



Carbon Management: Presentation to Colorado House Energy & Environment Committee

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About Your Presenters



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Useful Definitions

DECARBONIZATION

Broad term referring to the reduction of CO₂ emissions from human activity

CARBON MANAGEMENT Technologies that involve capture and utilization or storage of CO₂

CARBON DIOXIDE REMOVAL (CDR)

Activities that remove CO₂ from the atmosphere or oceans and durably store it in geological, terrestrial, or ocean reservoirs, or in products

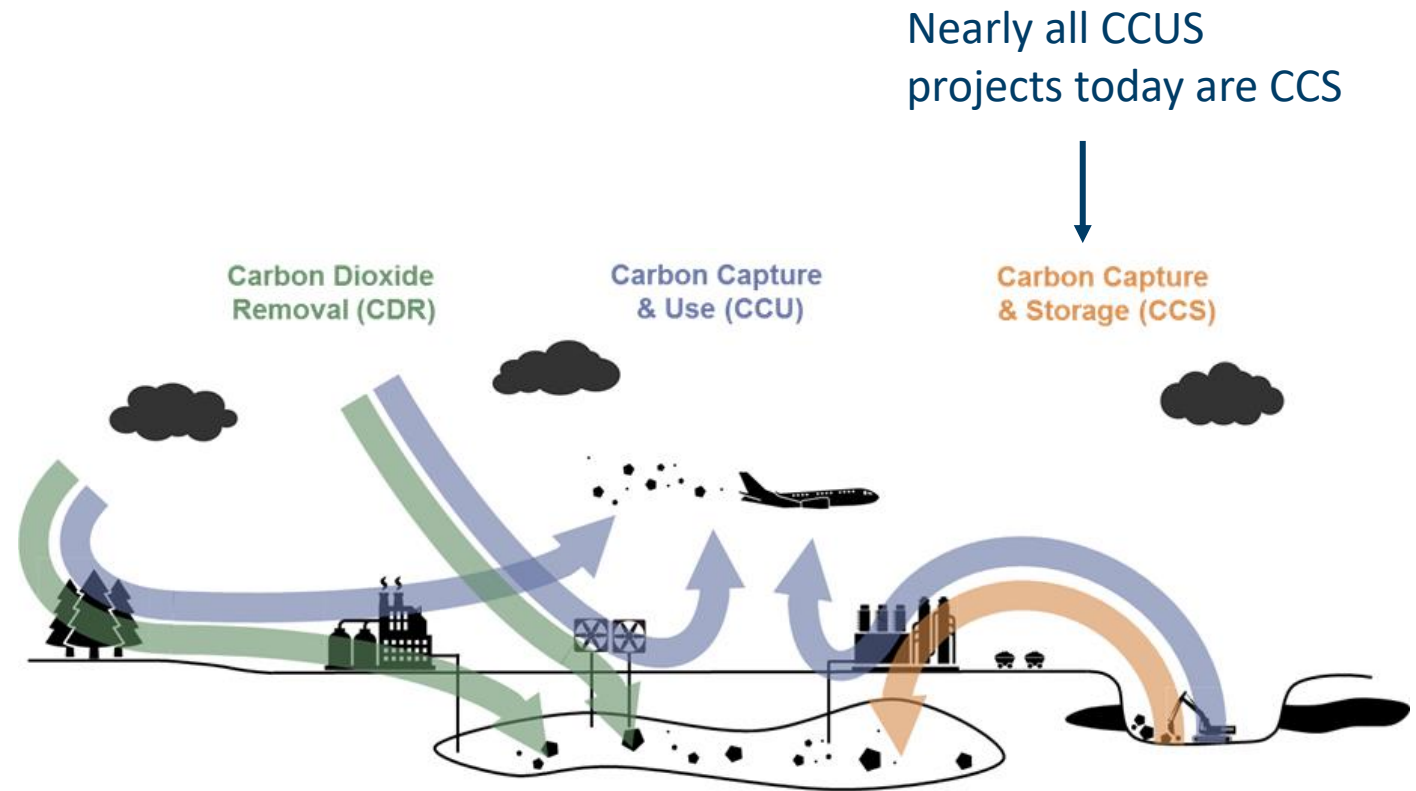
CARBON CAPTURE, UTILIZATION, AND STORAGE (CCUS)

Technology that captures CO₂ at a point source for utilization in other products or geological storage

Increasing Specificity

Carbon dioxide removal (CDR) vs. Carbon capture, utilization, and storage (CCUS)

- **Carbon capture, utilization, and storage (CCUS)** targets the capture of higher-purity streams of CO₂, capturing them from emissions sources like smokestacks before they reach the atmosphere.
- **Carbon dioxide removal (CDR)** removes CO₂ that is already in our atmosphere.



CCUS and CDR are waste removal strategies

Few industries exist at the gigaton scale



Waste can be thought of as a gigaton industry



CCUS and CDR are waste removal strategies

Select items	Gigatons/y
Coal	8
Oil	4.2
Cement	4.2
Iron Ore	3
Gas	2.7
Steel	1.9
Sugarcane	1.8
Corn	1.1

Current Global Municipal Solid Waste Production:
2.1 Gt/y



Current Global CO₂ Emissions:
36 Gt/y



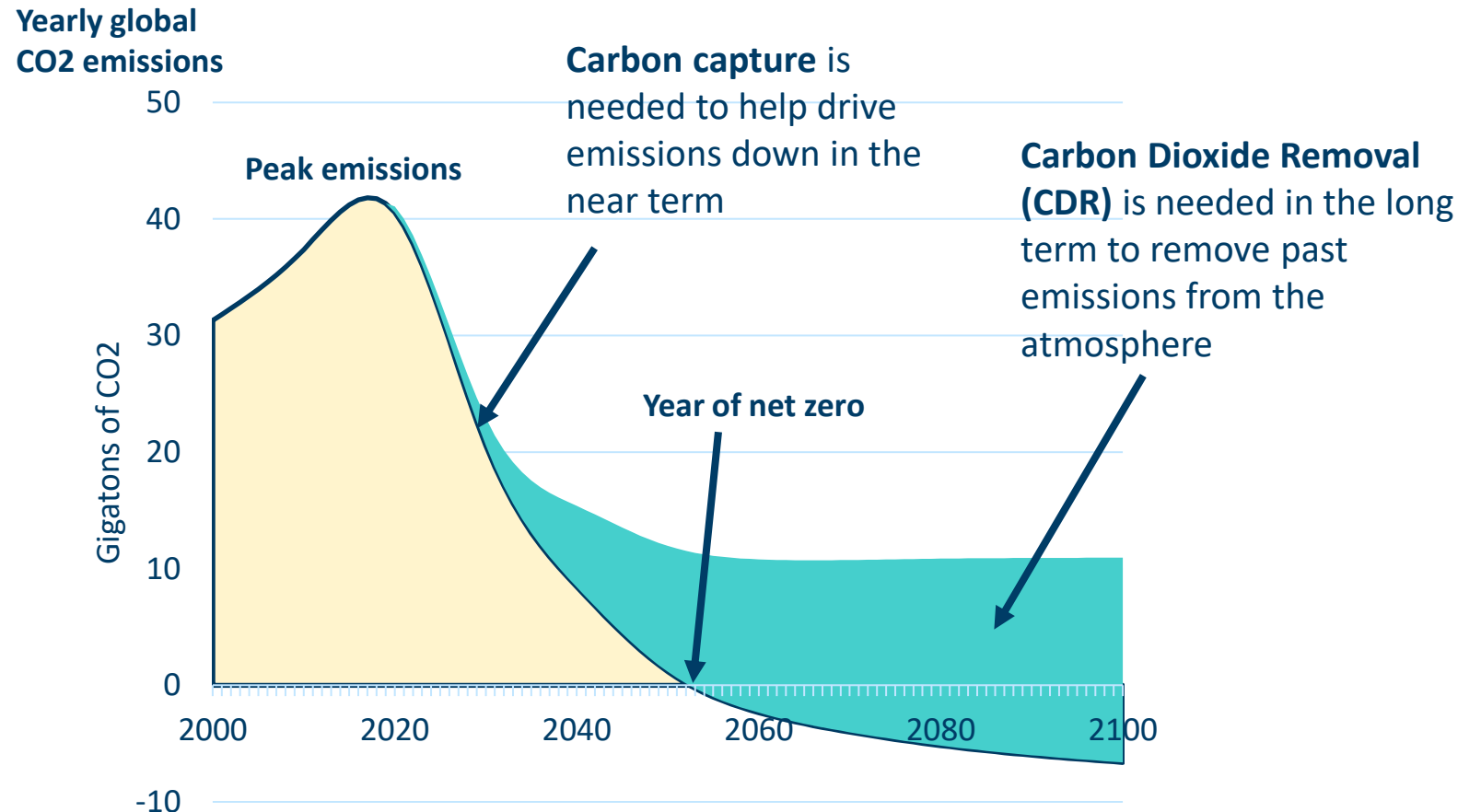
- **Carbon capture, utilization, and storage (CCUS)** can mitigate waste today
- **Carbon dioxide removal (CDR)** can be used to clean up waste in the future

Carbon Removal and Carbon Capture both have important roles to play in the energy transition

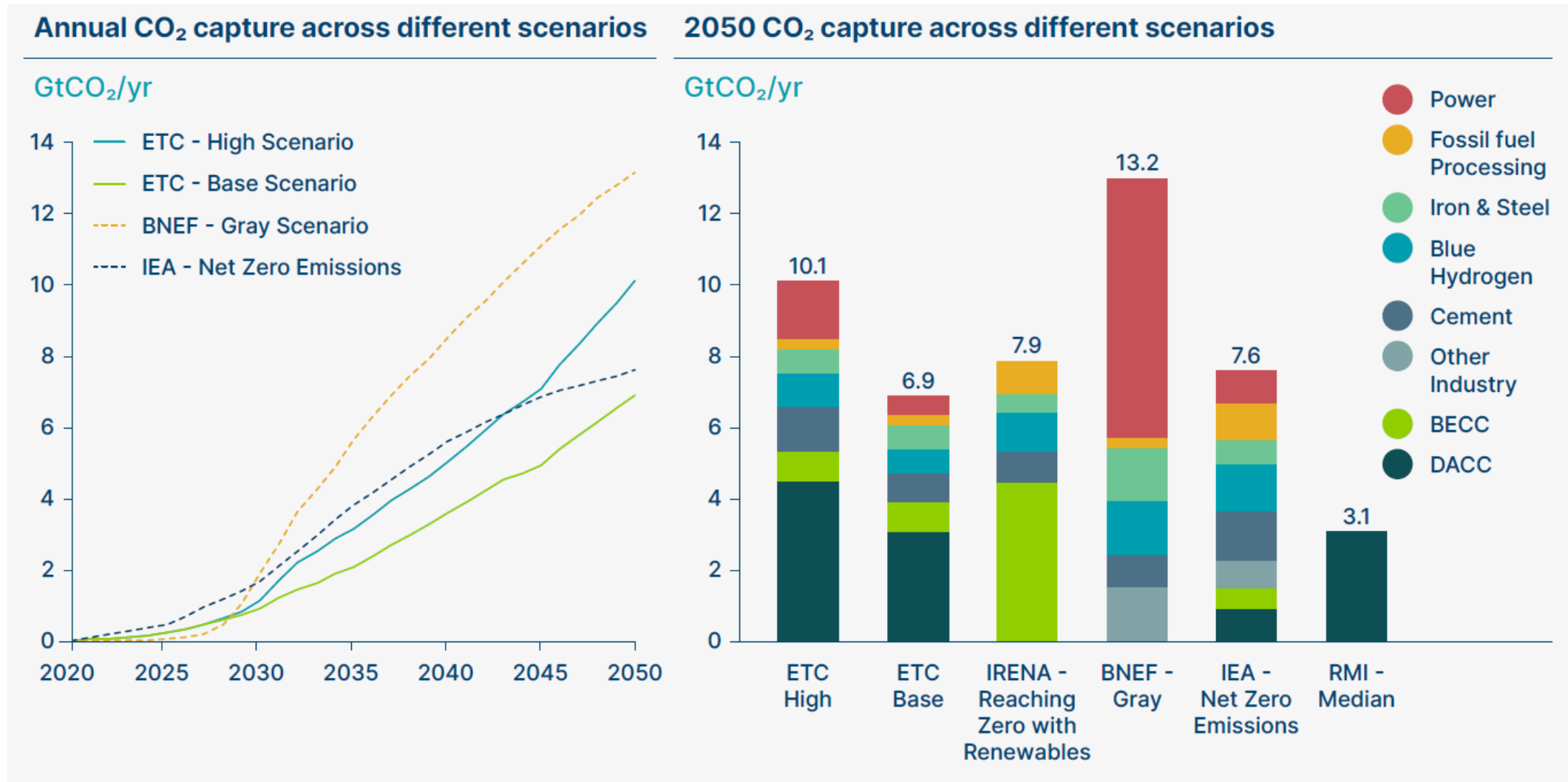
CDR and CCUS are different:

- Different technical applications
- Different deployment requirements
- Different policy implications

But both are important



Many major energy scenarios now expect a significant amount of CCUS and CDR by 2050



Remember: mitigation must come first

A climate aligned future:

1. Prioritizes mitigation
2. Prepares for **Carbon Dioxide Removal (CDR)** in the long term

Mitigation Strategies:

- Energy Efficiency
- Clean electricity
- Electrification of devices
- Decarbonization of industry, including with **Carbon Capture and Storage (CCS)**

Carbon Capture, Utilization, and Storage

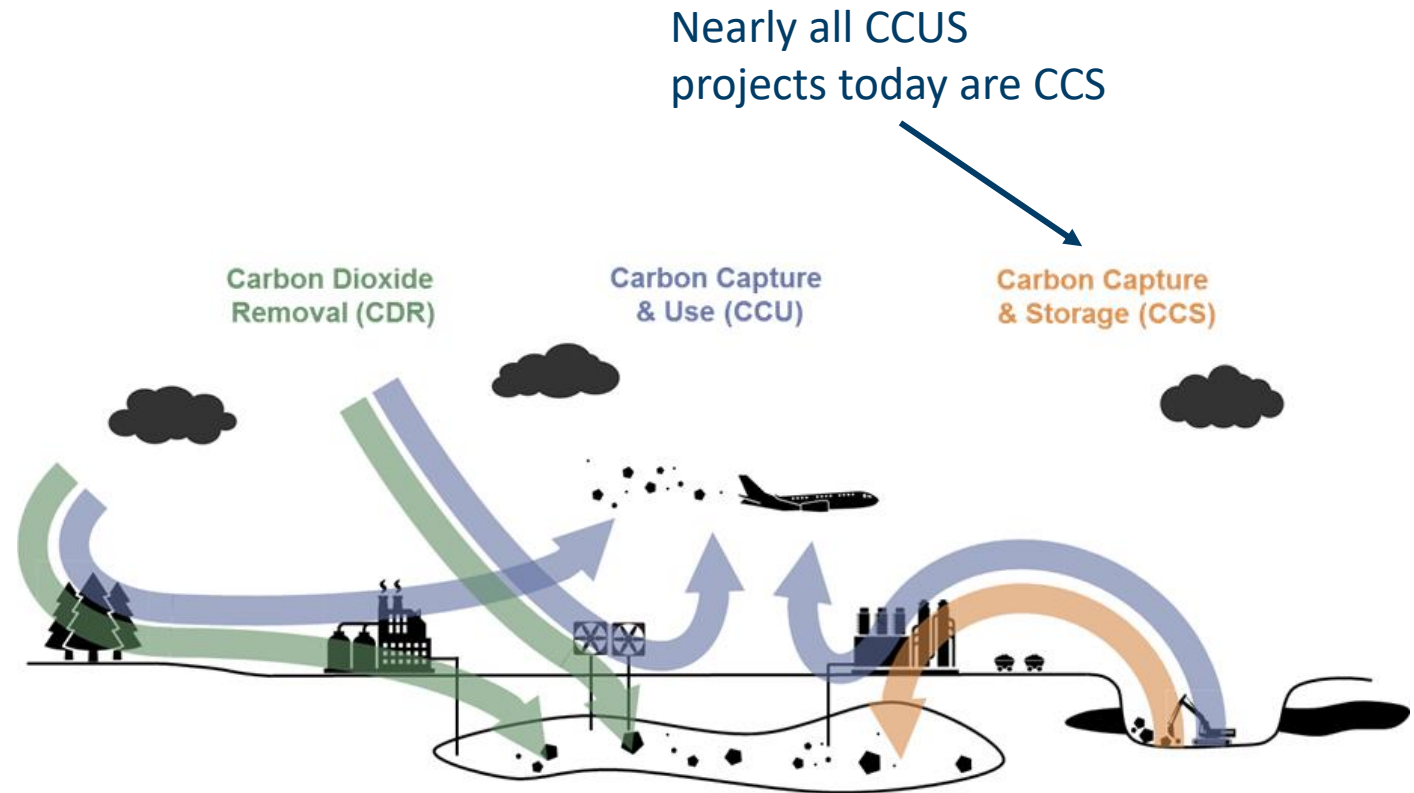


Carbon capture, utilization, and storage (CCUS)

Carbon capture, utilization, and storage (CCUS) targets the capture of higher-purity streams of CO₂ from emissions sources like smokestacks before they reach the atmosphere.

Point sources of carbon dioxide can include:

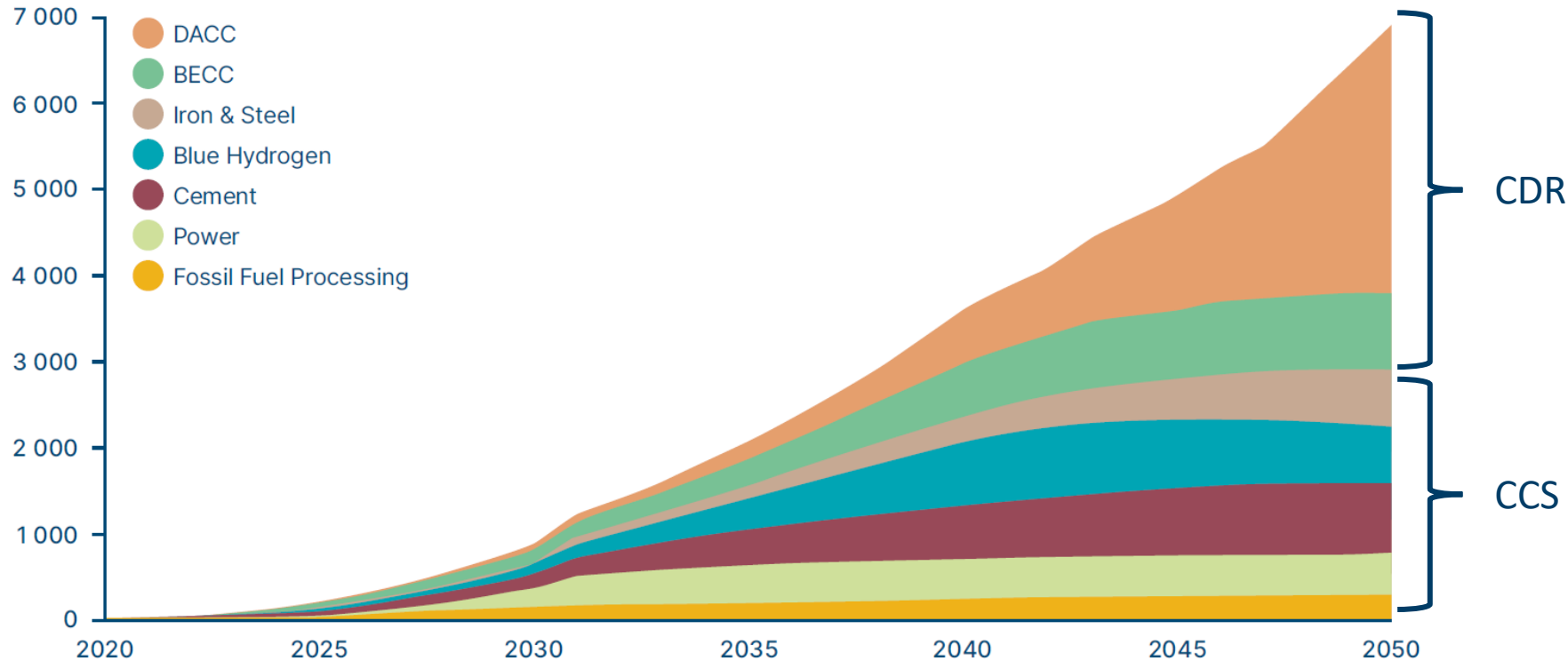
- Cement plants
- Fossil electric power plants
- Steel plants
- Petrochemical facilities
- Other industrial processes



CCS is largely seen as a transition strategy

CO₂ captured by sector in Base scenario

MtCO₂/year



CDR

In the long-term, **CDR** starts to play a bigger role in carbon management activities

CCS

CCS deployment is generally expected to play a near term role in decarbonizing “hard to abate” sectors

Future technical scope for CCS/CCUS is large

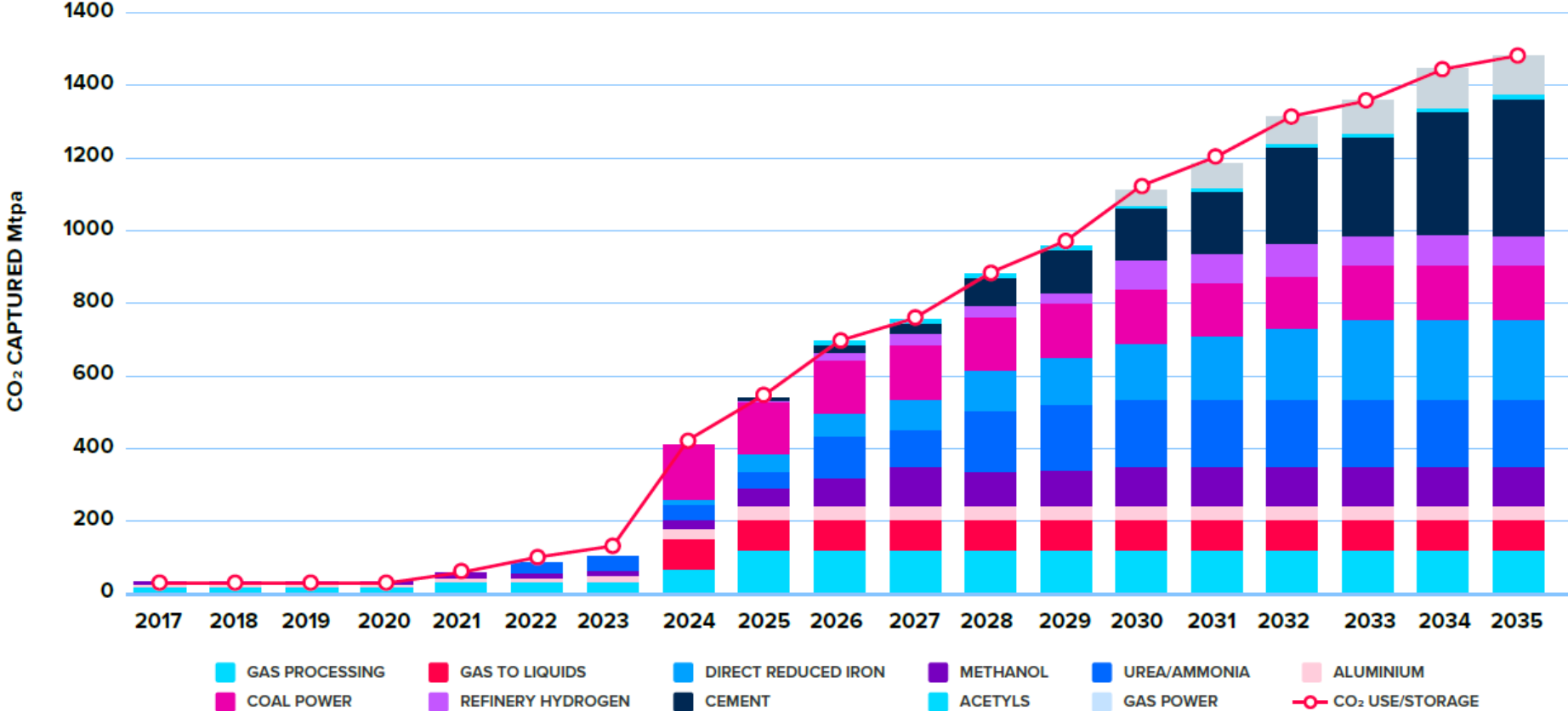
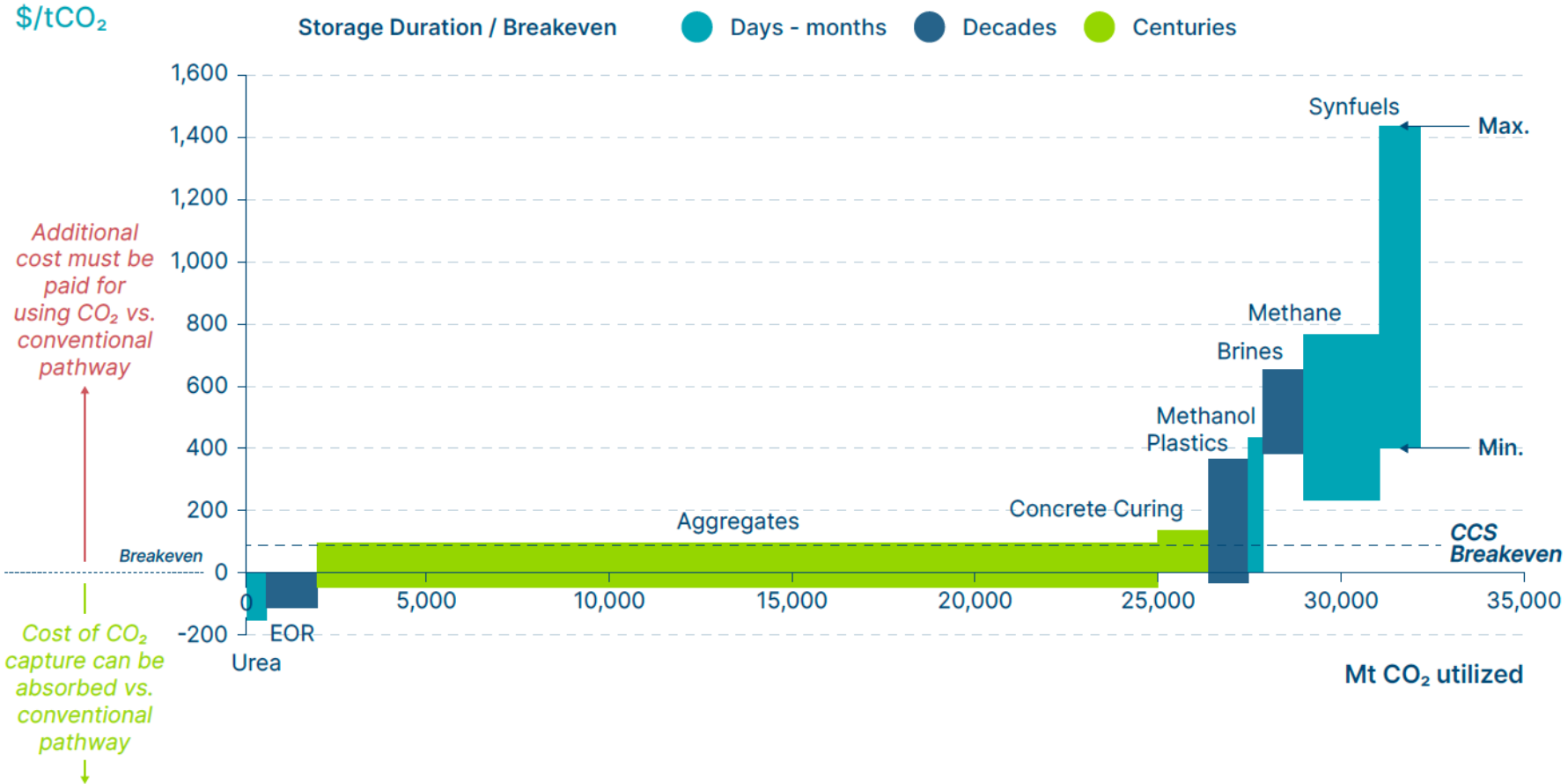


FIGURE 17 ESTIMATED TECHNICAL SCOPE FOR CCS ACROSS GCC REGION TO 2035, MILLION TONNES OF CO₂
 SOURCE: Qamar energy, GCCSI webcast, 23 feb 2021

Most carbon capture and use (CCU) applications cost more than storage (CCS)

CCU supply cost curve



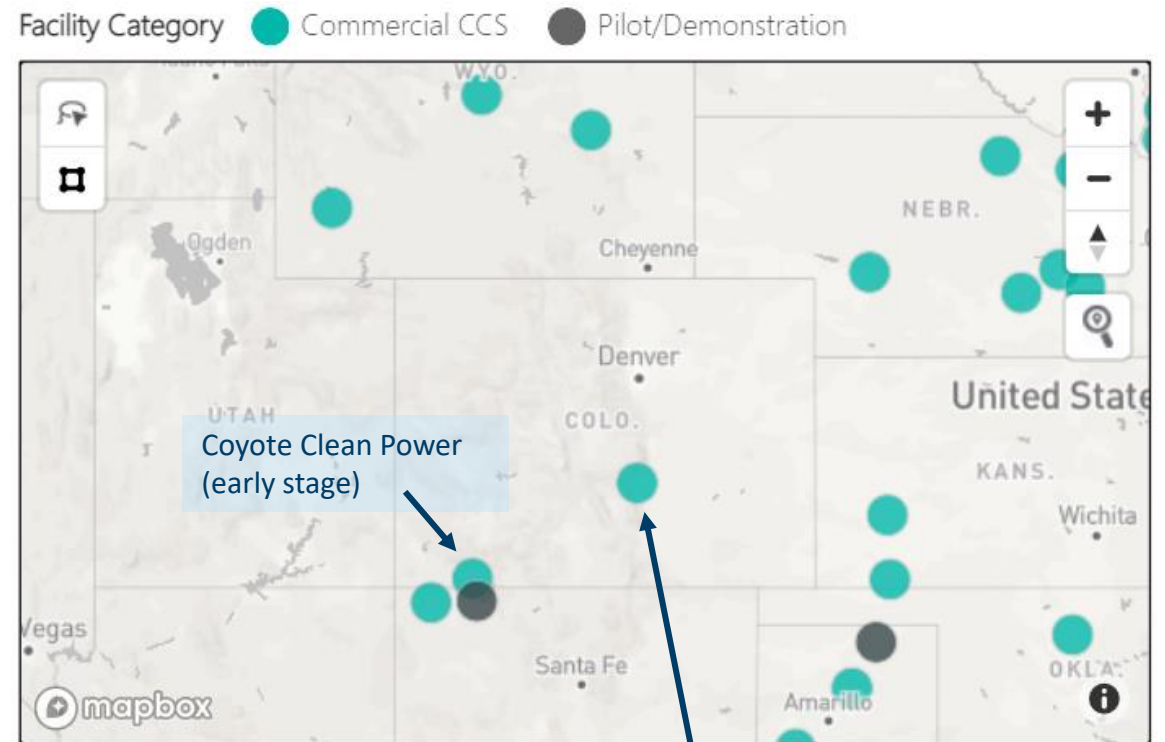
CCS is already being deployed in Colorado

CCS companies are establishing operations in Colorado

- Carbon America - CO₂ capture-transport-storage value chain (**Arvada**)
- Vartega – recycling carbon fiber (**Golden**)
- Ion Engineering – industrial CO₂ capture (**Boulder**)
- New Sky Energy – capture and conversion of CO₂ (**Niwot**)
- New Iridium – capturing CO₂ from the chemical supply chain (**Boulder**)
- Pioneer Energy – carbon capture in O&G operations (**Lakewood**)
- Red Rock Biofuels – CO₂ capture from woody biomass Fischer Tropsch synthesis (**Fort Collins**)

Colorado labs and universities are studying CCS

- NREL is conducting research on CCS
- CSU is developing COMET, a carbon accounting system for agriculture

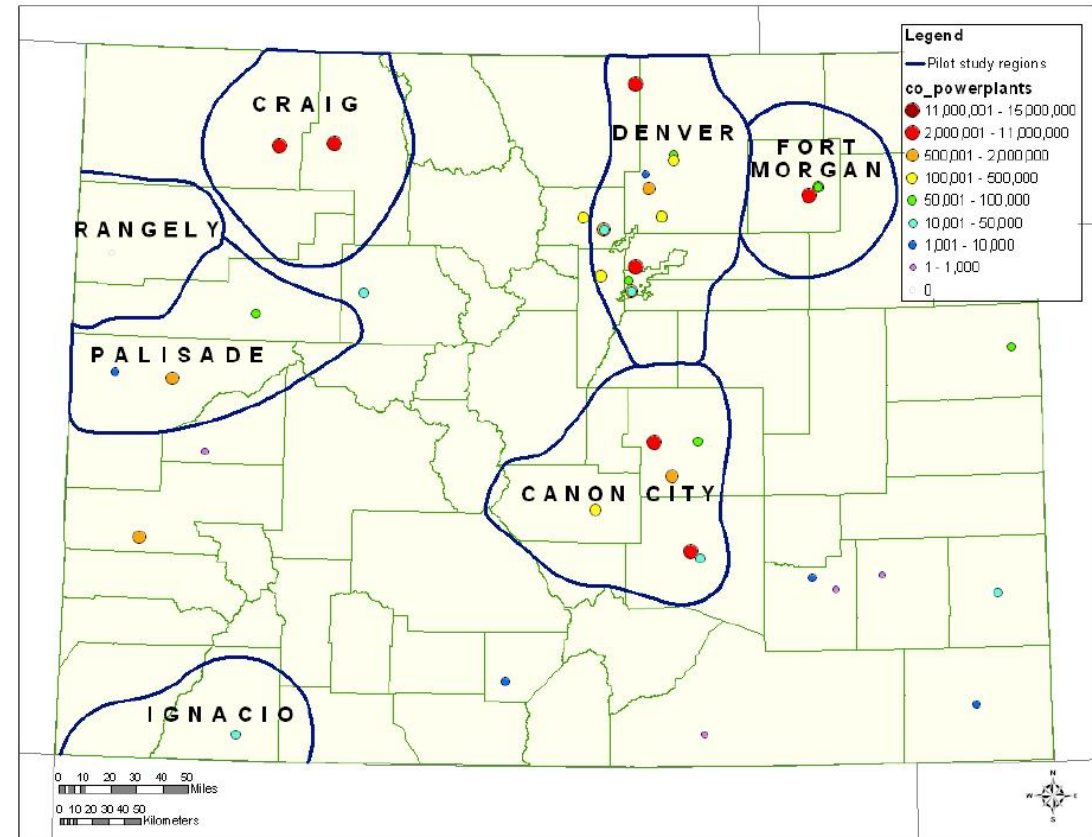


Svante, LafargeHolcim, Oxy Low Carbon Ventures, TotalEnergies, Keiwit and Electricore are conducting a study to assess the financial viability and design requirements of 1.0 – 2.0 million tonnes per annum CO₂ capture facility at LafargeHolcim's cement plant in Colorado, United States

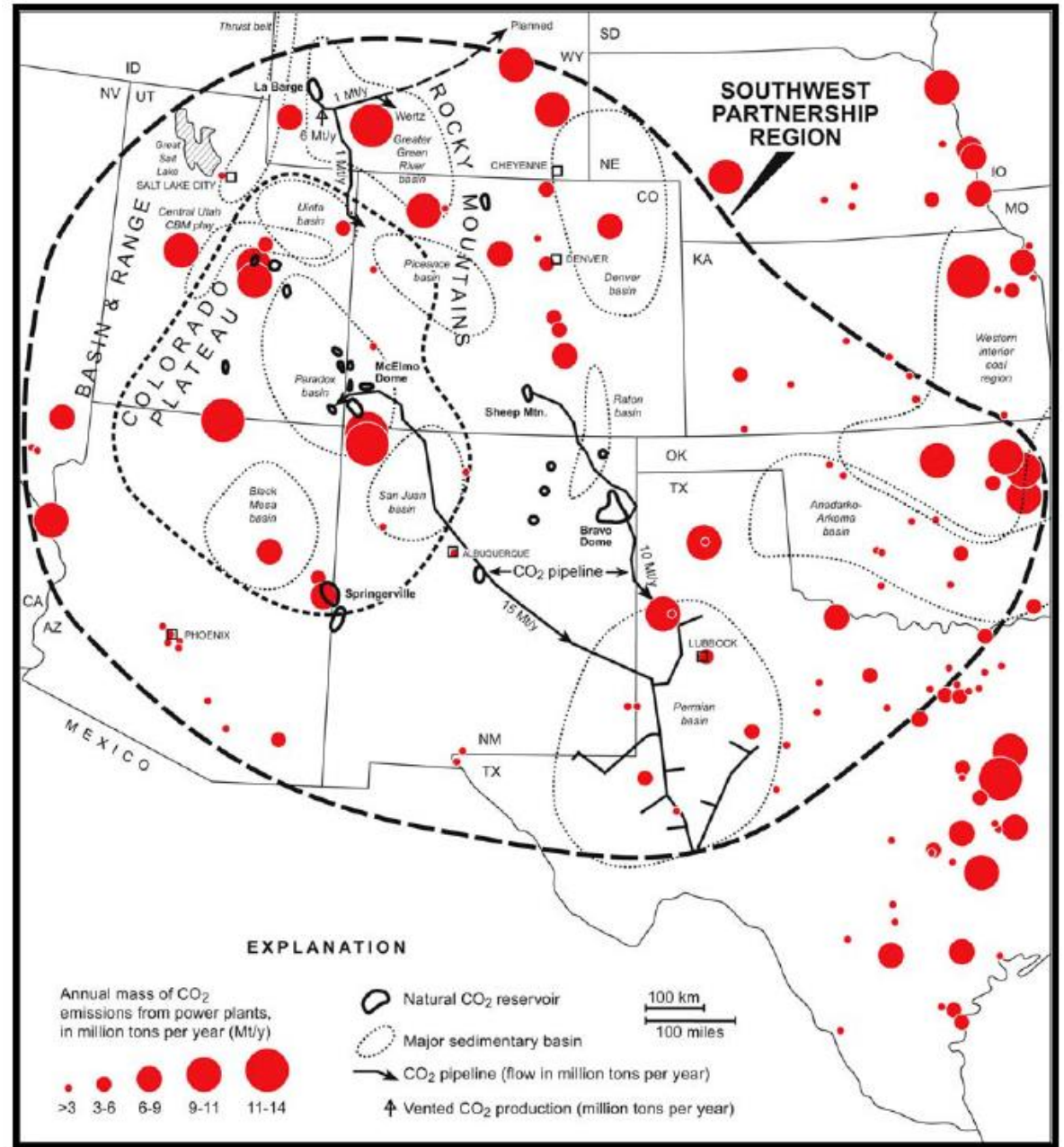
Colorado is not limited by storage capacity

Table 1.2: CO₂ sequestration capacities in million short tons estimated for Colorado

Pilot Study Regions	2000 Emissions	Geologic			Mineralization		Total Capacity
		Oil & Gas	CBM	Saline Aquifers	Silicates	Produced Waters	
Cañon City	9.4	0	493	122,118	2,200	0	124,811
Craig	14.4	123	11,059	46,209	30,000	0	87,391
Denver	14.1	557	602	129,138	0	<0.001	130,297
Fort Morgan	4.9	164	0	43,770	0	<0.001	43,934
Ignacio	31.5	186	2,809	92,142	0	0	95,137
Palisade	0.8	116	1,798	132,330	200	<0.001	134,444
Rangely	3.4	740	1,037	102,579	0	0	104,356
Total	78.5	1,886	17,798	668,286	32,400	0	720,370

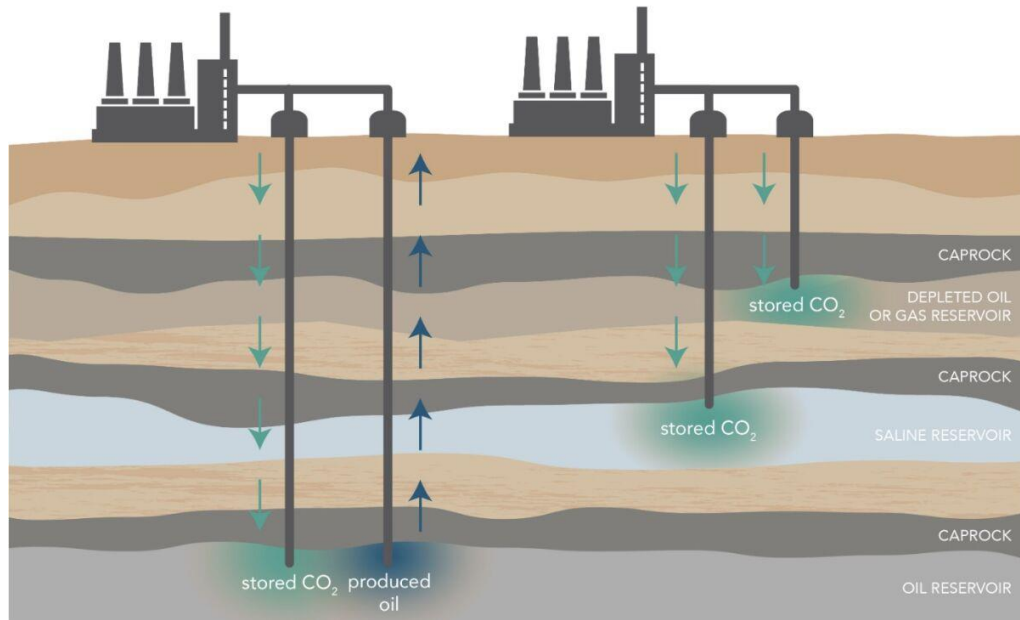


It is also possible for Colorado to participate in a partnership with neighboring states



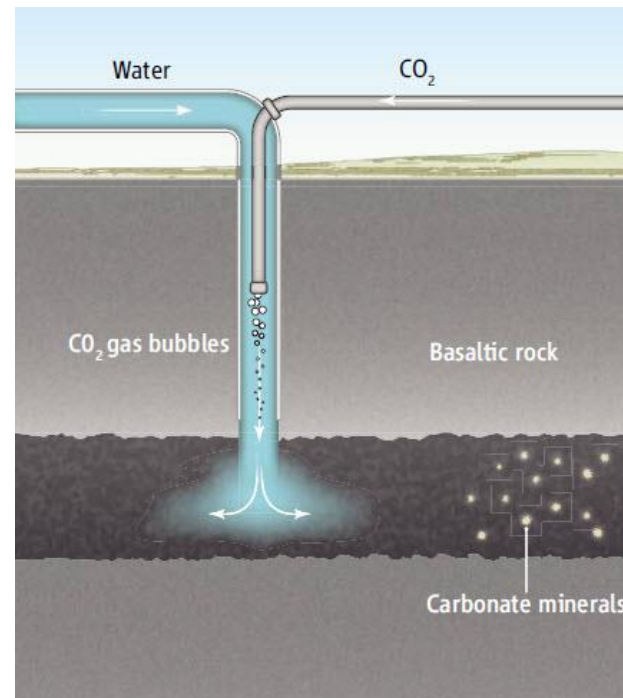
Captured CO2 is typically injected underground – Permitting is done with Class VI wells

CO2 can be injected underground into depleted oil and gas reservoirs or saline reservoirs

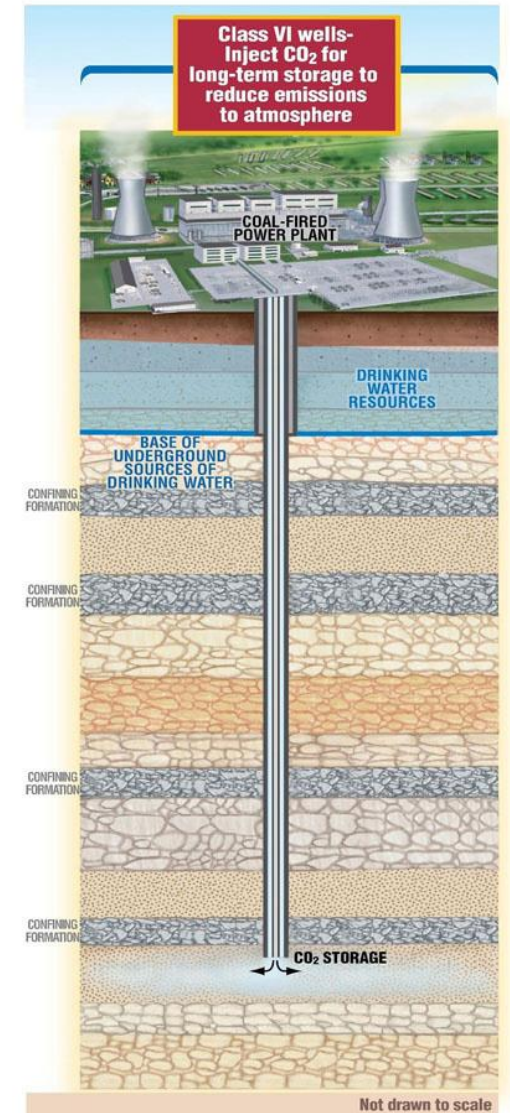


Source: Image from Los Angeles Times

CO2 can be reacted underground to form carbonate minerals



Source: Carbfix



Source: EPA class VI wells

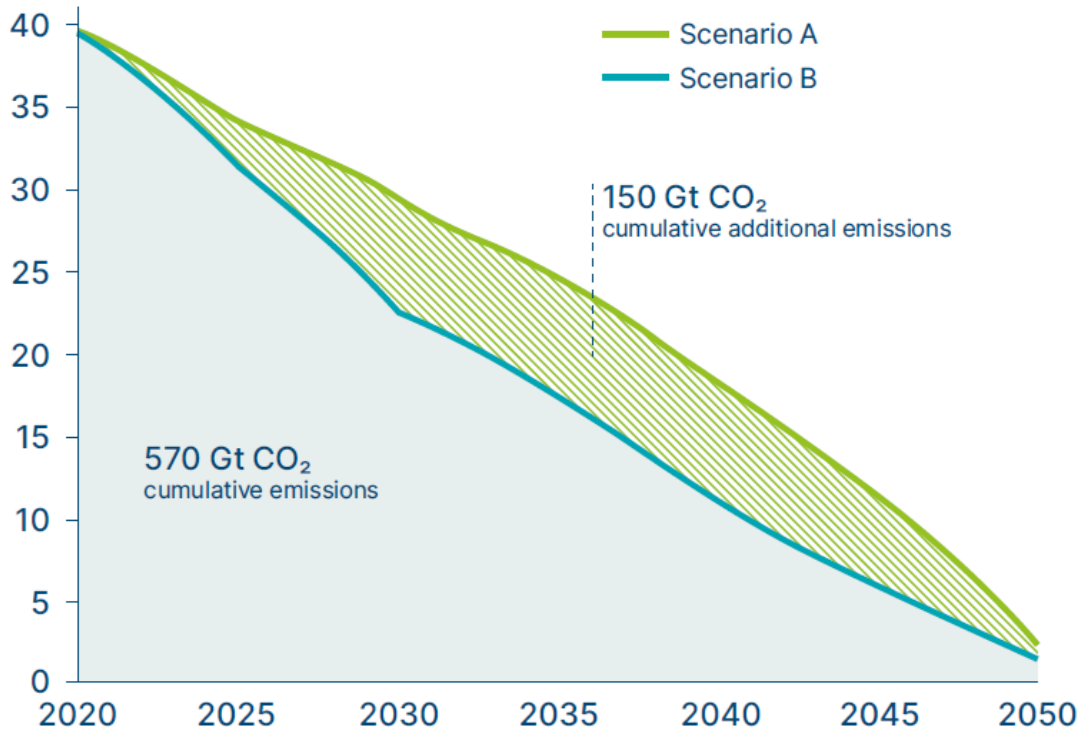
Carbon Dioxide Removal



Even with mitigation, we expect to need to remove excess CO2 from the atmosphere

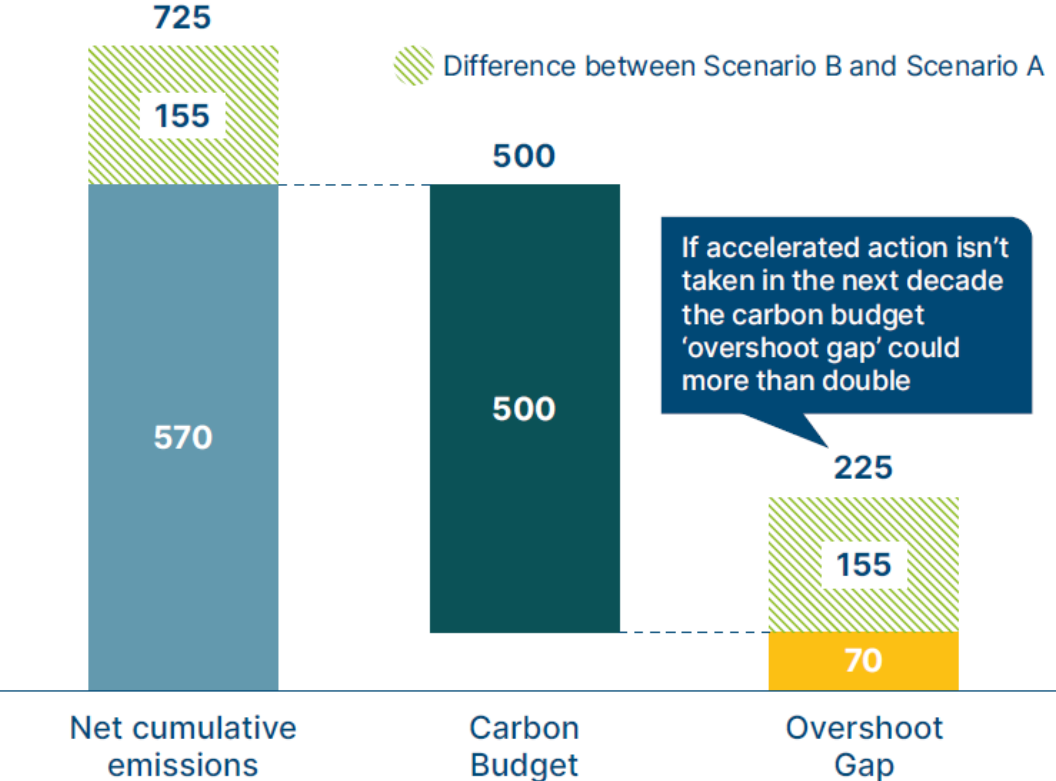
Global annual gross emissions by ETC scenario

GtCO₂/year



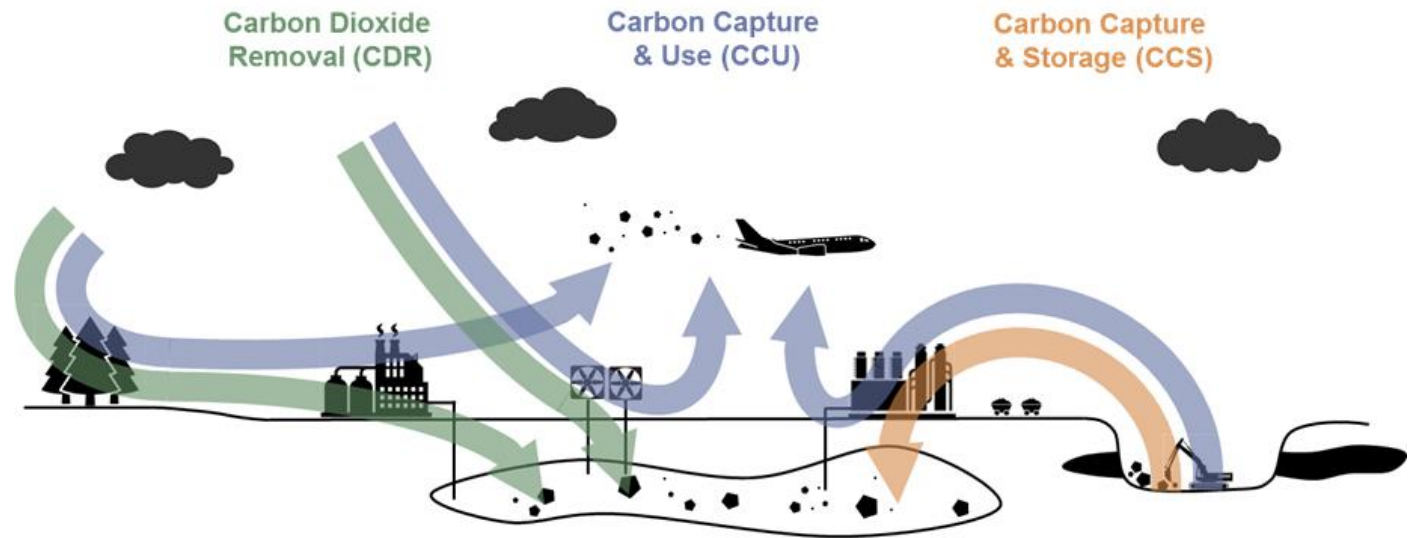
Cumulative emissions and budget

GtCO₂ 2020-50



Carbon Dioxide Removal (CDR): directly removing CO₂ from the atmosphere

Carbon dioxide removal (CDR) removes CO₂ that is already in our atmosphere.



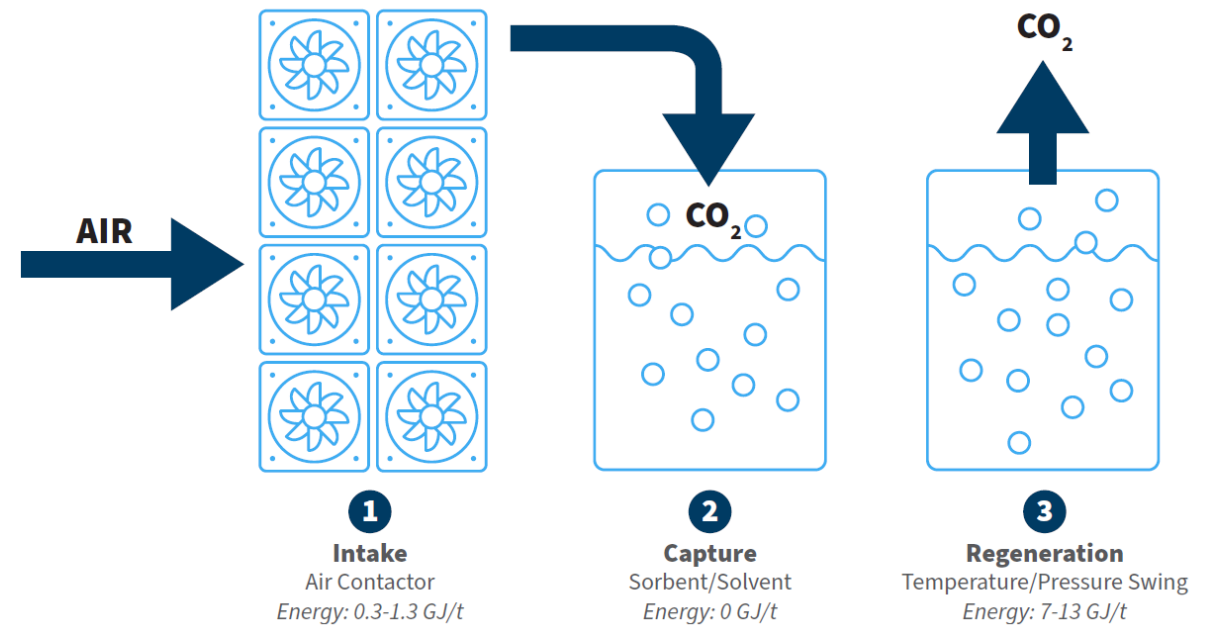
Direct air capture (DAC) is one of the most well-known CDR methods

Climeworks' Orca facility in Iceland can capture 4,000 tCO₂/y

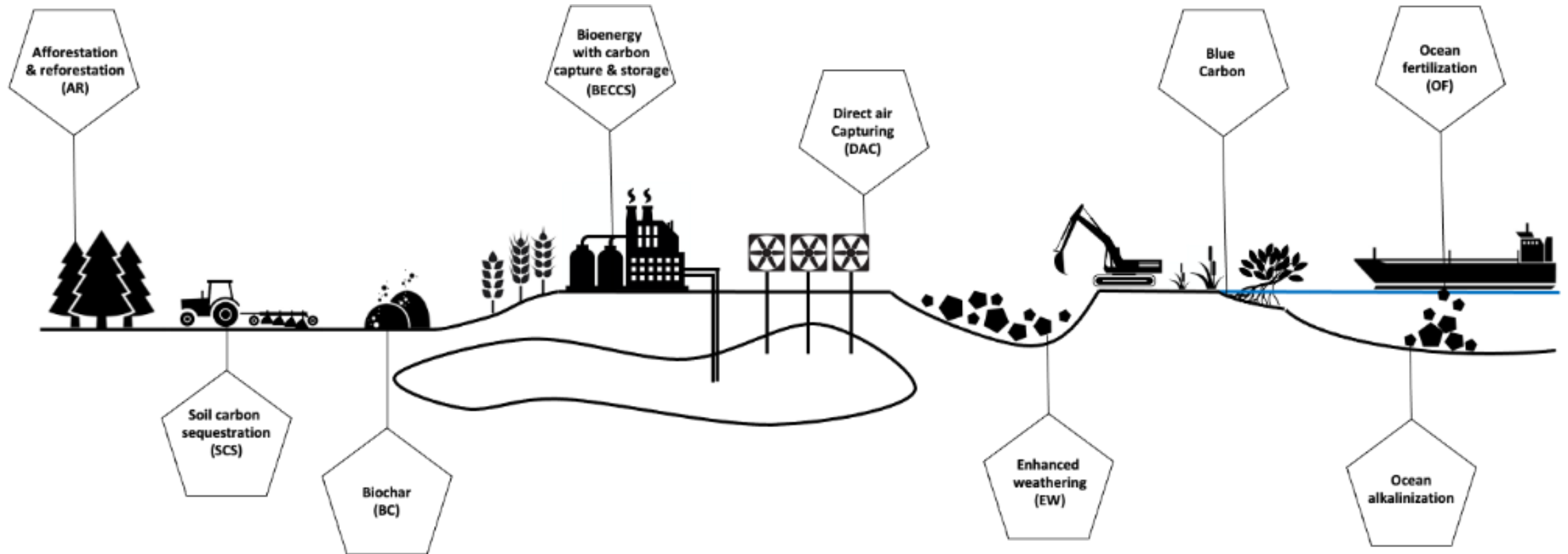


Image copyright: Climeworks

Direct Air Capture (DAC) captures CO₂ out of the air by absorbing it in a solvent.



Carbon Dioxide Removal can be accomplished with a variety of approaches



CDR is already being deployed in Colorado

CDR startups are establishing operations in Colorado

- Travertine – electrochemical mineralization (**Boulder**)
- Global Thermostat – direct air capture (**Brighton**)
- Charm Industrial – pyrolysis oil (**Fort Lupton**)
- Prometheus Materials – bio-concrete (**Boulder**)
- Biochar Now – biochar (**Berthoud**)
- Biochar Solutions – biochar (**Lafayette**)

Colorado labs and universities are studying CDR

- Direct air capture (DAC) is currently being researched at NREL
- The open FOA for federal DAC hubs may see applications from CO based companies



Source: Image from <https://globalthermostat.com/>

Who is expected to pay for carbon removals

GOVERNMENTS, VIA:



→ Direct finance & purchase of removals

→ Enhancing and creating compliance markets with a limited quantity of removals

→ Reforming existing policy and subsidy regimes



CORPORATES, VIA:



→ Meeting obligations in compliance markets (e.g., EU ETS)

→ Committing to net-zero decarbonisation pathways...

→ ...neutralising any remaining emissions with carbon removal credits in the voluntary market.

Role of policy in carbon management



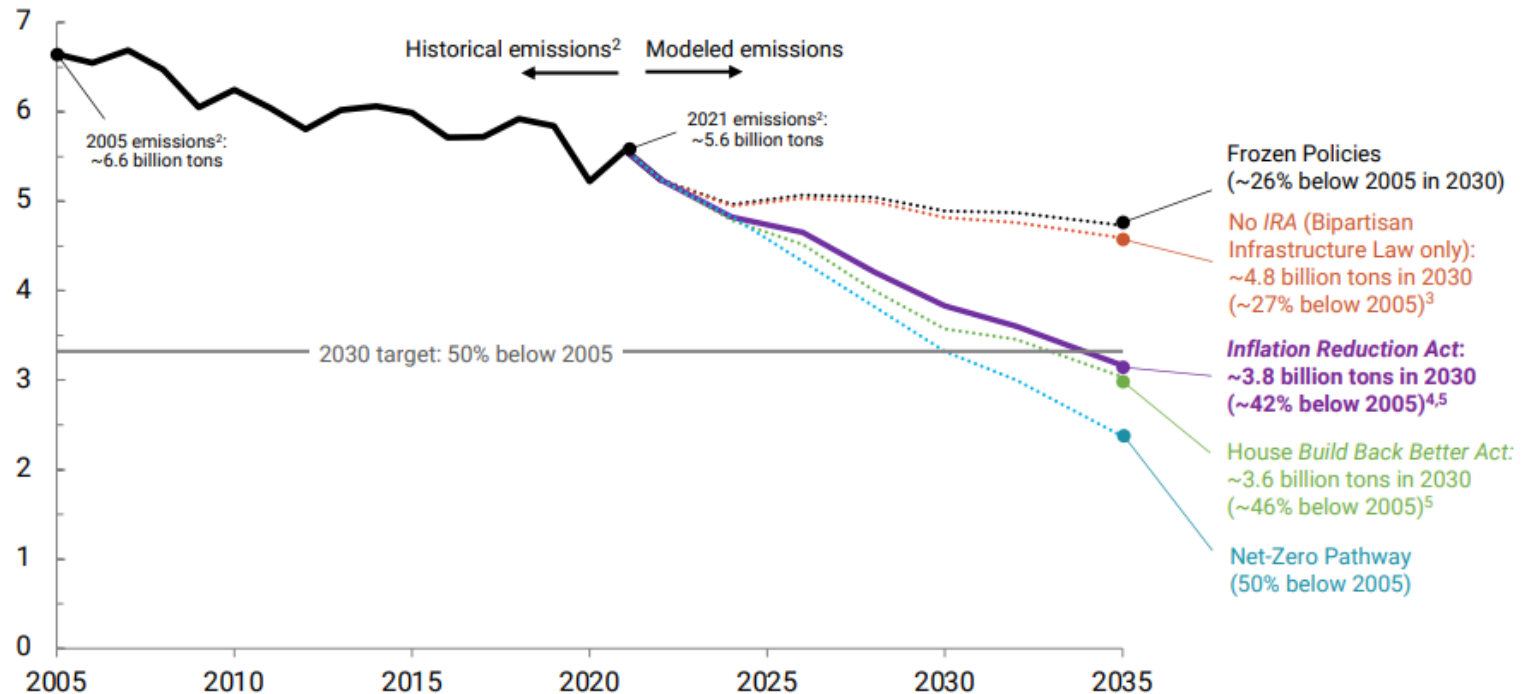
Federal policy is already building support for CDR and CCS

Stated White House Goals

1. Reduce greenhouse gas emissions by 50% (rel. 2005 levels) by 2030
2. Net zero emissions economy-wide by 2050
3. Removal of 1 GT CO₂e/year by 2050

Historical and Modeled Net U.S. Greenhouse Gas Emissions (Including Land Carbon Sinks)

billion metric tons CO₂-equivalent (Gt CO₂e)¹



Government role in scaling CDR

The primary role of government in scaling CDR is to establish clear guidelines in which markets can operate. E.g.:

- Establishing legal definitions
- Clarifying legal ownership rights, especially for pore space
- Facilitating class VI well permitting
- Establishing measurement, reporting, and verification (MRV) protocols and standards
- Facilitating the construction of supporting infrastructure, including pipelines
- Ensuring long term safety, justice, and stewardship within operations

NINE ACTIONS TO SCALE CDR IN THE 2020s

In addition to rapid and critical decarbonisation action



Legislative issues relevant to carbon management (CDR and CCS) in Colorado

	Legislative issues:	Why it matters
1	Definitions	Defining relevant terms around carbon management is essential to fostering healthy industries
2	Class VI Well Primacy	Establishing Class VI well primacy in CO will significantly expedite approval of new CO2 sequestration wells
3	Pore space	CO2 is being injected underground into pore space. It will be essential to clarify ownership rights
4	Aggregating property rights	Because underground pore space doesn't end at human-made property boundaries, clarity is needed on aggregate ownership rights
5	Long term site stewardship standards	Standards are needed for how to ensure safety and stewardship before, during, and after CO2 injection
6	Programmatic funding for carbon stewardship	Create a fund and define authority and responsibilities for a long-term carbon stewardship enterprise
7	Environmental Justice	Create rules to ensure that carbon management is done responsibly
8	CO2 pipelines	Create or delegate an authority for managing CO2 pipeline safety, planning, and eminent domain

A scenic landscape featuring a valley with green fields and a dense forest of evergreen trees. In the background, rugged mountains with rocky peaks are partially shrouded in mist or low clouds. The sky is filled with soft, grey clouds. In the foreground, there are trees with autumn-colored foliage. A large blue circle is overlaid on the left side of the image, containing the text 'Q&A' in white.

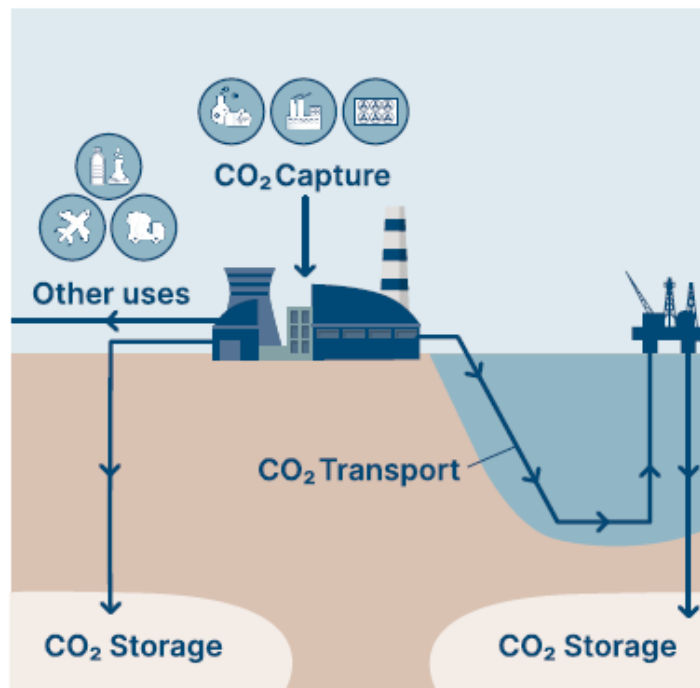
Q&A

Taxonomy of CDR approaches

Biogenic (bCDR)	Geochemical (gCDR)	Synthetic (sCDR)
<p>(1) Enhanced ecosystem techniques</p> <ul style="list-style-type: none">• Improved land/forest management• Conservation/protection of sinks• Restoration/creation of sinks• Soil CDR	<p>(4) Carbon mineralization</p> <ul style="list-style-type: none">• Ex-situ• In-situ• Surficial	<p>(7) Direct air carbon capture and storage</p> <ul style="list-style-type: none">• Absorption• Adsorption• Membranes• Cryogenics
<p>(2) Non-CO₂ carbon sequestration</p> <ul style="list-style-type: none">• Biochar• Bio oil• Microalgae• Macroalgae• Wood burial	<p>(5) Enhanced weathering</p> <ul style="list-style-type: none">• Coastal• On farmland• In forests	<p>(8) Electrochemical ocean CDR</p> <ul style="list-style-type: none">• Acid CO₂ evolving• Base carbonate precipitate
<p>(3) Geological CO₂ sequestration</p> <ul style="list-style-type: none">• BECCS• Waste energy with CCS	<p>(6) Mineral spreading in oceans</p> <ul style="list-style-type: none">• Ocean liming• Other alkaline materials	

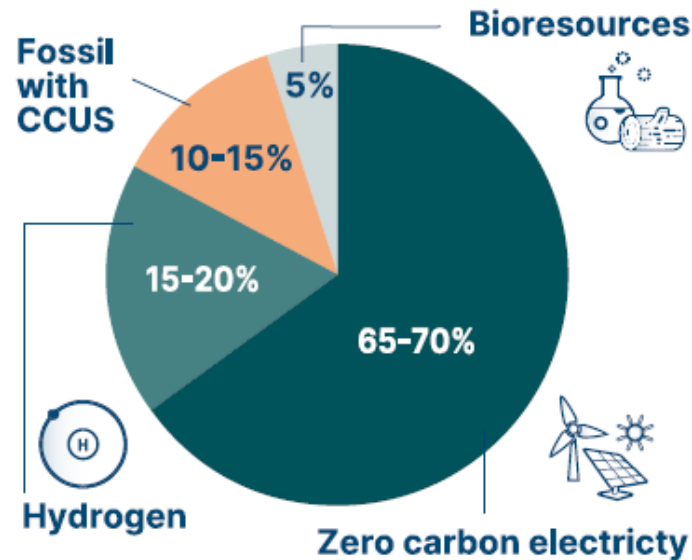
CCS is largely seen as a transition strategy

CCUS IS CAPTURING CO₂ FOR STORAGE OR USE



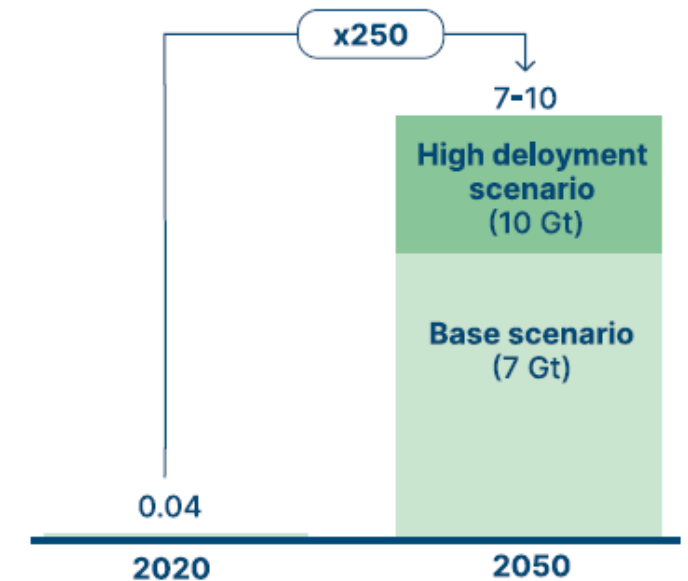
CCUS HAS A VITAL BUT LIMITED ROLE

Final energy mix in a zero-carbon economy by 2050



A SIGNIFICANT SCALE UP IS REQUIRED

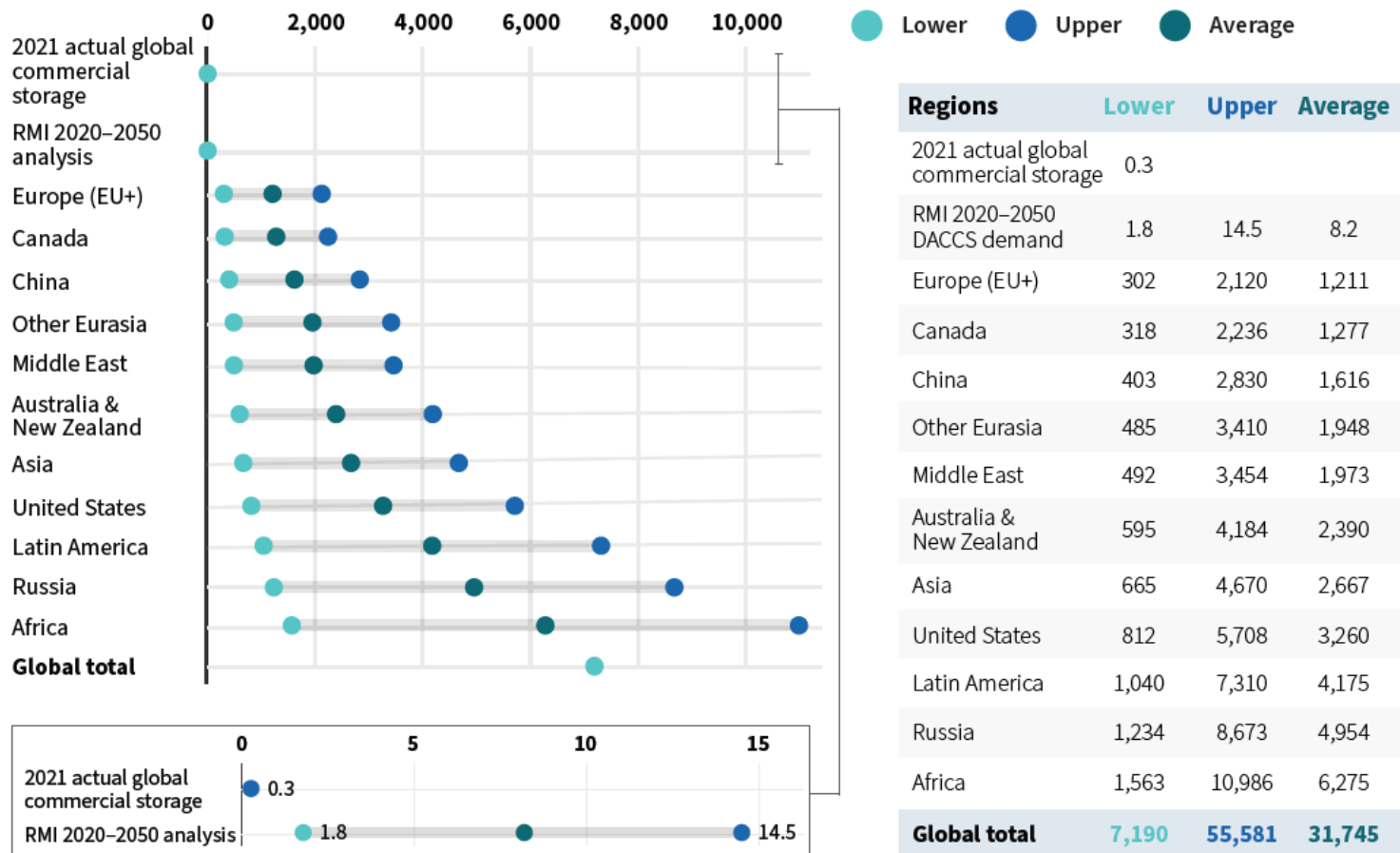
Carbon dioxide capture, GtCO₂/year



Global storage potential will not be limiting

Exhibit 8

Estimated practical geological storage capacity by region, onshore and offshore (GtCO₂)



Source: Kearns et al. (2017); RMI Analysis; OGCI - CO₂ Storage Resource Catalogue (2021)