State CDR Atlas

Methodology – Last Updated 11/5/24

Contributors and Acknowledgements

INTERNAL RMI CONTRIBUTORS

- **Project direction and creation:** Kyle Clark-Sutton, Isabel Wood, Megan Gross, and Daniel Pike
- **Content contributors:** Jane Sadler, Gareth Westler, Joaquin Rosas, Selene (Eli) Li, Kaveer Phillip, and Elizabeth Healy
- **Subject matter experts:** Cara Maesano, Matt Kirley, Rudy Kahsar, Kunal Khandelwal, Gloria See, Charithea Charalambous, Brianne Cangelose, and Hadia Sheerazi
- **General reviewers:** Annina Sartor, Eli Weaver, François de Rochette, Emily Rogers, and Guy Wohl
- **Operational support:** Jordan Parsons, Caitlin Beas, Amanda Sessler, and Vera Vinson

EXTERNAL REVIEWERS

RMI acknowledges and thanks the following reviewers:

- Brad Rochlin (Cascade Climate), Jason Hochman (DAC Coalition), Nikhil Neelakantan (Ocean Visions), Vikrum Aiyer, Toby Bryce (OpenAir Collective), Katie Lebling (WRI), Sarah Mastroni (Ocean Visions), Jason Grillo (AirMiners), Nate Walworth, Jimmy Voorhis (Kodama), Chris Neidl, Whit Childs (Woodcache), Sylvain Delerce (Carbon Gap), Nora Cohen-Brown (Charm Industrial)
- Several others who requested to remain anonymous

Introducing the State CDR Atlas

The Gap

States are central to scaling CDR but are relatively uninformed about CDR opportunities that exist in their state and what policy is needed to advance these opportunities.

CDR companies and investors need a more granular understanding of policy, infrastructure, and natural resources at the state level to make smart investments.

The Product

Provide an interactive database with insights on **all 50 states across 8 CDR approaches**, highlighting opportunities and gaps.

Provide **resources** such as educational information, best practices, and policy case studies to support states.

Provide a **central repository of data** that companies and states can use as a starting point to develop CDR plans.

The Use

- ✓ Shed light on possible CDR opportunities for policymakers
- ✓ Act as a starting point for more detailed deployment planning
- ✓ Direct policymakers to areas they should further research
- ✗ Provide enough information for project developers to identify exact project sites
- ✗ Disqualify any state from any type of CDR

Overview of all metric categories

This table shows 16 metric categories mapped across 8 CDR approach categories. ***Enabling*** metric categories are intended to capture the state's policy and regulatory environment across nearly 30 metrics. ***Opportunity*** metric categories capture the infrastructure, natural resources, and existing industrial activity that are relevant to CDR deployment.

#	Enabling or Opportunity	Metric Category	# of metrics	Direct Air Capture	Direct Ocean Capture	Ocean Geochemical CDR	Carbon Mineralization	Terrestrial Enhanced Weathering	Ocean Biomass CDR	Terrestrial Biomass CDR	Bioenergy + CCS
1.0	Enabling	Climate Governance	5	●	●	●	●	●	●	●	●
2.0		Supply/Demand Incentives	7	●	●	●	●	●	●	●	●
3.0		Community Engagement + Environmental Justice Policy	3	●	●	●	●	●	●	●	●
4.0		CO_2 Regulatory Clarity	9	●	●						●
5.0		Biomass Injection Well Regulatory Clarity	2							●	
6.0	Opportunity	Farm Coverage	3					●			
7.0		Biomass Availability	7						●	●	●
8.0		Coastal Access	2		●	●			●		
9.0		Biomass Injection Well Access	3							●	
10.0		Clean Energy Availability	6	●	●		●				
11.0		Mineral Feedstock Accessibility	3			●	●	●			
12.0		CO_2 Infrastructure	3	●	●		●				●
13.0		Geologic Storage Potential	3	●	●						●
14.0		Industrial Integration	3		●	●	●				
15.0		Workforce Relevance	Varies	●	●	●	●	●	●	●	●
16.0		Existing CDR HQs / projects	Varies	●	●	●	●	●	●	●	●

Defining CDR approach categories

This table shows how we define our 8 CDR approaches, including how these approach categories map to other taxonomies. The Atlas defines approach categories based on the feedstocks an approach needs, existing industry that it builds on, and policy and regulations that are necessary to help it scale.

CDR APPROACH CATEGORY	RMI AIR Taxonomy[1]	XPRIZE Taxonomy[2]	INCLUDED APPROACHES	WHY IS THIS A CATEGORY?
Direct Air Capture	Synthetic CDR	Air	All types of DAC	Requires clean energy as an input and clear carbon management regulations
Direct Ocean Capture	Synthetic CDR	Ocean, Air, Land, Rock	CO_2 stripping	Requires clean energy and clear carbon management regulations, but also access to the coast and clear regulations for ocean deployment
Ocean Geochemical CDR	Geochemical CDR	Ocean, Rock	Coastal enhanced weathering, ocean alkalinity enhancement (including electrochemical alkalinity production)	Requires access to the coast, clear regulations for ocean deployment, and abundant mineral feedstock
Carbon Mineralization	Geochemical CDR	Rock	Surficial mineralization, ex-situ mineralization	Requires abundant mineral feedstock and an existing industry to capitalize on industrial waste
Terrestrial Enhanced Weathering	Geochemical CDR	Rock, Land	Terrestrial enhanced weathering	Requires abundant mineral feedstock and plenty of appropriate land on which to deploy
Ocean Biomass CDR	Biogenic CDR	Ocean	Macroalgae and microalgae sinking	Requires biomass feedstock, access to the coast, and clear regulations for ocean deployment
Terrestrial Biomass CDR	Biogenic CDR	Land	Biochar, bio-oil, biomass burial, biomass building materials	Requires biomass feedstock and clear regulations for biomass procurement, burying, and/or well injection
Bioenergy + carbon capture and storage	Biogenic CDR	Land	BECCS to fuels, BECCS to electricity	Requires biomass feedstock and clear carbon management regulations

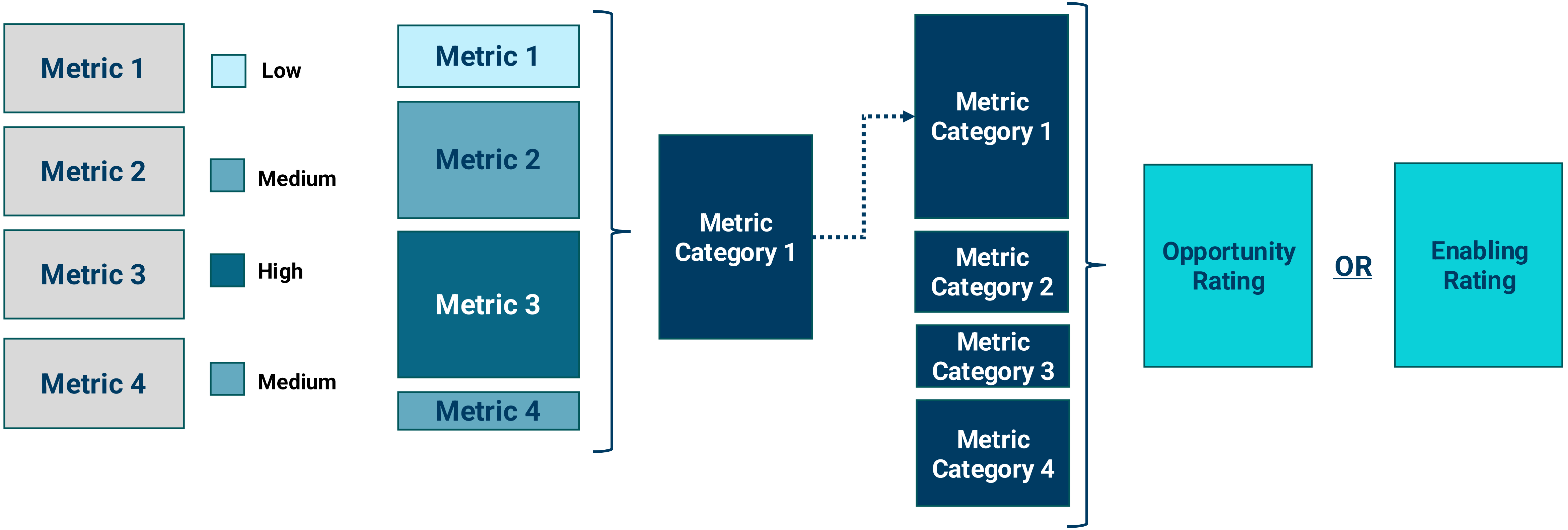
[1]RMI's Applied Innovation Roadmap (AIR) delineates CDR methodologies by feedstock. Synthetic CDR relies on clean energy as the main feedstock, geochemical CDR relies on alkaline minerals as the main feedstock, and biogenic CDR relies on sustainable biomass as the main feedstock. [2]XPRIZE's taxonomy is split into Rock, Land, Ocean, and Air solutions, based on a project location and inputs.

How Atlas ratings are assembled

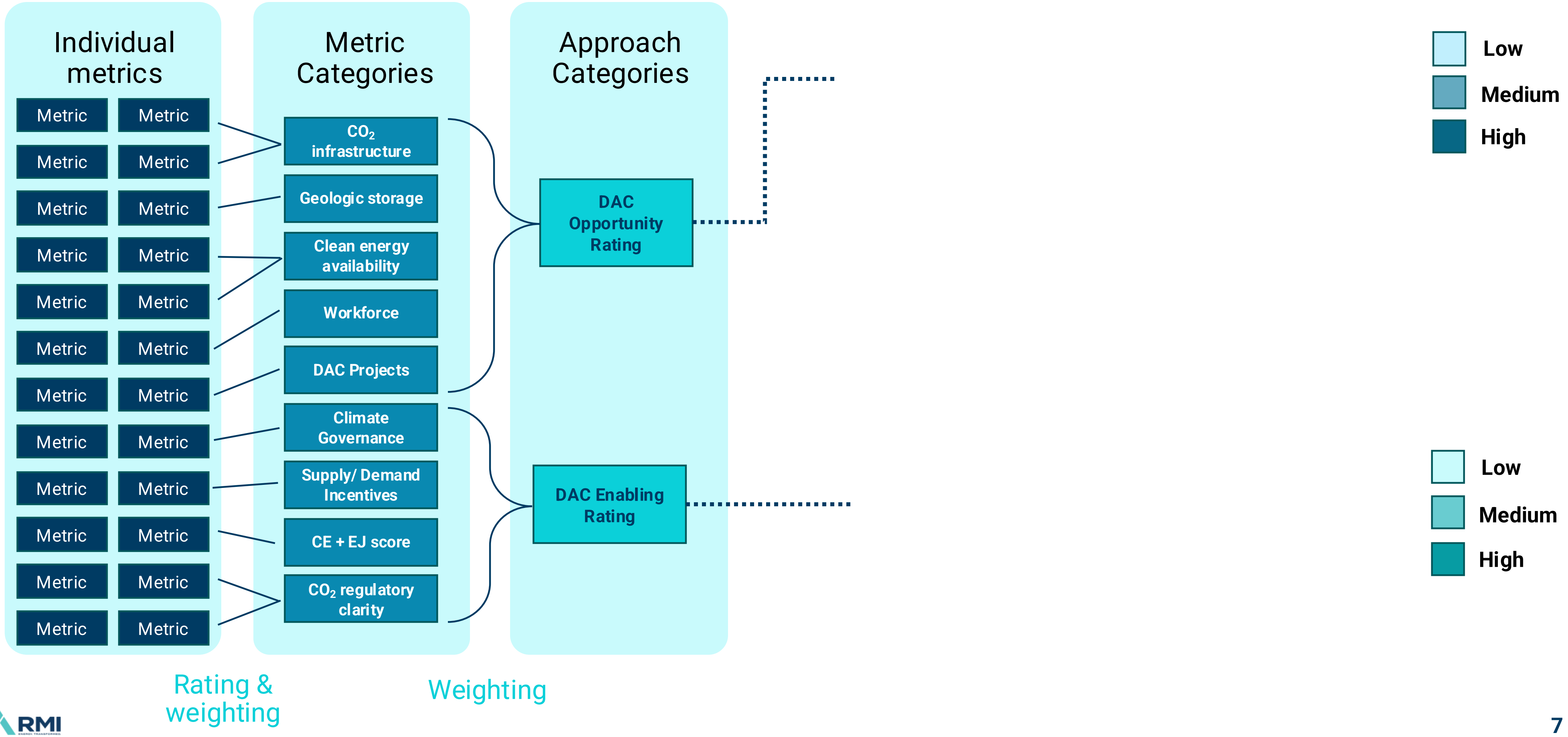
Step 1: Rate individual metrics

Step 2: Assemble metric categories with *weighted* metrics

Step 3: Calculate ratings for each approach using weighted metric categories



Sample Output. Direct Air Capture



Sample Output. Michigan

This sample output shows ratings for Michigan, including opportunity ratings for all 8 CDR approach categories, ratings for enabling and opportunity metric categories, and key insights. Similar outputs will be available for all 50 states in the final State CDR Atlas.

Michigan

State CDR Atlas Summary

KEY INSIGHTS: Michigan…

- Scores high for the opportunity to do carbon mineralization because of existing industry and relevant workforce.
- Scores high for terrestrial enhanced weathering opportunity because of its farm coverage and relevant workforce.
- Scores high for opportunity to do terrestrial biomass CDR because of its residue biomass, injection wells used for bio-oil projects, and relevant workforce.
- May have potential for DAC and bioenergy + CCS, but lack of CO_2 infrastructure is a potential hindrance to these projects.

CDR Approach Category	Opportunity Rating
Direct Air Capture	2.0
Direct Ocean Removal	1.0
Ocean Geochemical CDR	1.0
Carbon mineralization	3.0
Terrestrial Enhanced Weathering (TEW)	3.0
Ocean Biomass CDR*	1.0
Terrestrial Biomass CDR	3.0
Bioenergy + CCS	2.0

Metric Category	Rating
ENABLING ENVIRONMENT METRICS	
Climate Governance	1.85
Supply & Demand Incentives	1.20
Community Engagement & Env. Justice	1.60
CO_2 Regulatory Clarity	1.80
Biomass Injection Well Regulatory Clarity	2.25
OPPORTUNITY METRICS	
Farm Coverage	2.30
Biomass Availability – Residue	3.00
Biomass Availability – Energy	2.00
Biomass Availability – Marine	1.00
Coastal Access	0.00
Biomass Injection Well Access	2.70
Clean Energy Availability	1.60
Mineral Feedstock Accessibility	1.30
CO_2 Infrastructure	1.40
CO_2 Geologic Storage Potential	2.00
Industrial Integration – Carbon Mineralization	3.00
Industrial Integration – Water Treatment	2.00

*Ocean biomass does not take access to the Great Lakes into account.

Metric Categories Methodology

1.0. Climate Governance

TYPE	Enabling
DESCRIPTION	Climate governance metrics assess whether CDR is well-defined in legislation and/or if the state has integrated CDR into existing climate policy frameworks.

NOTES

- The "Is CDR considered in the state's climate action plan? " and "Does the state have a climate target with political buy-in?" metrics are both weighted slightly higher than the "Is the state climate target ambitious" and "Is CDR defined in legislation" metrics because the former metrics provide a mandatory climate target and planning, while the latter provide a framework for CDR but are less actionable.
- For binary metrics, a 'Yes' receives 3 points to align with 3-point metrics where typically having the full policy would result in a 3. 'No' receives a 1.

RATING DETAILS

#	Metric	Units	Low	Medium	High	Weighting	Data Source
1.1	**Does the state have a climate target with political buy-in?**	Multiple qualitative options	No target	• Executive Target • Recommended target	• Binding statutory target • Executive and statutory target	30%	Center for Climate and Energy Solutions
1.2	**Is the state climate target ambitious?**	Multiple qualitative options	No	Yes, but no mention of net zero goal	Yes, with mention of net zero goal (even if eventual)	15%	Center for Climate and Energy Solutions
1.3	**Does the state have an explicit target for removals?**	Binary (Yes/No)	No	--	Yes	10%	RMI Analysis
1.4	**Is CDR considered in the state's climate action plan?**	Multiple qualitative options	NA	CAP no CDR	CAP with CDR	25%	Center for Climate and Energy Solutions
1.5	**Is CDR defined in legislation?**	Binary (Yes/No)	No	--	Yes	20%	RMI Analysis

2.0. Supply and Demand Policy Metrics

TYPE

Enabling

DESCRIPTION

Supply and demand metrics assess what policies exist in the state that financially encourage either the supply or the demand of CDR technologies. While there are many different types of policies that may incentivize CDR indirectly, we decided to only look for direct incentivization on both the supply and demand side of the equation to avoid challenges of subjectivity.

NOTES

- CDR policies that must exist within broader programs (Cap and Trade, Low Carbon Fuel Standard) receive 2 points for having the broader program even if no CDR incentive.
- Specific features of supply or demand policy are the determining factors in how powerful an incentive may or may not be (e.g., $160/ton PTC is more powerful than $40/ton PTC). We have weighted these metrics based on the certainty that one would be used for CDR. For example, a PTC made for CDR is likely more valuable than a Buy Clean policy that may or may not be used for CDR, even with a route for CDR.

RATING DETAILS

#	Metric	Units	Low	Medium	High	Weighting	Data Source
2.1	Is there a Production Tax Credit (PTC) for CDR?	Binary (Yes/No)	No PTC	--	Yes, PTC	20%	RMI Analysis
2.2	Are there grants available for CDR producers?	Binary (Yes/No)	No Grants	--	Yes, grants	15%	RMI Analysis
2.3	Is there a state buy clean policy with a route for CDR?	Binary (Yes/No)	No state buy clean policy	--	Yes, state buy clean policy with CDR	10%	RMI Analysis
2.4	Is there state procurement of CDR?	Binary (Yes/No)	No state procurement	--	Yes, state procurement	20%	RMI Analysis
2.5	Is there an Investment Tax Credit (ITC) for CDR?	Binary (Yes/No)	No ITC	--	Yes, ITC	20%	RMI Analysis
2.6	Is there a clean fuel standard with a CDR credit route?	Multiple qualitative options	No clean fuel standard	Clean Fuel Standard, no CDR (or TBD) pathway	Clean Fuel Standard with CDR pathway	7.5%	RMI Analysis
2.7	Is there a cap-and-trade program with a CDR offset route?	Multiple qualitative options	No cap-and-trade	Cap-and-trade, no CDR pathway	Cap-and-trade with CDR pathway	7.5%	RMI Analysis

3.0 Community Engagement and Env. Justice

TYPE
Enabling

DESCRIPTION
Community engagement and environmental justice metrics assess how ready a state is to scale safe, community supported, equitable CDR, given how much a state prioritizes community engagement and environmental justice in its legislative landscape.

NOTES
- These metrics assume the prioritization of EJ in other state legislation may inform CDR deployment; however, without explicit mention of EJ or engagement guidelines in CDR policy, metrics may be irrelevant.
- Communities, opinions, and histories vary locally; these state-level metrics do not cover this level of nuance nor whether specific communities support CDR or not.
- ClimateXChange study is from 2021 focused on Climate Alliance States.

RATING DETAILS

#	Metric	Units	Low	Medium	High	Weighting	Data Source
3.1	Does the state have an environmental review requirement?	Y/N	No	--	Yes	60%	RMI Analysis
	Does the environmental review include cumulative burdens, EJ, and/or env. burdens?	Multiple qualitative options	NA (no environmental review)	Environmental review but no consideration of cumulative burdens/EJ	Environmental review with consideration of cumulative burdens/EJ		RMI Analysis
3.2	Does the state have an EJ definition?	Multiple qualitative options	No or N/A	Yes, implicit definition	Yes, explicit definition	20%	ClimateXChange, Vermont Law School
3.3	Does the state have dedicated EJ staff? Does the state have an EJ advisory body?	Multiple qualitative Options	Neither	Either an advisory body or dedicated staff	Both dedicated staff and an advisory body	20%	ClimateXChange, Vermont Law School

4.0. CO_2 Regulatory Clarity

TYPE

Enabling

DESCRIPTION

Legal clarity in CO_2 regulations fosters an enabling environment for developers by providing clear and consistent guidelines. This ensures projects comply with laws and regulations, mitigating the risk of legal disputes and penalties and facilitating project planning and execution.

NOTES

- Whether a state has adopted laws to clarify specific legal terms regarding CO_2 is not an assessment of the measure or approach taken.
- With the maturity of the CO_2 market and the adoption of more regulations and laws, it would be necessary to evaluate these measures to provide a more specific and valuable assessment of the readiness of each state.

RATING DETAILS

#	Metric	Units	Low	Medium	High	Weighting	Data Source
4.1	Pore space rights: owner type	Binary(Y/N)	Undecided	--	Surface/Mineral	10%	MIT, GPI
4.2	Is there regulatory clarity on pore space utilization?	Binary(Y/N)	No	--	Yes	10%	MIT, GPI
4.3	Primacy of minerals with regard CCS	Binary(Y/N)	No	--	Yes	10%	MIT, GPI
4.4	Long term liability: Post-closure transfer to state	Binary(Y/N)	No	--	Yes	10%	MIT, GPI, NP
4.5	Long term liability: CO2 trust fund	Binary(Y/N)	No	--	Yes	10%	MIT, GPI
4.6	UIC primacy - Class VI[1, 2]	Multiple qualitative options	No	In Process	Yes	20%	EPA
4.7	States participating in PHMSA's cooperative pipeline safety program[3]	Multiple qualitative options	No	Agreement	Certification	10%	PHMSA, Pipeline Safety Trust
4.8	CO2 pipelines: Identified in state statute?[4]	Binary(Y/N)	No	--	Yes	10%	NARUC, Columbia
4.9	CO2 pipelines: General permitting requirements?	Binary(Y/N)	No	--	Yes	10%	

[1]Although states without Class VI primacy can still have wells permitted through the EPA, timelines for permitting tend to be shorter when a state has primacy, as shown in North Dakota and Wyoming. [2]States with Class VI primacy were rated 3, or high; states in the process of obtaining primacy were also rated high but scored 2.5; states where the EPA has primacy were rated medium, or 2. No states were rated low because the EPA can still permit wells. [3]PHMSA, through this program, certifies state agencies to enforce PHMSA's safety standards. Definitions for "certification" and "agreement" are included here. [4]Since CO_2 does not fall under oil, gas, or hazardous liquid (as H_2), it is critical for states to add CO_2 explicitly into their statutes.

5.0. Biomass Injection Well Regulatory Clarity

TYPE	Enabling
DESCRIPTION	These metrics assess how ready a state is to regulate the injection of biomass as a form of carbon storage.

NOTES

- Some examples of biomass injection include bio-oil injection and biomass slurry injection.
- Primacy for Class II wells is weighted lower than Class V wells because while primacy is helpful when converting Class II to Class V wells, Class V wells are more useful in biomass injection projects.

RATING DETAILS

#	Metric	Units	Low	Medium	High	Weighting	Data Source
5.1	UIC primacy - Class II[1]	Y/N	--	No	Yes	25%	EPA
5.2	UIC primacy - Class V[1]	Y/N	--	No	Yes	75%	EPA

[1]States with primacy were rated 3, or high; states where the EPA has primacy were rated medium, or 2. No states were rated low because the EPA can still permit wells.

6.0. Farm Coverage

TYPE

Opportunity

DESCRIPTION

These metrics assess the potential of state to deploy CDR approaches that are reliant on the presence of farmland or a farming industry.

NOTES

- Metric 6.3 is included since terrestrial enhanced weathering (TEW) can be used for pH soil management. Ratings are based on the cutoff for acidic pH (pH<7) and state averages (pH=6.10).
- Ratings for metrics 6.1 and 6.2 based on state percentiles (33rd, 66th).

RATING DETAILS

#	Metric	Units	Low	Medium	High	Weighting	Data Source
6.1	Land in farms	1000 acres	*Used for metric calculation*			40%	USDA
	Land in farms	Acres	*Used for metric calculation*				USDA
	Land in farms	Square miles	*Used for metric calculation*				USDA
	% Farm coverage	% total state coverage	<26%	26%-44%	>44%		Census Bureau
6.2	State receipts for all agricultural commodities	Real 2024 USD	<$4B	$4B-$12B	>$12B	25%	USDA
6.3	Average soil pH	Average pH	>7	6.10-7	<6.10	35%	USGS

7.0. Biomass Availability

TYPE	Opportunity
DESCRIPTION	These metrics assess the amount of biomass production in a state and therefore the potential for the state to supply biomass for different forms of CDR.

NOTES

- The Billion-ton Report models market scenarios for biomass; see report table ES-1. We use this data to show general trends in which states will likely have more biomass rather than to show exactly how much biomass will be available per state.
- Macroalgae (seaweed) production in the Billion-ton Report was divided by coast, not state, so other data sources were used.
- To reflect the opportunity of CDR to reduce wildfires, forest metrics (forest residue and wildfire risk) were weighted highest for terrestrial biomass, then agricultural residue, then wastes production.

RATING DETAILS

#	Metric	Units	Low	Medium	High	Weighting[1]	Data Source
7.1	Wastes[2] production	Dry tons, near-term scenario	<1.7M	1.7M-4.2M	>4.2M	Terrestrial bio - 20%	Billion-ton Report 2023
7.2	Forest[3] residue	Dry tons, near-term scenario	<120k	120k-600k	>600k	Terrestrial bio - 20%	Billion-ton Report 2023
7.3	Agriculture[4] residue	Dry tons, near-term scenario	<300k	300k-1.7M	>1.7M	Terrestrial bio - 35%	Billion-ton Report 2023
7.4	Wildfire risk	Risk index value	<42.5	42.5-60.6	>60.6	Terrestrial bio - 25%	FEMA
7.5	Energy crops (herbaceous and woody)	Dry tons, medium market scenario	<430k	430k-4.6M	>4.6M	BECCS - 100%	Billion-ton Report 2023
7.6	Seaweed farms	Active, Permitted, None	None	Permitted	Active	Ocean biomass - 100%	National Sea Grant Seaweed Hub
7.7	Microalgae production	Dry tons, emerging scenario	0	–	>0		Billion-ton Report 2023

[1]Different types of biomass are relevant to different CDR. Metrics 7.1 through 7.4 inform terrestrial bCDR potential; Metric 7.6 informs industrial bCDR potential; metrics 7.7 through 7.8 inform ocean bCDR potential. [2]Wastes production residue includes fats, oils, and grease (FOG), solid waste, wet waste, and paper, all defined by the Billion-ton Report. [3]Forest residue includes fire reduction thinnings, forest processing waste, logging residues, and other forest waste, all defined by the Billion-ton Report. [4]Agriculture residue includes agriculture processing waste and agriculture residues, all defined by the Billion-ton Report.

8.0. Coastal Access[1]

TYPE	Opportunity
DESCRIPTION	These metrics assess not only if a state has coastline, but also how big that coastal area is in relation to the rest of the state to indicate potential for coastal/ocean CDR approaches.

NOTES

- Only coastal and territorial waters are included in this metric category because freshwater CDR is still early stage. These water areas were determined based on Census Bureau definitions.[2,3]
- Ratio rather than absolute value of coastal/territorial water area was used to reduce bias for larger states.
- Metrics about coastal economy were not included because some industries will actively support CDR while others will not.

RATING DETAILS

#	Metric	Units	Low	Medium	High	Weighting	Data Source
8.1	**Does the state have coastal access?**	Y/N	No	--	Yes	75%	Census Bureau
	Coastal and territorial water area	Square miles	*Used for metric calculation*				Census Bureau
	Total state area	Square miles	*Used for metric calculation*				Census Bureau
	Coast/area ratio	Unitless (sq. miles/sq. miles)	NA	<50th percentile of states with coastal area	>50th percentile of states with coastal area		Census Bureau
8.2	**Significant ports**	# of ports within top 50 US ports by tonnage	0	1	>1	25%	Bureau of Transportation Statistics

[1]This metric category is not a comprehensive measurement for where ocean CDR projects should be deployed. Just having coastal access or large ports does not guarantee conditions will be correct to do ocean CDR. Certain natural metrics such as air-sea gas exchange and other ocean dynamics are important to consider but too granular to include in this Atlas. Similarly, political and environmental metrics such as the presence of Marine Protected Areas will influence project siting but are also too granular to include. [2]Census Bureau definitions of Coastal, Inland, Great Lakes, and Territorial waters are explained on page 15-6 of this document. [3]Coastal waters were included to account for large bodies of water within a state's coastal area; territorial seas were included to measure the area of ocean in which states have some level of jurisdiction.

9.0. Biomass Injection Well Access

TYPE	Opportunity
DESCRIPTION	These metrics assess the presence and availability of wells to inject and store biomass slurries/bioliquid underground.

NOTES

- Ratings are based on averages across the 50 states; Class V wells have higher cutoffs because there are generally more Class V wells in all 50 states.
- All three metrics are weighted evenly; the datasets for Class II Wells and orphaned wells may have overlap (e.g., Class II Wells that have been abandoned), but together they are weighted higher than Class V Wells because of the opportunity to plug them.

RATING DETAILS

#	Metric	Units	Low	Medium	High	Weighting	Data Source
9.1	Class II Wells	# of wells	0	1-70	>70	33%	EPA
9.2	Class V Wells	# of wells	<2731	2731-12787	>12787	33%	EPA
9.3	Orphaned Wells	# of wells	0	1-490	>490	33%	Environmental Defense Fund

10.0. Clean Energy Availability

TYPE	Opportunity
DESCRIPTION	These metrics asses the availability of near, medium, and long-term clean energy in a state, also considering existing energy burdens.

NOTES

- The increase in planned renewables assumes no new nonrenewable production. As a result of this assumption, the metric receives low weighting (10%).
- Ratings were calculated using 33rd and 66th percentiles.

RATING DETAILS

#	Metric	Units	Low	Medium	High	Weighting	Data Source
10.1	2022 total statewide energy consumption	MWh	*Used for metric calculation*			30%	EIA
	2022 total statewide energy consumption	MW	*Used for metric calculation*				EIA
	Installed renewable generation capacity	MW	*Used for metric calculation*				EIA Energy Atlas
	Percent installed renewables	%	<10.9%	10.9% - 19.6%	>19.6%		RMI Calculation[1]
10.2	Renewable net generation	1000 MWh	*Used for metric calculation*			30%	EIA Electricity Data Browser
	Percent generation in renewables	&	<1.5%	1.5% - 4.3%	>4.3%		RMI Calculation[2]
10.3	Planned Renewable Interconnections	MW	*Used for metric calculation*			10%	Lawrence Berkeley Nat'l Lab
	Increase in planned renewables	%	<21.0%	21.0% - 33.4%	>33.4%		RMI Calculation[3]
10.4	Renewable interconnection queue approval pace	Months	>40	25-40	<25	10%	Lawrence Berkeley Nat'l Lab
10.5	Renewable generation potential	MWh	<3.3B	3.3B - 7.7B	>7.7B	10%	NREL SLOPE
10.6	Energy burden	%	>7%	4% - 7%	<4%	10%	DOE LEAD Tool

[1]Percent installed renewables is calculated by dividing installed renewable generation capacity (MW) by statewide energy consumption in MW. [2]Percent generation in renewables is calculated by dividing renewable net generation (MWh) by statewide energy consumption in MWh. [3]Increase in planned renewables = ((planned renewable interconnection(MW) + total statewide energy consumption(MW))/(planned renewable interconnections(MW)+ total statewide energy consumption(MW))) – percent installed renewables.

11.0. Mineral Feedstock Availability[1]

TYPE	Opportunity
DESCRIPTION	These metrics assess a state's opportunity to mine and supply minerals necessary for different types of gCDR.

NOTES

- All low ratings indicate the state has no prospect of the mineral either currently being mined or mined in the future. All medium and high ratings are based on the range of values across the states.
- Found or mined minerals include commodities, ore, and gangue.

RATING DETAILS

#	Metric	Units	Low	Medium	High	Weighting	Data Source
11.1	Basalt found	# of locations	Sum of mined and found = 0	Sum of mined and found = 1 or 2	Sum of mined and found > 2	33%	USGS
	Basalt mined	# of locations					USGS
11.2	Wollastonite found	# of locations	Sum of mined and found = 0	Sum of mined and found = 1 through 5	Sum of mined and found > 5	33%	USGS
	Wollastonite mined	# of locations					USGS
11.3	Olivine found	# of locations	Sum of mined and found = 0	Sum of mined and found = 1 through 10	Sum of mined and found > 10	33%	USGS
	Olivine mined	# of locations					USGS

[1]Because certain industrial processes can produce alkaline feedstock, the Mineral Feedstock Availability metric (11.1, 11.2, 11.3) and the Industrial Integration metric (14.1, 14.2) are related; however, they are separated based on the source of the feedstock. The Mineral Feedstock Availability metric focuses on bulk rock and bulk mineral materials that can be extracted directly for CDR purposes. It includes feedstock used commercially for enhanced weathering on farmland (basalt, olivine, and wollastonite). These metrics are not perfect representations of the minerals that will be available for different types of CDR. This data shows the number of sites, not the amount of available material. Many factors need to be considered to determine if a mining site is appropriate for CDR. We are still searching for data to update this metric category.

12.0. CO_2 Infrastructure

TYPE	Opportunity
DESCRIPTION	These metrics assess the presence of supporting infrastructure for carbon removal projects with a stream of CO_2 including pipelines, wells, and the presence of industry that would increase demand for further buildout of carbon management infrastructure.

NOTES

- Facilities that are in development are counted as 0.5 for metric 12.1.

RATING DETAILS

#	Metric	Units	Low	Medium	High	Weighting	Data Source
12.1	CCUS facilities	# of facilities	0	0-1.5	>1.5	20%	CATF CCUS Tracker
12.2	CO_2 pipelines	Total miles	0	<104.4	>104.4	40%	PHMSA
12.3	Class VI wells	# of wells	0	1	> 1	40%	EPA

13.0. CO_2 Geologic Storage Potential

TYPE	Opportunity
DESCRIPTION	These metrics assess the opportunity for a state to store CO_2 in geologic formations given the presence of a variety of geologic formations and pore space.

NOTES

- Metrics 13.2 and 13.3 are based on polygon areas in GIS mapping. The rating is determined using percentiles of the relative polygon areas.
- Total storage resource (oil and gas reservoirs, coal storage, and saline aquifers) is weighted higher because of existing efforts to store CO_2 in these resources and because of potential barriers to using ultramafic and mafic storage.

RATING DETAILS

#	Metric	Units	Low	Medium	High	Weighting	Data Source
13.1	**Total storage resource**	Billion tons	<0.83	0.83-60.68	>60.68	50%	NETL Carbon Storage Atlas
13.2	**Ultramafic storage**	Relative polygon area in GIS	0	< 66th percentile	> 66th percentile	25%	USGS Carbon Mineralization Feasibility Study
13.3	**Mafic storage**	Relative polygon area in GIS	<33rd percentile	33rd - 66th percentile	> 66th percentile	25%	USGS Carbon Mineralization Feasibility Study

14.0. Industrial Integration[1]

TYPE	Opportunity
DESCRIPTION	These metrics are used to assess the opportunity for a state to integrate CDR into existing facilities or industries, specifically for carbon mineralization, direct ocean capture, and ocean alkalinity production. These metrics apply to existing industry infrastructure rather than existing workforce.

NOTES

- Municipal desalination plants and industrial wastewater treatment may be integrated with forms of CDR such as Direct Ocean Capture.
- Metric 14.3 only provides data for the 24 states that have SMCRA-approved Abandoned Mine Land Programs.

RATING DETAILS

#	Metric	Units	Low	Medium	High	Weighting	Data Source
14.1	Value of nonfuel mineral production[2]	% of US total	<0.74%	0.74%-1.92%	>1.92%	60%	USGS
14.2	Cement production[3]	# of facilities	0	1-2	≥ 2	40%	EPA GHGRP 2022
14.3	Municipal desalination facilities	# of facilities	Sum <3	Sum between 3 and 6	Sum >6	Direct Ocean Capture - 100%	Mike Mickley, PhD, 2020
	Industrial wastewater treatment facilities	# of facilities					EPA GHGRP 2022

[1]Because certain industrial processes can produce alkaline feedstock, the Mineral Feedstock Availability metric (11.1, 11.2, 11.3) and the Industrial Integration metric (14.1, 14.2) are related; however, they are separated based on the source of the feedstock. The Industrial Integration metric measures the presence of the mining and cement industries in a state, each of which create by-products that could be used for CDR purposes (mine tailings and cement kiln dust). Not all of these industrial by-products will be suitable for CDR. While materials included in the Mineral Feedstock Availability can be used in enhanced weathering, ocean geochemical CDR, and carbon mineralization, the Industrial Integration metrics 14.1 and 14.2 apply only to carbon mineralization due to environmental risks of applying industrial waste on farmland or to the ocean. [2]This metric is the % of the US total value of nonfuel mineral production (e.g., coal is not included). While not all minerals included in this metric can be used for CDR, this metric acts as a proxy both to show which states have the largest mining industries and which states currently benefit the most economically from these industries. [3]This metric shows generally which industries are prevalent in which states; however, not every industrial facility will be able to integrate CDR into its functions because of economics, size, etc. This metric is a proxy and further research is needed on an individual facility basis.

15.0. Workforce Relevance

TYPE	Opportunity
DESCRIPTION	These metrics assess the presence of a relevant workforce in each CDR bucket per state, which acts as a proxy for the availability of local workers trained in relevant fields.

NOTES

- All data is based on BLS NAICS codes.
- Total employment (metric 15.1) combines, rates, and weights job data across several NAICS codes for each CDR bucket depending on which codes are relevant to an approach. For example, the NAICS codes relevant to ocean bCDR are “water transportation” and “aquaculture.”
- All CDR buckets were calculated with the same methodology shown in the ocean bCDR example below.

RATING DETAILS

#	Metric	Units	Low	Medium	High	Weighting	Data Source
15.1	Total employment	# of jobs, December 2023	<33rd percentile	33rd-66th percentile	>66th percentile	100%	BLS
Example CDR bucket	Ocean biomass relevant workforce	# of jobs, December 2023, "aquaculture" and "water transportation" NAICS codes	<145	145-763	≥ 764	100%	BLS – job data for NAICS “aquaculture” & NAICS “water transport”

15.0. Workforce Relevance (Continued)

TYPE Opportunity

DESCRIPTION These metrics assess the presence of a relevant workforce in each CDR bucket per state, which acts as a proxy for the availability of local workers trained in relevant fields.

NOTES

- The table below maps NAICS categories to each CDR bucket.
- These are 3-digit NAICS categories (except for “Aquaculture” and “Solid Landfills”) to provide broad enough categories for what is considered relevant workforce for a bucket of CDR. Numbers in parentheses are the numerical codes.
- Ocean biomass is shown as a case study in the previous slide. All other buckets were calculated in the same way.

NAICS codes	1	2	3	4	5	6	7	8
Direct Air Capture	Machinery manufact. (333)	Chemicals manufact. (325)	Support activities for mining[1] (213)	Utilities (221)	Electrical equipment manufact. (335)	Oil and Gas Extraction (211)	–	–
Direct Ocean Capture	Machinery manufact. (333)	Chemicals manufact. (325)	Support activities for mining (213)	Utilities (221)	Electrical equipment manufact. (335)	Oil and Gas Extraction (211)	–	–
Ocean geochemical CDR	Mining (except Oil and Gas) (212)	Nonmetallic mineral product manufact. (327)	Support activities for mining (213)	Water transportation (483)	–	–	–	–
Carbon mineralization	Mining (except Oil and Gas) (212)	Nonmetallic mineral product manufact. (327)	Support activities for mining (213)	Machinery manufact. (333)	Electrical equipment manufact. (335)	Oil and Gas Extraction (211)	–	–
Terrestrial enhanced weathering (TEW)	Mining (except Oil and Gas) (212)	Nonmetallic mineral product manufact. (327)	Support activities for mining (213)	Support activities for agriculture and forestry (115)	–	–	–	–
Ocean biomass CDR	Aquaculture (1125)	Water transportation (483)	–	–	–	–	–	–
Terrestrial biomass CDR	Chemicals manufact. (325)	Support activities for agriculture and forestry (115)	Support activities for mining (213)	Construction of buildings (236)	Wood product manufact. (321)	Heavy and civil engineering construction (237)	Solid landfills (562212)	Forestry and logging (113)
Bioenergy + CCS	Machinery manufact. (333)	Chemicals manufact. (325)	Support activities for mining (213)	Utilities (221)	Electrical equipment manufact. (335)	Oil and Gas Extraction (211)	–	–

[1]"Support activities for mining" is defined by the BLS as industries that provide support services required for mining and quarying of minerals as well as for the extraction of oil and gas. As a result, we included both support activities for mining and O&G for any approach that will need CO_2 pipeline infrastructure. For terrestrial biomass CDR, we include only support activities for mining, to account for jobs related to drilling wells that might be relevant for biomass injection. We did not also include O&G because largescale CO_2 infrastructure buildout is not necessary for this approach, especially for biochar and biomass burial.

16.0. Existing CDR HQs/Projects

TYPE	Opportunity
DESCRIPTION	These metrics assess the presence of an already existing CDR ecosystem in a state. The presence of CDR HQs or projects can clarify which states have actors already working towards deploying CDR, clarifying permitting pathways, beginning education campaigns, completing R&D, and more.

NOTES

- This dashboard includes one metric per CDR bucket that includes data on HQs and projects within that bucket rather than using one broad metric that includes all types of CDR that exist in a state (i.e., total number of DAC HQs and projects in CA are included in the DAC bucket rather than using the total number of CDR HQs and projects in CA).
- This is not a comprehensive view of all HQs and projects.

RATING DETAILS

#	Metric	Units	Low	Medium	High	Weighting	Data Source
16.1	CDR HQs and/or projects	# of HQs or projects	<33rd percentile	33rd-66th percentile	>66th percentile	100%	CDR.fyi, RMI Applied Innovation Roadmap

CDR Approach Categories Methodology

A. Direct air capture (DAC)

APPROACHES

Direct Air Capture

DESCRIPTION

The following weighting was used to calculate a state's opportunity to deploy DAC as well as score the actions a state has taken to enable DAC buildout (or CDR buildout broadly).

NOTES

- **Enabling policy metrics.** Incentives to support deployment and demand are the most important policy blockers, followed by the slow pace of CO_2 infrastructure development due to permitting delays.
- **Opportunity metrics.** Clean energy availability and access to geologic storage suitable for CO_2 are primary constraints to DAC deployment. CO_2 infrastructure (e.g., existing pipelines and wells) is important but not as critical a constraint as many DAC projects will ideally co-locate with storage. Existing HQs/projects may enable scaling in a state.

DAC ENABLING POLICY

#	Metric category	Weighting
1.0	Climate governance	20%
2.0	Supply/demand incentives	40%
3.0	Community engagement and Environmental justice	15%
4.0	CO_2 regulatory clarity	25%

DAC OPPORTUNITY

#	Metric category	Weighting
10.0	Clean energy availability	35%
13.0	CO_2 geologic storage potential	35%
12.0	CO_2 infrastructure	15%
15.0	Workforce relevance	10%
16.0	Existing HQs / projects	5%

B. Direct ocean capture (DOC)

APPROACHES

CO_2 stripping

DESCRIPTION

The following weighting was used to calculate a state's opportunity to deploy DOC as well as score the actions a state has taken to enable DOC buildout (or CDR buildout broadly).

NOTES

- **Enabling policy metrics.** A lack of regulatory clarity around permitting DOC projects and access to geologic storage are the two most critical policy barriers to DOC deployment.
- **Opportunity metrics.** Clean energy, access to geologic storage, and access to water are primary constraints to DOC deployment.

DOC ENABLING POLICY

#	Metric category	Weighting
1.0	Climate governance	20%
2.0	Supply/demand incentives	20%
3.0	Community engagement and Environmental justice	30%
4.0	CO_2 regulatory clarity	30%

DOC OPPORTUNITY

#	Metric category	Weighting
8.0	Coastal access	20%
10.0	Clean energy availability	20%
13.0	CO_2 geologic storage potential	20%
12.0	CO_2 infrastructure	15%
14.0	Industrial integration (DOC)	10%
15.0	Workforce relevance	10%
16.0	Existing HQs / projects	5%

C. Ocean geochemical CDR (gCDR)

APPROACHES

Coastal enhanced weathering, ocean alkalinity enhancement

DESCRIPTION

The following weighting was used to calculate a state's opportunity to deploy geochemical CDR approaches on the coast or in the ocean as well as score the actions a state has taken to enable this type of CDR deployment (or CDR buildout broadly).

NOTES

- **Enabling policy metrics.** While demand support is critical for all CDR approaches, the lack of coastal regulations to clarify a permitting path for ocean geochemical projects is the most critical near-term barrier to deployment.
- **Opportunity metrics.** States that create a clear permitting path for ocean geochemical and states that have mineral feedstock are both well-positioned to support deployment.

OCEAN GCDR ENABLING POLICY

#	Metric category	Weighting
1.0	Climate governance	35%
2.0	Supply/demand incentives	35%
3.0	Community engagement and Environmental justice	30%

OCEAN GCDR OPPORTUNITY

#	Metric category	Weighting
8.0	Coastal access	40%
11.0	Mineral feedstock accessibility	25%
14.0	Industrial integration	15%
15.0	Workforce relevance	15%
16.0	Existing HQs / projects	5%

D. Carbon mineralization

APPROACHES

Surficial mineralization, ex-situ mineralization

DESCRIPTION

The following weighting was used to calculate a state's opportunity to deploy surficial mineralization projects as well as score the actions a state has taken to enable this type of CDR deployment (or CDR buildout broadly).

NOTES

- **Enabling policy metrics.** Support for deployment and stimulating demand (metric category 2.0) are the most important roles for policy in this approach. Note that mine sites are promising locations for carbon mineralization and the Atlas does not yet reflect policy that more directly regulates the mining sector—this may be an important future addition.
- **Opportunity metrics.** The availability of the right mineral feedstock and the presence of complementary industries (e.g., mining, which is often the feedstock source as well) are the most important factors in determining the most promising regions for deployment.

CARBON MINERALIZATION ENABLING POLICY

#	Metric category	Weighting
1.0	Climate governance	35%
2.0	Supply/demand incentives	40%
3.0	Community engagement and Environmental justice	25%

CARBON MINERALIZATION OPPORTUNITY

#	Metric category	Weighting
10.0	Clean energy availability	15%
11.0	Mineral feedstock accessibility	20%
12.0	CO2 infrastructure	15%
14.0	Industrial integration	40%
15.0	Workforce relevance	5%
16.0	Existing HQs / projects	5%

E. Terrestrial enhanced weathering (TEW)[1]

APPROACHES

Terrestrial enhanced weathering (TEW)

DESCRIPTION

The following weighting was used to calculate a state's opportunity to deploy TEW projects as well as score the actions a state has taken to enable this type of CDR deployment (or CDR buildout broadly). This does not include coastal enhanced weathering (CEW) which is included in Ocean Geochemical CDR.

NOTES

- **Enabling policy metrics.** Support for deployment and stimulating demand (metric category 2.0) are the most important roles for policy in this approach. Note that farmland is the primary site for TEW, and the Atlas does not yet reflect policy that more directly regulates emissions from agriculture, which could be an important future addition.
- **Opportunity metrics.** The availability of the right mineral feedstock and the presence of an appropriate site (e.g., farmland) are the most important factors in determining the most promising regions for deployment.

TEW ENABLING POLICY

#	Metric category	Weighting
1.0	Climate governance	30%
2.0	Supply/demand incentives	40%
3.0	Community engagement and Environmental justice	30%

TEW OPPORTUNITY

#	Metric category	Weighting
6.0	Farm coverage	40%
11.0	Mineral feedstock accessibility	30%
15.0	Workforce relevance	20%
16.0	Existing HQs / projects	10%

[1]Terrestrial enhanced weathering (TEW) relies heavily on farm coverage as a metric because of the opportunity for farm owners to use ERW as a soil management tool; however, in the end, individual decisions of landowners is more important than any metric mentioned here.

F. Ocean biomass CDR

APPROACHES

Macroalgae and microalgae sinking

DESCRIPTION

The following weighting was used to calculate a state's opportunity to deploy macroalgae and microalgae sinking projects as well as score the actions a state has taken to enable this type of CDR deployment (or CDR buildout broadly).

NOTES

- **Enabling policy metrics.** Support for deployment and stimulating demand (metric category 2.0) are the most important roles for policy in this approach, but states that clarify rules around accessing coastline and coastal waters will be better positioned to support deployment.
- **Opportunity metrics.** Availability of feedstock and access to suitable waters for sinking are the most important opportunity factors. Note that some biomass sinking efforts use biogenic feedstocks other than micro- or macroalgae; these are not currently reflected in the Atlas.

OCEAN BIOMASS STORAGE ENABLING POLICY

#	Metric category	Weighting
1.0	Climate governance	35%
2.0	Supply/demand incentives	35%
3.0	Community engagement and Environmental justice	30%

OCEAN BIOMASS STORAGE OPPORTUNITY

#	Metric category	Weighting
7.0	Biomass availability (algae)	40%
8.0	Coastal access	40%
15.0	Workforce relevance	15%
16.0	Existing HQs / projects	5%

G. Terrestrial biomass CDR

APPROACHES

Biochar, bio-oil, biomass burial, biomass building products

DESCRIPTION

The following weighting was used to calculate a state's opportunity to deploy terrestrial biomass storage projects as well as score the actions a state has taken to enable this type of CDR deployment (or CDR buildout broadly).

NOTES

- **Enabling policy metrics.** Support for deployment and stimulating demand (metric category 2.0) are the most important roles for policy in this approach, but states that make it easier to access geologic storage will be better positioned to support deployment.
- **Opportunity metrics.** Availability of appropriate feedstock and access to suitable storage are the most important opportunity factors.

TERRESTRIAL BIOMASS STORAGE ENABLING POLICY

#	Metric category	Weighting
1.0	Climate governance	35%
2.0	Supply/demand incentives	35%
3.0	Community engagement and Environmental justice	15%
5.0	Biomass injection well regulatory clarity	15%

TERRESTRIAL BIOMASS STORAGE OPPORTUNITY

#	Metric category	Weighting
7.0	Biomass availability (residue)	50%
9.0	Biomass injection well access	20%
15.0	Workforce relevance	20%
16.0	Existing HQs / projects	10%

H. Bioenergy + carbon capture and storage (BECCS)[1]

APPROACHES	BECCS to fuels, BECCS to electricity
DESCRIPTION	The following weighting was used to calculate a state's opportunity to deploy BECCS projects as well as score the actions a state has taken to enable this type of CDR deployment (or CDR buildout broadly).

NOTES

- **Enabling policy metrics.** Support for deployment and stimulating demand (metric category 2.0) are the most important roles for policy in this approach, but states that make it easier to access geologic storage will be better positioned to support deployment.
- **Opportunity metrics.** Availability of appropriate feedstock, existing CO_2 infrastructure, and access to suitable storage are the most important opportunity factors.

BECCS ENABLING POLICY

#	Metric category	Weighting
1.0	Climate governance	35%
2.0	Supply/demand incentives	35%
3.0	Community engagement and Environmental justice	15%
4.0	CO_2 regulatory clarity[2]	15%

BECCS OPPORTUNITY

#	Metric category	Weighting
7.0	Biomass availability (energy)	35%
12.0	CO_2 infrastructure	30%
13.0	CO_2 geologic storage potential	25%
15.0	Workforce relevance	5%
16.0	Existing HQs / projects	5%

[1]BECCS plants need to be scrutinized to determine if production is net negative; only then is it considered CDR. Clean energyavailability is not a hindrance, because BECCS plants create their own energy, but any energy powering BECCS needs to come from its own operations or from a clean grid. [2]CO_2 regulatory clarity includes CO_2 from bioenergy production.