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THE CONTRIBUTION OF CCU TOWARDS CLIMATE NEUTRALITY IN THE EU

A SCENARIO DEVELOPMENT AND MODELLING EXERCISE

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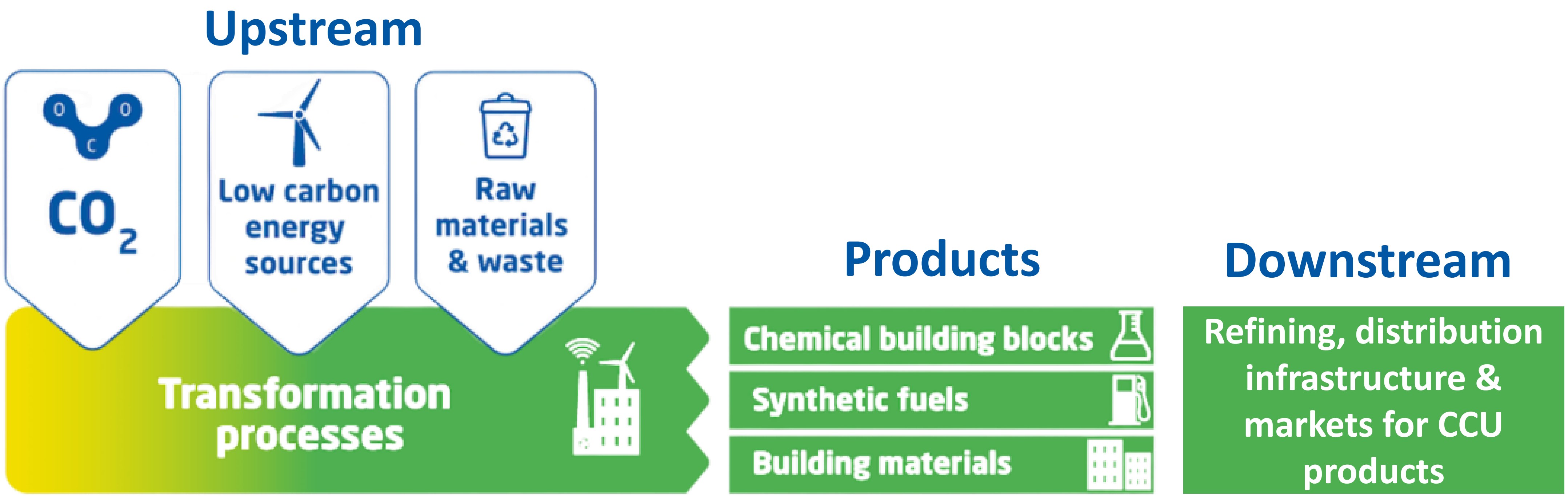
Our organisation

CO_2 Value Europe is the European association dedicated to CO_2 Utilisation, bringing together stakeholders from the complete CCU value chain and across sectors.



Multinational Companies, SMEs, Regional Clusters, Research Institutions, Universities

CO_2 Value Europe: 118 members

38 Large Companies	27 Research Organisations	47 SMEs	6 Clusters

38 Large Companies

AGC, ALBIOMA, alco, Axens, CARMEUSE, Celanese, CMA CGM, climeworks, drax, CRISTAL UNION, E+H, CRH, fortum, ENGIE, Endress+Hauser, iba, FLUOR, GRTgaz, HOLCIM, Keppel Seghers, LYB LyondellBasell, Mitsubishi Corporation, LESAFFRE, Lhoist, MITSUBISHI HEAVY INDUSTRIES, SAIPEM, NEA GROUP, ORLEN, PAUL WURTH SMS group, SIBELCO, GC, SOLVAY, suez, SYENSQO, Stepan, TERÉGA, VEOLIA, VICAT, WIEN ENERGIE

27 Research Organisations

cea liten, DIFFER, DANISH TECHNOLOGICAL INSTITUTE, EPFL, GHENT UNIVERSITY, ICIQ, ifp Energies nouvelles, imec, KIT, iit ISTITUTO ITALIANO DI TECNOLOGIA, LEITAT, net4CO2, nova Institute, NOVAID, SINTEF, SOTACARBO, SWERIM, tecnalia, TNO innovation for life, UCLouvain, Universidad LOYOLA, ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA, LIÈGE université, UMONS, UNIVERSITY OF SURREY, vito, VTT

47 SMEs

accelera, again, Biostoom, blended, carbon8, carbon clean, CARBONFREE, CARBON RECYCLING INTERNATIONAL, CarbonWorks, carbon upcycling, cinergie, D-CRBN, Dioxycle, eChemicles, ENVIRO Ambient, ENERGO, IC2R, econic, fairbrics, hynamics, GCT, H2V, HYSYTECH, INERATEC, INFINIUM, KHIMOD, LanzaTech, MGH energy, NeoCarbons, neustark, Nordic Electrofuel, norsk e-fuel, orbix, Paebbl, Qair, Revcoo, ROHRDORFER, SEABOUND, SKYNRG, skytree, solmeyea, sunfire, TES, UP CATALYST, Value Carbon, VERSO energy, ZETON

6 Clusters

axelera, cdec, ePURE, EURAÉNERGIE, GREEN WIN, THE JAPAN GAS ASSOCIATION

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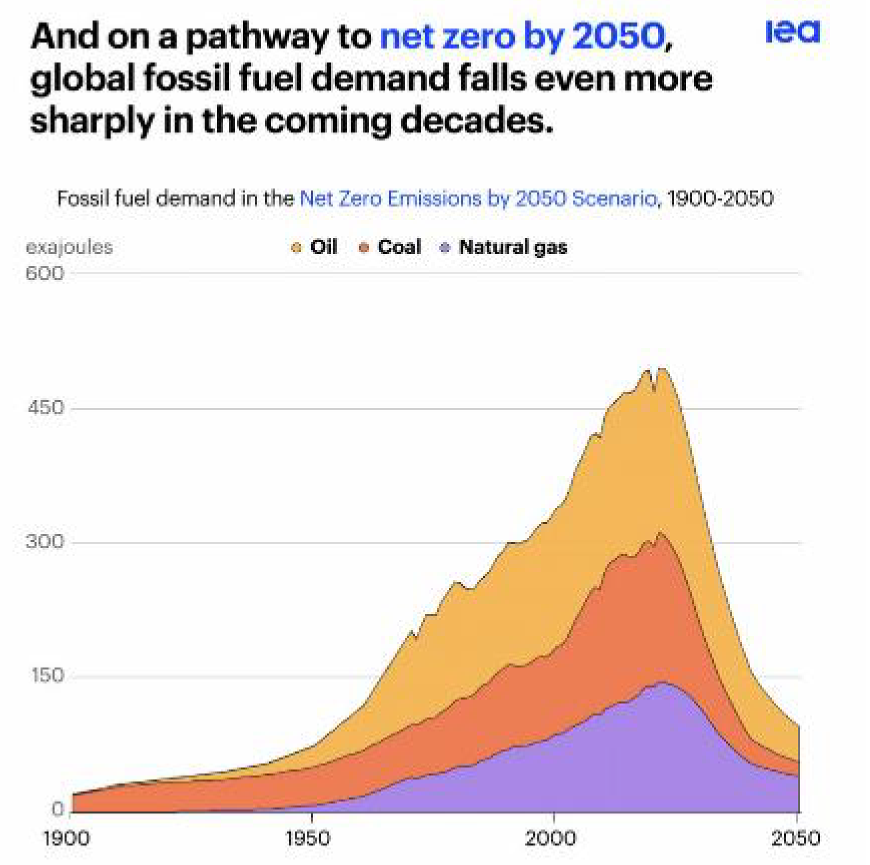
Decarbonising emissions, but «defosilising» the economy



- **No more investments on fossil carbon infrastructures** are compatible with reaching climate objectives (IPCC 2021):
  - 2030: Coal production should decrease by 76%
  - 2050: no more coal. Oil and gas plants should close prematurely
- **Urgent need for more low carbon energy sources, but also for alternative carbon feedstock (e.g. CO_2, biomass, recycled plastic)**

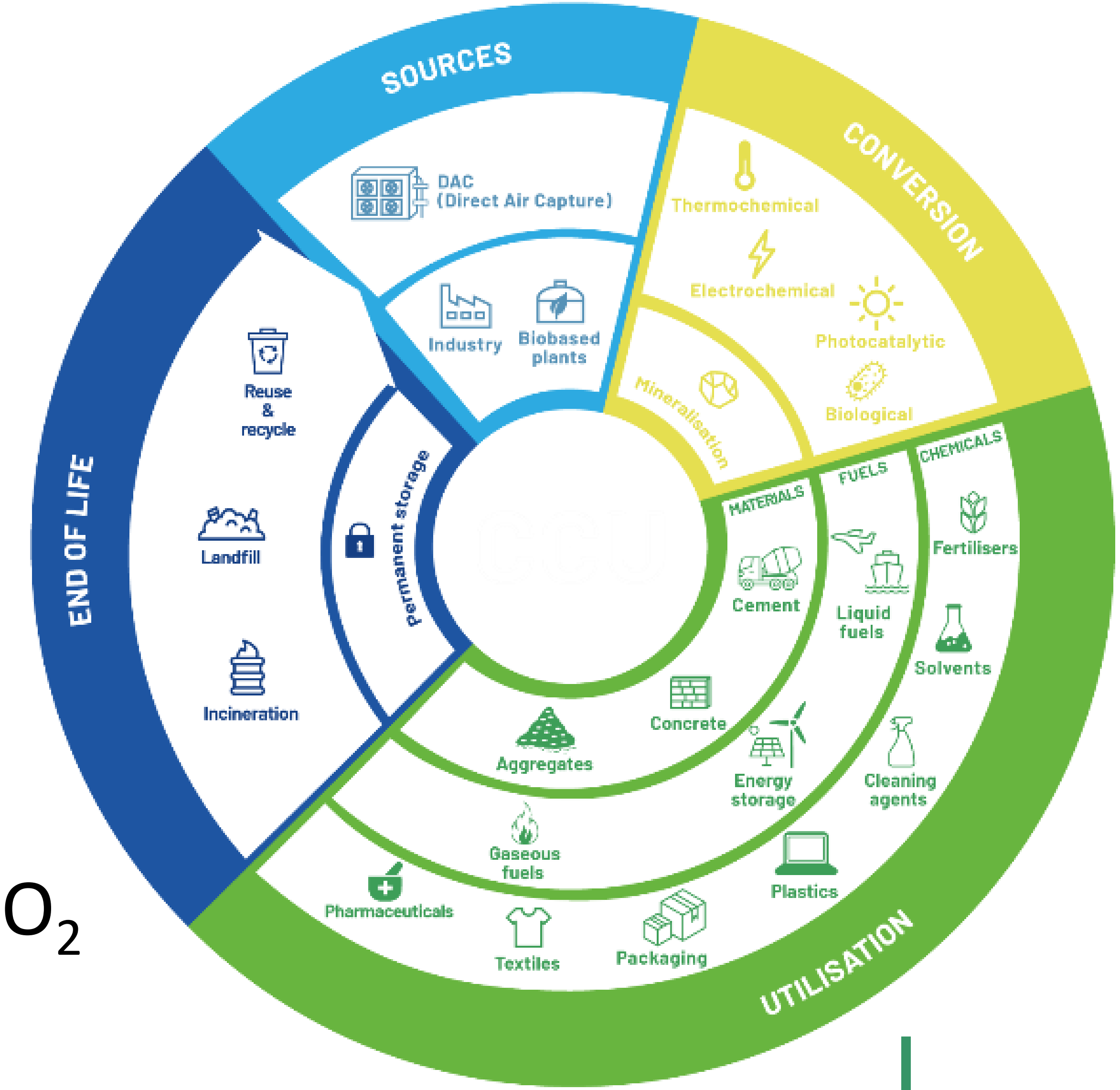
NEED FOR THE CREATION OF A CIRCULAR CARBON ECONOMY

The role of Carbon Capture and Utilisation (CCU)

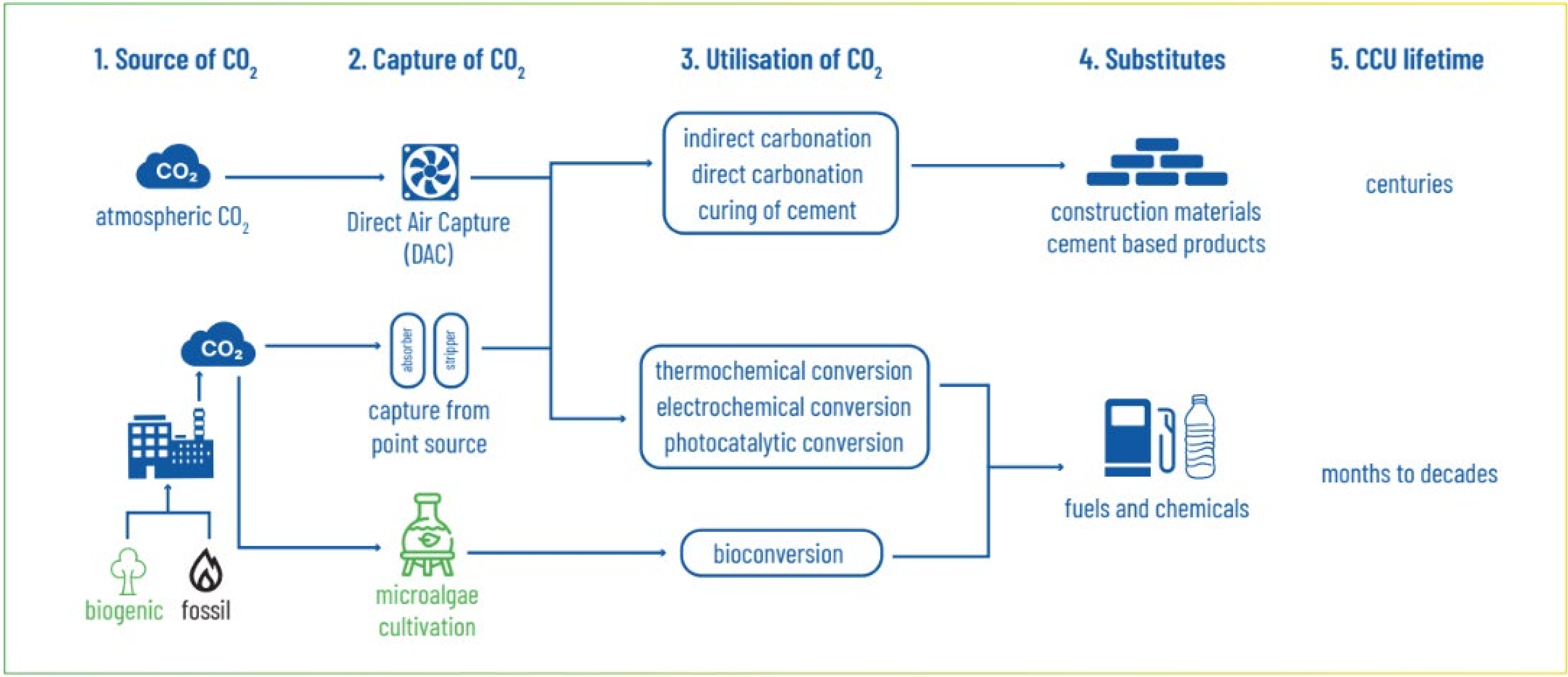
Carbon Capture and Utilisation (CCU) aims at capturing CO_2 from flue gas or directly from the air and converting it into useful products such as renewable fuels and chemicals or building materials.

CCU technologies enable to…

REDUCE AVOID REMOVE CO_2

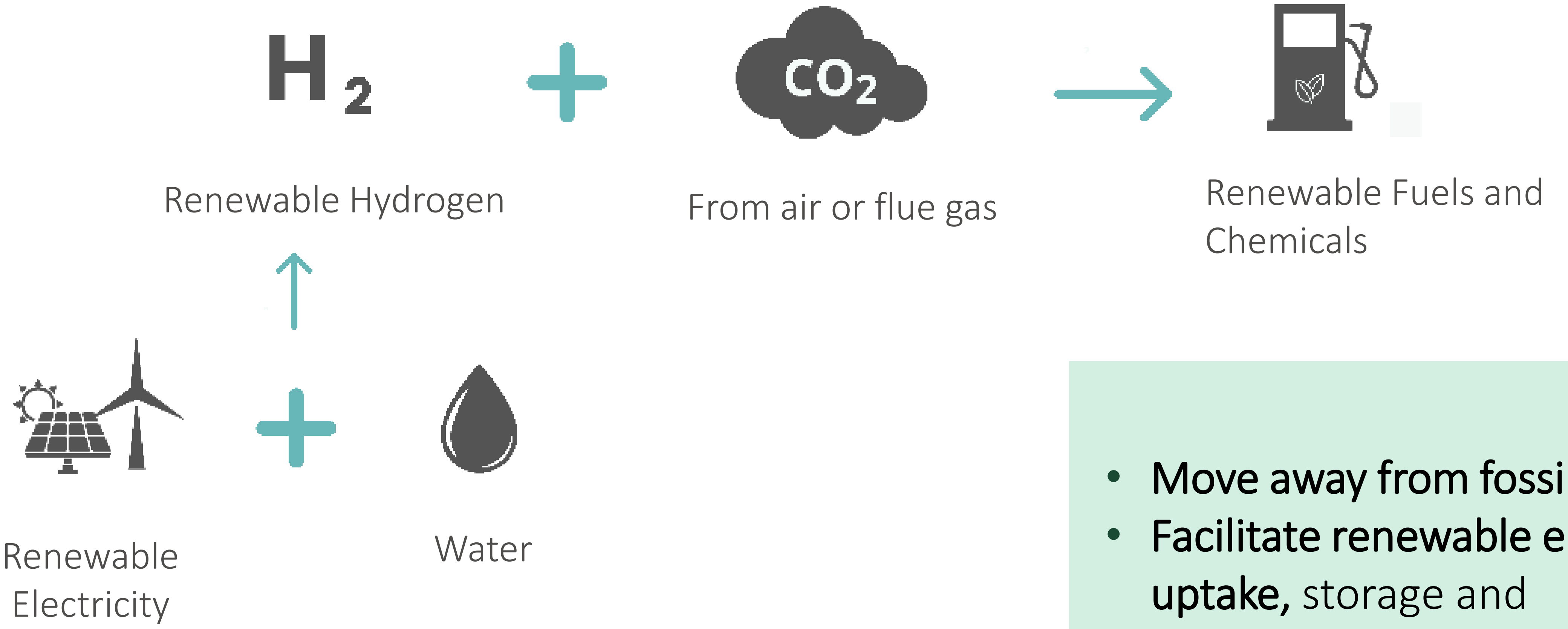


Different CCU applications, different impact on climate change



Source: adapted from de Kleijne et al, 2022

The role of Renewable Fuels and Chemicals



- **Move away from fossil fuel**
- **Facilitate renewable electricity uptake,** storage and transportation
- **Reduce CO_2 emissions**

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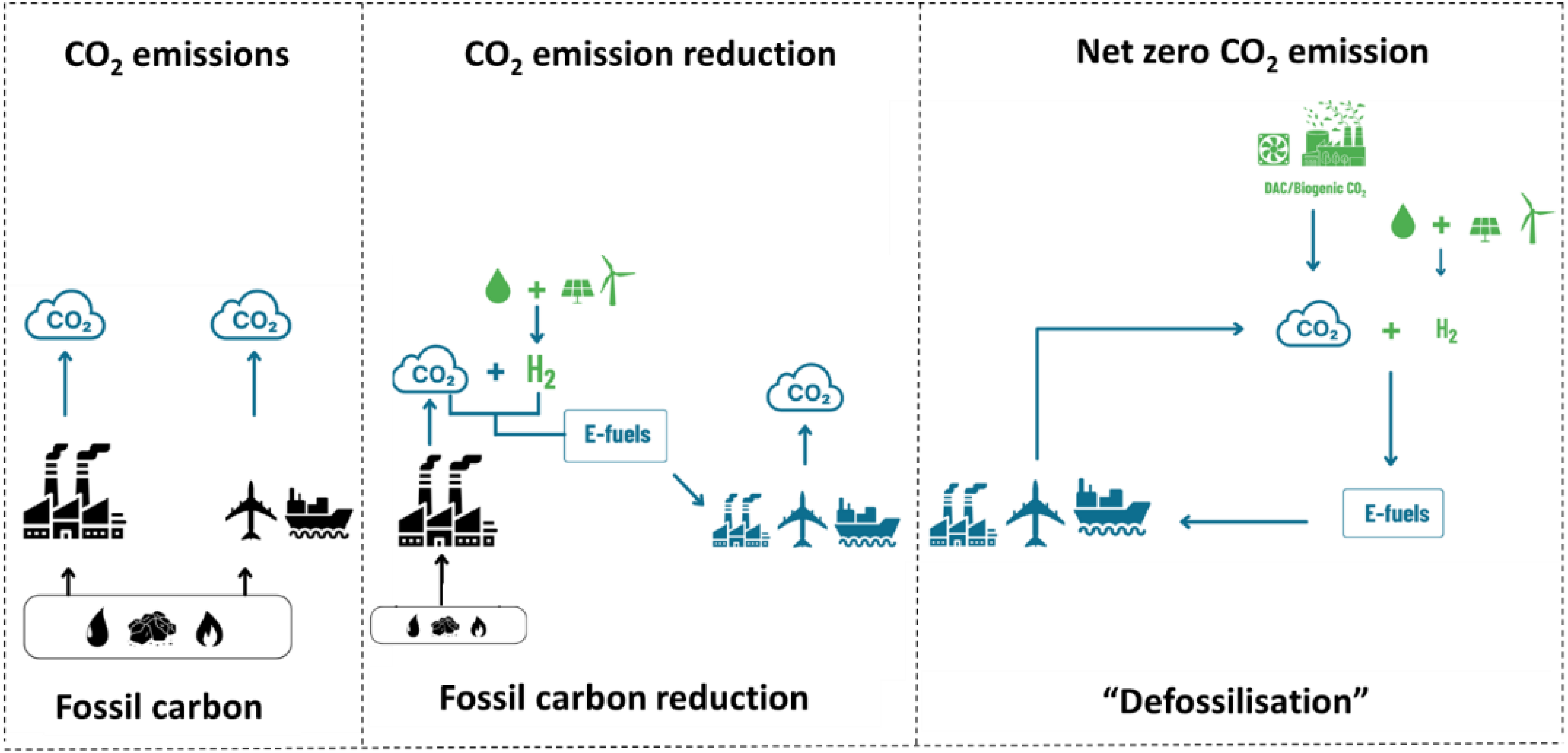
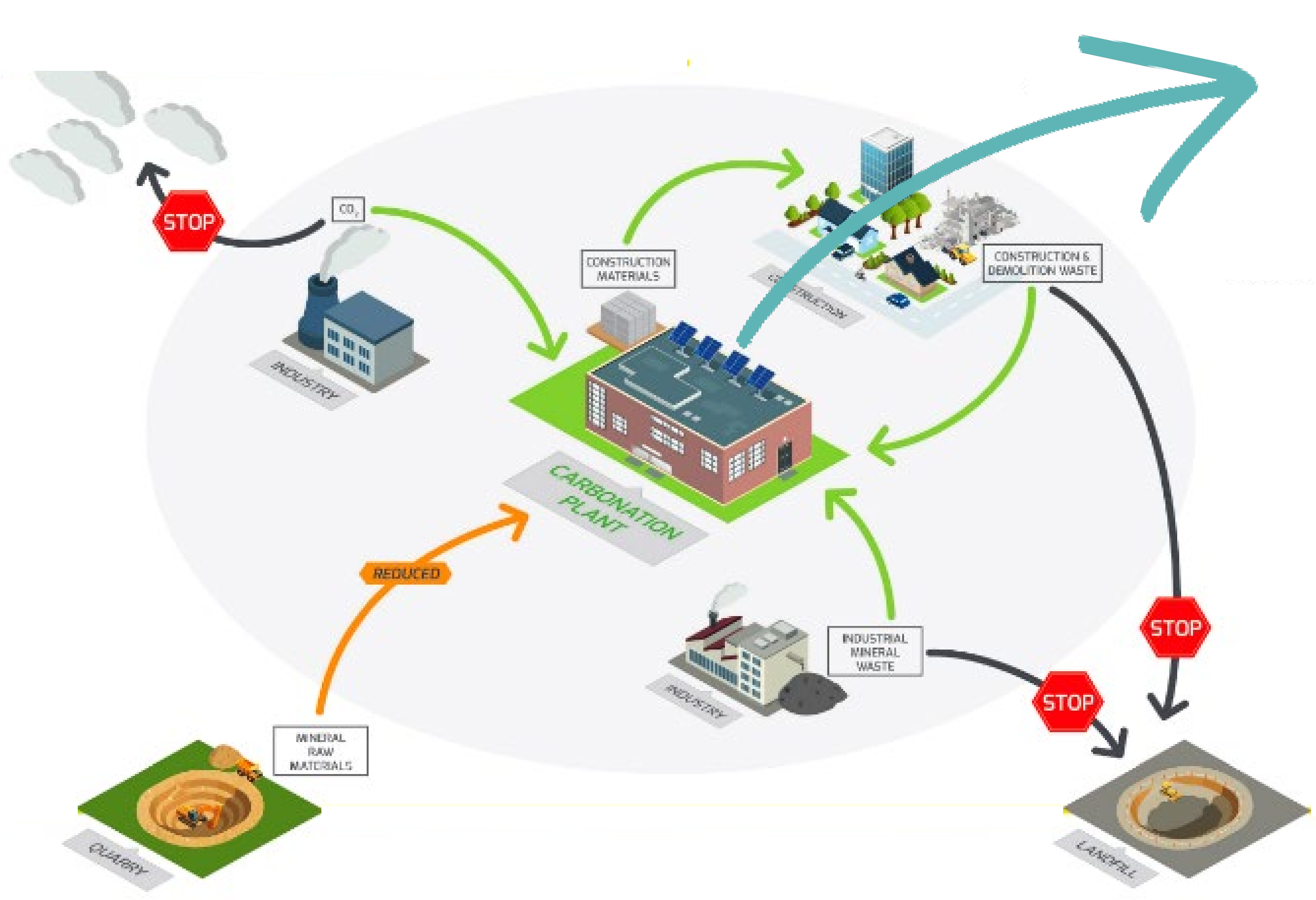
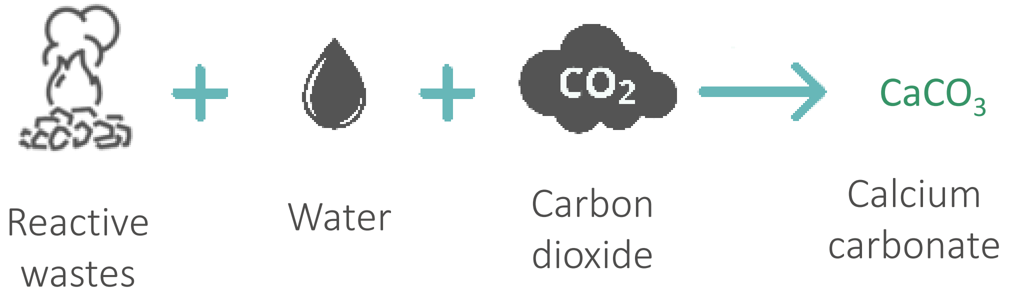
The role of renewable fuels and chemicals



Source: adapted from Mertens et al., Joule, 2023

The role of CCU in the building sector





- Reduction of **landfill**
- Reduction of **mineral raw material use**
- **CO_2 is stored permanently** in building material
- **Stronger and more sustainable** material

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There is an urgent need to quantify the contribution of CCU

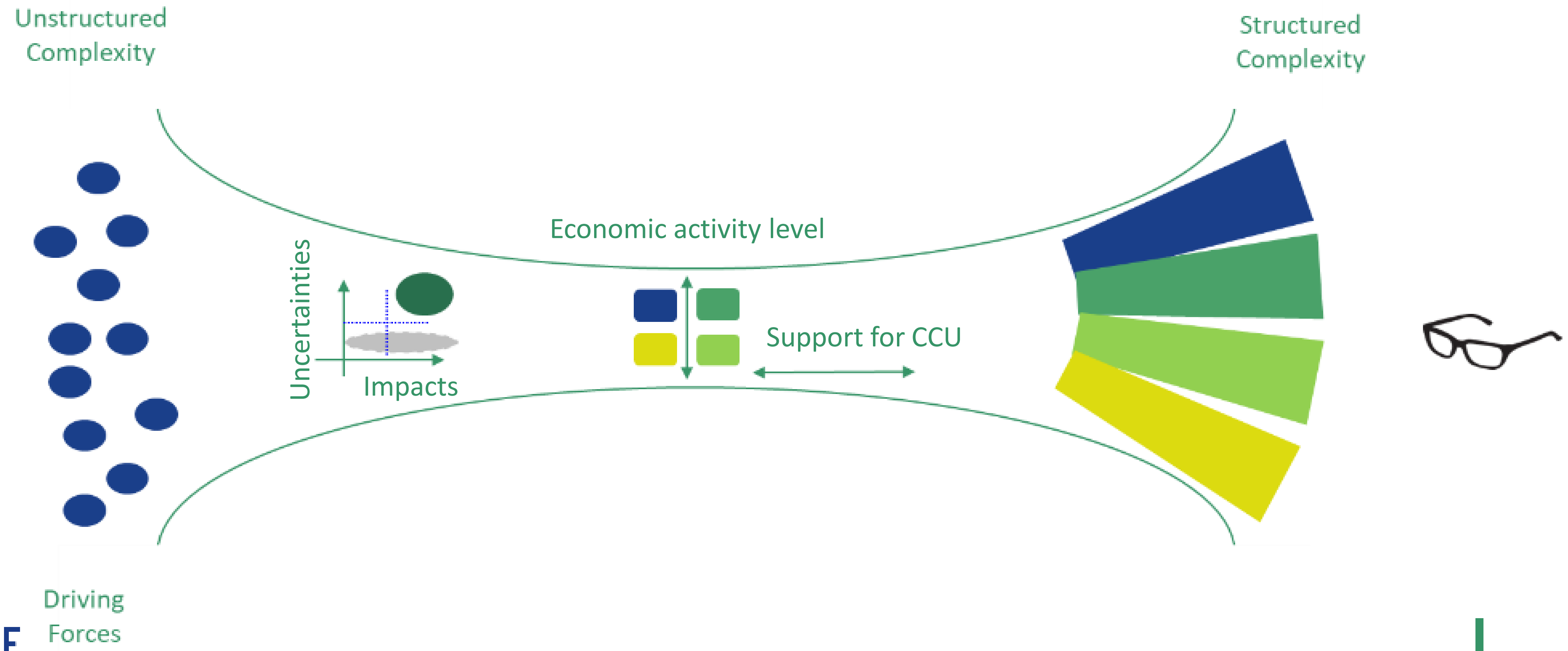
CCU has been so far largely neglected in climate and energy models; its contribution is not visible in future energy and climate projections.

CCU has not been so far integrated in studies that include a more holistic examination of different options (technological and not) leading to net-zero.

There is a lack of a foundational quantification of CCU, preventing policy making from presenting concrete and ambitious plans to accelerate CCU deployment.

Quantifying CCU mitigation potential: What was our approach?

1. Identification of the major driving forces and key uncertainties for the future deployment of CCU.
2. Development of contrasted scenarios => our Vision.
3. Identification of representative CCU pathways.
4. Development of the 2050 Pathways Explorer to model scenarios.



How was the CVE Expert Vision inspired?

	EU Emission reduction (vs 2022)	Final energy demand	Societal changes	Technology level	Carbon demand for CCU	% of CCU penetration	Electricity consumption (CCU/Total)	Water consumption	Material consumption	Impact on planetary boundaries	EU energy sovereignty
Salamander	-99%	7100 TWh	High	Medium	123 Mt CO_2	Fuels 9% Chemicals 5% Concrete 20%	22% 858 TWh/ 3970 TWh	Low	Low	Low	High
Phoenix	-85%	10300 TWh	Medium	High	305 Mt CO_2	Fuels 12% Chemicals 28% Concrete 20%	26% 1658 TWh/ 6360 TWh	High	High	Medium	High
Metropolis	-31%	14600 TWh	Low	Medium	5 MtCO2	Fuels 0% Chemicals 0% Materials 0%	2.5% 181 TWh/ 7440 TWh	High	High	High	Low
Icarus	-75%	7240 TWh	High	Low	9 Mt CO2	Fuels 1% Chemicals 0% Materials 0%	5% 130 TWh/ 2420 TWh	Low	High	Medium	Medium
Vision	-100%	8868 TWh	Medium-high	High	173 $MtCO_2$	Fuels 10% Chemicals 30% Concrete 20% Ceramics 76%	22% 1187TWh/ 5328 TWh	Medium	Medium	Low-Medium	High

Identification of representative CCU pathways

Groups		Technology			
		Name	Description	Container	Replacement
Usage	CCU-Fuels	E-Methane	through methanation ⚡ $+H_2+$ ☁ → CH_4	in synthetic methane	replaces natural gas
		Fischer-Tropsch process	through Fischer-Tropsch process ⚡ $+H_2+$ ☁ → Synthetic fuel	In synthetic liquid fuel	replaces liquid fossil fuels
		e-Methanol	through methanol synthesis ⚡ $+H_2+$ ☁ → Synthetic methanol	In synthetic methanol	replaces maritime fuels
	Chemicals	e-MTO	MTO with synthetic methanol ⚡ $+H_2+$ ☁ → Synthetic methanol → Olefins	In Olefins	Fossil based olefins
		e-Dehydration	Dehydration of synthetic ethanol ⚡ $+H_2+$ ☁ → ⚡ +Synthetic ethanol → Olefin	In Olefins	Fossil based olefins
	Buildings materials	Cement CO_2 curing	Curing to store carbon in the concrete Cement + ☁ → Concrete	In concrete	Concrete with water-based curing
		Mineralisation in industrial waste	Carbon bricks ⚡ + ☁ + Ca/Mg+… → Ceramic	In ceramics	Ceramic bricks
Storage	Industry	CCS	Capture of industrial emissions	stored	/
	Energy supply	CCS	Capture of energy supply emissions	stored	/

Legend	
⚡	Power
☁	CO_2
H_2	Hydrogen

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The 2050 Pathways Explorer for CCU: a unique model

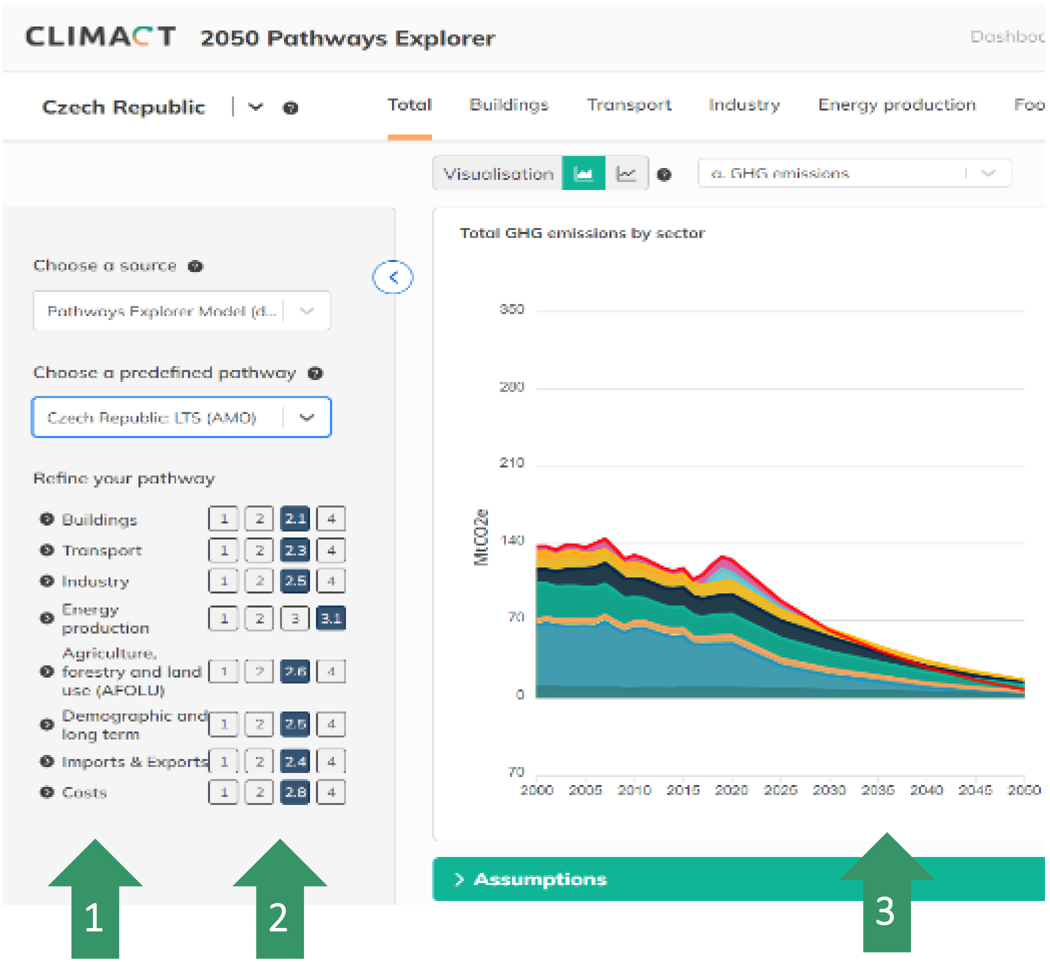
The Pathways Explorer provides a **robust analytical foundation**, enabling the development of **energy transition scenarios**.

Behind the process is **an open-access web-based tool** which enables to explore possible futures and assess the implications and trade-offs of their choices.

Simulations can be **performed in real time** offering a direct understanding of the key levers of the low carbon transition.

The exploration scope encompasses **the energy system and its dynamics, all GHG emissions**, and the associated resources and socio-economic impacts.

1. Per sector, **a wide range of 'levers' is provided** (i.e. what will happen with efficiency, fuel & technology mix, etc.).
2. **For each lever, an** ambition level **has to be set** (Level 1: minimum - Level 4: disruptive/transformational change).
3. **The model provides** outputs on a number of KPIs (i.e. emission, per sector, energy, costs; all every 5 years).



How the Pathways Explorer works (in a nutshell)?

User inputs

User can make assumptions about:

Socio-demographic evolutions	(e.g. population growth, household size, urban vs. non-urban population, ...)
Societal choice	(e.g. mobility demand and modes, housing surfaces & renovation rates, diets, product use and lifetime, land management, ...)
Technological evolutions	(e.g. energy mix, energy efficiency, production technologies, carbon capture rates, ...)
Economic parameters	(e.g. price trajectories for fuels, materials and technologies, import/export rates, ...)

Based on CVE EXPERT VISION

Model outputs

Model provides impact on:

GHG emissions and removals	(per sector, per technology)
Energy use	(per carrier, per sector, per technology, ...)
Product demand and activity levels	(e.g. Demand for steel, cement, construction materials, plastics, ... and much is produced via each technology route)
Costs (not yet implemented)	(CAPEX, OPEX, fuels) NOTE: Costs are calculated *ex post* (not an optimization)

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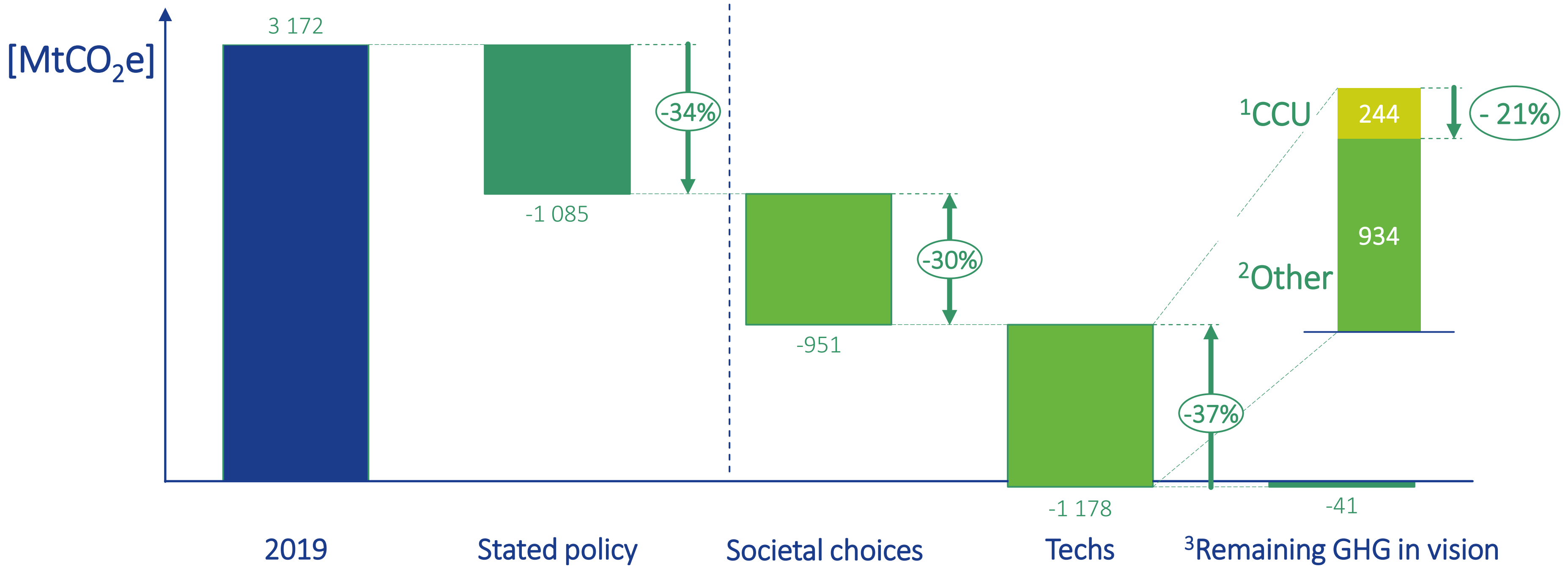
RESULTS: What is the contribution of CCU to reach climate neutrality in the EU?

Impact of categories of actions to reduce **overall GHG emissions in the EU until 2050**



Total EU GHG emissions

Emission reduction resulting from stated policy in 2050 (based on a projection of the EU27 WEM scenario version 2022)

EXPERT VISION SCENARIO including emission reduction and CO_2 removal (e.g. DACCS and DACCU)

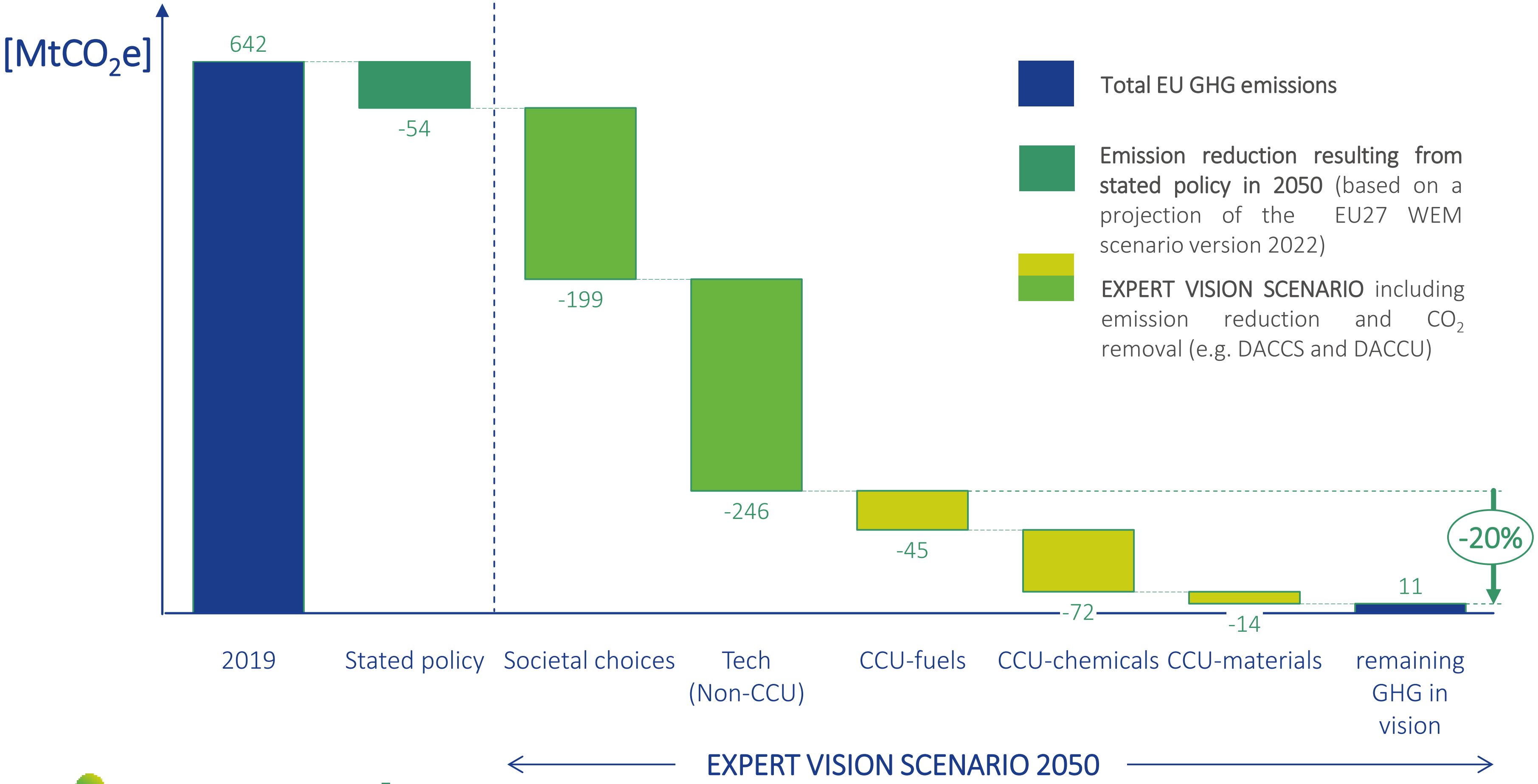
Key results

CCU technologies are essential to reduce GHG emissions and **will contribute to about 8% of the road to net zero emissions in the EU.**

NOTES: [1] This includes benefits from CCU fuels imported from outside of Europe.
[2] Others: Aggregates benefits of actions from low carbon electrification, technology switch, efficiency improvements, fuel switches and CCS
[3] Final value in 2050 is sensitive to small changes in the modelling and can go from -50 Mt to +50Mt due to high sensitivity of results for land-use carbon sinks.

RESULTS: What is the role of CCU to de-fossilise the industry?

Impact of categories of actions to reduce GHG emissions in the industry until 2050



Key results

- **CCU can reduce by at least 20% GHG emissions** by using captured carbon as feedstock in the chemical industry (11%), by using CCU fuels (7%) and by capturing CO_2 permanently in building materials via mineralization (2%).

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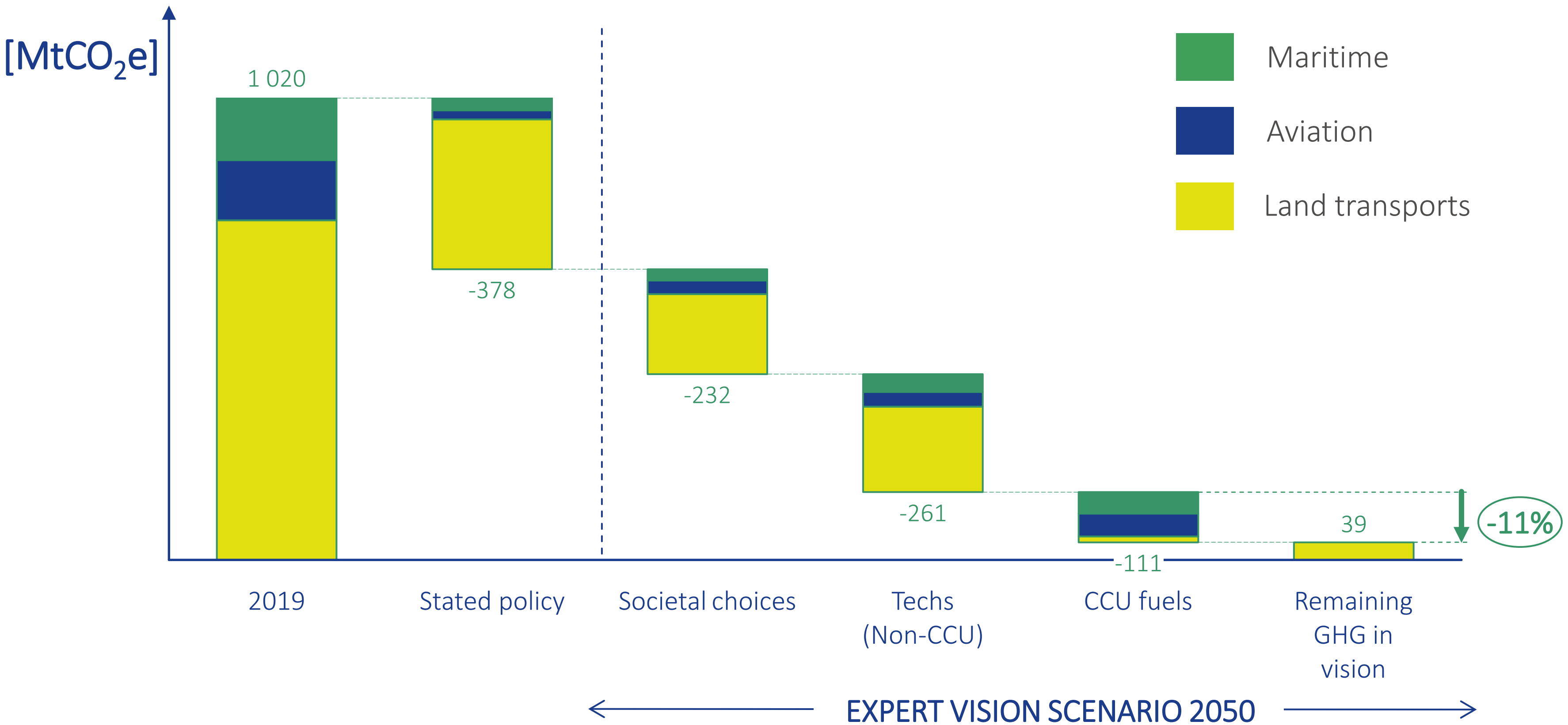
NOTE: Every increment to the right represents the net reduction in emissions that is enabled by the represented category of assumption. This does not correspond to negative emissions or any form of Carbon Direct Removal (CDR)

RESULTS: What is the role of CCU in the transport sector?

Impact of categories of actions to reduce greenhouse gas emissions in transport until 2050



Key results

- By 2050, **11% of emission reductions in transports will be coming from CCU** fuel usages reducing emissions from the maritime, aviation and inland transports by 35%, 38% and 2% respectively.

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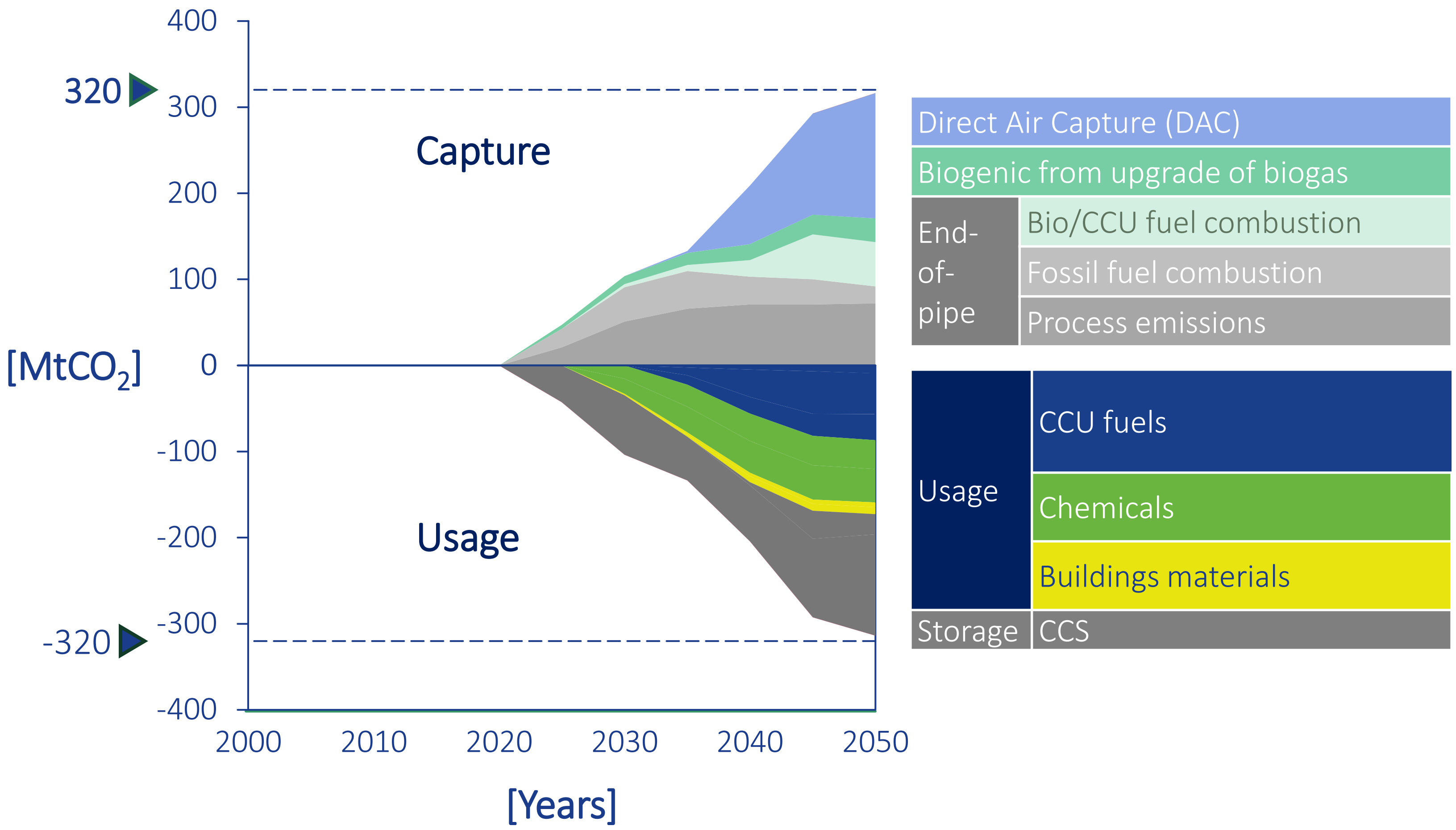
NOTES: (1) Every increment to the right represents the net reduction in emissions that is enabled by the represented category of assumption. This does not correspond to negative emissions or any form of Carbon Direct Removal (CDR).
(2) Inland Water Ways (IWW) are included in Land transport.

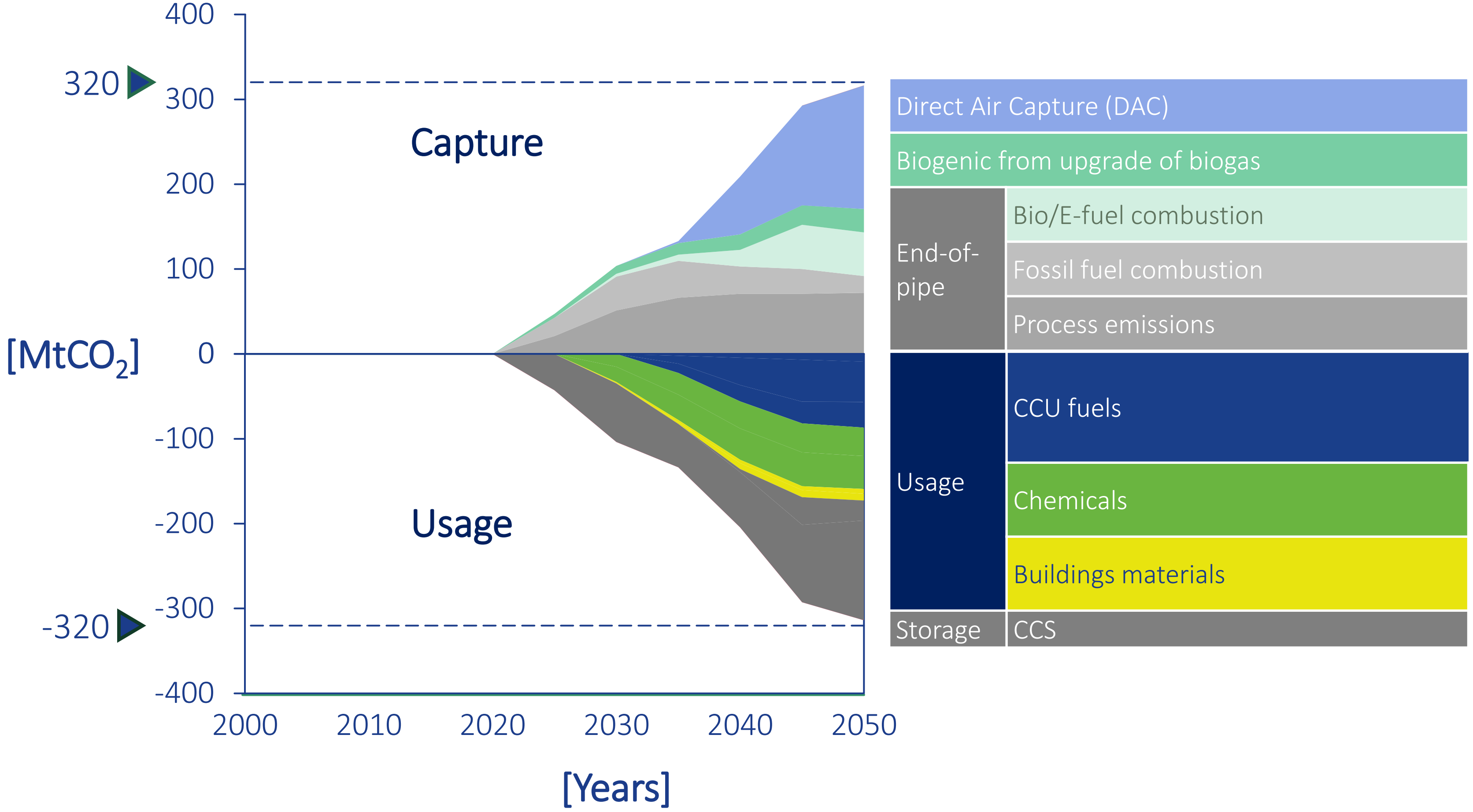
RESULTS: Which type of CO_2 will be captured and for which applications?



<u>Key messages</u>

- In 2050, **55% of the captured carbon will be used as feedstock** to answer the non-fossil carbon demand and the rest will be stored underground via CCS.
- From **the 173 $MtCO_2$ utilized, 50% will be used to produce fuels, 42% for chemicals production and 8% will be mineralized in building materials.**

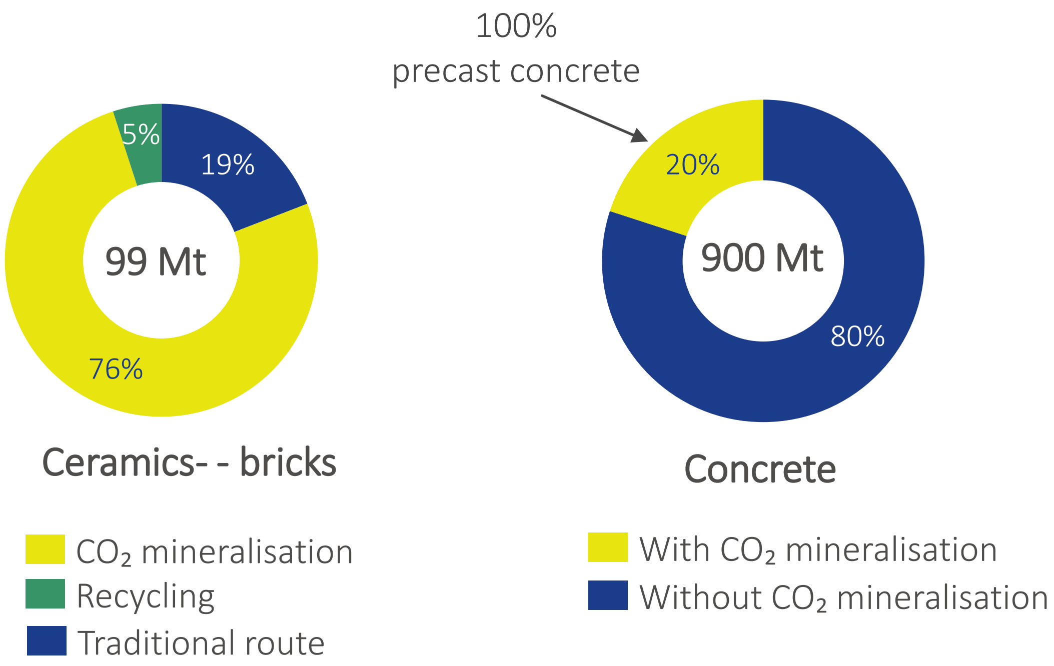
RESULTS: Which type of CO_2 will be captured and for which applications?



	Share	Mt CO_2
CO_2 from biogenic sources	23%	72.6
CO_2 from CCU-fuel combustion	2%	6
CO_2 from fossil fuel combustion[1]	6%	20
CO_2 process emissions	23%	72
CO_2 from DAC	46%	147

	Share	Mt CO_2
CO_2 used for fuels production	28%	87
CO_2 used in chemicals production	23%	72
CO_2 stored in building materials	4%	14
CO_2 stored as CCS	45%	141

RESULTS: What will be the share of CCU products in building materials?

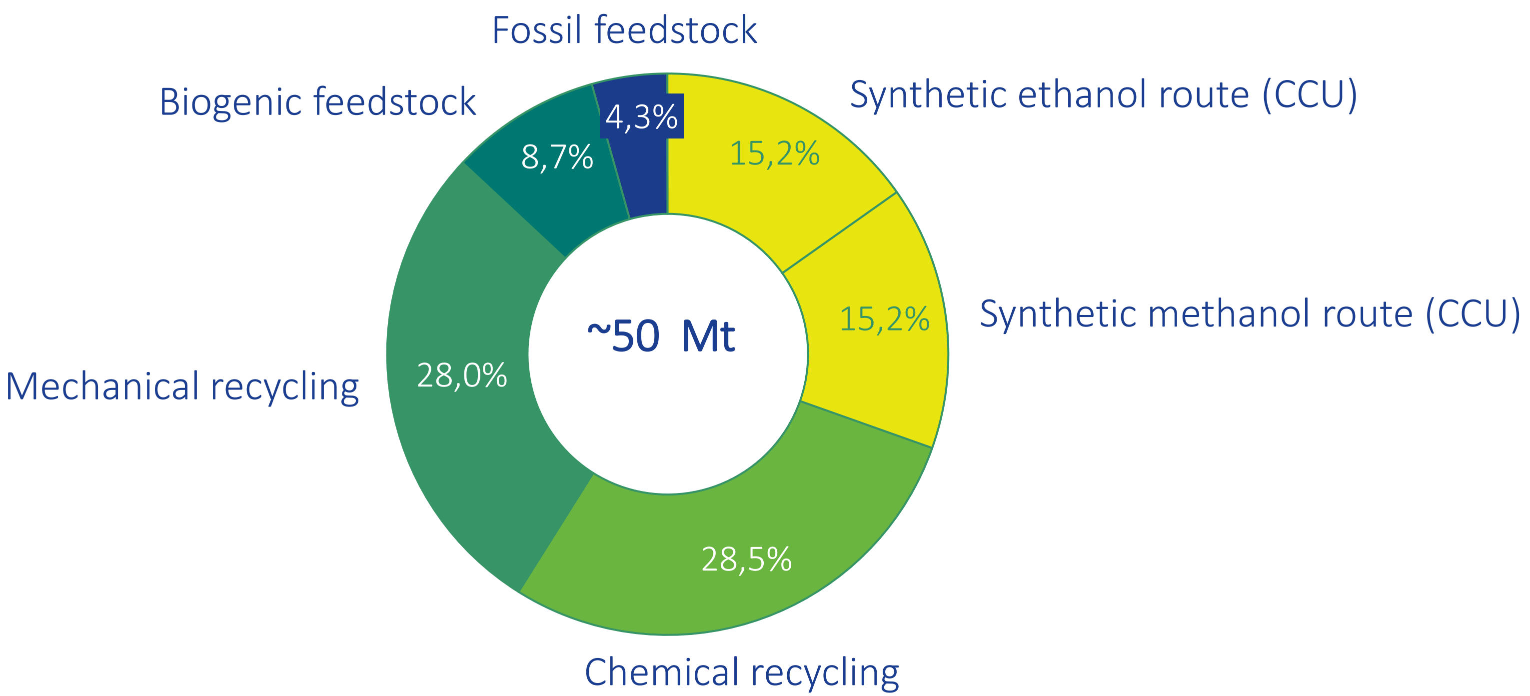


Building materials production [Mt]

<u>Key results</u>

- Mineralisation has the potential to **sequester permanently at least 4% of the carbon captured and will represent 10% of the storage capacity.**
- By 2050, this process will produce at least **76% of total ceramics/bricks production (99Mt) and 20% of the EU concrete (900Mt) will be CO_2-cured**.
- Other potential breakthrough technologies have not been considered and may increase significantly these numbers.

RESULTS: What will be the share of CCU products in the chemical industry?

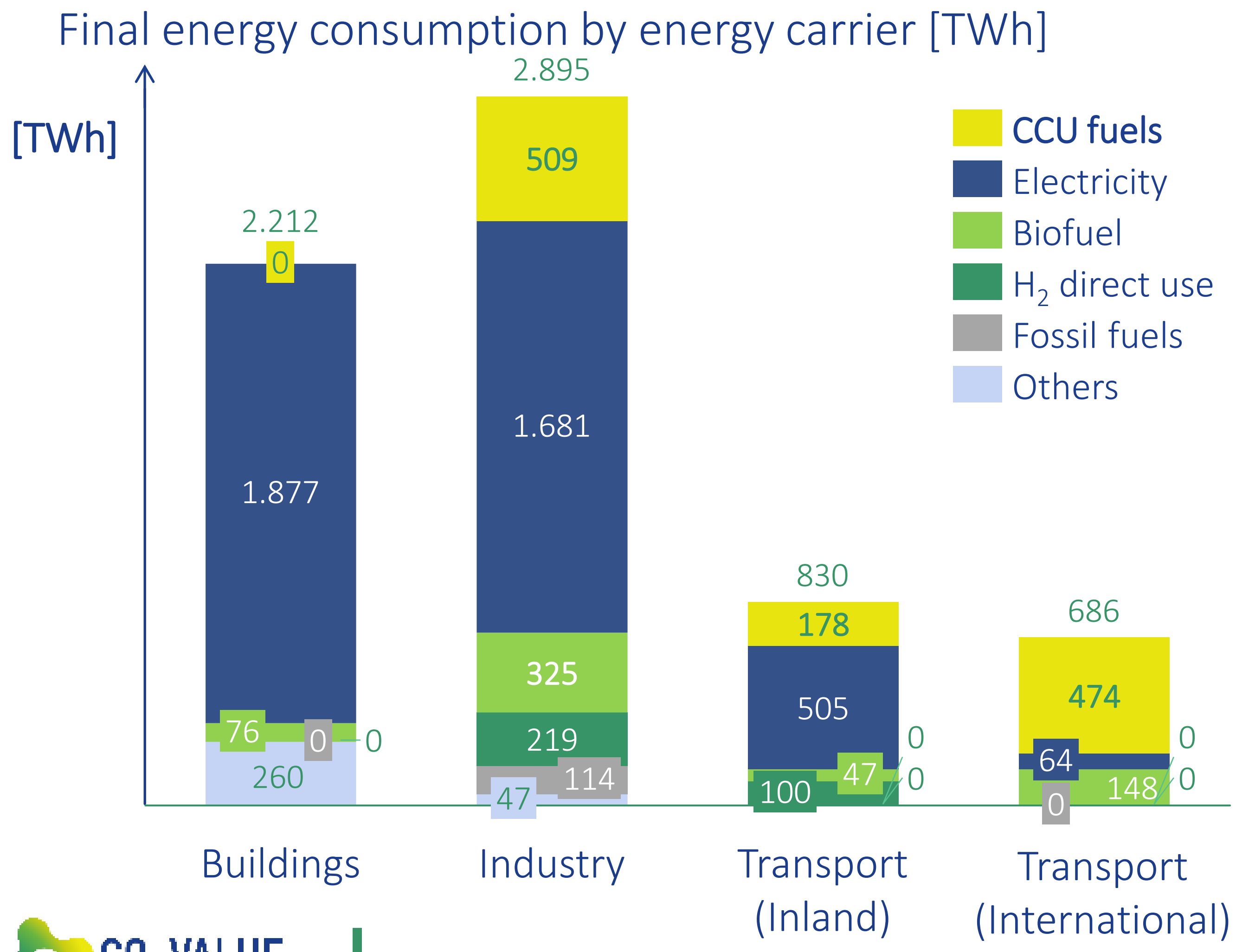


Chemical (Olefin) production [Mt]

Key results

- **CCU olefins represent approx. 2/3 of primary olefin production** and the CCU share represents approx. 30% of the total olefin production (primary and secondary).
- This is coupled with a reduction of demand (65Mt → 50Mt).

RESULTS: In which sectors will CCU-fuels be used?

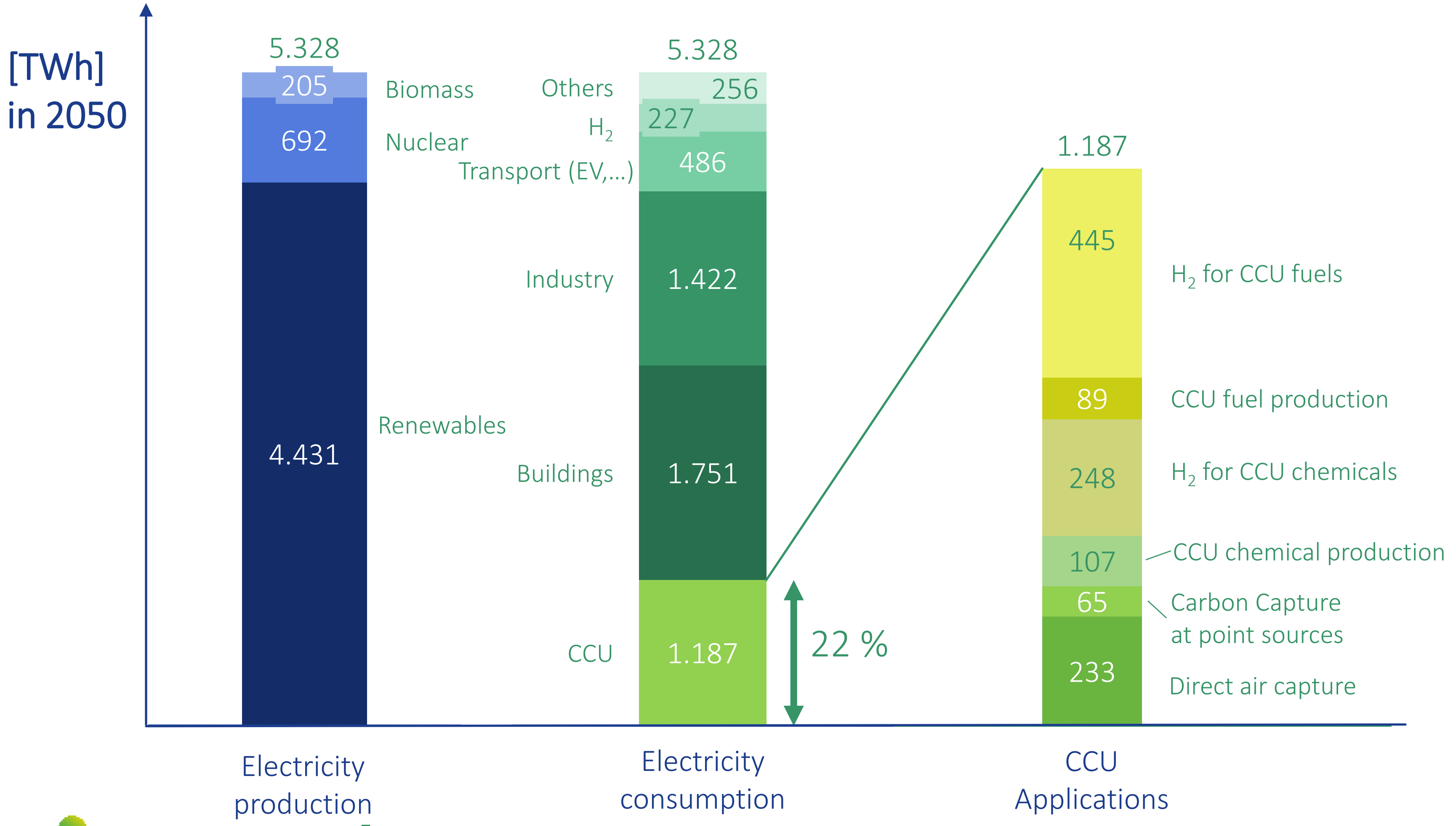


<u>Key results</u>

About 1161 TWh of CCU fuels will be consumed by 2050 (17,5% of total final energy consumption), mainly:

- In aviation and maritime transport (474 TWh)
- To replace fossil fuels in industries (509 TWh)
- In heavy duty road vehicles and fluvial transports (178 TWh)
- **It represents a share of 69% (Transport Int), 21% (Transport Inl) and 18% (Industry).**

RESULTS: What will be the electricity consumption of CCU applications compared to other sectors?



Key results

- The **domestic production of CCU fuels and chemicals for the transport and industry sectors will require up to 1187 TWh** in 2050 which represents approx. 22% of the modelled low carbon electricity production in the EU by that year..
- Imports of CCU fuels (45%) and/or H_2 (30%) from regions with abundant RES-electricity are necessary to limit electricity demand and costs.

NEXT

This exercise is the first stage of a continuous process to monitor and quantify the contribution of CCU towards climate neutrality in the EU.

One of the main results is the creation and maintenance of the first-of-a-kind, open-access, web-based tool to explore and contextualise the contribution of CCU in the EU.

The next stages will focus on:

- **Adding more CCU technological pathways in the model, especially biogenic sources such as Pulp&Paper, etc.**
- **Calculating costs**
- **Implementing our approach at national level**
- **Better quantifying the impact of technological developments on environmental limits**

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A SCENARIO DEVELOPMENT AND MODELLING EXERCISE

Full report:
https://co2value.eu/wp-content/uploads/2024/01/FINAL-LAYOUT_CVEs-EU-Roadmap-for-CCU-by-2050.pdf

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Thank you!

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