Energy
Transitions
Commission

Low Carbon Molecules

ETC Representatives Meeting

15th May 2025

Carbon molecules project: Sizing the demand for carbon based molecules within a low emissions economy and assessing the sustainable and feasible options for their supply.

Aim:

Shape the narrative and conversation around low-carbon emission molecules in the lead-up to COP30

Organised in four phases / questions

1. How large a role can and should direct electrification play in a zero emission economy?
2. The role of hydrogen and non-carbon H2 derivatives
3. The potential to recycle and reuse carbon molecules
4. Sources of primary carbon: costs and sustainability and end-of life carbon management *Our topic today*

Phase 3: Sources of primary carbon: costs and sustainability

Integration in broader carbon molecule project

Having understood how maximum electrification and circularity of carbon to reduce reliance on primary carbon molecules, the last phase of work focuses on how we can meet the remaining demand for carbon molecules and manage end of life carbon

	2024 Q4	2025 Q1	2025 Q2	2025 Q3 / Q4
Workplan	**Phase 1A** How large can and should the **role of direct electrification** be in a zero-emission economy **Phase 1B** **The role of hydrogen** and **derivatives (i.e., ammonia)** in a zero-emission economy?	**Phase 2** The potential to **recycle** and **reuse carbon molecules**	**Phase 3** **Sources** of **primary carbon: costs** and **sustainability** and **end-of life carbon management**	**Phase 4** **Report production and communication campaign running into COP30**
Deliverables	• A 5-pager published externally • A series of short innovation briefs for publication	• A 5-pager published externally • Report chapter • Innovation brief(s)	• A 5-pager published externally • Report chapter • Innovation brief(s)	• Publication of the ETC report ahead of COP • A series of short innovation briefs for publication
Key interactions	• 1-2 workshops with ETC Commissioners	• 1-2 workshop with ETC reps/ commissioners	• 1-2 workshop with ETC reps/ commissioners	• Workshop • Report reviews • Report launch at COP

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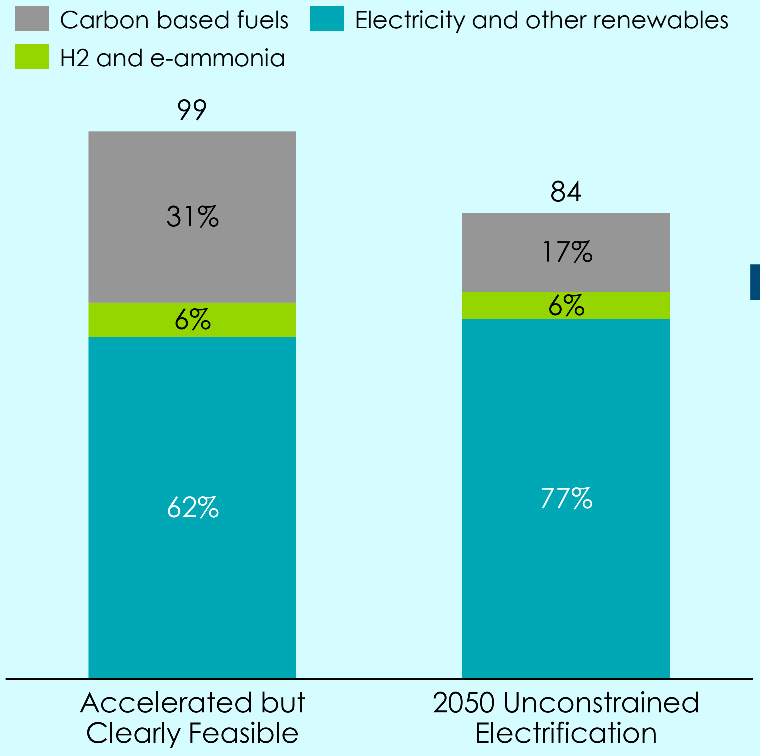
Outputs of the first two phases of work inform phase 3 analysis

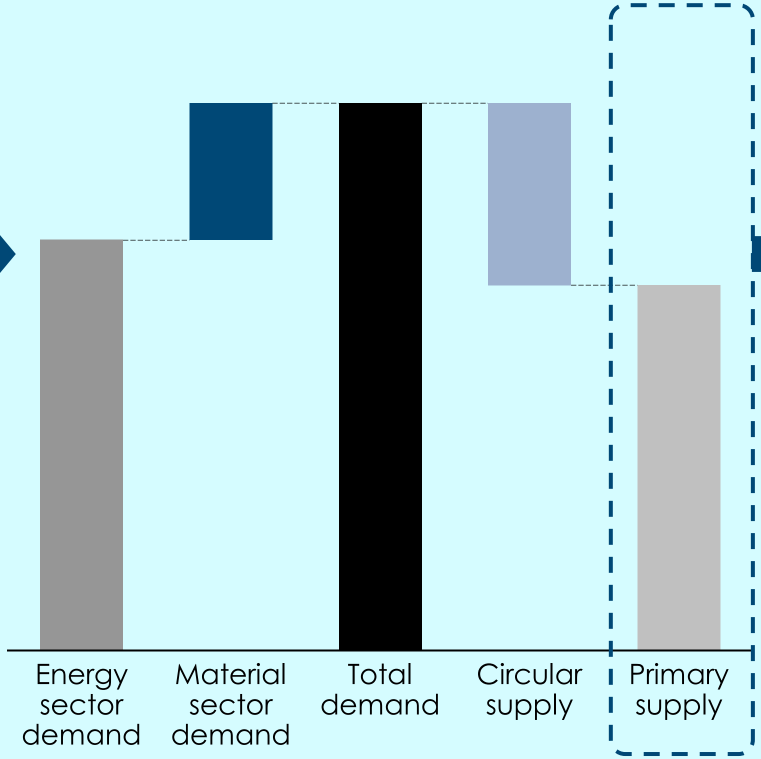
Phase 1
How much can we reduce carbon energy by maximising electrification

Final Energy Demand for ETC's ACF scenario in 2050
Thousand of TWh



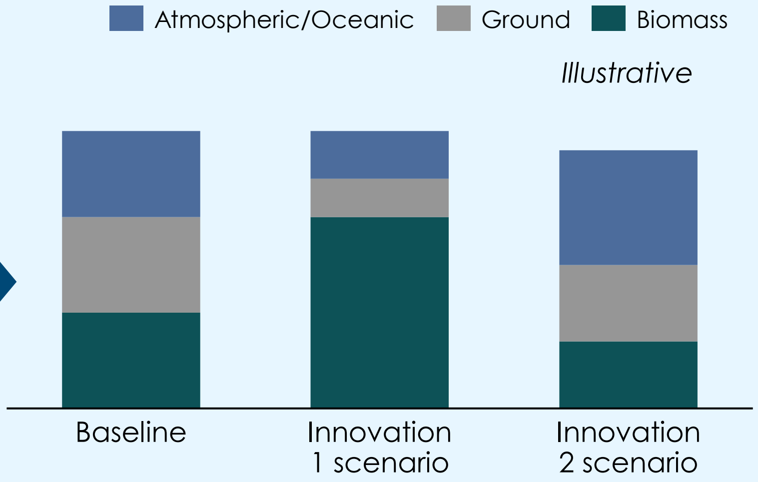
Phase 2
What is total carbon demand and how much of it can be circular

Carbon demand and supply, 2050
Gigatons of carbon (C)



Phase 3
How do we sustainably source primary carbon & manage carbon at end of life

Scenarios for sourcing primary carbon supply
Gigatons of carbon (C)



Plus – system trade-offs using cross-phase outputs

Examples conclusions

- Pushing circularity as far as we can will saving X million tonnes of primary carbon
- This will save DAC requirements of X tonnes of CO_2/y
- Investment requirements for such as system are X

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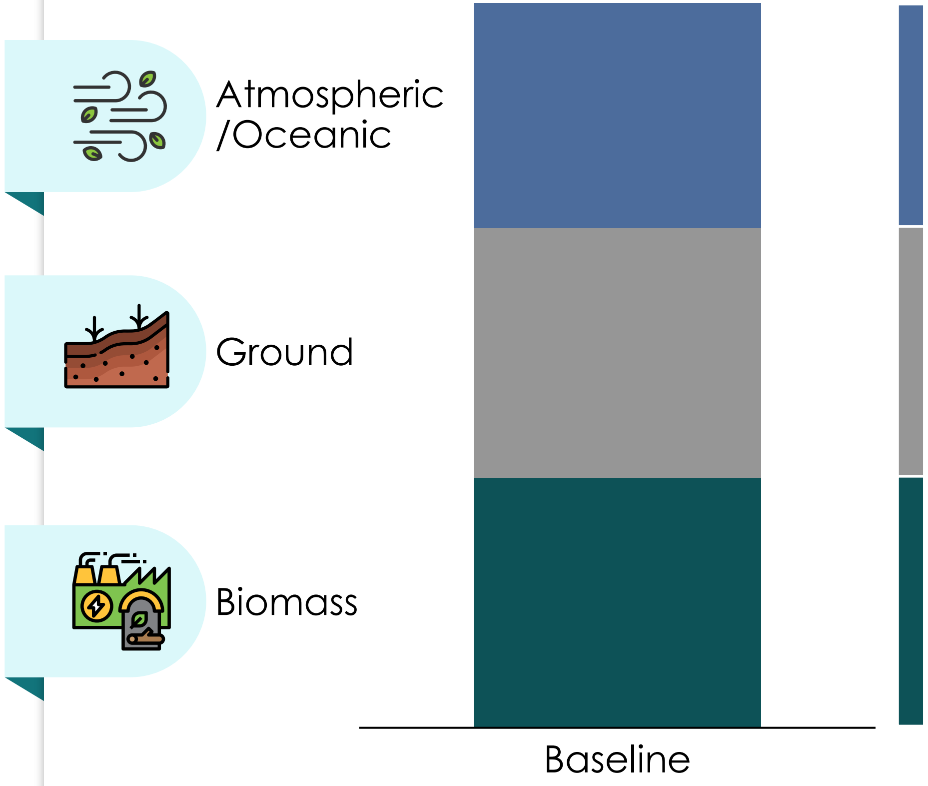
The analysis will focus on sustainable pathways for primary carbon sourcing and end-of-life carbon management

Sources of primary carbon supply

Illustrative



Direct Capture + Utilization/Storage

Fossil + Point Source Capture + Utilization/Storage
OR
Fossil + Landfill

Biomass that meets sustainability criteria (e.g. not competing with other critical land-use)

Our analysis will focus on key questions and technologies related to sustainable supply

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Analysis will focus on key questions to assess available volumes, levers and technologies to understand sustainable supply of carbon

Primary carbon source	Key questions
1. Atmospheric /Oceanic	• What are the latest technology developments for Direct Capture? • How can Direct Capture be more cost effective?
2. Ground	• What are the latest technology developments for point source capture? • What are the scope 1 and 2 emissions in fossil fuel production and how can emerging capture technologies reduce them close to net zero?
3. Bioresources	• How could conversion efficiency of biomass be improved? • How much more biomass could be made available through: 1. More available land 2. More productivity from land 3. New sources of biomass

End of life management

Key questions

(cross-cutting sources of carbon)

- What are the latest technology developments to store and manage carbon?
- What is the feasible capacity and scalability of storing/management technologies?

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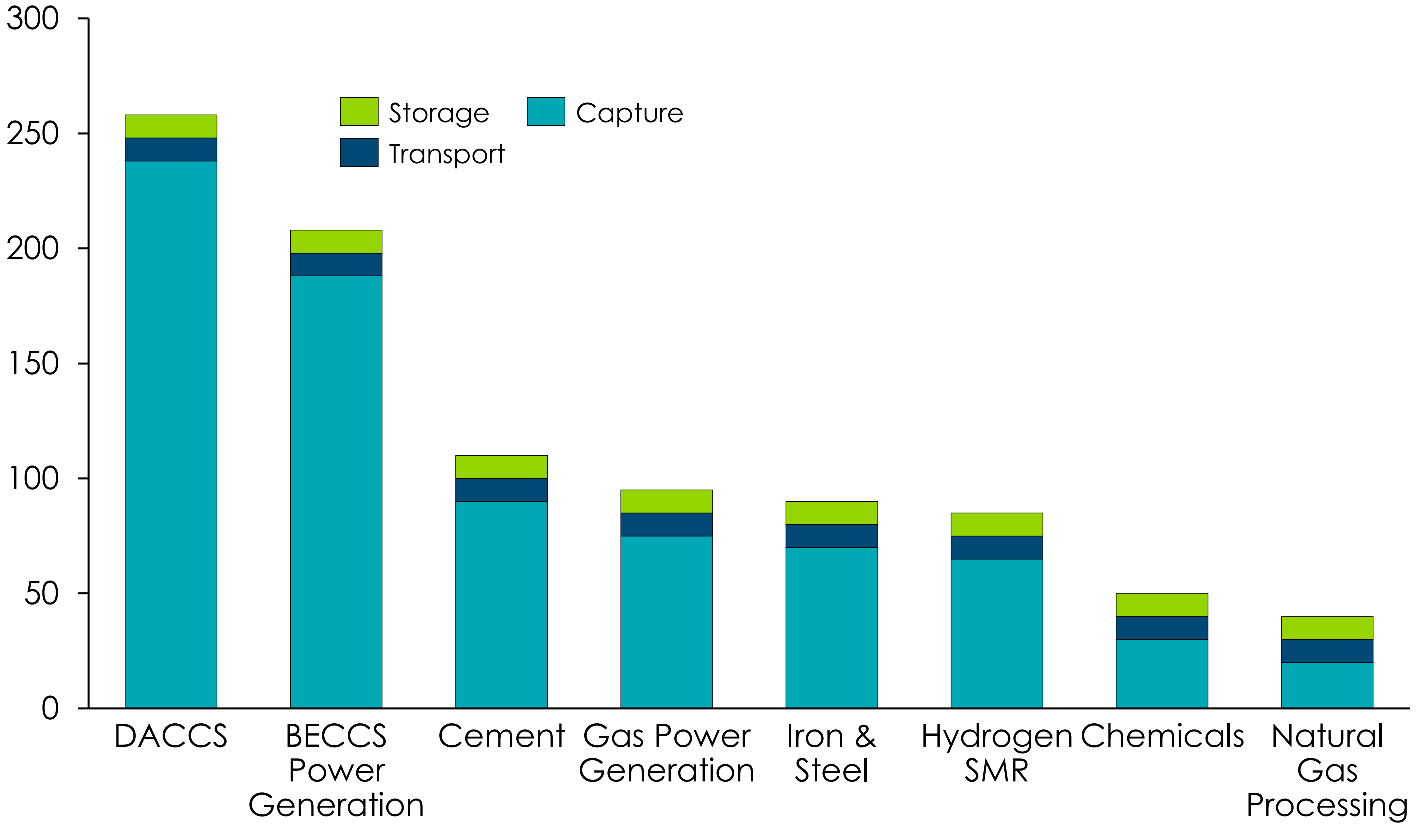
Recap on carbon capture: ETC has previously explored costs of carbon capture and expected volumes through to 2050

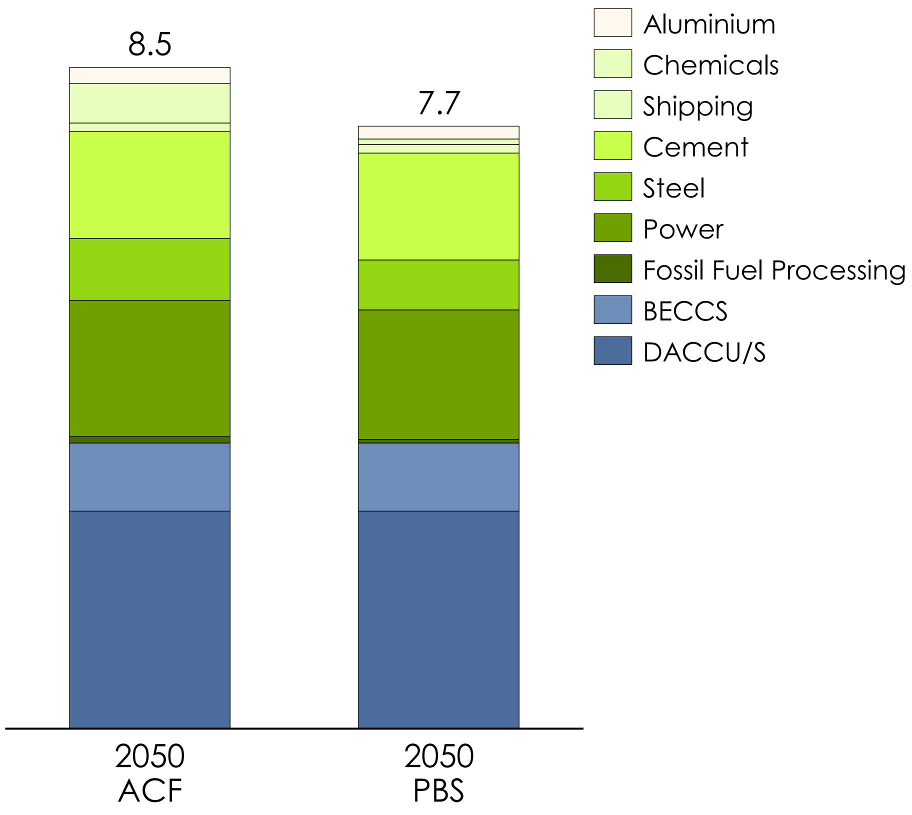
Levelised cost of capture, transport and storage by application today

$/tCO2



Scenarios for CCUS volumes in 2050 – by source of capture

$GtCO_2$/year



Note: ACF= Accelerated but Clearly Feasible scenario. PBS=Plausible But Stretching Scenario. Source: ETC (2022) *Carbon Capture, Utilisation and Storage in the Energy transition: Vital but limited* and ETC (2023) *Fossil Fuels In Transition*

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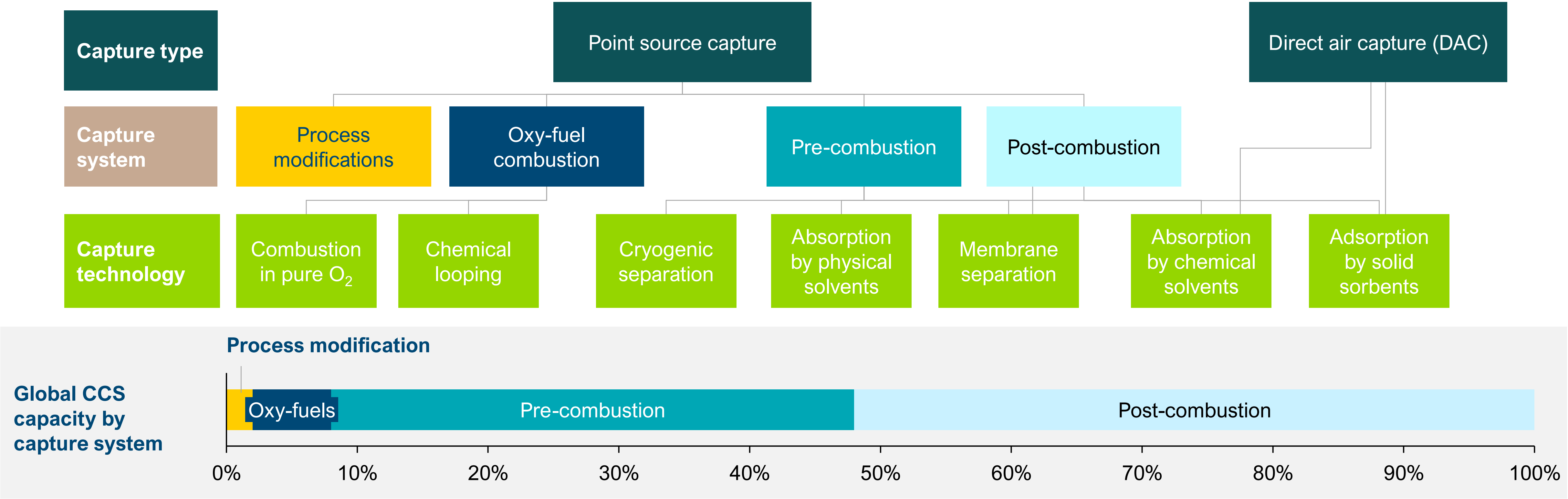
Carbon capture technologies can be categorised according to capture type, system and technology, and advancements are being made..

Standard Carbon capture technologies



Source: Systemiq for the ETC (2022), Cancawe (2018) Technology scouting – carbon capture

Atmospheric/Oceanic – new liquids and sorbents in DAC and Direct Water Capture are innovations to be explored in the new analysis

Key questions in focus

- What are the latest technology developments for Direct Capture?
- How can Direct Capture be more cost effective?

Technologies in focus

Technology	Description	TRL	Companies
Direct Air Capture (liquid and solid sorbents)	Liquid DAC uses a strong hydroxide solution to capture CO_2. Solid DAC uses fans to pass air over chemicals on a solid surface that bind CO_2.	6-9	Carbon Engineering, Heirloom, climeworks
Direct Water Capture	Electrochemical processes to extract CO_2 directly from seawater. The seawater returns to the ocean with increased capacity to absorb more atmospheric CO_2.	5-6	captura, SeaCO2, Equatic

NOTES: LCOH/E = levelised cost of heat/electricity; Levelised Cost of CO_2 Direct Air Capture breakdown refers to a fully electrified high temperature DACC system for 5,000 Full Load Hours per annum. Assumes overnight cost of capital for 1MtCO_2 plant in 2020 of $1,470m, weighted average cost of capital of 7% and plant lifetime of 20 years, growing to 30 years by 2050. Capital, heat and electricity costs refer to an advantaged region with abundant wind and solar resources.

SOURCE: SYSTEMIQ for the ETC (2022) based on models developed by Fasihi et al. (2019) Techno-economic assessment of CO_2 direct air capture plants; Keith et al. (2018) A Process for Capturing CO_2 from the Atmosphere.

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Ground – Point source capture is a core technology to allow a sustainable pathway with fossil carbon sources, and advancements continue to be made

Key questions in focus

- What are the latest technology developments for point source capture?
- What are the scope 1 and 2 emissions in fossil fuel production and how can emerging technologies reduce these close to net zero?

Technologies in focus

Technology		Description	TRL	Companies
Point source capture	Process modification (Allam-Fetvett Cycle)	Instead of being exhausted, flue gas containing CO_2 and water vapor drives a special sCO_2 turbine to produce electricity, after which pure CO_2 stream is collected.	7	NETPOWER
	Calcium looping	Transformative techniques capturing CO_2 with lime by forming $CaCO_3$, then regenerated or burning fuel in pure oxygen	6-7	AIR PRODUCTS; ExxonMobil

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Ground – Scope 1 and 2 emissions from fossil fuels would need to be reduced to close to zero by cost-effective technologies

Fossil as a carbon source in energy and materials sectors

FOSSIL CARBON SOURCES USED IN ENERGY AND MATERIAL

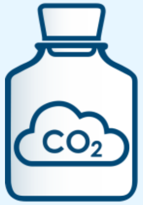
Some processes have **limitations on decarbonizing** via other zero carbon solutions so are likely to still need **fossil carbon sources**

Scope 1 and 2 Emissions created from fossil carbon

EMISSIONS FROM USE OF FOSSIL FUELS IN ENERGY AND INDUSTRIAL PROCESSES

Scope 1 and 2 emissions created from sectors still using fossil such as **power, cement, steel** and **chemicals**

Cost-effective capture technologies needed to reduce emissions to near net-zero



FOSSIL FUELS PLUS CARBON CAPTURE

CCUS can capture up to 90% or more of CO_2 emissions from flue gases in power and industrial plants[1] - **higher capture rates** prove to be **highly uneconomical** today

Advancements in technologies will need to be **cost-effective** with **high capture rates**

1. ETC (2022) Carbon Capture, Utilisation & Storage in the Energy Transition: Vital but Limited

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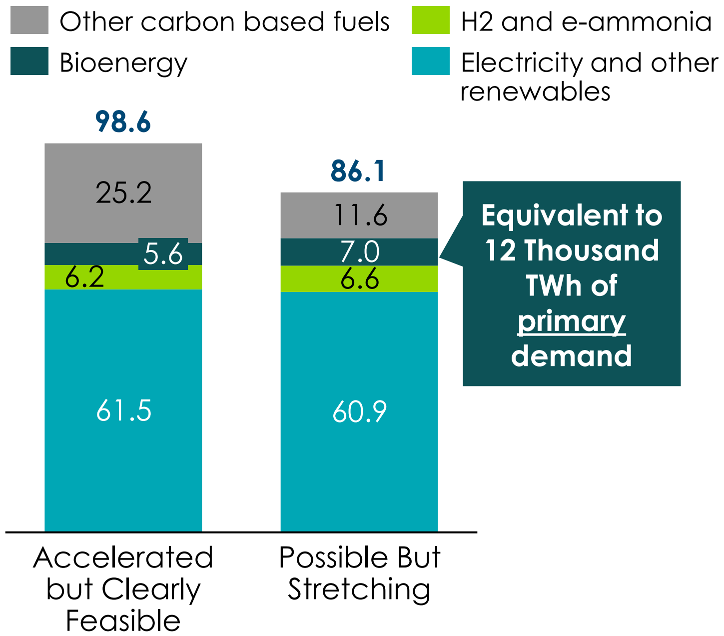
Bioresources – Better conversion technologies could reduce the required primary biomass required to meet final energy demand

Key question: Can biomass conversion to energy be more efficient?

Global final energy demand by energy source and scenario

Thousand TWh (%), 2050



Technologies in focus

Technology		Description	TRL	Companies
Biofuels conversion	Advanced catalysts	Development of proprietary catalysts which increase selectivity for hydrocarbon synthesis, improving biofuel conversion	6-7	ExxonMobil, Luleå University of Technology, BASF
Biofuels conversion	Advanced reactor designs	New reactor designs, such as microchannel and membrane reactors, which either improve conversion rates or integrates different process into a single process step	6-7	HyET NoCarbon, Velocys, H2SITE

Source: Systemiq analysis for ETC (2024) based on *Fossil Fuels in Transition* analysis by the ETC (2023)

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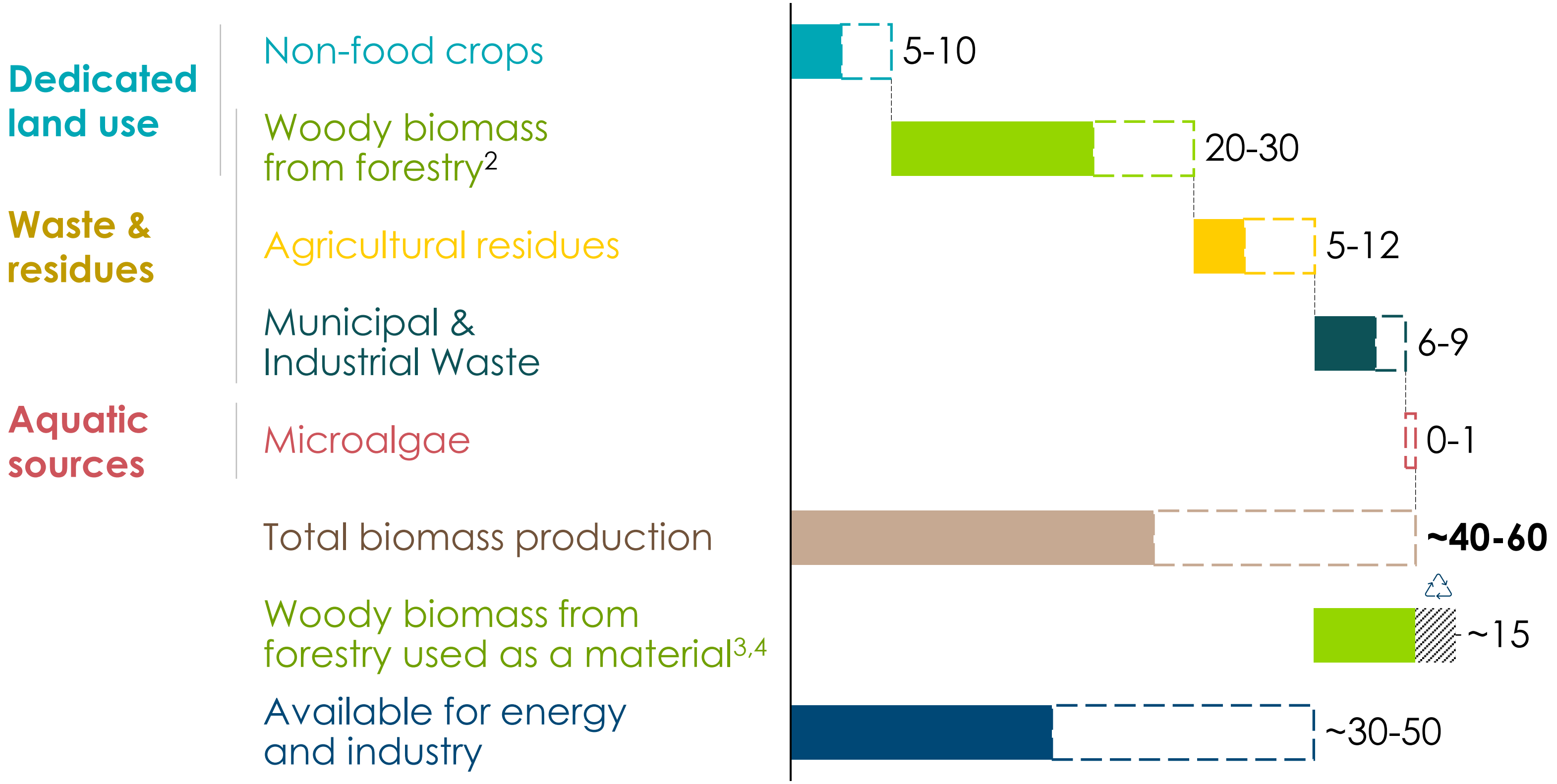
Bioresources – ETC has previously estimated global supply of sustainable biomass at ~40-60 EJ/year, but disruptive innovation could change this

Global sustainable biomass[1] supply (2050) – illustrative scenario

EJ/year (primary energy)



Extra Bioresource if radical change can happen

1 More available land (more ha)

Dietary shifts from animal based-protein

Less food waste

2 More productive land (more MJ/ha)

More productive plants (traditional crops, algae)

3 New Sources (more MJ)

Development of macroalgae

Increased collection to organic waste

(1) The term 'sustainable biomass' is used to describe organic material that is renewable, has a lifecycle carbon footprint equal or close to zero (including considerations for the opportunity cost of land), and for which the cultivation and harvesting practices used are mindful of ecological considerations such as biodiversity and health of the land and soil. (2) Includes high-quality stemwood from forestry suitable for the timber and pulp & paper sectors (~10 EJ/year today, FAO Industrial Roundwood production less by-products used for energy). This category also includes residues from forestry but excludes traditional fuelwood (~25 EJ/year today, assumed to reduce with modernisation) due to collection and sustainability assurance challenges. (3) E.g., timber, pulp & paper. Based on current harvests from commercial forestry; additional high-quality stemwood could be made available if freed up land were dedicated to forestry. (4) Additional supply from recycled materials (~4 EJ/year today). Source: SYSTEMIQ analysis for ETC (2021).

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Bioresources – technologies that allow reduction in land-use for food production, more land productivity and new sources of biomass are in focus

Key question: How much more biomass might be made available?

Technologies in focus

	Technology		Description	TRL	Companies
1 **More available land**	Alternative foods	Precision fermentation	Uses genetically modified yeast or fungi to produce functional ingredients (e.g. casein, collagen, egg white) with high efficiency	7	Perfect Day, Geltor, Every
		Biomass fermentation	Single-cell proteins grown using CO_2 and hydrogen in bioreactors	6-8	Solar Foods, Air Protein
		Cultivated meat	Grows animal muscle cells in bioreactors, bypassing livestock farming.	3-5	Upside Foods, Mosa Meat, Believer
2 **More productive land**	More productive plants	Energy Cane	Energy cane is a type of sugarcane specifically bred for its high biomass production	6-7	Nuseed, Raízen, Nufarm, Unilever
3 **New Sources**	New sources of supply	Macro algae (biofuels/bio materials)	Open-ocean farming of kelp/seaweed for feed, biomaterials, or fuels with high CO_2 uptake and fast growth, increasing supply of total available biomass.	5-7	kelp blue, Sea6 Energy

Beyond technologies, trends are considered

- Dietary shifts (enabled by technologies shown)
- Uptake of farming practices with higher yield potential (precision and regenerative agriculture)
- Increased waste collection rates

End of life management: Phase 2 focused on utilization of carbon; Phase 3 will focus on non-circular carbon at end of life

The CCUS value chain

Focus of this phase of work

Focus of completed re-use and recycling work

Carbon Source → **Capture** → **Transport** → **End of Life**: **Storage** / **Utilization**

Carbon Source
- Atmospheric/ Oceanic
- Ground
- Bioresources

Sector usage
- Blue hydrogen
- Cement
- Steel
- Coal power
- Bioenergy power
- Bioenergy H_2
- Refineries
- Gas power

Capture technology

Standard techniques
- Liquid solvents & solid sorbents
- Oxy-combustion
- Membranes
- Process modifications

Transport options
- Pipeline
- Ship
- Truck
- Rail

> 1 Gt
- Depleted oil & gas fields
- Saline aquifers
- Mineralization

< 1 Gt

Long-term use (non-exhaustive):
- Concrete curing
- Aggregates
- Long life-time plastics, e.g. construction

Short-term use (non-exhaustive):
- Synfuels
- Low life-time plastics
- Food industry
- Fertiliser (urea)

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End of life management – Advancements in emerging technologies for carbon storage and end-of-life management will be explored

Key questions in focus

- What are the latest technology developments for carbon capture and storage?
- What is the feasible capacity and scalability of storing/ management technologies?

Emerging technologies in focus

Technology		Description	TRL	Companies
Storage	Advanced landfill	• Concentrates the carbon in a stable form of biochar. • Bioreactor landfills recirculate moisture and leachate into waste to accelerate decomposition. • Cleaning, compacting and automated monitoring of gas leakage • Methane capture and utilization	7-9	CARBOFEX, carbon clean, BIOCHAR SOLUTIONS
	Sub-sea CO2 injection	Sub-seabed geological injection is the offshore equivalent of traditional CCS	6-7	equinor, Carbfix
	CO_2 to stone	Reacting CO2 with minerals or alkaline waste, inside or outside the ground, to form solids or strengthen materials (e.g. concrete)	4-7	CARBON CURE, carbon8, CarbonBuilt, aramco

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Outputs from the all the phases will be used to quantify scenarios, trade-offs and provide recommendations

Quantification and conclusions workstream

01

Primary carbon scenarios

Develop 2-5 'what if' scenarios where disruptive technologies stretch or disrupt the way we source primary carbon

02

Trade-off analysis

Quantify trade-offs between carbon management routes at a technology and at a system level (costs, GHG's etc., bang for buck)

03

Recommendations and conclusions

Develop recommendations for the coming decade, for policy makers, producers, buyers, financer players and consumers to ensure availability of carbon molecules in a net-zero system.

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Next steps

Deep-dives on technologies in focus

Develop innovation scenarios and explore trade-offs

Workshop on 13th of June