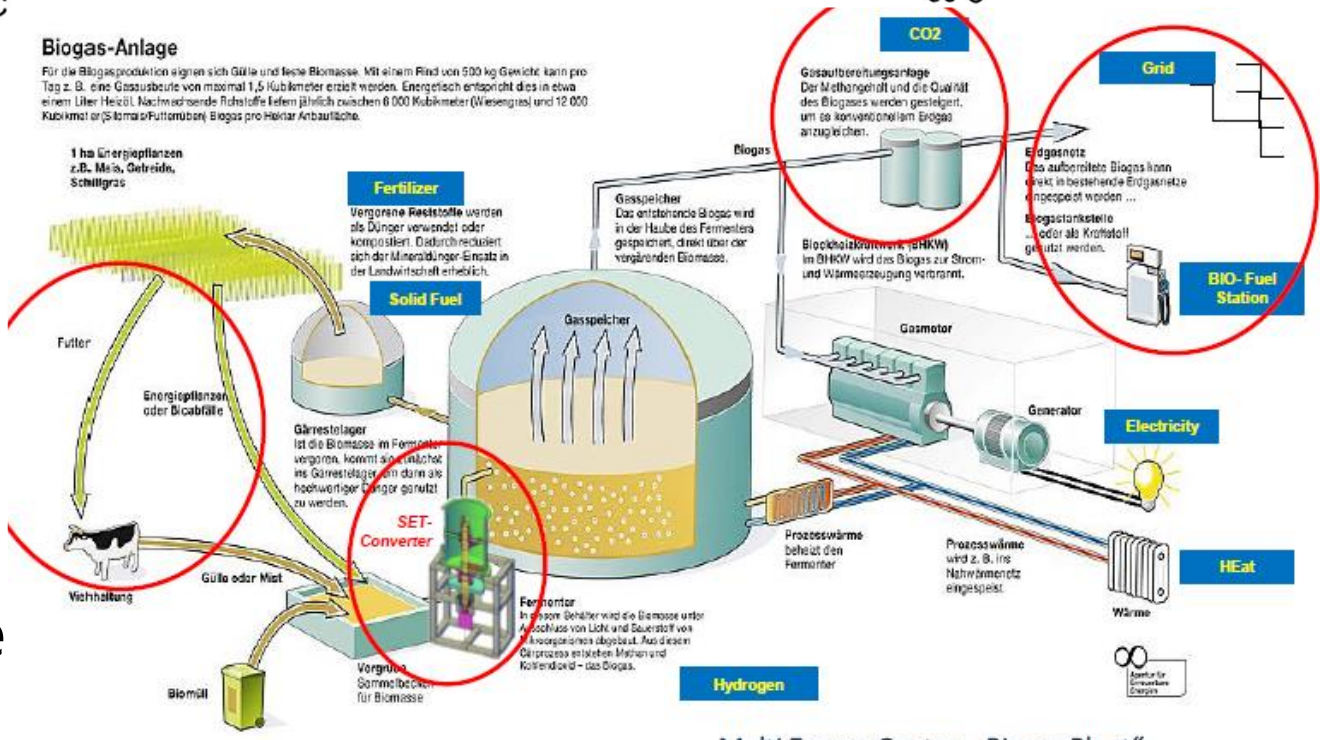


Biogas via:

1. Gasification (more suitable for lignocellulosic biomass)

2. Digestion (more suitable for wet biomass streams)

Both routes allow for fairly easy CO2 capture



[SET Sustainable Energy Technologies GmbH]

„Multi Energy Center – Biogas Plant"
SET - Key Technologies and alternative Substrates

EU_{2018} GHG EMISSIONS 4.4 GTON $CO2_{EQ}$ VS BBE

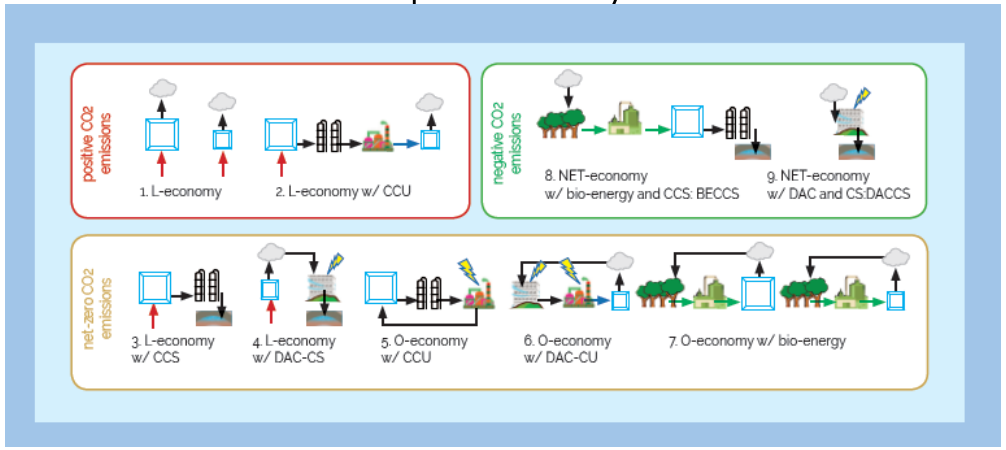
Main product	GHG emissions biomass value chains (Mton CO2eq)		Avoided emissions fossil reference products (Mton CO2eq)		Net avoided emissions (Mton CO2eq) (low impact defined as higher emissions biomass value chain + low deployment; high impact defined as lower emissions biomass value chains + high deployment	
	Low	high	Low	High	low	High
Biofuels (2nd gen ethanol, DME, FT)	51	71	205	1014	154	943
Electricity (larger scale)	25	0	84	96	59	96
Heat (larger scale & Industrial)	24	0	145	0	121	0
Biogas	-1	-42	10	34	10	76
Bulk biochemicals	3	0	24	332	22	332
Totals	102	29	468	1476	366	1447

In addition: - BECCS options may contribute up to 700 Mton/yr. [Faaij, Energies 2022]
- Carbon stock increases due to additionally planted perennial crops, increased productivity of marginal and degraded lands and increased carbon stocks due to improved agricultural productivity may contribute another 10-50 Mton/yr up to 2050.

BBE OPTIONS ESSENTIAL FOR DEEP GHG MITIGATION AND ENERGY & INDUSTRY TRANSITIONS: IAM'S, ESM'S (EU, NATIONAL) WITH THE RIGHT GRANULARITY SAY:

- EXCLUDING biomass from increases mitigation costs substantially and in many cases makes achieving a 1,5oC pathway impossible.
- Over time, optimal biomass use shifts from heat and power to advanced fuels and feedstock for industry.
- Sustainable biomass is always a highly attractive mitigation option.
- BECCS options are of major importance to achieve negative emissions, lower overall mitigation costs and essential to deal with the overshoot emission pathways.

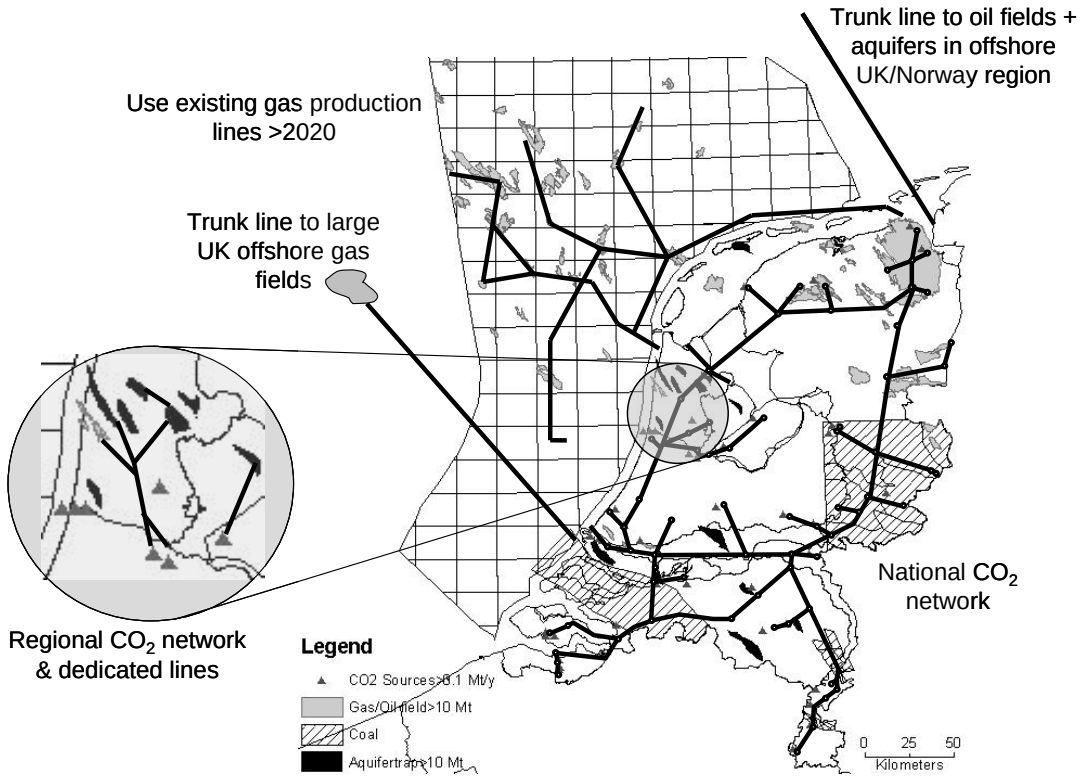
- Biomass use get's intermixed with green Hydrogen and CCUS options; not so much competition but synergy between these key mitigation options.



- Scenario's that include LUC and carbon stock impacts show the additional benefit of increased C-storage combined with good land use practices.

CLOSING REMARKS

- Given the time pressure and need for negative GHG emissions, CCS is in particular relevant for BECC(U)S.
- 50 Mton/yr for the Netherlands till 2100 is a real perspective in this context
- Can lead to considerable reduction of overall future energy system costs.
- Deployment especially in future (NET) heavy industries.
- Key precondition is availabilility of sustainable biomass resources
- …on which the perspective needs to shift from ‘’causing conflicts” to ‘’achieving synergies”.
- To be built up in NW EU context.



Possible future configuration
Of CCS infrastructure…

[Damen et al., IJGHGC, 2009]

TNO innovation for life