CICE IBET

Catalyzing Carbon Dioxide Removal at Scale

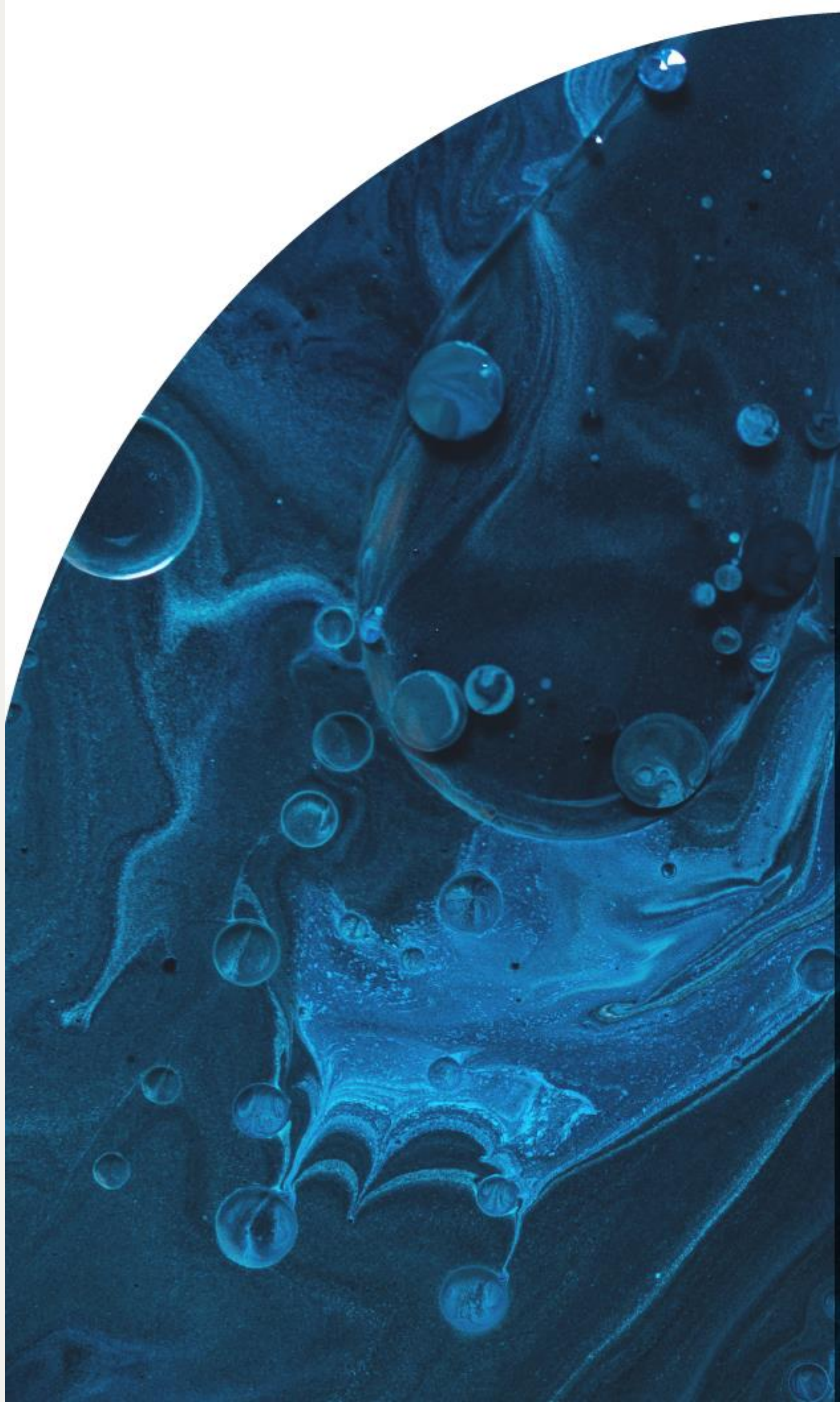
A techno-economic analysis of gigatonne opportunities

Presenters -

Chantelle Carden- Carbon Management Lead, CICE

Mike Sherman - Negative Emissions Lead, IBET

March 6, 2024



Territorial Land Acknowledgment

The BC Centre for Innovation and Clean Energy respectfully acknowledges that it operates on the traditional, ancestral, and unceded territories of the First Nations, Inuit, and Métis peoples.

Fast-tracking innovation like the planet depends on it

Because it does.

Who is CICE?

- Independent not-for-profit organization
- Founded: Fall 2021
- $105M raised through public/private Member partnerships and grants:
  - Government of British Columbia
  - Shell Canada
  - NRCan (Government of Canada)

Why we exist

- **Lead early-stage, catalytic seed investment into innovation** where the lack of validation and revenue metrics are often a barrier to funding
- **Drive market adoption and scale-up** to adopt cleantech faster and more cost effectively – at less risk
- **Enable a world-class clean energy sector** to leverage BC's natural resources and clean energy advantages and attract global investment, build IP, create good jobs and lead a prosperous economy

CICE

Companies supported by CICE

$ 141.63M
TOTAL PROJECT FUNDING

$ 22.6M
INVESTMENT BY CICE

1.74MT/YR
T/YR POTENTIAL GHG ABATEMENT

ANODYNE
ARCA
ATLAS POWER TECHNOLOGIES
Cascadia SEAWEED
Corvus Energy
DEADWOOD INNOVATIONS
EKONA
FPInnovations
H2 PORTABLE — CLEAN POWER. ANYWHERE.
HTEC — FUELING THE DRIVE TO HYDROGEN
hydra
HYDRON
illuming power
INNOVATREE CARBON GROUP
INVINITY ENERGY SYSTEMS
LAFARGE
Lheidli T'enneh
MANGROVE LITHIUM — Unlocking a battery-powered future
Metaspectral
metrovancouver — SERVICES AND SOLUTIONS FOR A LIVABLE REGION
miraterra
moment energy
Parkland
Quatern Forest Products
RAINHOUSE MANUFACTURING CANADA LTD.
TAKACHAR — TECHNOLOGY • EQUITY • ENVIRONMENT

BATTERY & ENERGY STORAGE

CARBON MANAGEMENT

LOW CARBON BIO & SYNTHETIC FUELS

LOW CARBON HYDROGEN

CICE

Agenda & Objectives

Agenda

- Why do we need CDR?
- TEA - Air, Ocean, Land, Rock
- TEA Conclusions
- Opportunities for Canada and B.C.
- Questions & discussion

Objectives

Explain the approach and results of the report to the community

Gather feedback on how B.C. can support critical innovation to scale CDR

Why do we need Carbon Dioxide Removal (CDR)?

Why do we need Carbon Dioxide Removal (CDR)?

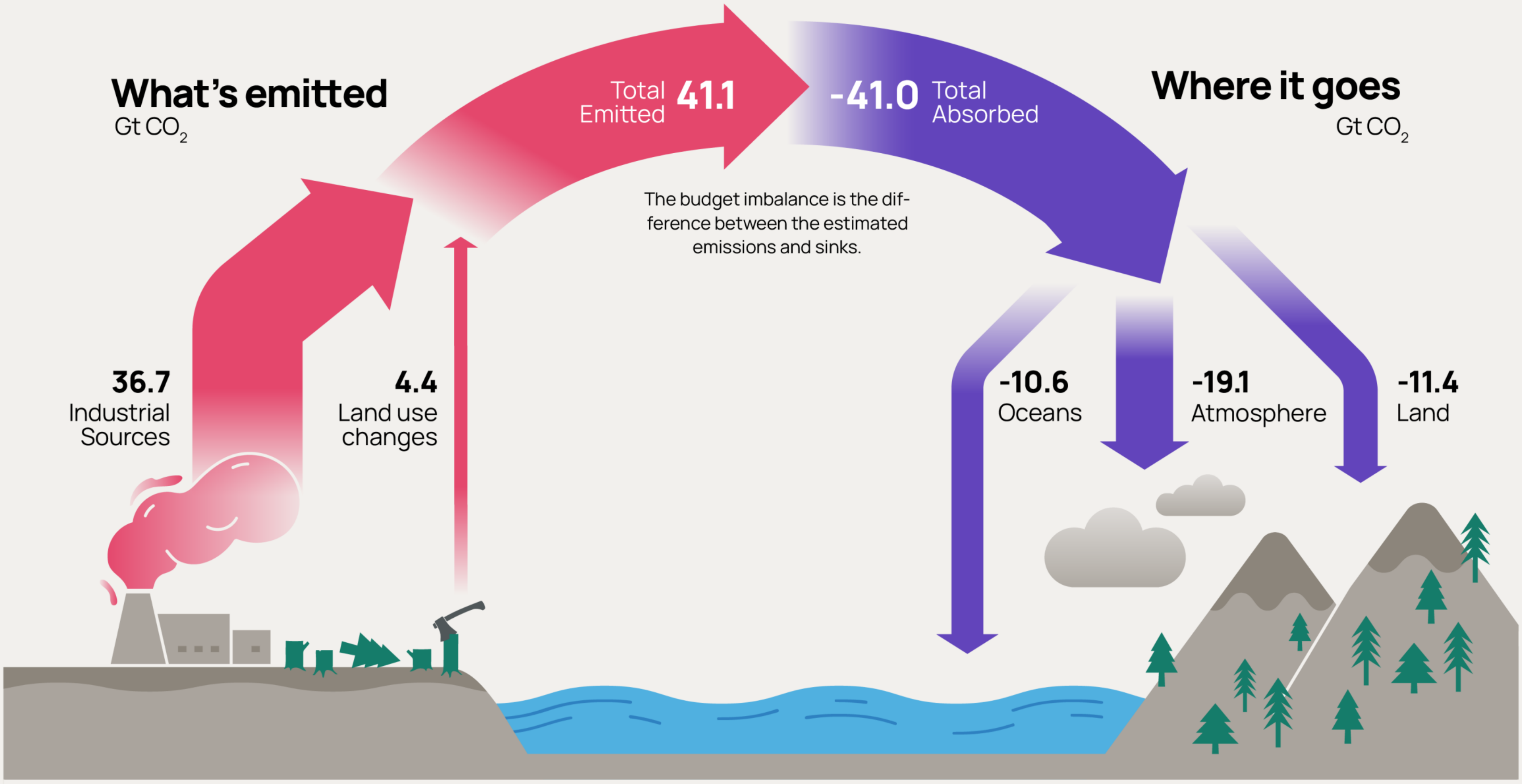
There is no pathway to reaching net-zero emissions and a 1.5°C future without CDR. But CDR is only effective in combination with the required significant and rapid emissions reductions.

"The deployment of carbon dioxide removal (CDR) to counterbalance hard-to-abate residual emissions is unavoidable if net zero CO_2 or GHG emissions are to be achieved. The scale and timing of deployment will depend on the trajectories of gross emission reductions in different sectors."

- IPCC (2022)

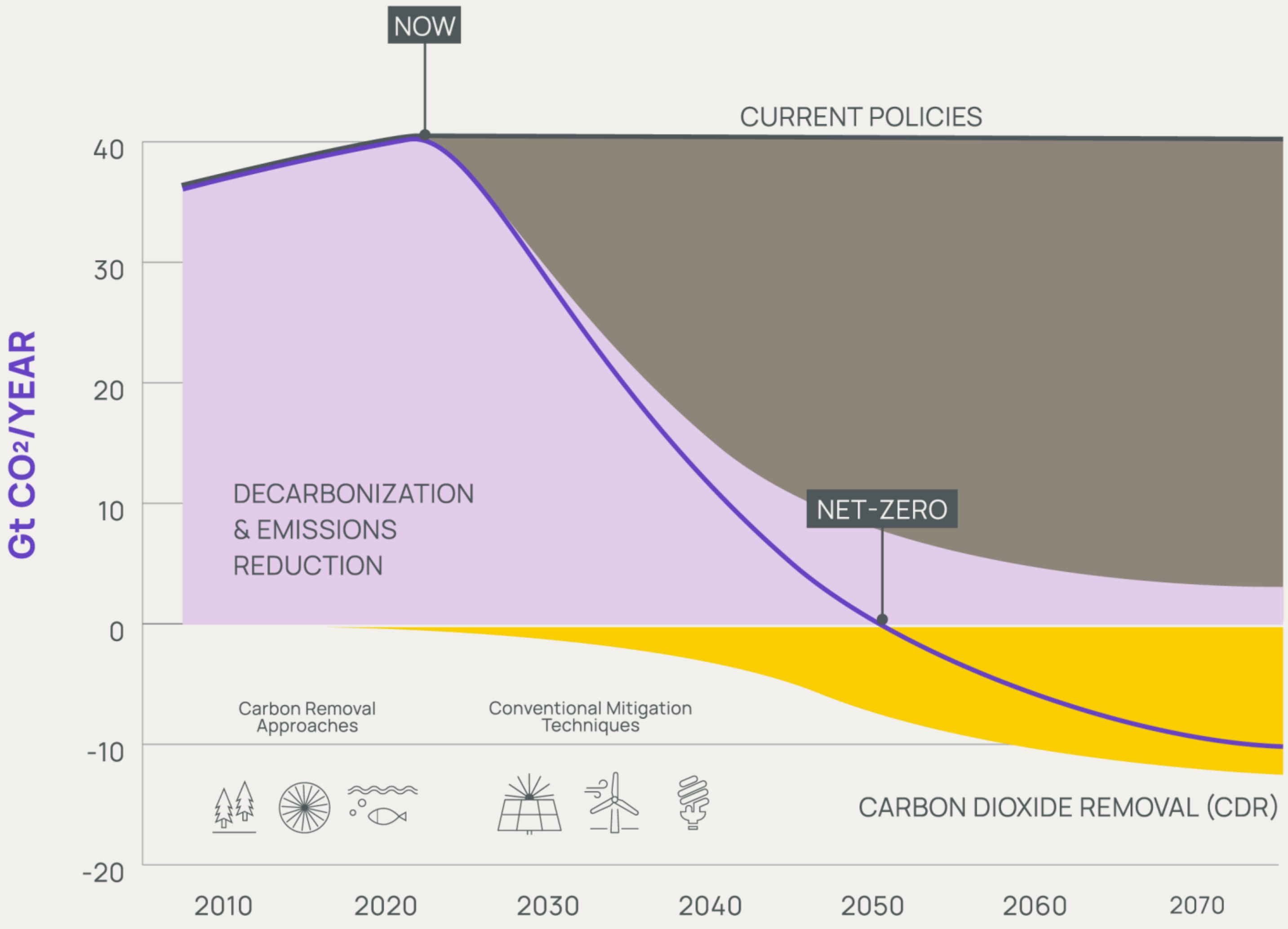
CICE

The 2022
Global Carbon Cycle



How much CDR do we need?

How much CDR do we need?

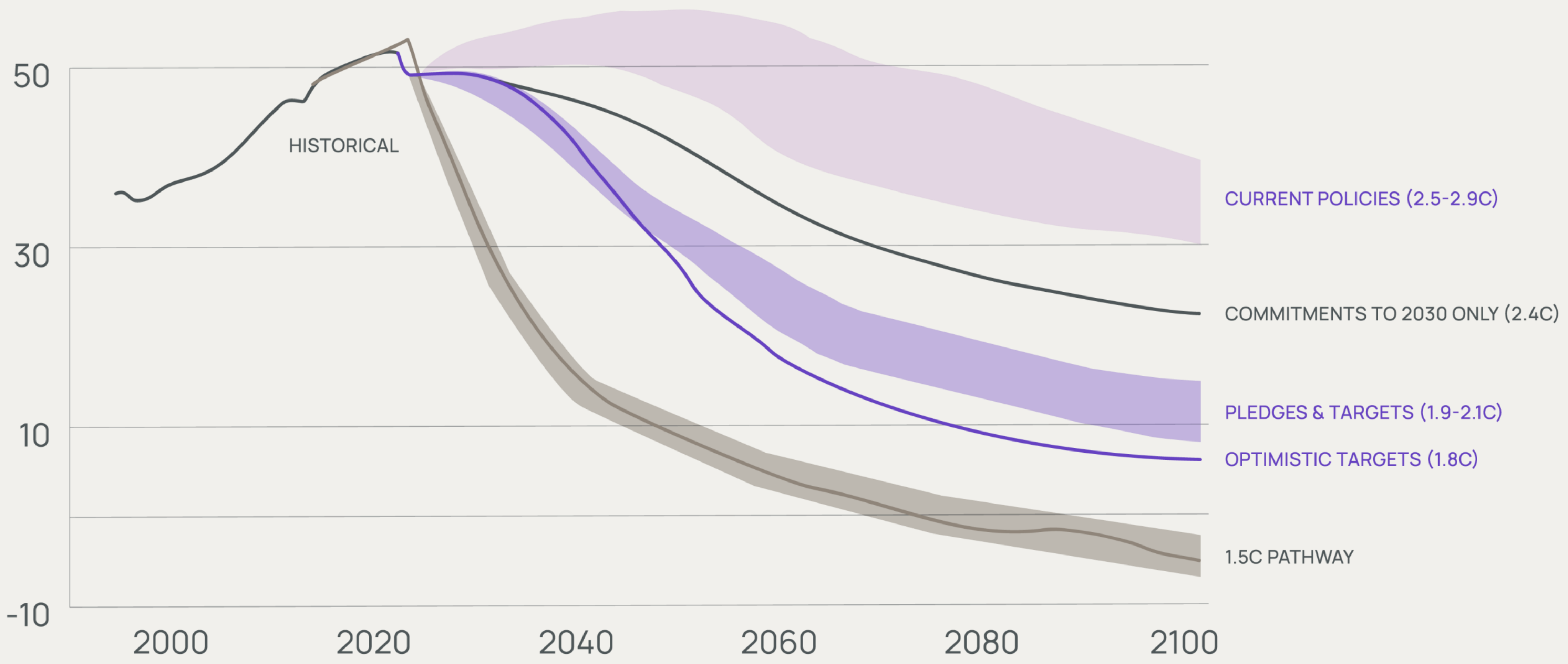


YEAR	AVERAGE CDR IN IPCC 1.5C SCENARIOS WITH NO OVERSHOOT (C1)[1]
2030	2.3 $GtCO_2/y$
2040	7.0 $GtCO_2/y$
2050	10.8 $GtCO_2/y$
2100	17.6 $GtCO_2/y$

Source - Based on IPCC (2018) and CAT (2021), World Resources Institute

CICE

Level of likely overshoot, given current policies



Source - Climate Action Tracker / BBC

CICE

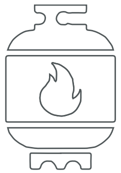
How much CDR do we need?

Minimum 10 GtCO_2 removal per year is needed by 2050. Assumes 75% reduction and no overshoot, which is unlikely.

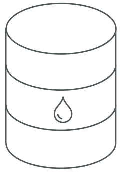
“Obtaining net negative CO_2 emissions requires massive deployment of carbon dioxide removal (CDR) in the second half of the century, on the order of 220 (160–370) GtCO_2 for each 0.1°C degree of cooling.”

This means that a 0.5°C overshoot to 2°C would require an additional 1100 Gt of CO_2 removal to reduce temperatures back to 1.5°C.

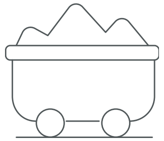
Annual Global Production



= 3 Gt/y

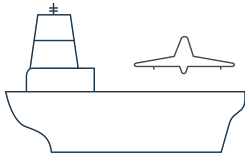


= 4 Gt/y



= 8 Gt/y

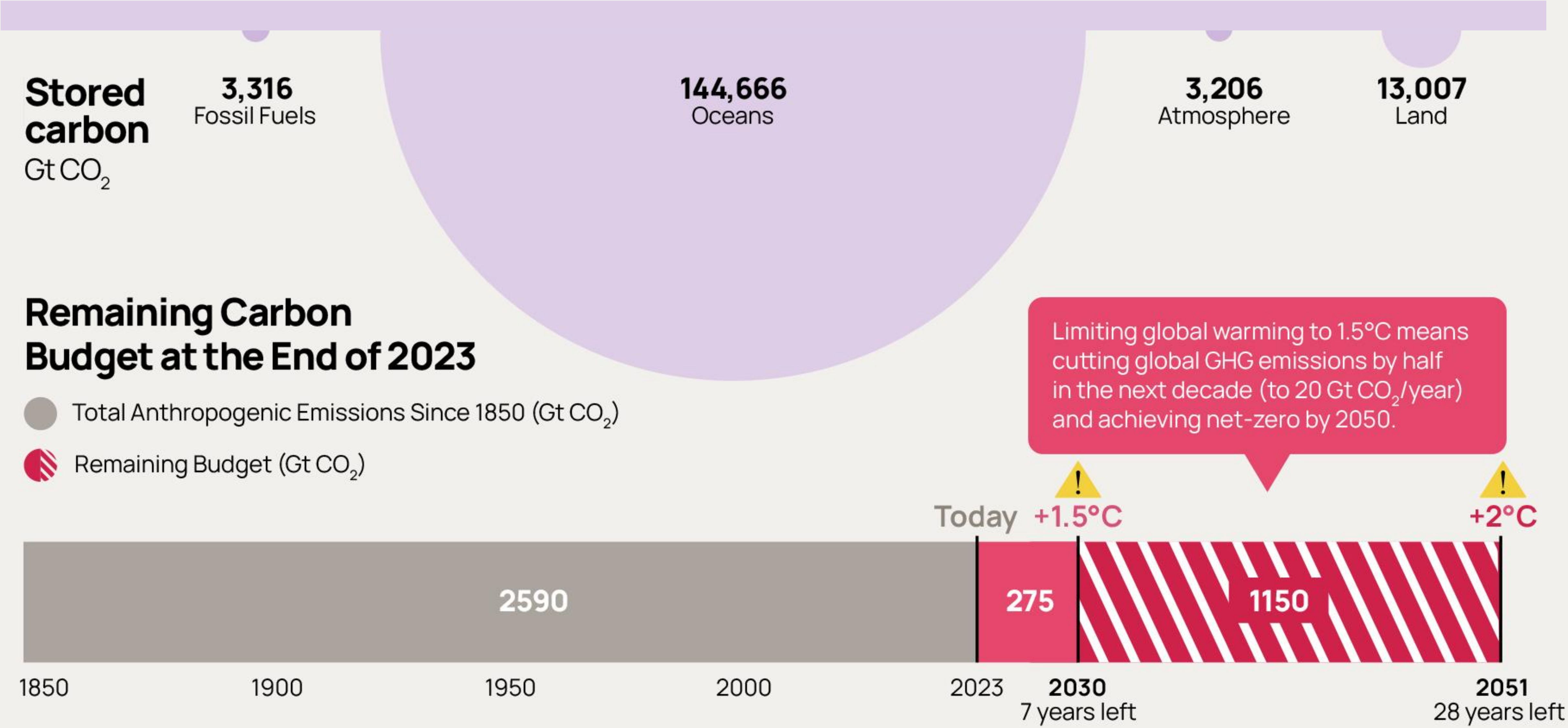
100,000 Aircraft Carriers



=10 Gt/y

CICE

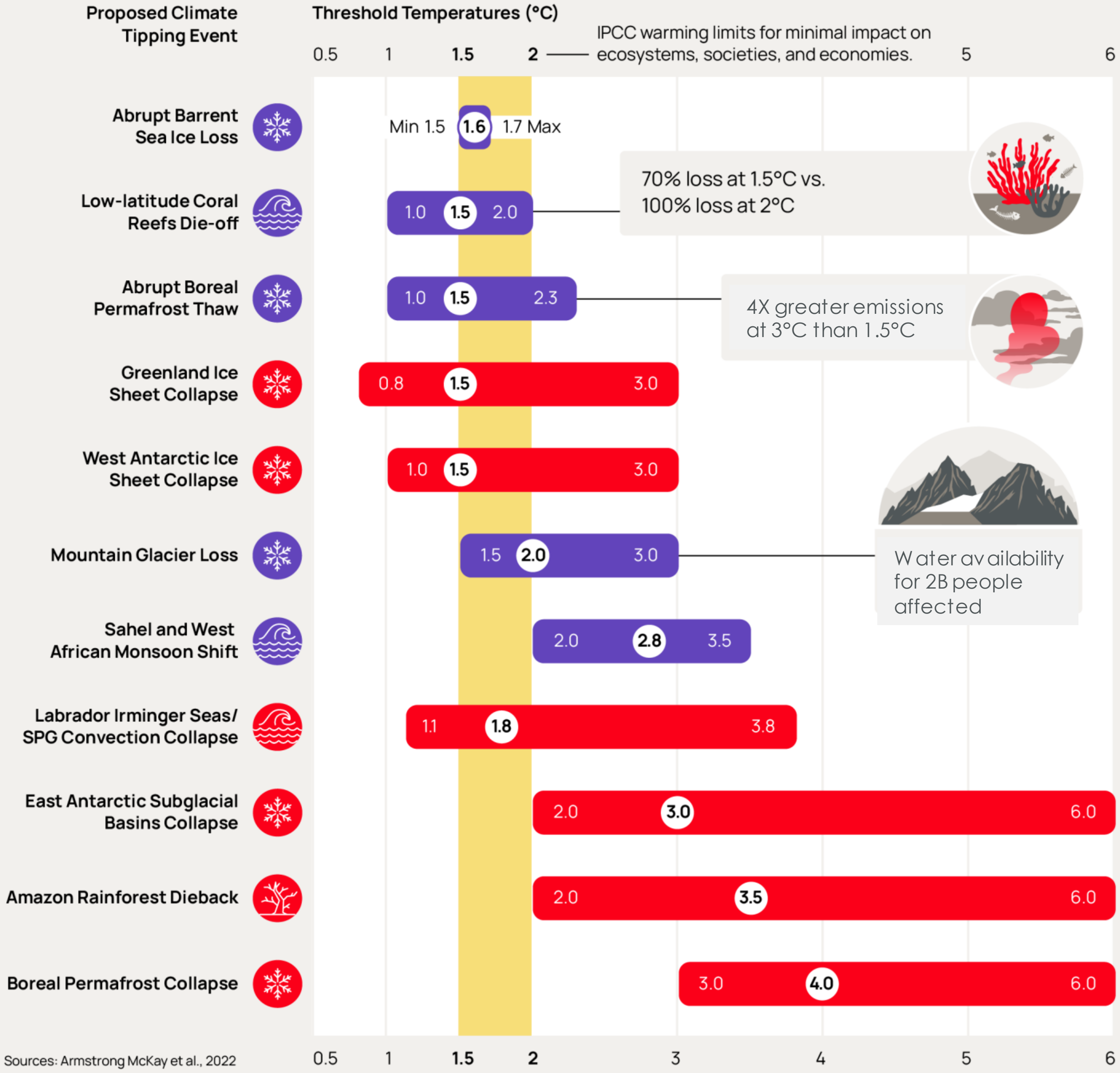
How much time do we have to scale CDR?



Degrees of Peril

Climate Tipping Events at Various Degrees of Warming

- Global Core Tipping Events
- Regional Impact Tipping Events
- Central Estimate



Sources: Armstrong McKay et al., 2022

CDR capture pathway segmentation

Air

CDR Pathways using engineered processes to directly capture CO_2 from air. Requires the regeneration of a sorbent/solvent to release the gaseous CO2. Must be coupled with geological storage or use in products.

Land

CDR Pathways that leverage land based biological pathways (photosynthesis) to capture CO_2 and convert it to biomass (trees, plants, or soil). The biomass is either left living, treated or converted to a more stable form of carbon. Storage may be in living biomass, soil, products, or geological sequestration.

Ocean

CDR Pathways that use the ocean as a capture medium, or ocean-based biological pathways for capture and storage of CO_2. Certain methodologies may also produce gaseous CO_2 that will need to be stored geologically.

Rock

CDR Pathways that directly capture and store CO_2 in rocks, such as through enhanced mineralization of mine tailings.

Techno-economic analysis approach

Criteria for performing pathway TEA

We performed TEA on CDR pathways that met the following criteria:

- Developmental CDR pathway (versus mature)
- Potential for 1 Gt of removals
- Sufficient scientific and engineering data to perform analysis was available

Analysis: Mature pathways - demonstrated at scale

- Summary of reported cost estimates at scale
- Analysis of scaling metrics, opportunities and barriers

Analysis: Developmental Pathways - not yet demonstrated at commercial scale

- TEA of performance improvement and cost reduction potential at scale
- Analysis of scaling metrics, opportunities, and barriers

CICE

Comparison of DAC approaches

Mild | Moderate | High

	Energy Source	Energy (TWhs / EJ/yr)	Global Energy % (Electricity: 29,000 TWh, Natural Gas: 145 EJ/yr)	Land (Acres)	Land Ratio vs. lowest requirement (50,000 acres)	Materials	Materials % of current production	Water (Bm3)	Cost/t CO_2	Gt Y/N
Waste Heat										
DAC Liquid sorbent low temp (Holocene)	Waste heat generation	5.3	13.6% (Waste Heat)	125,000	2.5	3,000,000	29%	3-6	$100	Y
DAC Solid structured sorbent (Climeworks, Global Thermostat)	Waste heat generation	7	17.9% (Waste Heat)	500,000	10.0	5,000,000	0.007%	<1	$220	Y
NG Thermal										
DAC Solid Unstructured Sorbent (Heirloom)	Oxy fired heat generation	4.9	3.38%	450,000	9.0	2,300,000,000	35%	2-5	$127	Y
DAC Liquid Sorbent High Temp (CE)	Oxy fired heat generation	9.3	6.41%	50,000	1.0	5,000,000	0.007%	5	$110	Y

CICE

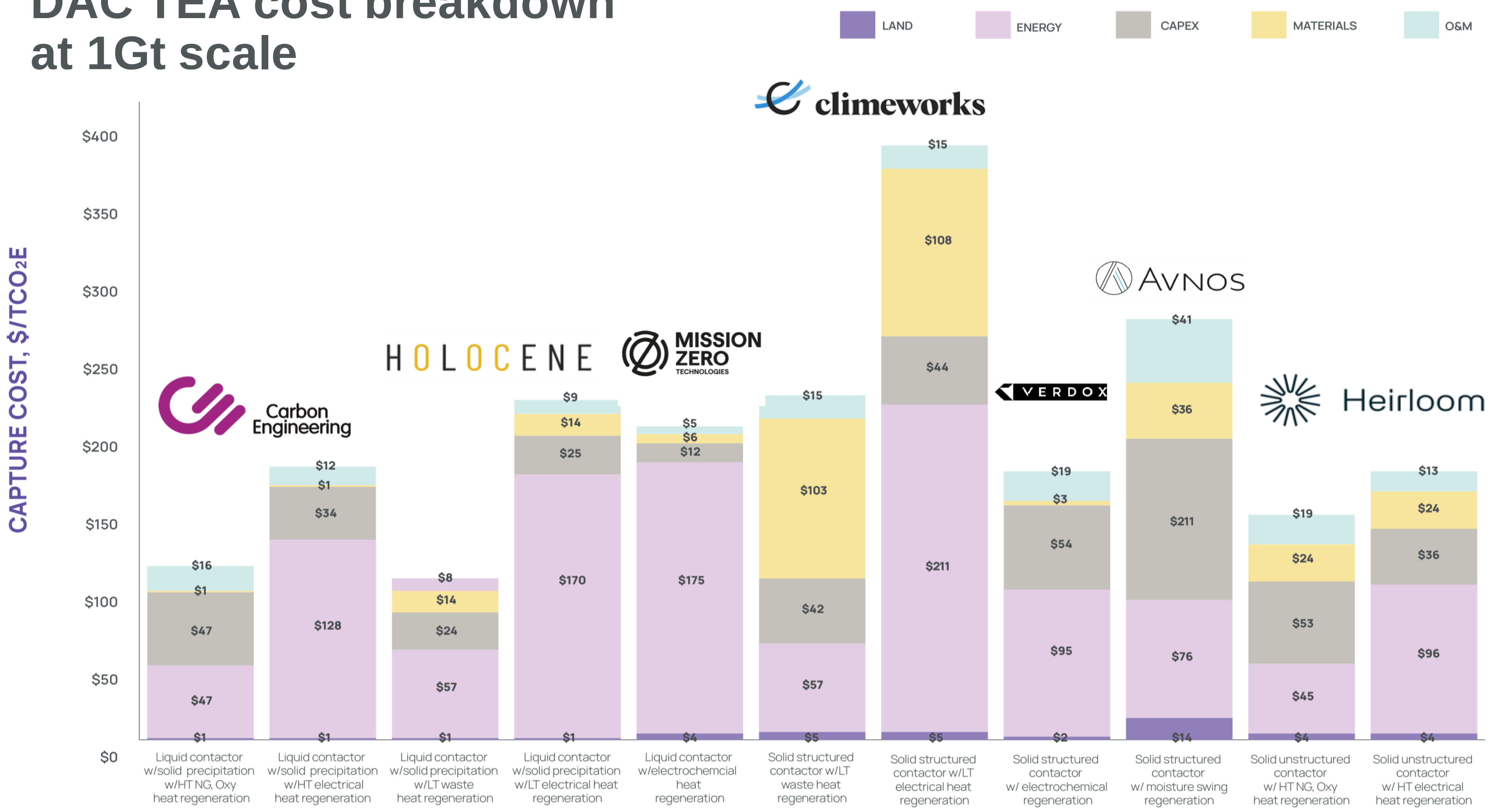
Comparison of DAC approaches

Mild | Moderate | High

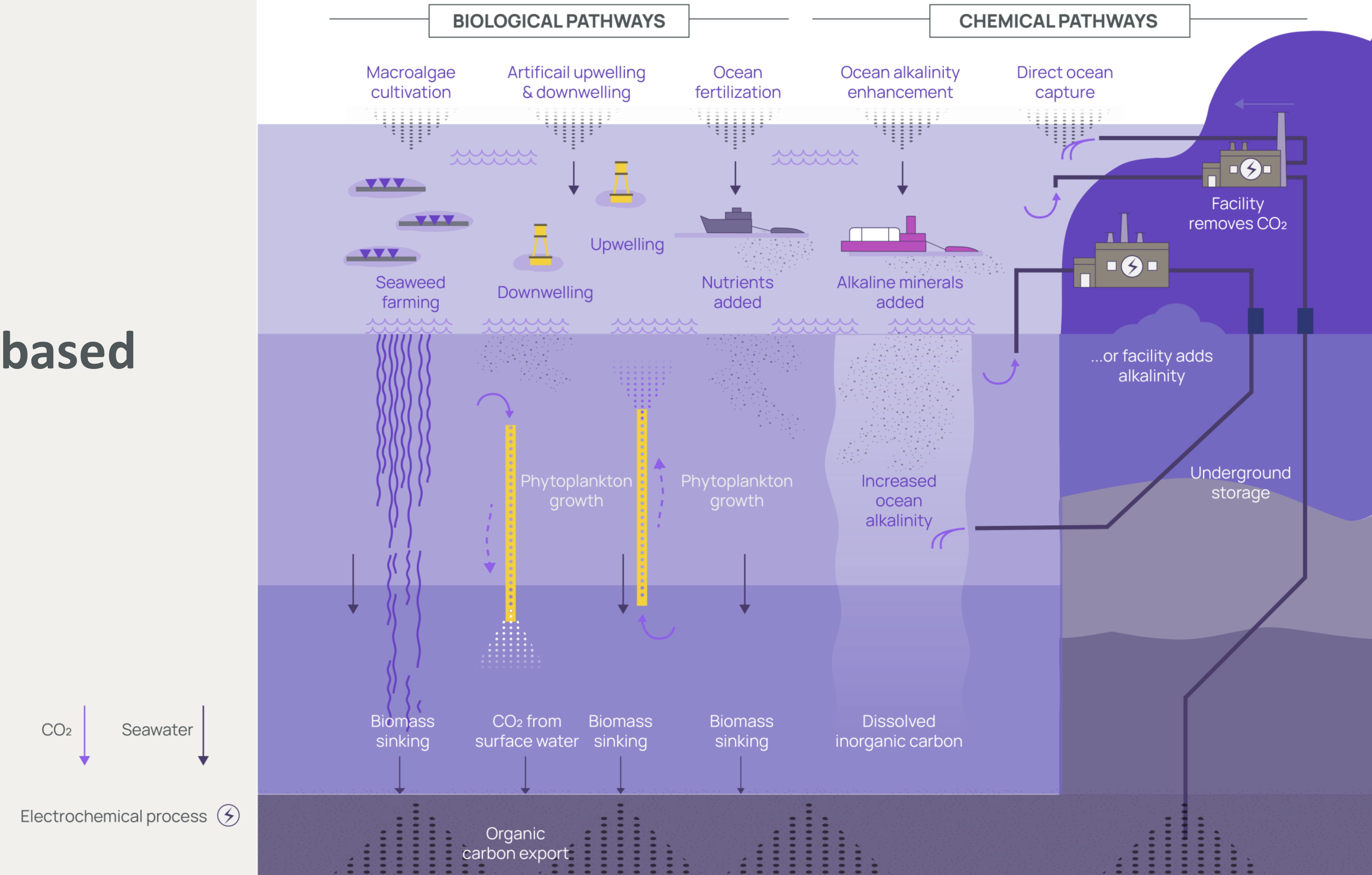
Electrical	Energy Source	Energy (TWhs / EJ/yr)	Global Energy % (Electricity: 29,000 TWh, Natural Gas: 145 EJ/yr)	Land (Acres)	Land Ratio vs. lowest requirement (50,000 acres)	Materials	Materials % of current production	Water (Bm3)	Cost/t CO_2	Gt Y/N
DAC Humidity Swing (Avnos)	Electrical	1,000	3.4%	700,000	14.0	7,000,000	0.009%	<1	$270	Y
DAC Electrochemical solid sorbent (Verdox/MIT)	Electrical	1300	4.48%	200,000	4.0	700,000	0.001%	0	$170	Y
DAC Solid unstructured sorbent (Heirloom)	Electrical heat generation	1400	4.83%	450,000	9.0	2,300,000,000	35%	2-5	$155	Y
DAC Liquid sorbent high temp (CE)	Electrical heat generation	1800	6.21%	50,000	1.0	5,000,000	0.007%	5	$175	Y
DAC Liquid sorbent low temp (Holocene)	Electrical heat generation	2276	7.85%	125,000	2.5	3,000,000	29%	3-6	$215	Y
DAC Liquid sorbent electrochemical regen (Mission Zero, E-questor)	Electrical	2300	7.93%	500,000	10.0	5,000,000	0.007%	5	$200	Y
DAC Solid structured sorbent (Climeworks, Global Thermostat)	Electrical heat generation	2800	9.66%	500,000	10.0	5,000,000	0.007%	<1	$380	Y
DAC Membrane pressure gradient separation	Electrical	9,000	31.03%	60,000	1.2	N/A	NA	0	$940	N
DAC Cryogenic	Electrical	9,200	31.72%	60,000	1.2	N/A	NA	0	$1,000	N

CICE

DAC TEA cost breakdown at 1Gt scale



Ocean based CDR



Ocean based CDR insights

OAE
- Lowest cost engineered approach $100-130 (depending on energy source)
- No material feedstock constraints

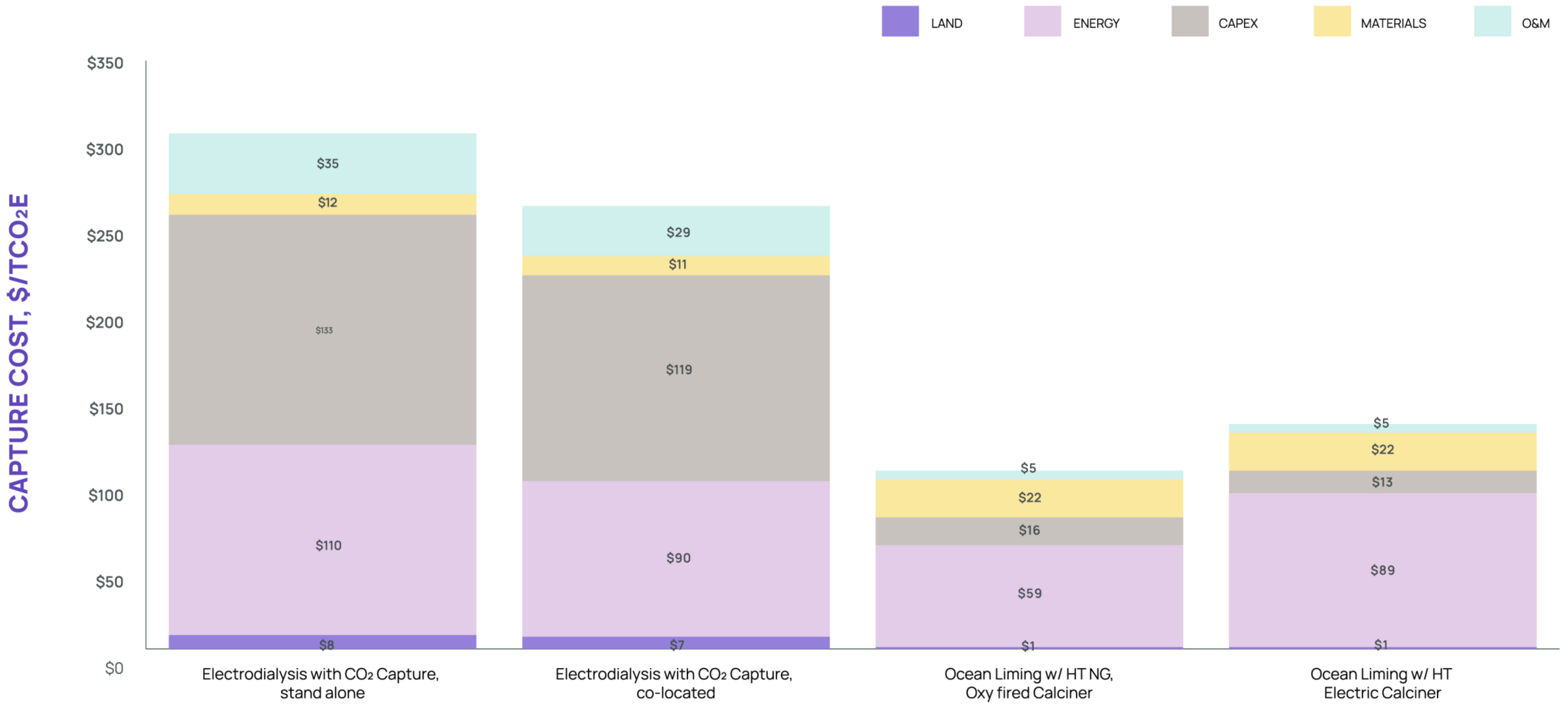
DOC
- Very high electric demands - 6000 TWh/Gt (20% Global production)
- 2/3 energy for pumping water, 1900 TWh/Gt if co-location (limited to 4% of 1Gt)

BCP (ocean fertilization, upwelling and downwelling)
- Lack of scientific consensus on the efficacy
- Very limited demonstration data, MRV challenging

Macro Algae (seaweed)
- 1Gt requires 1km x 730,000 km of coastline, or 63% of globally available coastlines
- Estimates of $100-400 / t CO2

Blue Carbon
- Low cost at $10-50/t$CO_2$, but MRV challenging (600x variability of CO_2 removal)
- Gt removals is unlikely with most estimates 0.1-0.4 Gt/year

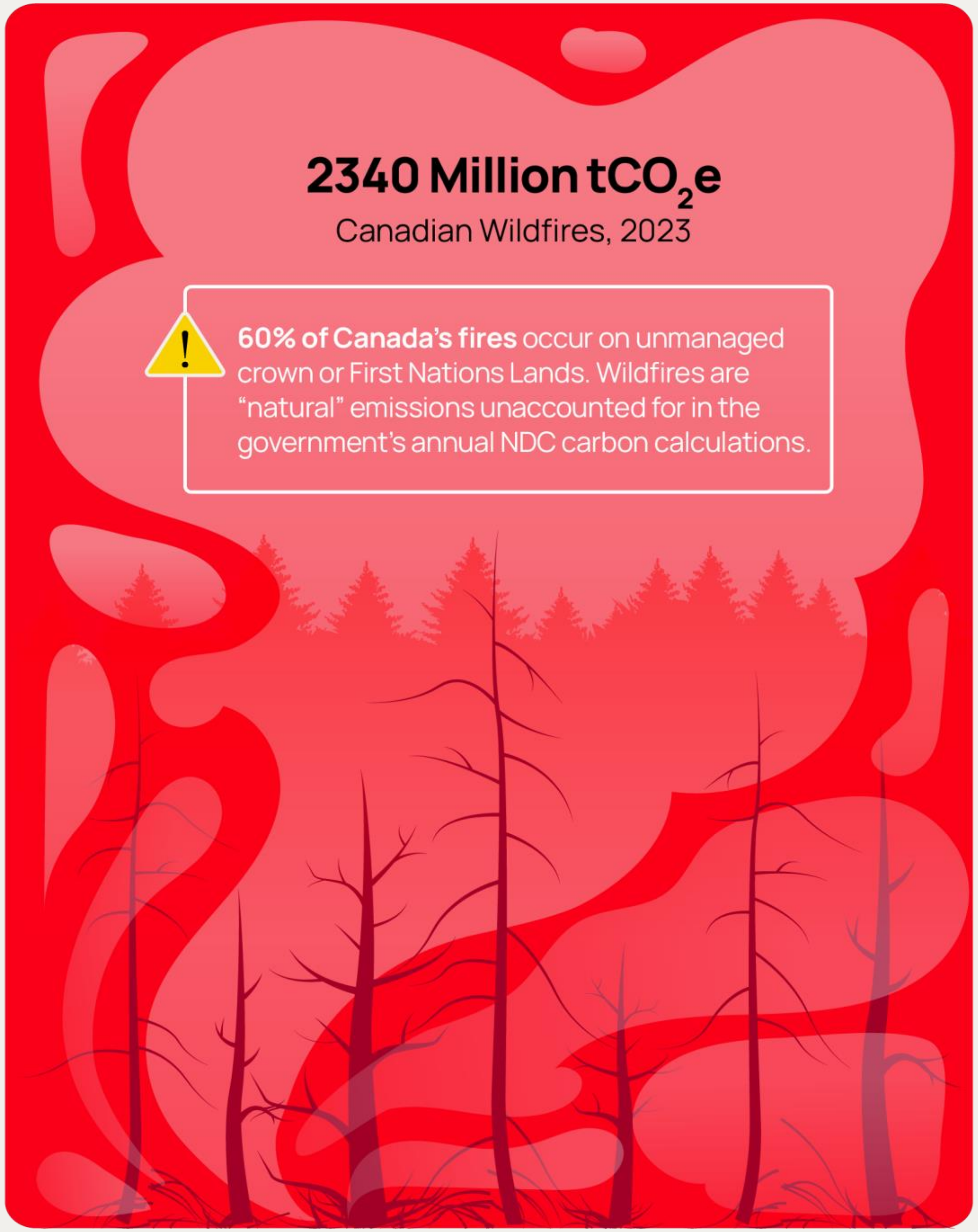
DOC and OAE TEA cost breakdown at 1Gt scale



CICE

The Colossal Impact of
Canada's 2023 Wildfires

Total Emissions
Metric Tonnes of CO_2e



Canadian Forest Loss from Wildfires in 2023

18.4M
Burnt forest, 2023

2.2M
Annual average burnt forest, 1983-2022

Land based CDR insights

Forest Based CDR (Afforestation / Forest management)

- Estimated below $100/tonne of CO2 (t$CO_2$), with lower bounds of $10-$20/tonne in some cases.

Afforestation

- 1 Gt/year removals require 27.3M hectares in tropical Asia, Africa, and Latin America, or 227.1M hectares in the boreal forest of Canada and Russia.
- 24.6M hectares lost on average through deforestation over the past 10 years.

Forest management

- Specifically fire prevention reducing the emissions form wildfire, is the nearest term potential to reach Gt scale. (2.4Gt in 2023 Canadian Wildfires)

BioCDR (Biochar, bio oil, BECCS)

- 1Gt Requires 10% to 15% of the estimated global sustainable biomass supply (>10 EJ) vs. 10% available (IEA)
- Bioenergy cropland dedication: 130M acres for BECCs to 230M acres for biochar.

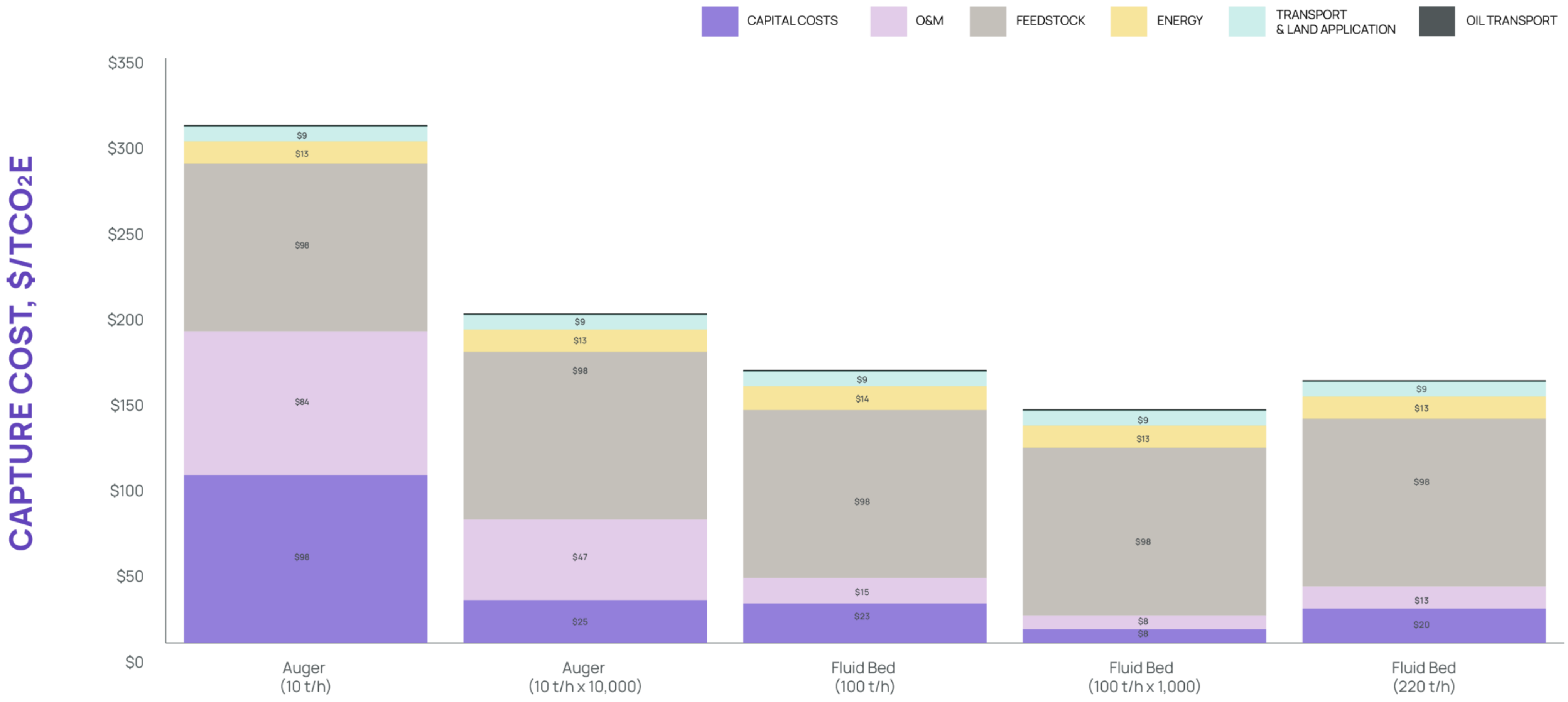
Agricultural soil management

- 1 Gt of CO_2/yr. removal would require application of agricultural soil management best practices on 1.1 billion acres of annual cropland (36% of 3.7 billion acres globally).

CICE

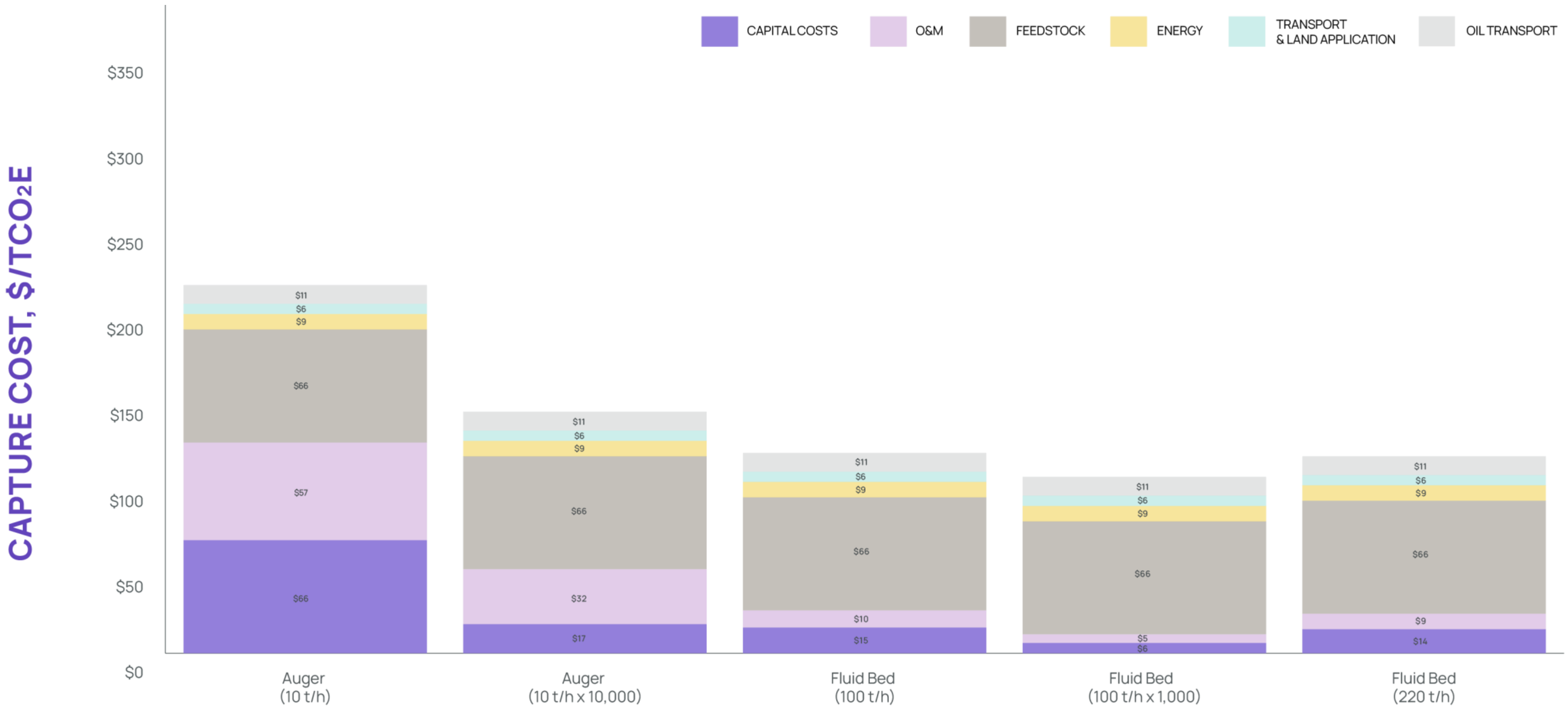
BioCDR TEA Cost Breakdown

Cost of stored carbon in char



BioCDR TEA Cost Breakdown

Cost of stored carbon in char and oil



CICE

Rock Based CDR Insights

Barriers to scaling: local availability of alkaline material / availability of land.

Cost estimates: \$20–500/tCO_2 removed — function of resource quality (i.e. grade and mineral composition) and material handling required.

Coastal Enhanced Weathering:

- The world has 344,100 km of sandy shoreline
- To spread this material in a thin layer of olivine sand, 10cm thick, would require over 1M km of sandy shoreline for 1Gt.

Surface mineralization:

- Global production of metals that produce ultramafic mine tailings generates 420 Mt of tailings material; = 75 Mt of CO_2 sequestration per year
- Carbonation has the potential to offset 65% to 100% of a mine's emissions depending on composition of tailings and carbon intensity of operations

Terrestrial Enhanced Weathering:

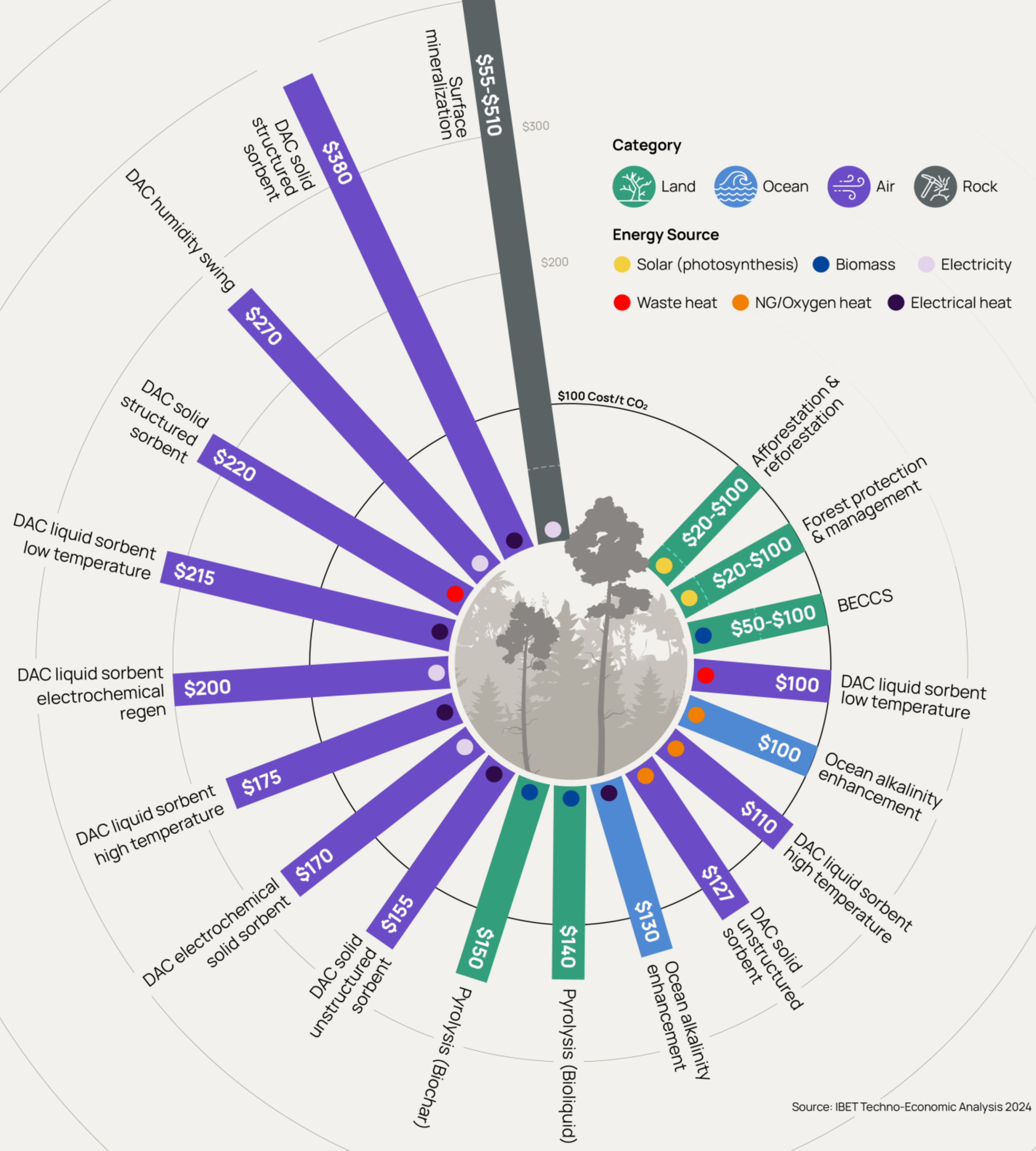
- Land requirements for TEW per Gt of CO2 removal is 10x larger than Surface mineralization
- Pure olivine applied to global cropland would sequester 0.2 to 0.9 tonnes of CO_2 per acre.
- 1 Gt of CO_2 removal would require up to 1 billion acres of cropland (approximately 27% of global croplands) and participation from millions of farmers.

Scaling barriers to realizing 1Gt

CATEGORY	CRD APPROACH	COST ESTIMATE	BARRIERS	DESCRIPTION OF BARRIER TO REALIZING 1 GT/YR REMOVALS
Ocean	Coastal Blue Carbon	\$10 - 50	Land Use, MRV	Most estimates show global potential of .11 to 1.064 Gt CO_2/yr., with one estimate significantly higher at 1.22-2.14 Gt CO_2/yr. MRV challenging with 600x variability in site-specific estimates of natural carbon burial rates
Land	Agriculture: Soil carbon sequestration	\$45-100	Land use	1 Gt of CO_2/yr. removal would require application of agricultural soil management best practices on 1.1 billion acres of annual cropland (36% of 3.7 billion acres globally).
Rock	Coastal Enhanced Weathering	\$55 - \$120	Land, Materials	1 Gt requires 171x current global mine tailings production, application on 1.2 million Acres of coastline, if it were 10cm thick you would need over 1M km of sandy shoreline vs 344,100 km of sandy shoreline worldwide.
Rock	Terrestrial Enhanced Weathering	\$75 - \$250	Land, Materials	1 Gt requires 214x current global olivine production application on application on 1 Billion Acres of cropland
Ocean	Kelp and Seaweed Cultivation	\$100 - \$400	Land use	1 Gt of CDR would require a 1 kilometre wide continuous belt of seaweed farm along 730,000 km of coastline, or 63% of globally available coastlines (180 million acres).
Ocean	DOC (Electrochemical) Co-located with desalination plant	\$250	Siting	Global Desalination (51 Bm^3/yr.) and Global Cooling Water Outfall (470 Bm^3/yr.) total 521 Bm^3/yr. which is only 4% of 13,000 Bm^3 required
Ocean	DOC (Electrochemical) Stand Alone	\$290	Energy Use	1 Gt requires more than 20% of global electricity production
Air	DAC Membrane pressure gradient separation	\$940	Energy Use	1 Gt requires more than 30% of global electricity production
Air	DAC Cryogenic	\$1,000	Energy Use	1 Gt requires more than 30% of global electricity production
Ocean	Ocean Fertilization	Insufficient data to esitmate	Scientific Validation	Scientific Validation insufficient for estimation
Ocean	Artificial Ocean Upwelling / Downwelling	Insufficient data to esitmate	Scientific Validation	Scientific Validation insufficient for estimation

CO_2 Removal Approaches

Ranked by Cost



Source: IBET Techno-Economic Analysis 2024

B.C. resources compared with CDR requirements and potential scale

AIR: DAC	BC ANNUAL PRODUCTION	Mt IF ALL RESOURCES USED FOR CDR	BC 2020 GROSS EMISSIONS MT CO_2E	% OF 2020 BC EMISSIONS IF ALL RESOURCES USED FOR CDR	BC RESIDUAL EMISSION TARGET 2050 (MT CO_2E)	% OR BC RESOURCES TO REMOVE 13 MT RESIDUAL EMISSIONS TO REALIZE NET ZERO IN 2050
Electricty (Twh)	64.3	64.3	64.6	99.5%	13.00	20%
Natural gas (Trillion cubic feet)	2.1	428.6	64.6	663.5%	13.00	3%
LAND: BECCS						
Forest waste biomass Mt(dry)/yr (2018)	7	10	64.6	15.5%	13.00	130%
Proejcted forest waste biomass Mt(dry)/yr (2028)	3	4.3	64.6	6.6%	13.00	303%
LAND: WILDFIRE PREVENTION	**MILLION HECTARES BURNT**	**ESTIMATED WILDFIRE EMISSIONS GT CO_2E**				
2023 BC Wildfires	2.84	360	64.6	557.3%	13.00	4%
10 year BC Wildfire average prior to 2023	0.407	52.7	64.6	81.6%	13.00	25%
LAND: AGRICULTURE LAND MANAGEMENT	**HECTARES CROPLAND**	**Mt IF APLIED TO ALL HA**				
Cropland 0.5 tC/ha/yr (1.8 tCO_2/ha/yr)	557,009	1	64.6	1.5%	13.00	1300%
OCEAN: OAE	Requires further assessment					
ROCK: SURFACE MINERALIZATION	Requires further assessment					

CICE

What are the primary opportunities in B.C. for scaling CDR to multi-gigatonne levels?

Ocean Alkalinity Enhancement (OAE)

- Develop sensors and infrastructure necessary for measuring baseline processes and impacts of interventions.
- Establish robust, credible scientific baseline for ocean carbon processes off of the B.C. coast.
- Establish regulatory framework for responsible piloting of ocean based CDR with clear permitting processes to allow a range of field tests of various ocean carbon removal methods to take place.
- Increase coastal community engagement and education on the impacts of ocean acidification and climate change on marine ecosystems and fisheries.

Which approaches can have the most immediate impact?

Wildfire protection

- Increasing provincial investment in forest fire prevention
- Expand partnerships with First Nations around fire protection, similar to the Great Bear Rainforest project
- Establish robust, credible scientific baseline for fire management protection credits to fund these projects
- Invest in innovation in forest carbon management and fire prevention data science, and innovative practices and technologies for wildfire prevention

CICE

How can B.C. support critical innovation to scale CDR?

1. Support local innovation ecosystems

- Foster collaboration between academia, industry, and government to facilitate a CDR innovation ecosystem.
- Encourage R&D in emerging, high-potential areas.

2. Industry collaboration

- Support and collaborate with leaders in heavy industry that can contribute to and benefit from CDR initiatives.
- Explore public-private partnerships to facilitate investment and collaboration in CDR.

3. Indigenous engagement

- Build on Indigenous climate leadership and make opportunities for Indigenous ownership and partnership.
- Integrate the wisdom of Indigenous traditional ecological knowledge holders into carbon management strategies.

How can B.C. support critical innovation to scale CDR?

4.

Resource utilization:

- Take advantage of B.C.'s natural resources to implement nature-based or hybrid CDR solutions.
- Promote the use of low carbon electricity to power CDR technologies.

5.

Policy and infrastructure development:

- Establish policies and regulations that incentivize development and adoption of CDR.
- Invest in infrastructure to facilitate the deployment and scalability of CDR.

6.

Stakeholder engagement:

- Develop robust stakeholder-relations practices, including transparent communication and collaboration.
- Consider public awareness campaigns to educate the public about the importance of CDR and garner support.

CICE

Any other questions?

Chantelle Carden: chantelle.carden@cice.ca
Mike Sherman: msherman@ibetclimate.com

Download the report https://cice.ca/cdr-report/