THE CONTRIBUTION OF CCU TOWARDS CLIMATE NEUTRALITY IN THE EU

A SCENARIO DEVELOPMENT AND MODELLING EXERCISE

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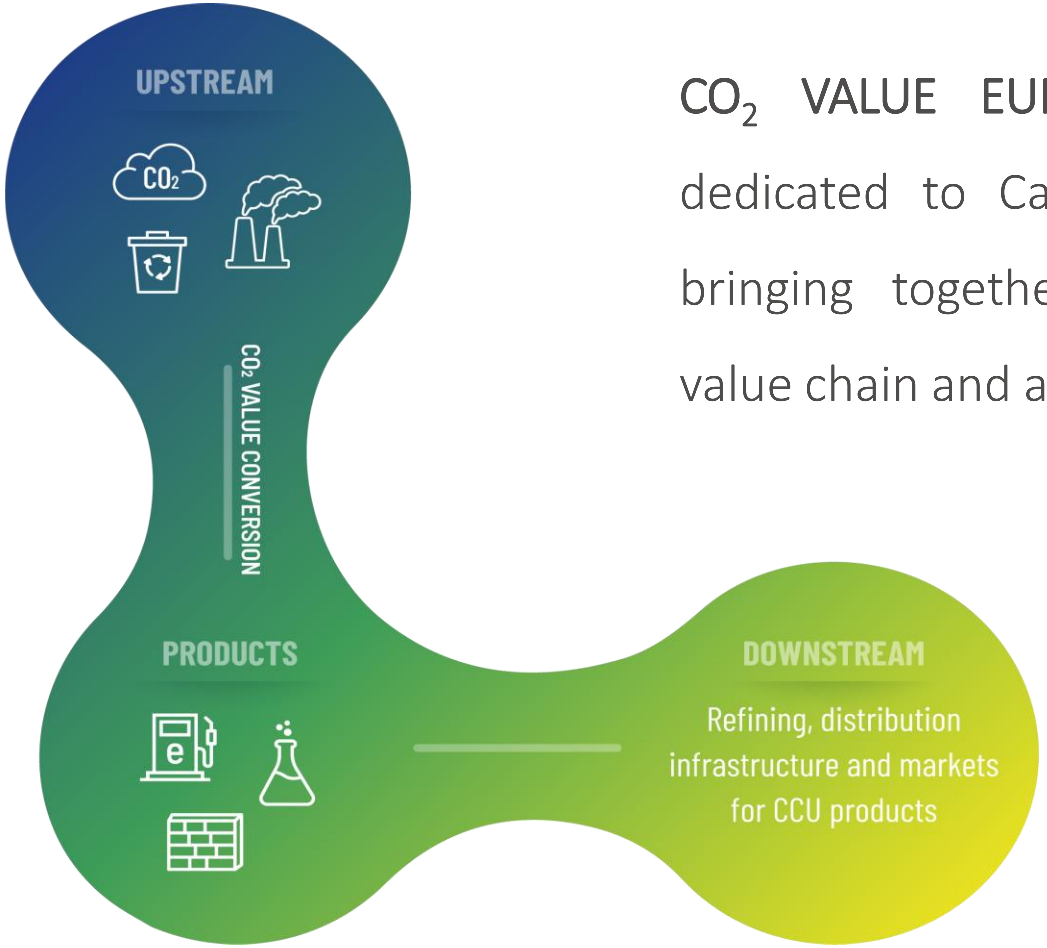


CO_2 VALUE EUROPE is the European association dedicated to Carbon Capture & Utilisation (CCU), bringing together stakeholders from the complete value chain and across industries.

Why do we need quantify the contribution of CCU in the EU?

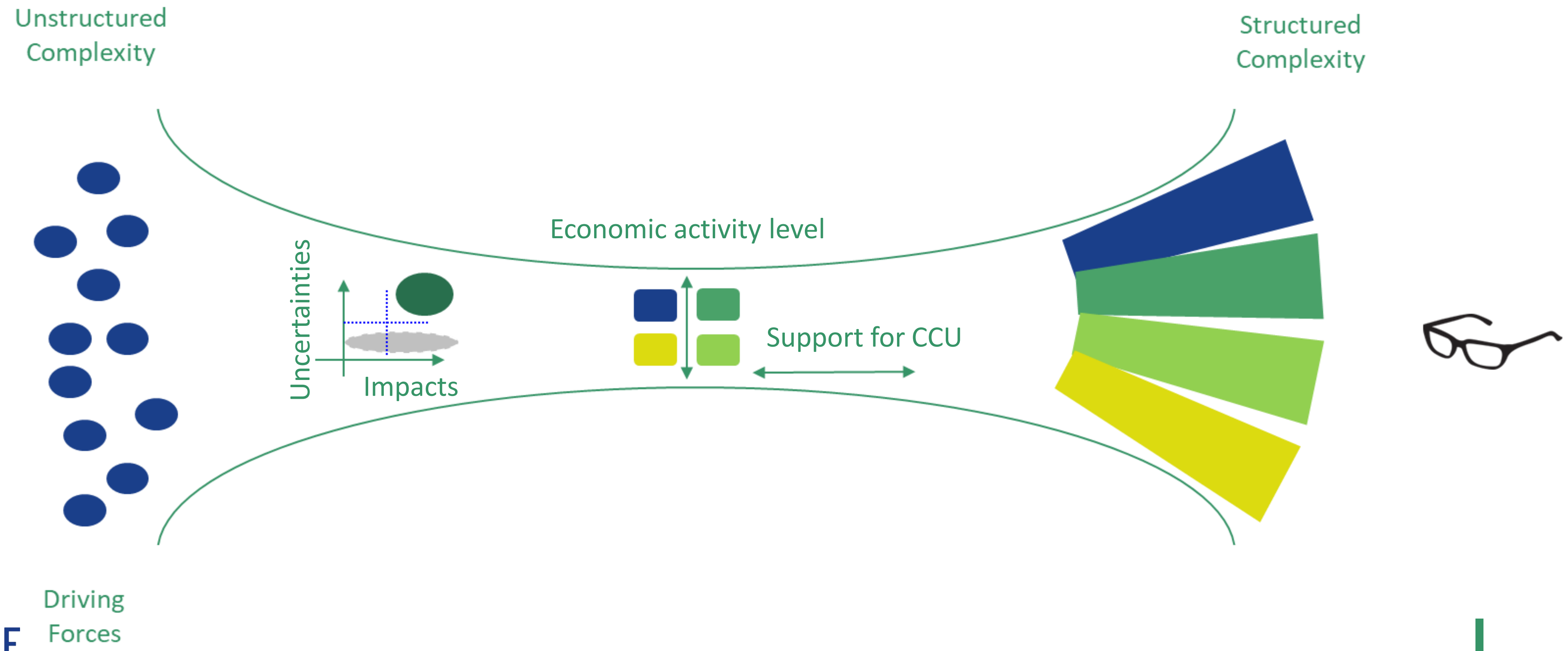
CCU has been so far largely neglected in climate and energy models; its contribution is not visible in future energy and climate projections.

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.

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.



Development of contrasted scenarios

High economic activity levels

Metropolis

- Populist, individualist society; emphasis on cost-efficiency
- Geopolitical instability reduces globalization; protectionism prevails
- EU invests in renewables, nuclear and recycling to become more independent
- Opportunistic «greening» as long as economic opportunity
- Emphasis on CCS & blue H_2, CCU starting late depending on backbone status.
- Social acceptance based on the «feel less guilty» principle
- Opportunistic partnerships, new colonialism, more inequality spread everywhere

Phoenix

- United EU, policy-driven and society-backed course towards sustainability
- Shift from consumerism to service providing
- Technology-oriented, reindustrialisation
- EU not self-sufficient, outward looking for structural partnerships (client/investor)
- Strong investments in infrastructure (grid, CO_2, hydrogen)
- Balanced approach in high/low TRL funding from public and private sources
- CCU having an important role, DAC, e-fuel imports

Smaller role/support for CCU

Larger role/support for CCU

Icarus

- Geopolitical turmoil leads to economic recession and confrontations
- Inward looking societies; investing in military
- Focusing on recycling, low-tech, low-efficiency, high product life solutions
- Change in consumption, lifestyle patterns out of necessity (poverty), not choice
- Massive migration pressure
- No room for innovation and investment, CCU very limited (linked to some sectors)
- Temperature beyond Paris limits; other short-term priorities than climate

Salamander

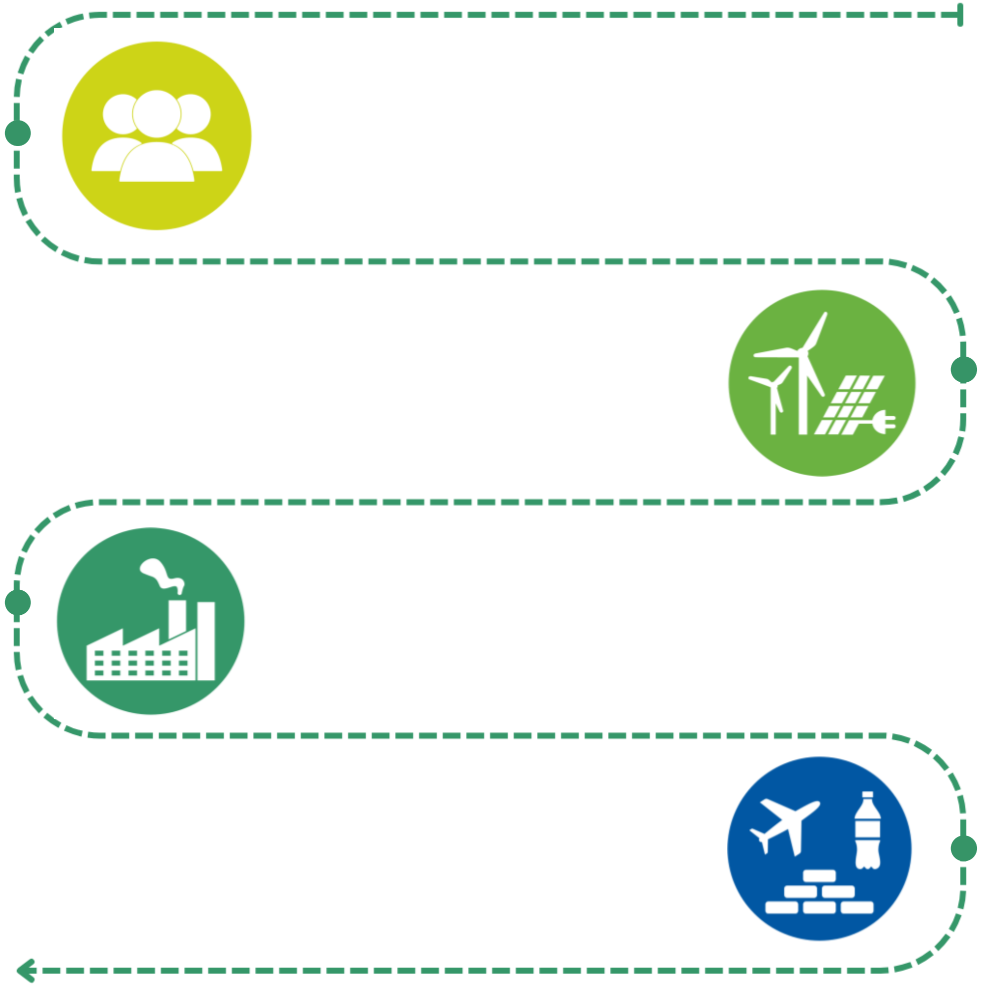
- Conscious lifestyle changes; well-being over financial wealth; in sync with nature
- Systematic valorisation of waste and strong focus on circularity
- Reduced investment capacity, focus on education of new generations
- Resources shared within EU, strong united front
- Carbon recycling is BAU, driven by the non-abatable sectors; no fossil investments
- Reduced industrial production, decentralization, more systems integration
- Consumer acceptance of CCU products

Low economic activity levels

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

CVE Expert Vision: The 4 Pillars of the scenarios



Societal Choices

Reducing energy demand requires a societal switch towards more sustainable behaviours, including sobriety, frugality and circularity.

Technological Investments and Energy Efficiency

Decarbonisation requires a massive switch towards renewable energy sources, coupled with massive electrification. Circularity in the industrial sector and improved energy efficiency in buildings is also key.

Carbon Capture

For sectors where full decarbonisation is impossible/the most difficult: cement process emissions, steel industry, etc.

CCU Products (Circularity)

Recycling of captured carbon through CCU products: building materials, chemicals, CCU fuels for shipping and aviation and heavy road transport

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

The 2050 Pathways Explorer for CCU: a unique model

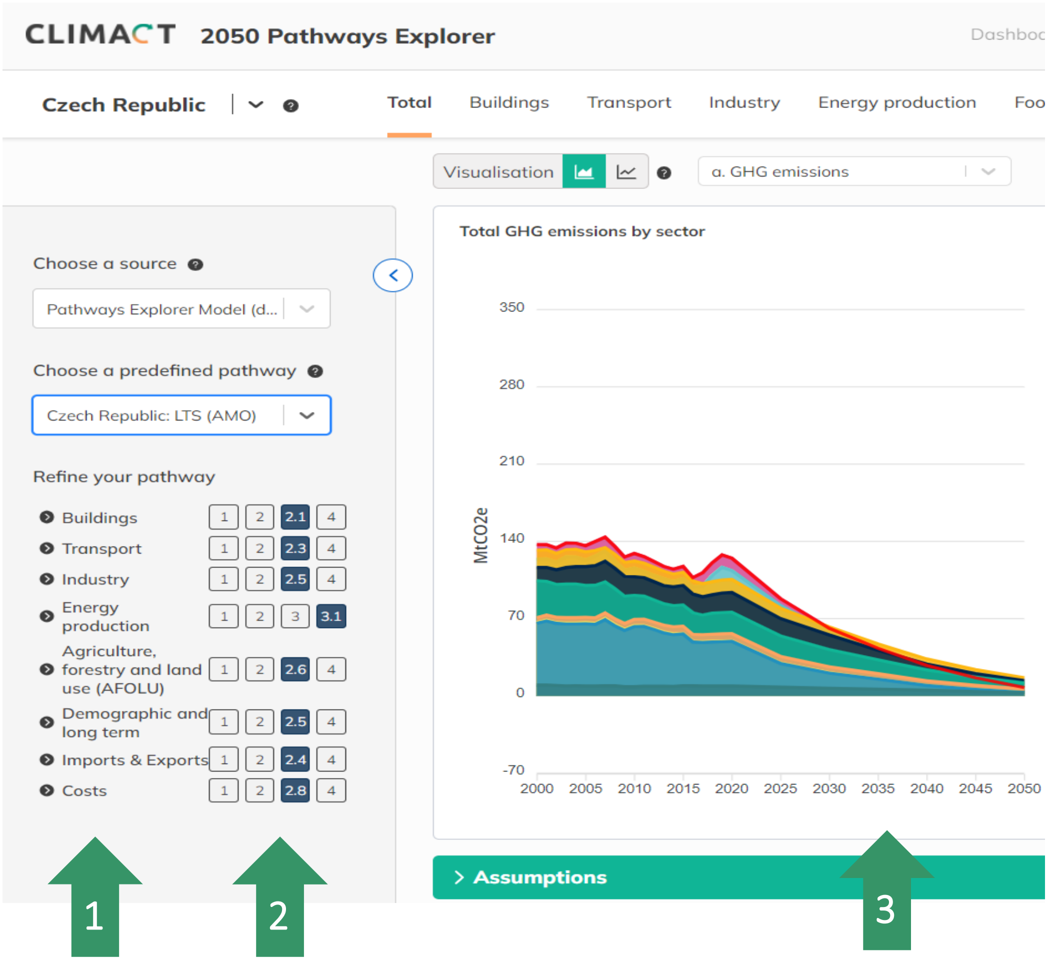
The Pathways Explorer provides a **robust analytical foundation**, enabling the development of **energy transition scenarios**.

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

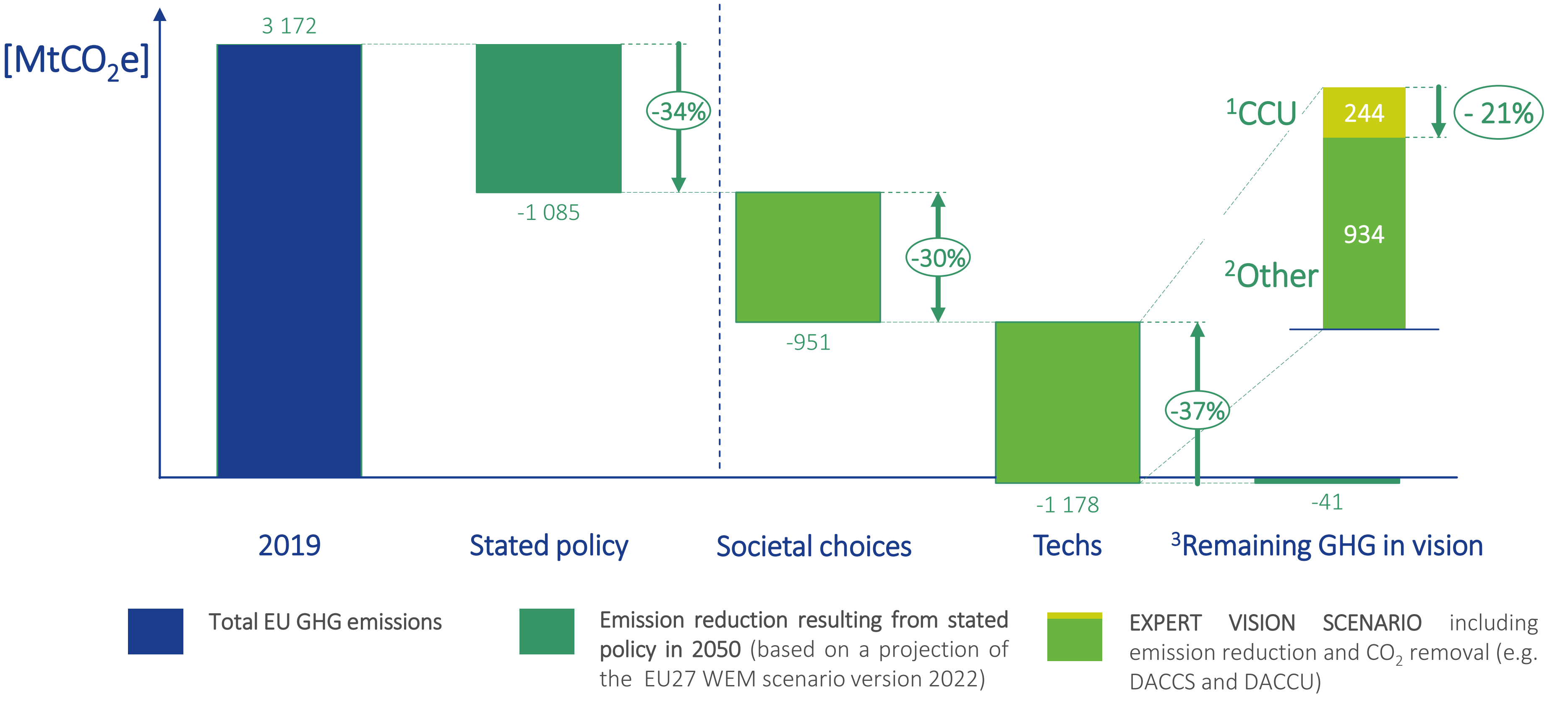
Model outputs

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)

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



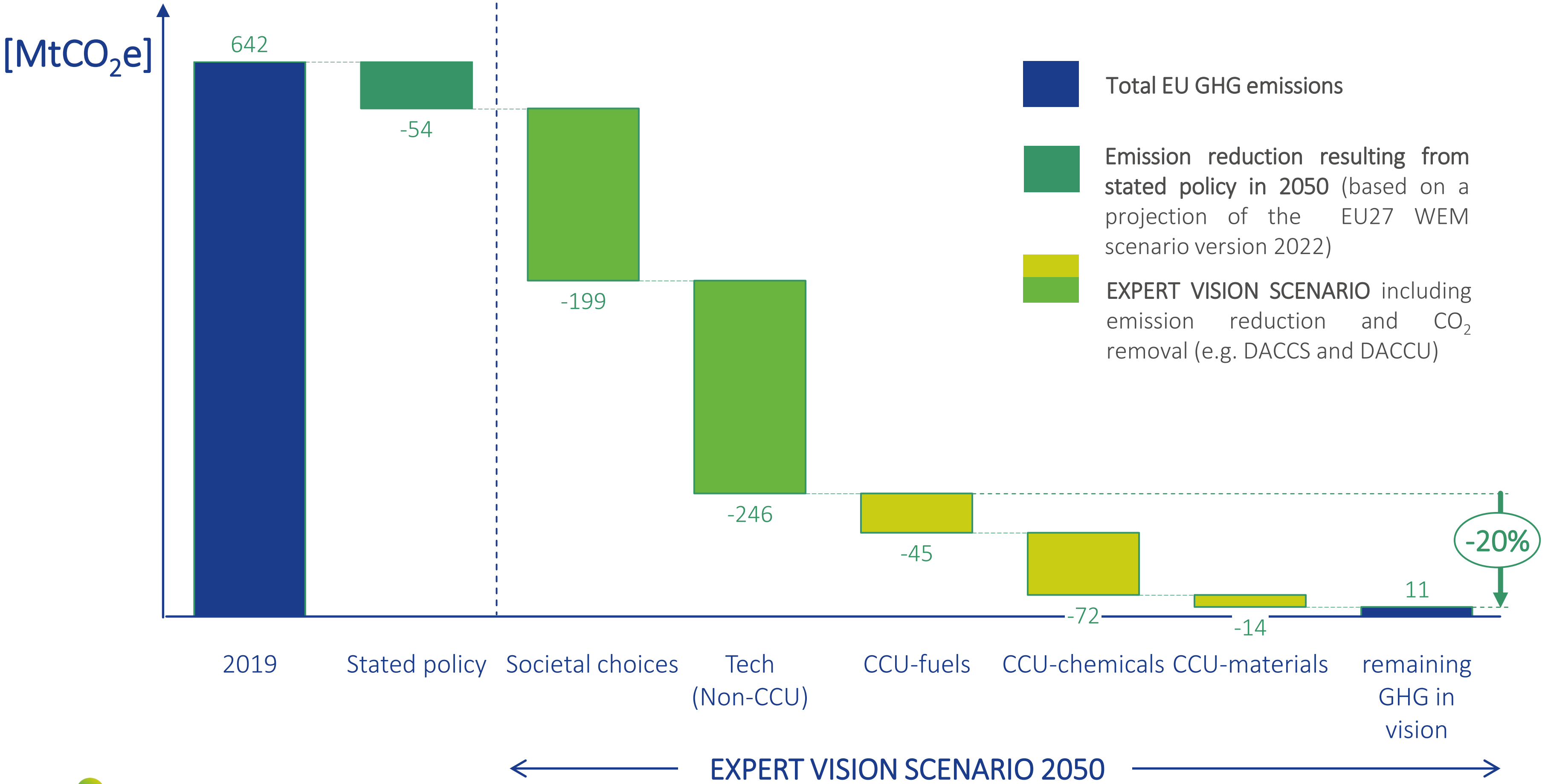
Key results

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



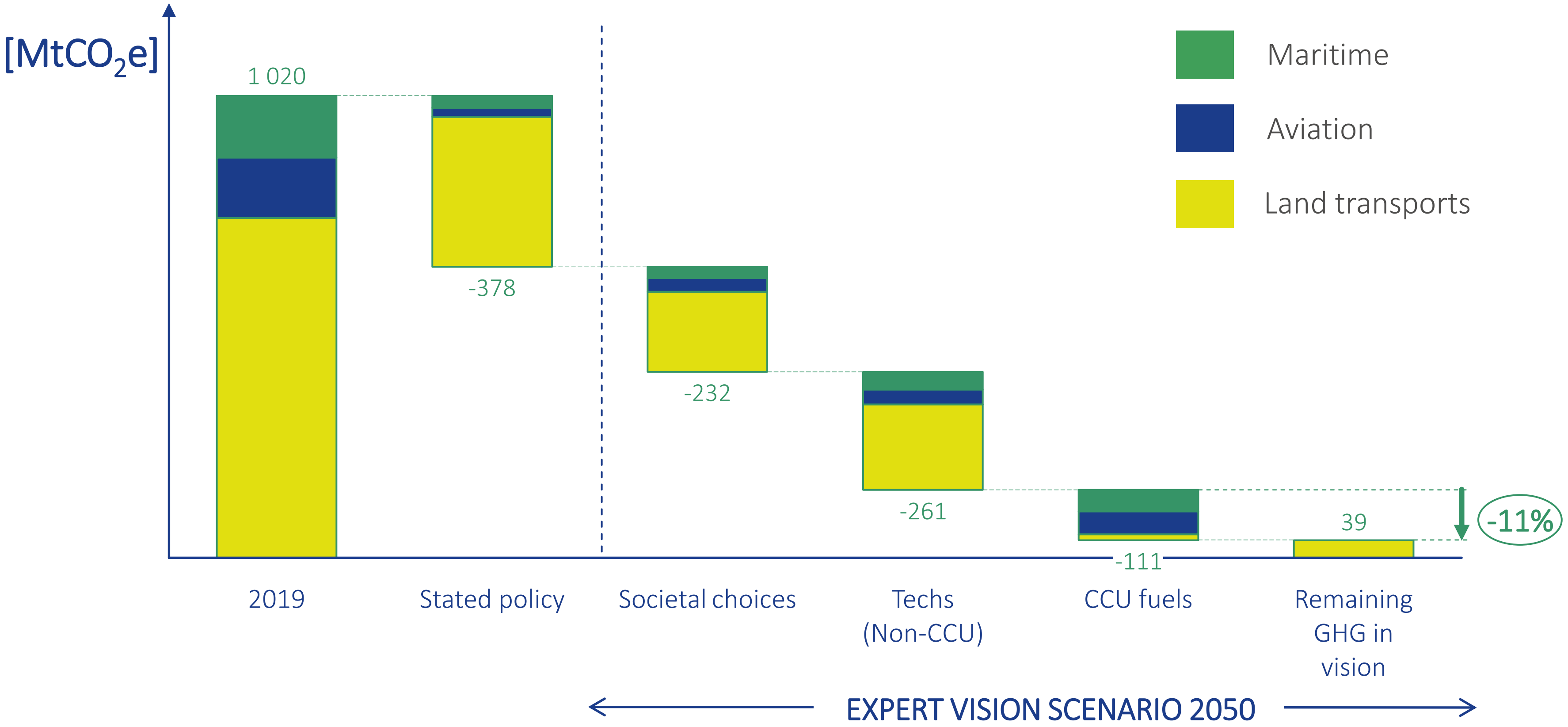
Key results

- **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%).
- To reach net zero, residual emissions, e.g. from process emissions will need to be compensated by Carbon Dioxide Removal (CDR).

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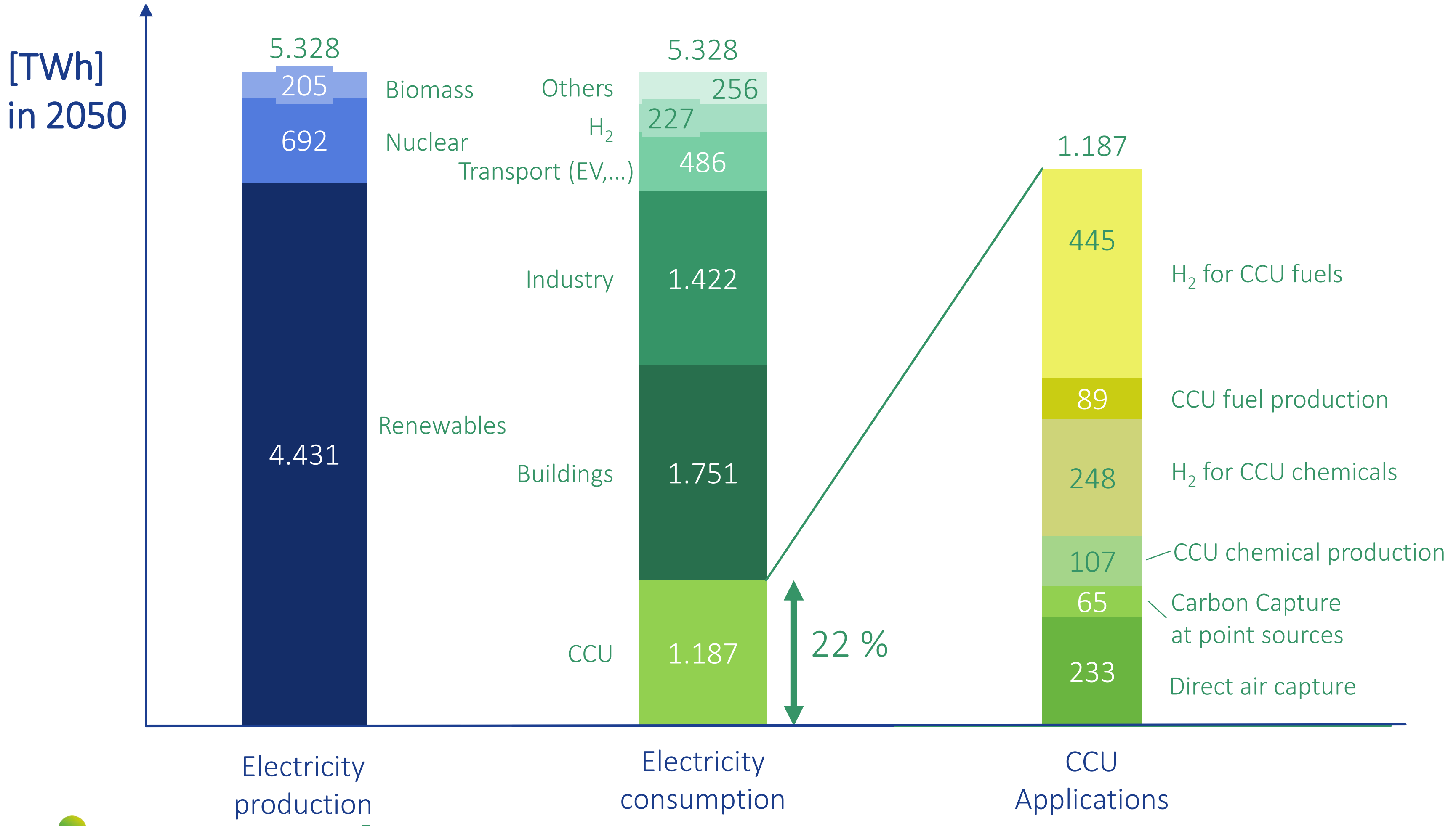
NOTES: (1) Every increment to the right represents the net reduction in emissions that is enabled by the represented category of assumption. This does not correspond to negative emissions or any form of Carbon Direct Removal (CDR).
(2) Inland Water Ways (IWW) are included in Land transport.

RESULTS: 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.

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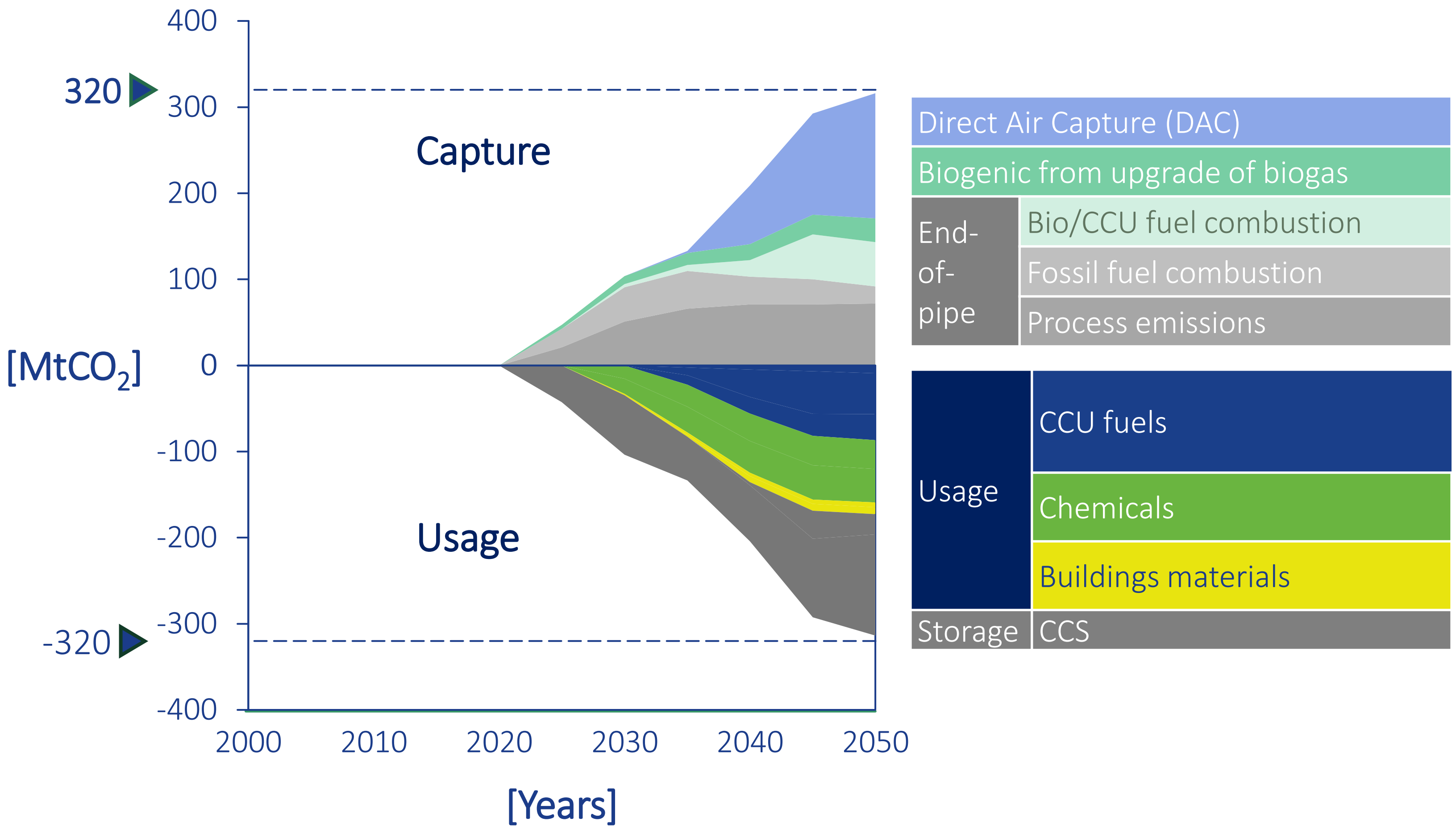
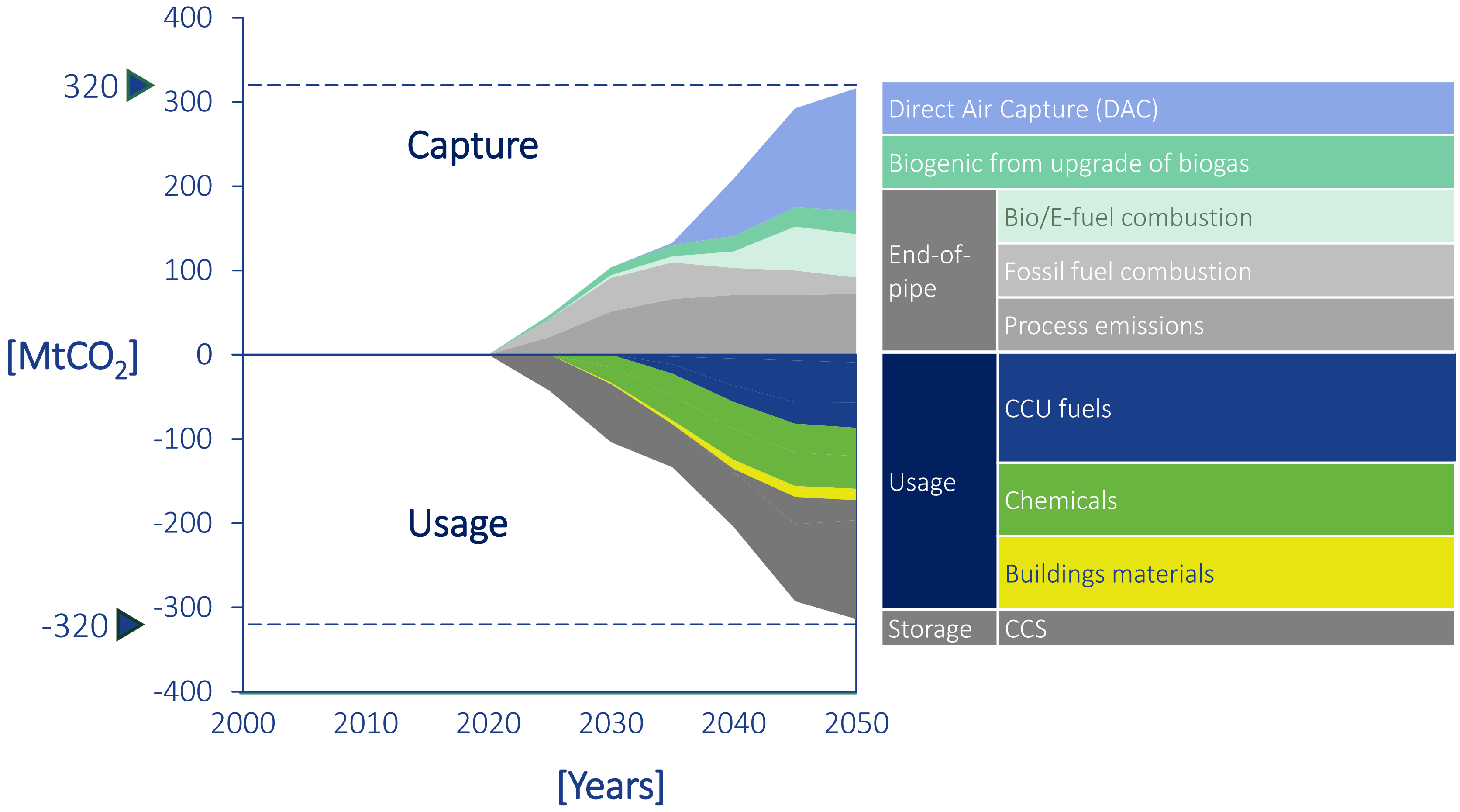
RESULTS: Which type of CO_2 will be captured and for which applications?



Key messages

- 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

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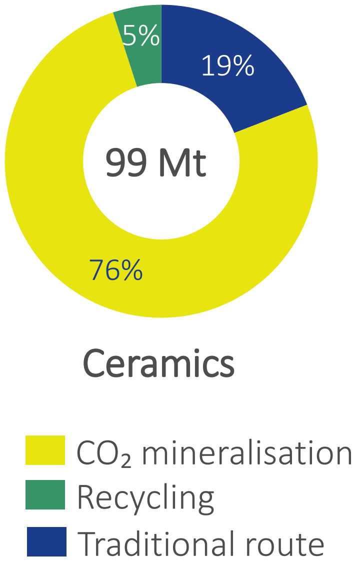
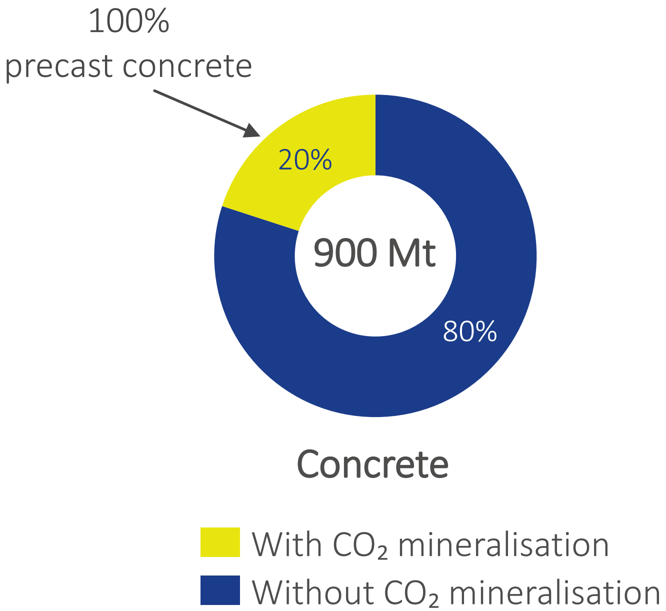
RESULTS: What will be the share of CCU products in building materials?



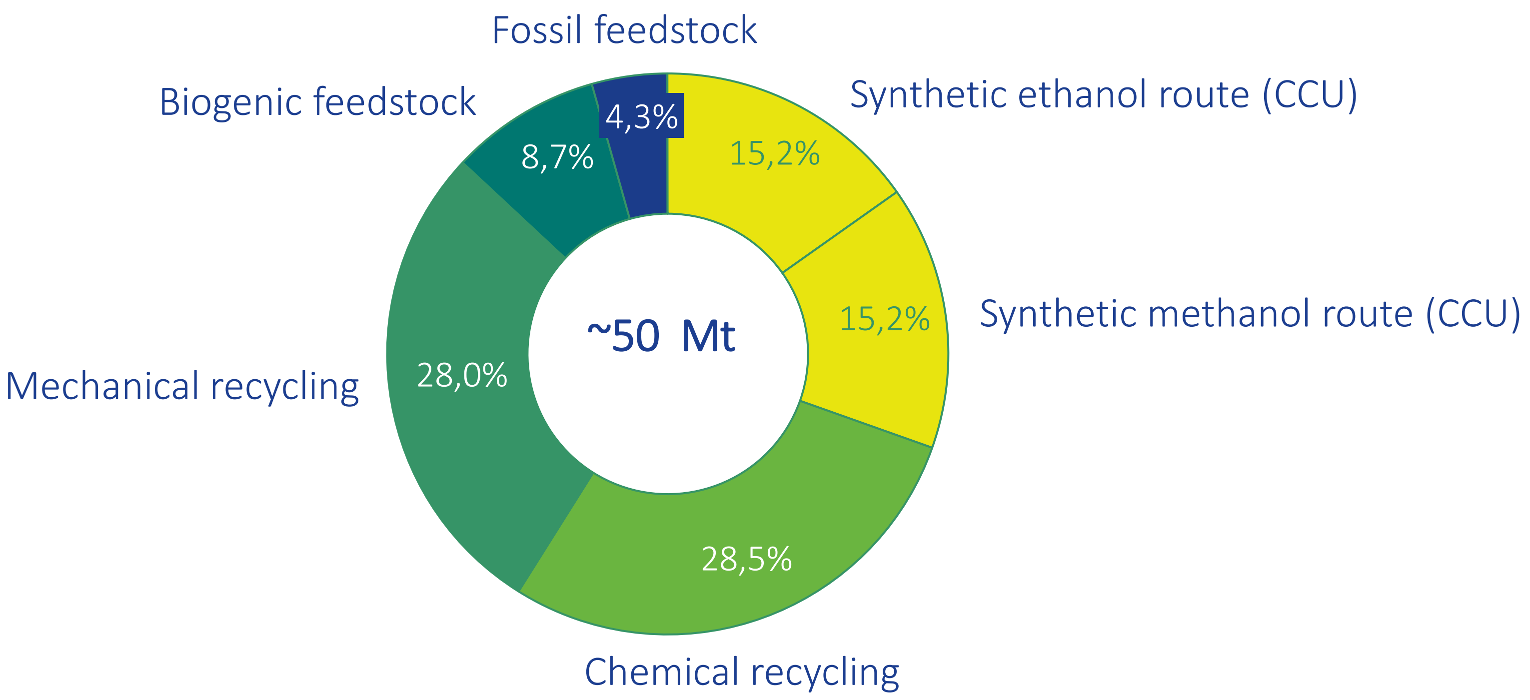


Building materials production [Mt]

<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 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?

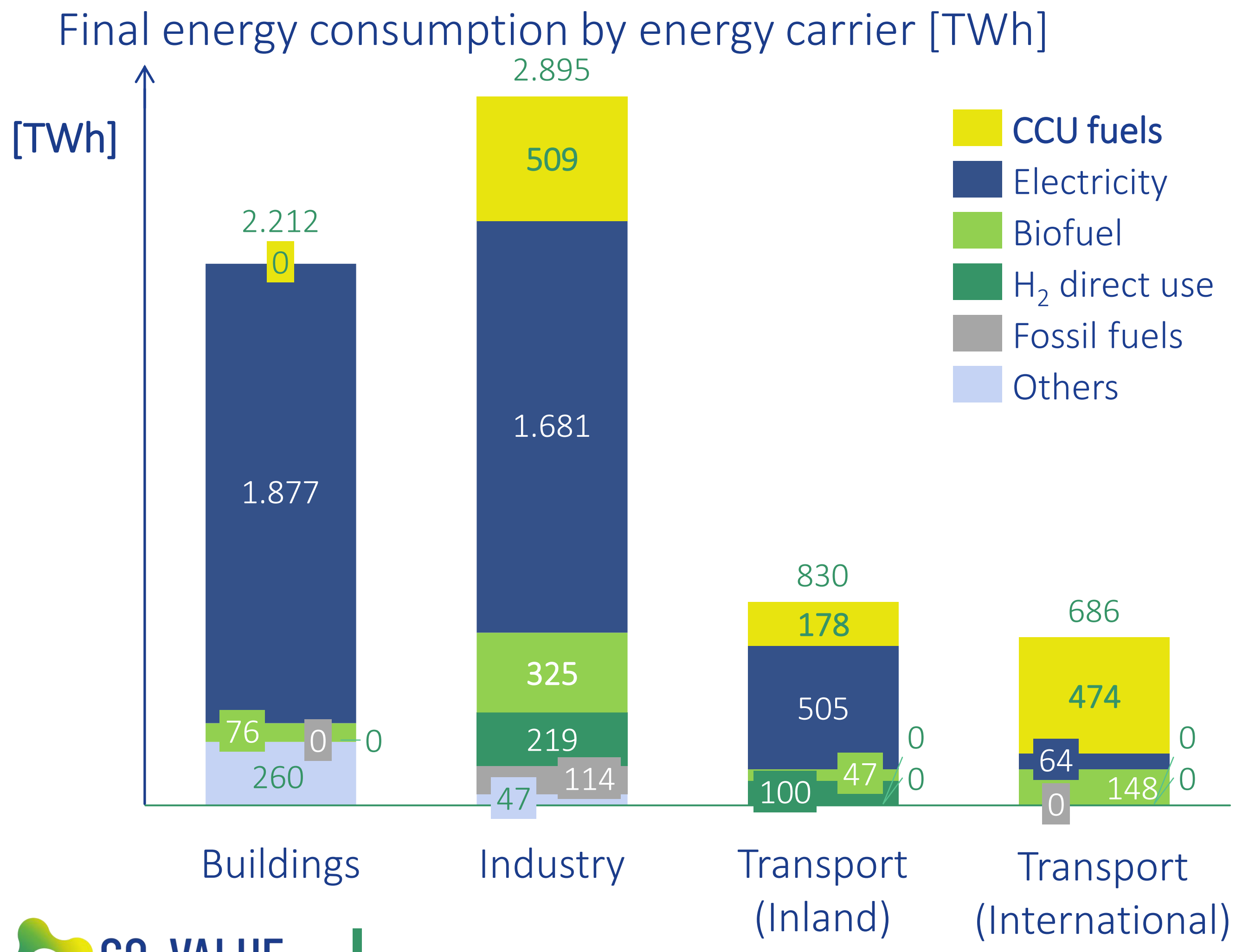


Chemical (Olefin) production [Mt]

<u>Key results</u>

- **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?



Key results

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).**

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Key messages

The EU will not reach climate neutrality without CCU as climate-mitigating solution.

- By 2050, CCU will be responsible for 21% of GHG reduction achieved by technologies
- **About 320 $MtCO_2$ will be captured**, 46% will come from DAC, 23% from process emissions, 23% from biogenic emissions, 2% from CCU fuel combustion and 6% from the remain fossil fuel emissions.
- **55% of the captured carbon will be used as feedstock** to answer the non-fossil carbon demand.
- **30% of the total production of the main chemical building block**, olefin, will be produced using captured carbon as feedstock.
- **At least 14 $MtCO_2$ (10% of the total CO_2 stored) could be stored permanently in building materials**.
- **11% (111 $MtCO_2$) of emission reductions in transports will be coming from CCU fuels**. GHG emissions from the maritime, aviation and inland transports sectors will be reduced by 35%, 38% and 2% respectively.
- **CCU fuels will represent 1161 TWh of the energy mix in the EU (17,5%),** including 474 TWh for the aviation and marine transports, 509 TWh to replace fossil fuels in the industry and 178 in land transports. **Half of it will need to be imported.**
- **The domestic production of CCU fuels and chemicals for the transport and industry sectors will require up to 1187 TWh** which represents approx. 22% of the modelled low carbon electricity production in the EU by that year.

KEY RECOMMENDATIONS

The EU must create a comprehensive policy framework for CCU, in order to unleash its potential:

- **Scale up carbon capture**. Whether for storage or utilisation, EU should support capture as a strategic activity
- **Embrace carbon circularity in EU policies**. Set targets and objectives for CCU products (quotas, incentives, market-pull mechanisms…)
- **Frontload public funding for CCU.** Encourage EU funding mechanisms & national initiatives (e.g. NECPs) to support CCU
- **Adapt EU rules to make CCU attractive for the entire value chain.** Additional rules need to be set to recognise the value of reusing unavoidable carbon e.g. in chemicals
- **Create EU quotas for non-fossil carbon feedstock** e.g. packaging, textiles, cosmetics, detergents, etc.
- **Support CO_2 mineralisation projects** e.g. through public procurement
- **Reinforce incentives to boost CCU fuels for aviation/maritime/heavy duty vehicles** e.g. by reinforcing new targets around ReFuelEU Aviation or FuelEU Maritime
- **Build strong certification and compliance systems for manufacturing in & outside Europe of CCU products**. Part of production will need to be imported to Europe, strong criteria and rules must be in place and enforced

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**

- **adding cost information**

- **better quantifying the impact of technological developments on planetary boundaries**.

Thank you!

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