EESI
Environmental and Energy Study Institute

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CONGRESSIONAL BRIEFING
Direct Air Capture
Briefing Series: Scaling Up Innovation to Drive Down Emissions

Wednesday, May 25, 2022

About EESI

Non-partisan Educational Resources for Policymakers

A bipartisan Congressional caucus founded EESI in 1984 to provide non-partisan information on environmental, energy, and climate policies

Direct Assistance for Equitable and Inclusive Financing Program

In addition to a full portfolio of federal policy work, EESI provides direct assistance to utilities to develop "on-bill financing" programs

Commitment to Diversity, Equity, Inclusion, and Justice

We recognize that systemic barriers impede fair environmental, energy, and climate policies and limit the full participation of Black, Indigenous, people of color, and legacy and frontline communities in decision-making

Sustainable Solutions

Our mission is to advance science-based solutions for climate change, energy, and environmental challenges in order to achieve ***our vision of a sustainable, resilient, and equitable world***.

Policymaker Education

Briefings and Webcasts

Live, in-person and online public briefings, archived webcasts, and written summaries

Climate Change Solutions

Bi-weekly newsletter with everything policymakers and concerned citizens need to know, including a legislation and hearings tracker

Fact Sheets and Issue Briefs

Timely, objective coverage of environmental, clean energy, and climate change topics

Social Media (@EESIOnline)

Active engagement on Twitter, Facebook, LinkedIn, and YouTube

Upcoming Briefings & Series

Living with Climate Change

Polar Vortex – April 13

Sea Level Rise – May 18

Wildfires – June 13

Extreme Heat - TBA

Scaling Up Innovation to Drive Down Emissions

Green Hydrogen – April 27

Direct Air Capture – May 25

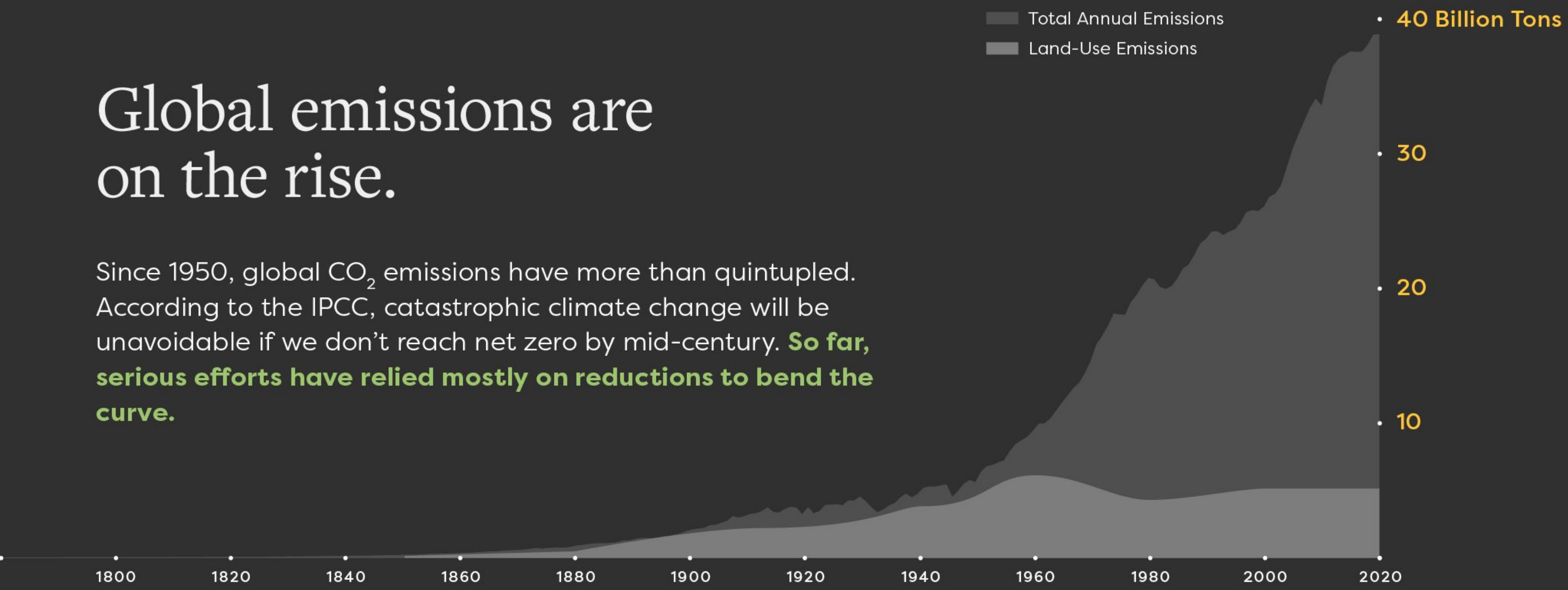
Electric Vehicle Charging – June 02

Offshore Wind Energy - TBA


Reversing two centuries of carbon emissions.
Carbon180

Global emissions are on the rise.

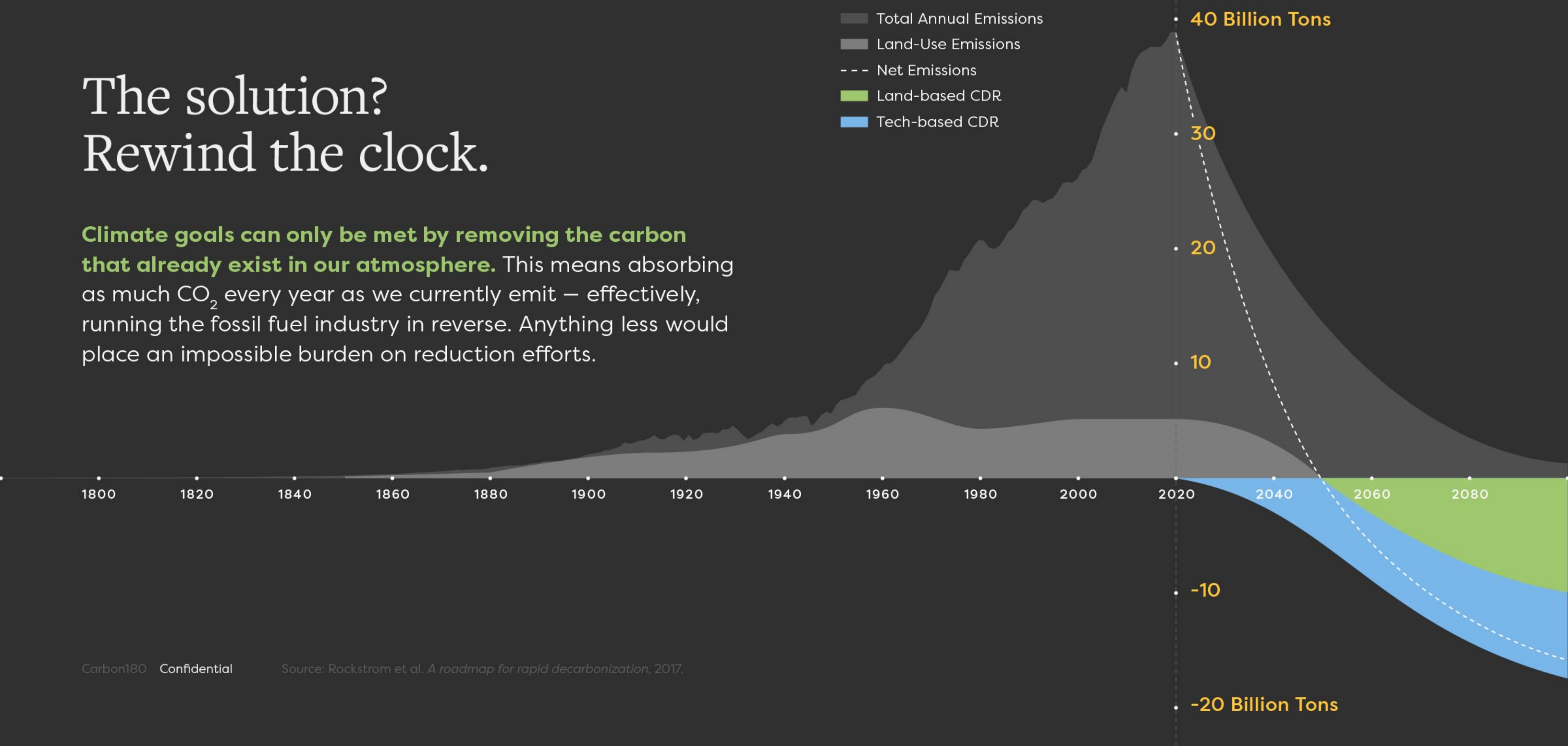
Since 1950, global CO_2 emissions have more than quintupled. According to the IPCC, catastrophic climate change will be unavoidable if we don't reach net zero by mid-century. **So far, serious efforts have relied mostly on reductions to bend the curve.**



Source: Our World in Data "Annual total CO_2 emissions, by world region"

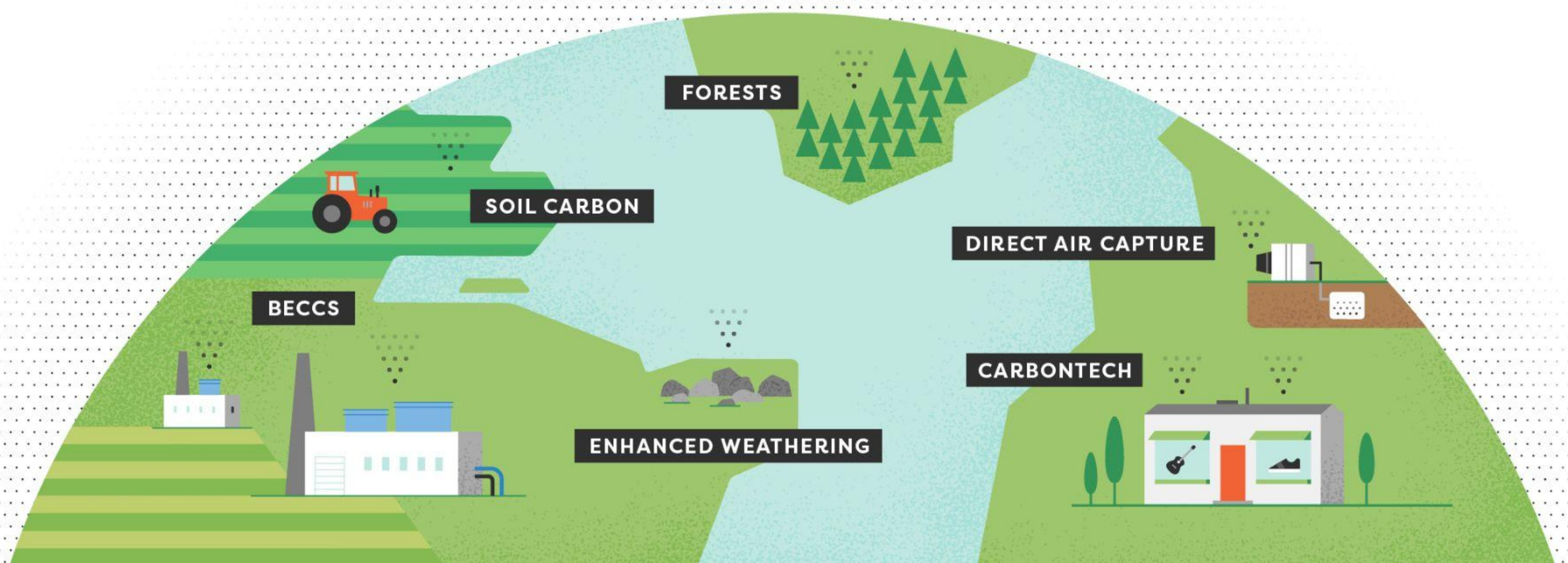
The solution?
Rewind the clock.

Climate goals can only be met by removing the carbon that already exist in our atmosphere. This means absorbing as much CO_2 every year as we currently emit — effectively, running the fossil fuel industry in reverse. Anything less would place an impossible burden on reduction efforts.



Source: Rockstrom et al. *A roadmap for rapid decarbonization*, 2017.

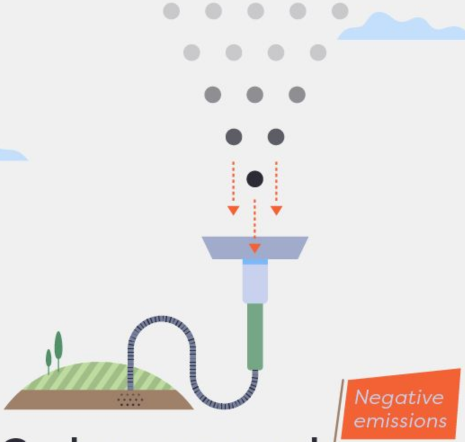
Solutions are within reach.



Carbon180

Carbon removal is not carbon capture

Though the confusion isn’t farfetched. Both climate solutions clean up carbon pollution — but differ significantly in methods and impacts.



Carbon removal

“Sucks” existing CO_2 from the air using land-, ocean-, and tech-based pathways, rather than preventing emissions at the source

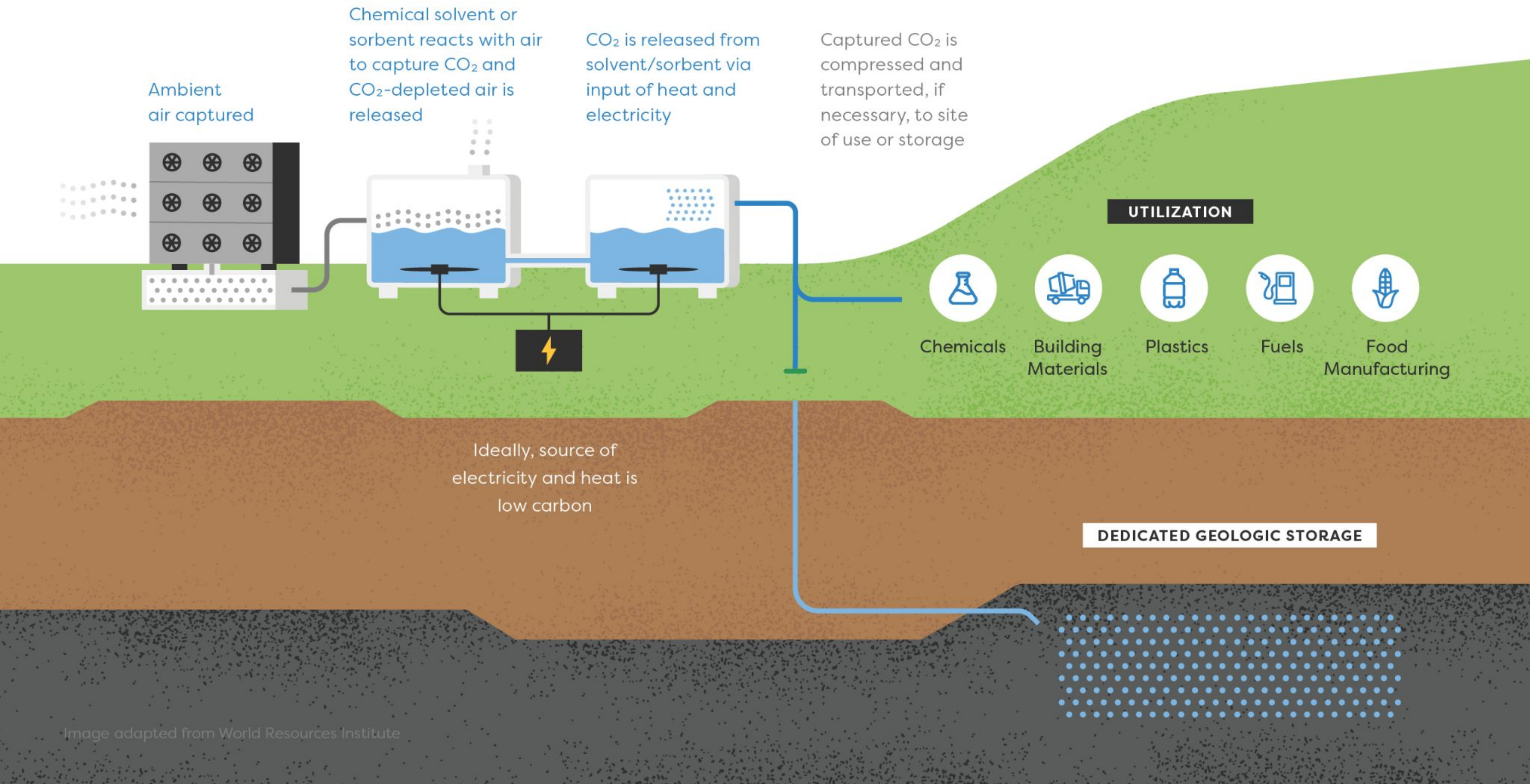
Can target *legacy emissions* and address climate impacts on frontline communities

Carbon capture

“Scrubs” CO_2 from a *point source* — a localized source of emissions, such as a power plant or industrial facility

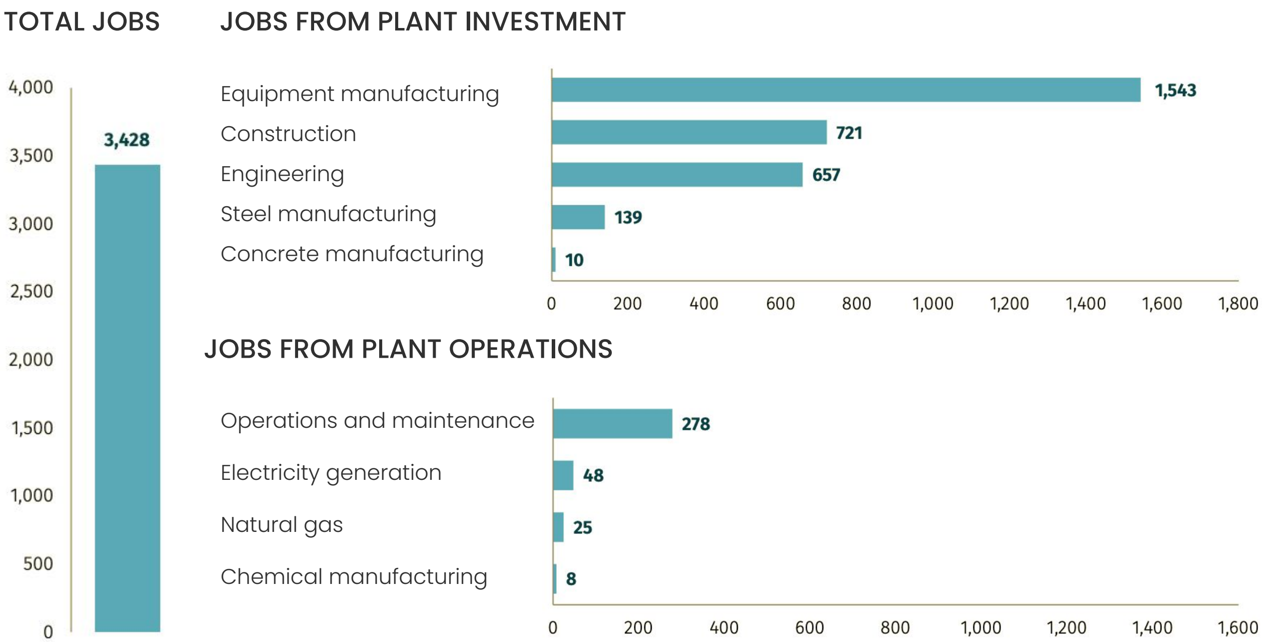
Lowers or zeroes out the footprints of traditional, carbon-intensive industries

Direct air capture


Ambient air captured
Chemical solvent or sorbent reacts with air to capture CO_2 and CO_2-depleted air is released
CO_2 is released from solvent/sorbent via input of heat and electricity
Captured CO_2 is compressed and transported, if necessary, to site of use or storage
UTILIZATION
Chemicals
Building Materials
Plastics
Fuels
Food Manufacturing
Ideally, source of electricity and heat is low carbon
DEDICATED GEOLOGIC STORAGE
Image adapted from World Resources Institute

Job Creation

The majority of jobs are associated with design, engineering and construction of the plant as well as the manufacturing of plant equipment. A typical DAC plant requires 278 workers to maintain and operate the facility once it's constructed.

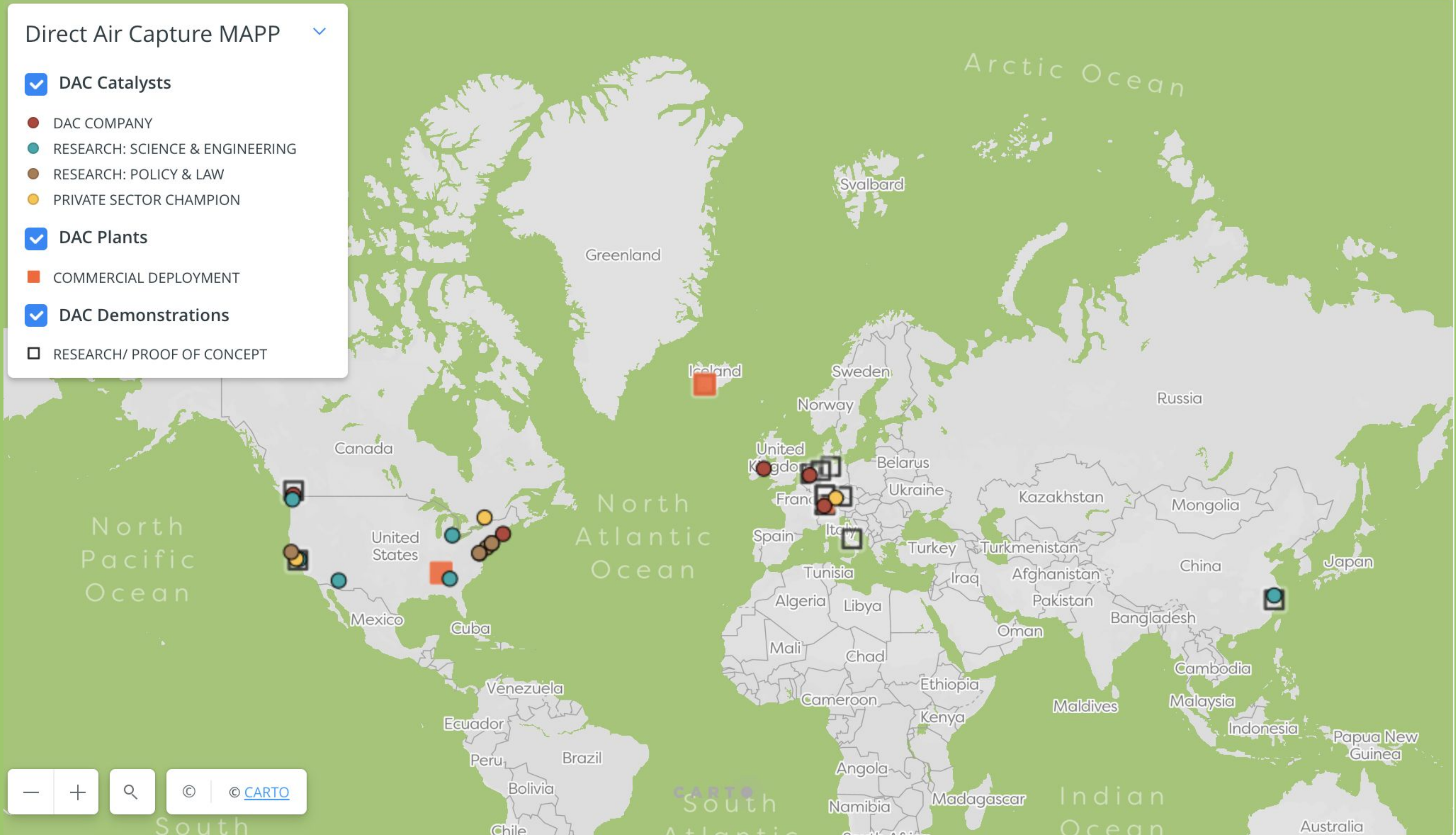


Source: IMPLAN Group, Keith et al. 2018. NAS, AISC, Rhodium Group analysis. Note: All values reflect DAC plant median cost and performance estimates. Values will vary depending on technology type and configuration.

A $1T Opportunity

Carbon180's market-sizing report estimates a $1T total available market in the US for product derived from CO_2 — and $6T globally.

Where we are today


Direct Air Capture MAPP
DAC Catalysts
DAC COMPANY
RESEARCH: SCIENCE & ENGINEERING
RESEARCH: POLICY & LAW
PRIVATE SECTOR CHAMPION
DAC Plants
COMMERCIAL DEPLOYMENT
DAC Demonstrations
RESEARCH/ PROOF OF CONCEPT
Arctic Ocean
Svalbard
Greenland
Iceland
Sweden
Norway
Russia
United Kingdom
Belarus
Ukraine
Kazakhstan
Mongolia
Canada
North Atlantic Ocean
North Pacific Ocean
United States
Spain
Italy
Turkey
Turkmenistan
China
Japan
Tunisia
Iraq
Afghanistan
Pakistan
Algeria
Libya
Mexico
Cuba
Oman
Bangladesh
Mali
Chad
Ethiopia
Cambodia
Venezuela
Cameroon
Maldives
Malaysia
Ecuador
Kenya
Indonesia
Papua New Guinea
Peru
Brazil
Angola
Bolivia
Madagascar
Indian Ocean
Namibia
Australia
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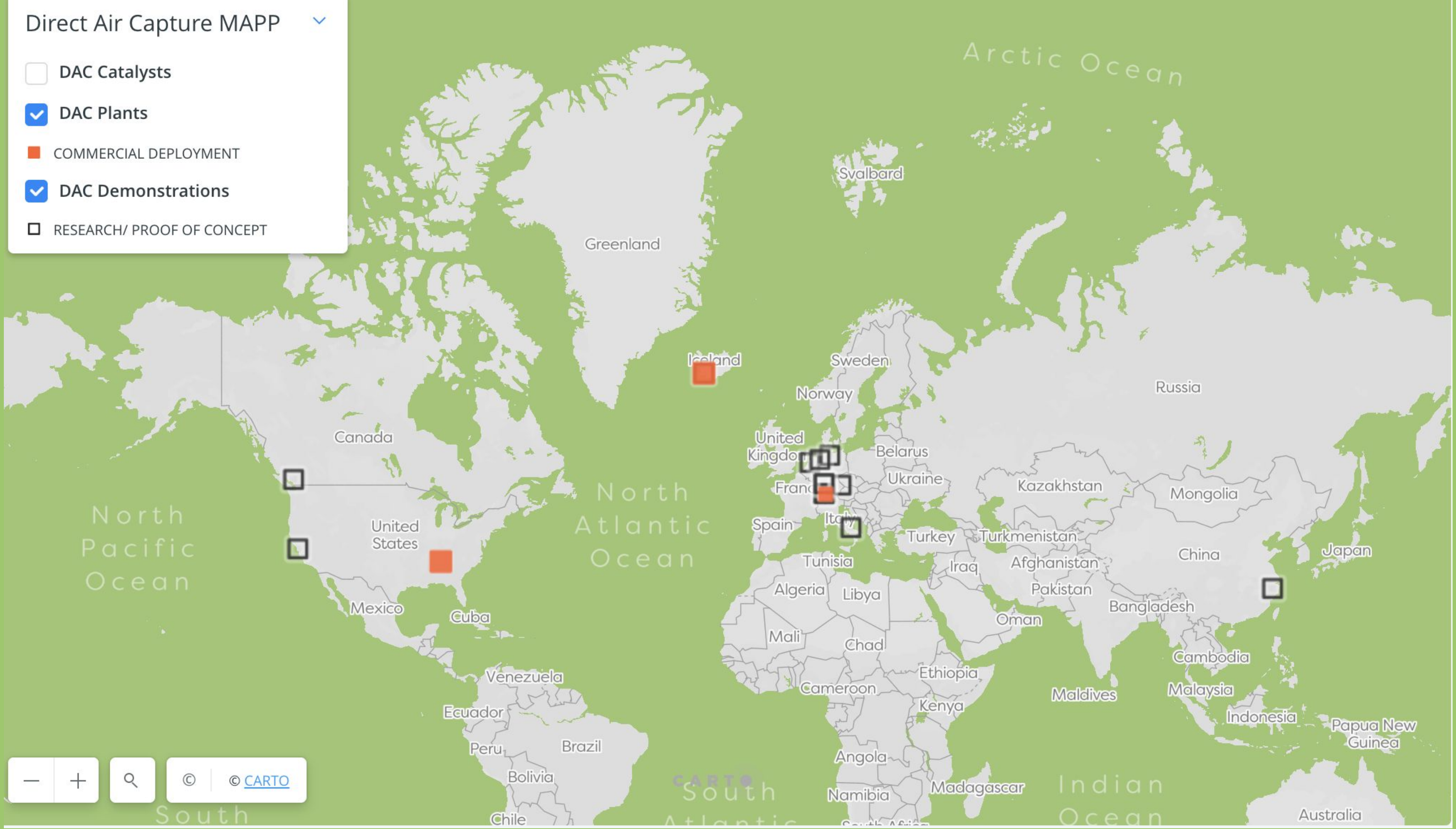
Direct Air Capture MAPP
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RESEARCH/ PROOF OF CONCEPT
Arctic Ocean
Svalbard
Greenland
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Belarus
Ukraine
Kazakhstan
Mongolia
North Atlantic Ocean
North Pacific Ocean
United States
Spain
Turkey
Turkmenistan
China
Japan
Tunisia
Iraq
Afghanistan
Algeria
Libya
Pakistan
Mexico
Cuba
Bangladesh
Oman
Mali
Chad
Cambodia
Venezuela
Ethiopia
Cameroon
Maldives
Malaysia
Kenya
Ecuador
Indonesia
Papua New Guinea
Peru
Brazil
Angola
Bolivia
Madagascar
Indian Ocean
Namibia
Chile
Australia
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Startup Progress

Heirloom

$53M Series A

climeworks

$650M Round

XPRIZE

287 Teams - 6 DAC companies in shortlist

Frontier

An advance market commitment to accelerate carbon removal

Frontier is an advance market commitment to buy an initial $925M of permanent carbon removal between 2022 and 2030. It's funded by Stripe, Alphabet, Shopify, Meta, McKinsey, and tens of thousands of businesses using Stripe Climate.

Buyers
Get in touch →

Suppliers
Get in touch →

stripe Alphabet shopify Meta McKinsey & Company

Barriers to Scale

High Costs

Current capture costs are $200-$600/ton of CO_2, but need to be much lower to be deployed at scale.

Durable Markets

Private sector companies are starting to purchase DAC tons, but long-term, high quality markets are necessary

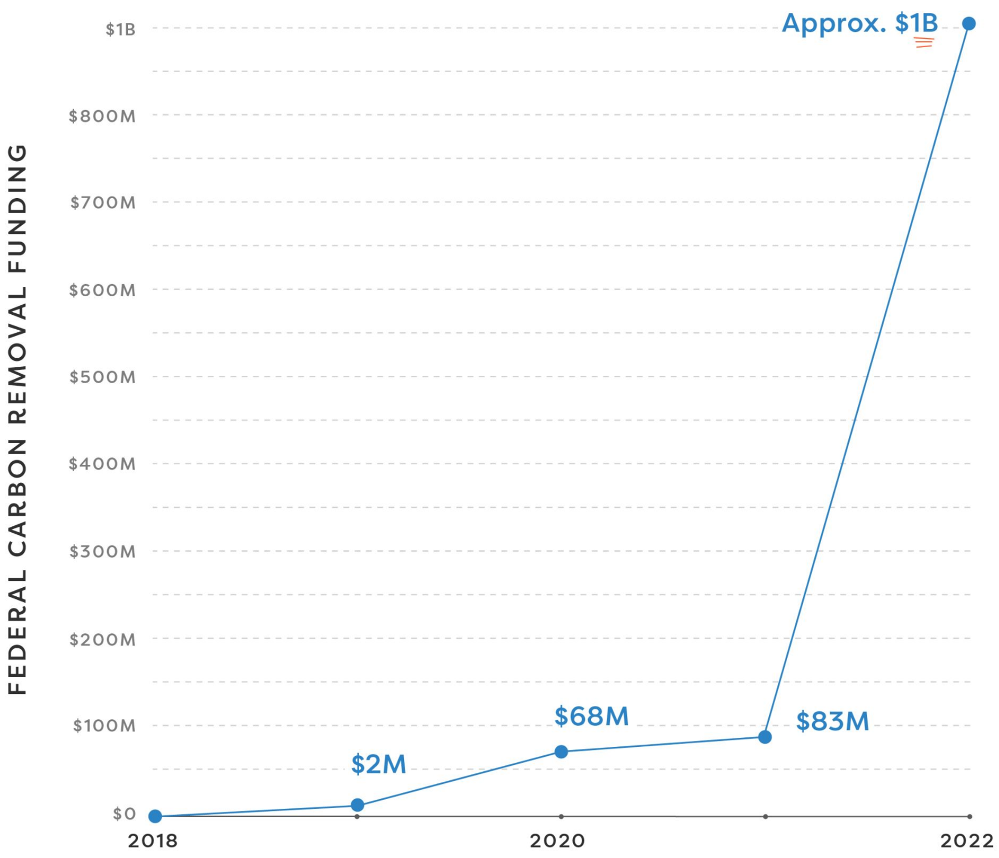
Shared Infrastructure

Many smaller DAC companies face barriers developing geologic and energy infrastructure

Policy Opportunities

$1 Billion in FY22

Funding for CDR has increased more than 1500% in just two years.



Carbon180

Source: Annual congressional appropriations and Infrastructure Investments and Jobs Act (IIJA)

New Policy Action

$3.5B for DAC Hubs

Supports 4 regional, million-ton-scale direct air capture and storage hubs across the US

SCALE Act

Provides financing and implementation support for CO_2 transportation and storage networks

Funding for EPA Class VI

Expanding the agency's capacity to permit CO_2 storage

CDR RD&D Legislation

Engaging in efforts to secure next-level support for CDR RD&D + improve cross-agency coordination

ESIC Act

Investment tax credits supporting direct air capture alongside other clean energy technologies

Procurement

Leveraging state wins to scale federal purchasing of carbontech materials and new legislation on direct air capture procurement

Policy Opportunities

Updated 45Q

Increasing the DAC-to-storage 45Q tax credit, reducing the capture thresholds, and instituting direct pay

Federal Procurement

Creating a long-term, durable market for DAC to scale + setting standards

Modernize Regulation

Ensure we have the necessary regulations that both protect communities and work for startups

U.S. DEPARTMENT OF
ENERGY
Fossil Energy and
Carbon Management

Direct Air Capture

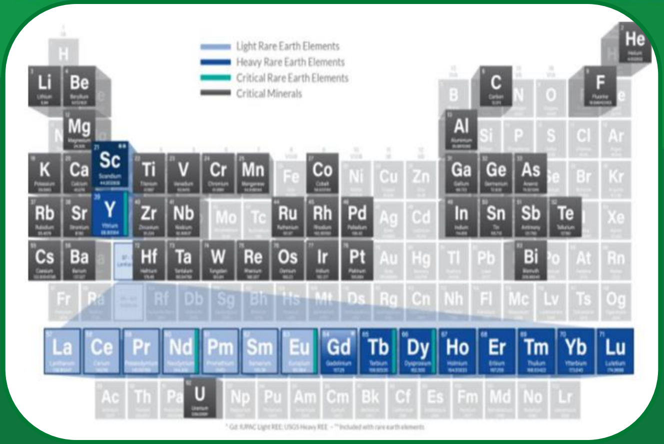
Opportunities, Challenges, and Role of Policy

Dr. Jennifer Wilcox

PRINCIPAL DEPUTY ASSISTANT SECRETARY
FOSSIL ENERGY AND CARBON MANAGEMENT

May 25, 2022





Office of Fossil Energy and Carbon Management

Advancing Carbon Management Approaches Toward Deep Decarbonization

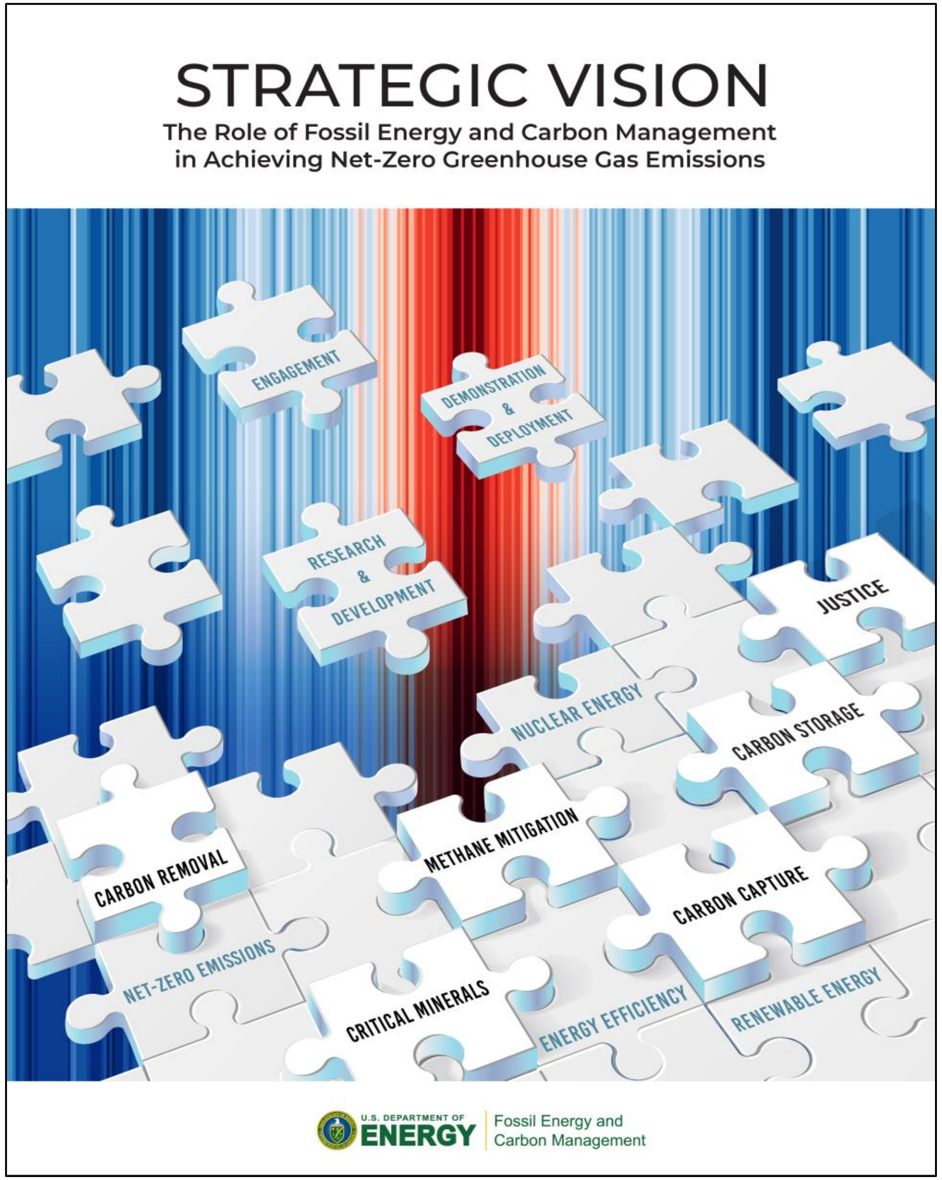
Priorities: *Point-source carbon capture, carbon dioxide conversion, carbon dioxide removal (CDR), and reliable carbon transport and storage*

Advancing Technologies that Lead to Sustainable Energy Resources

Priorities: *Hydrogen with carbon management, domestic critical minerals (CMs) production, and methane mitigation*

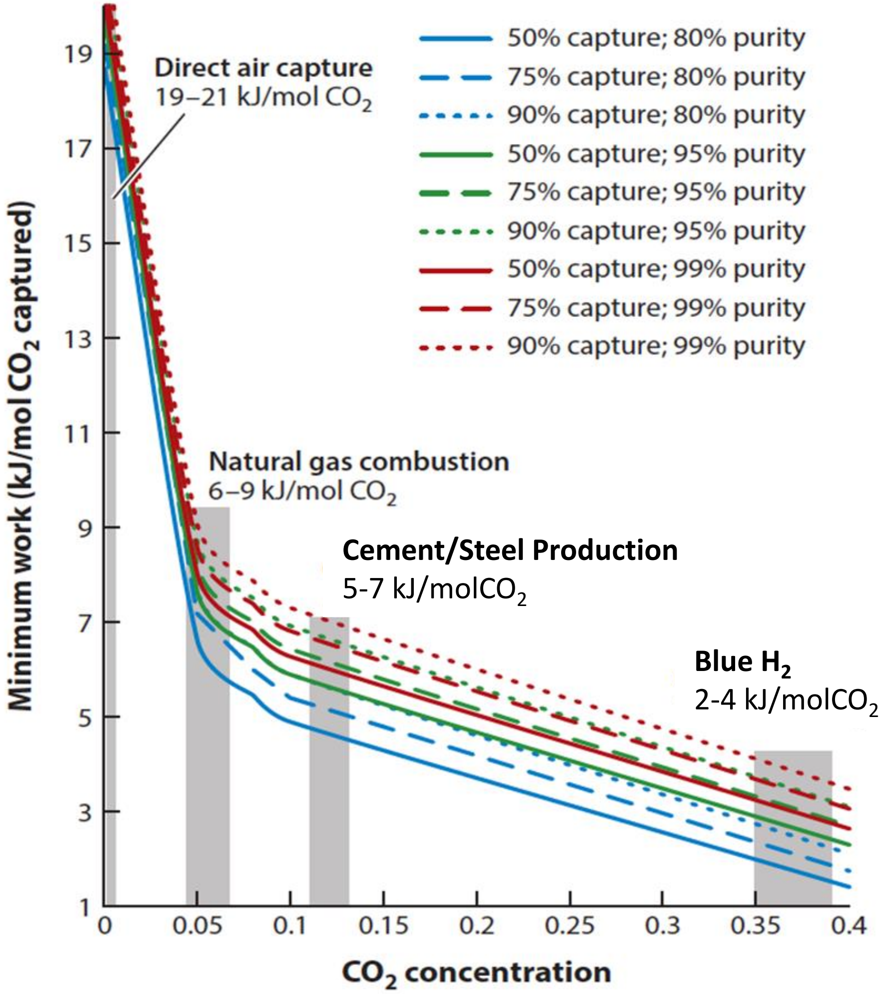
Advancing Justice, Labor, and Engagement

Priorities: *Justice, labor, and international and domestic partnerships*

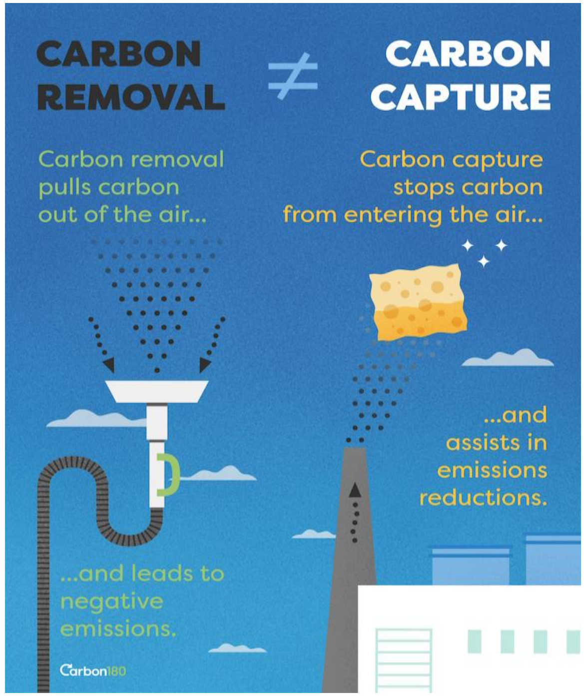


CCS and CDR Need to Be Done In Parallel

- Minimum work for separation may be derived from combined 1st and 2nd laws of thermodynamics
- Energy scales with dilution – > 3× more energy to do DAC vs exhaust streams
- 300× greater contactor area for CO_2 separation to do DAC vs exhaust
- High purity is desired for transport
- Direct air capture should not be seen as a replacement for avoiding carbon



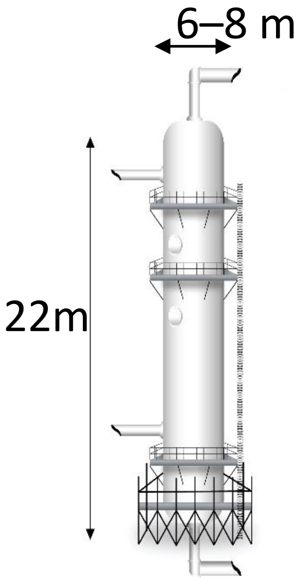
Distinction Between Point-Source Capture and Direct Air Capture



Source: https://grist.org/wp-content/uploads/2021/12/carbon180-carbon-removal-is-not-carbon-capture.png

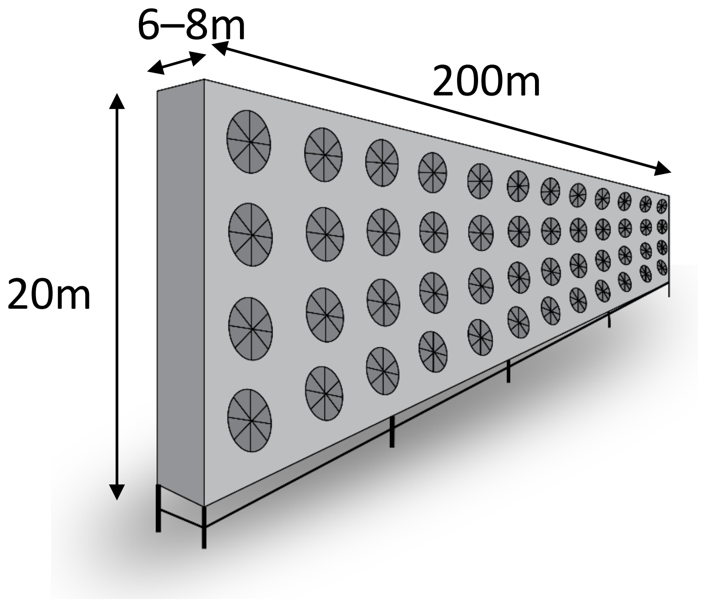
Different designs and various technologies lead to different impacts, energy, land, and water requirements

Power Plant MEA Scrubber



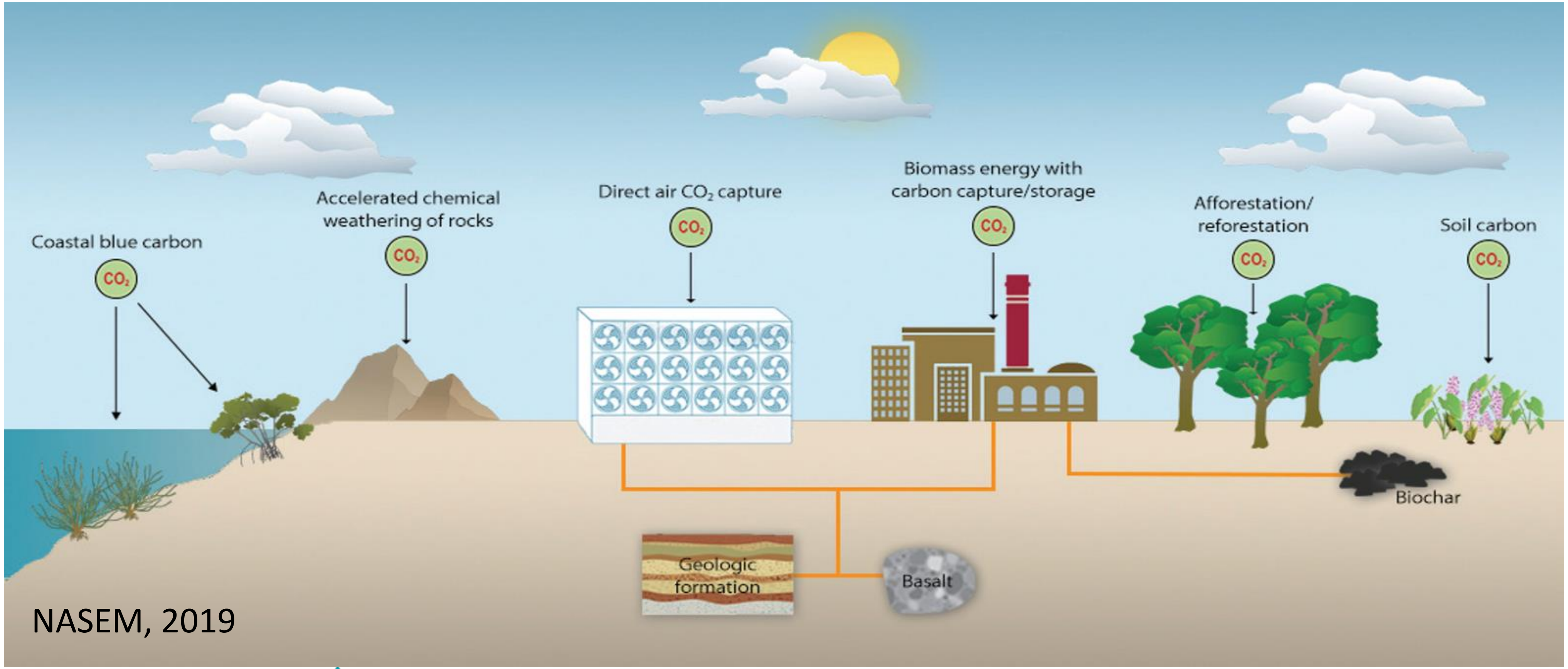
x2

DAC Contactor



x10

Carbon Dioxide Removal and Importance of MRV



ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Carbon Negative

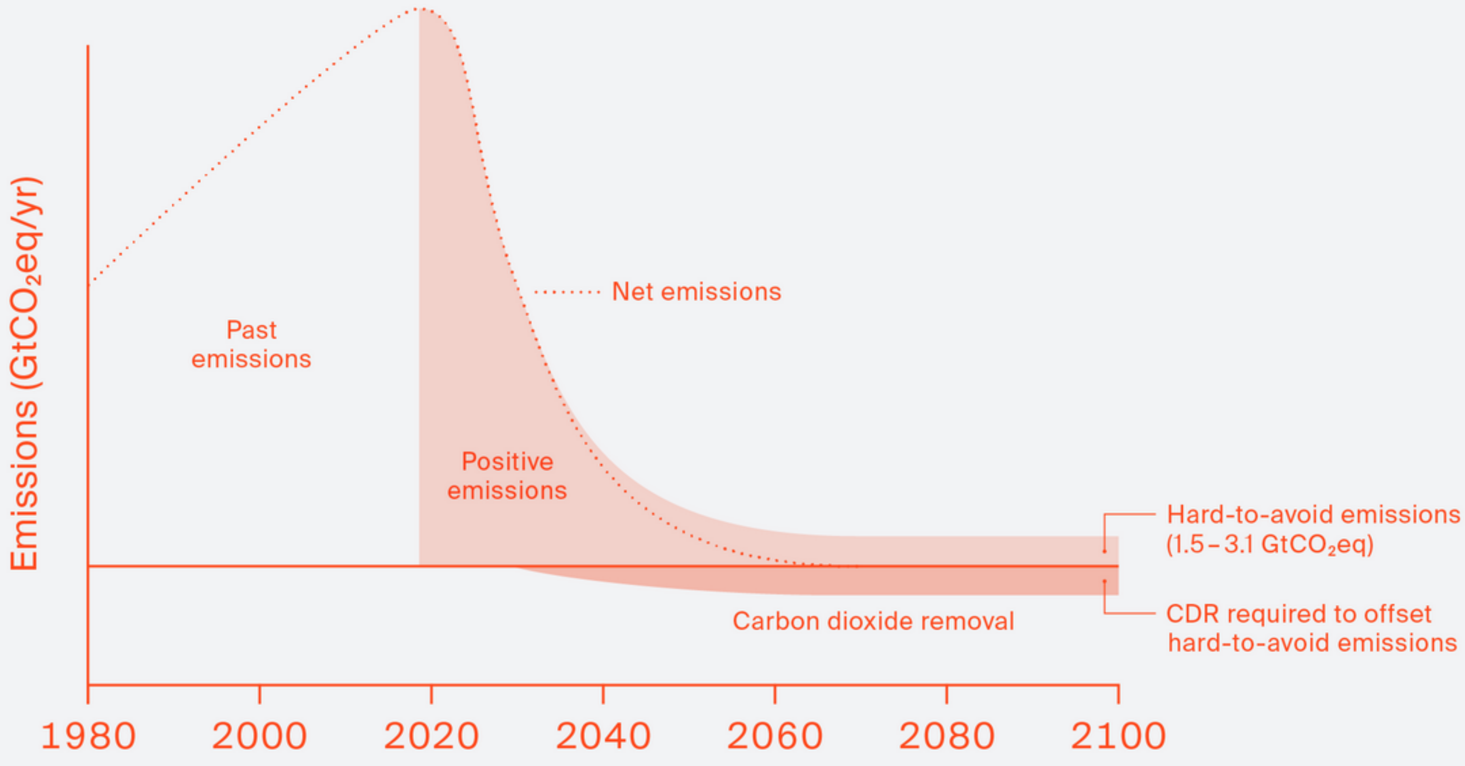
Durable and scalable carbon dioxide removal under $100/net metric ton within a decade

Net-Zero and Role of Carbon Dioxide Removal

Figure

1.1 →

Schematic of hard-to-avoid emissions and the CDR needed to offset them. Adapted from a figure produced by Glen Peters (2020)



CDR Primer, 2021

Recent FECM awards focus on coupling DAC to Existing Utilities

- As a leader in advancing carbon management technologies, FECM is researching and investing in DAC technologies to help scale them up for the commercial market
- DAC coupled to durable storage for carbon dioxide removal is energy intensive, relying on both heat and electricity inputs
- FECM recently awarded $11 million (federal) for 4 FEED studies leveraging existing sources of clean heat for DAC – nuclear, geothermal, and industrial waste heat

DAC coupled to nuclear heat: $3.4m ($2.5m federal) FEED study led by Battelle with AirCapture, Carbonvert, Sargent & Lundy, Southern Company, and the University of Alabama to be located at Southern Company's Joseph M. Farley nuclear power plant in Columbia, AL. Image: NRC

DAC coupled to nuclear heat and power: $3.1m ($2.5m federal) FEED study led by Exelon with Carbon Engineering, Worley Group, 1PointFive, Univ. of Illinois, and PNNL to be located at Exelon's Byron Generating Station for 250k net tons CO_2/year captured with permanent storage. Image: CE

DAC coupled to geothermal energy: $3.1m ($2.5 federal) FEED study led by UIUC with Climeworks, Ormat, Sentinel Peak, Visage Energy, LLNL, and Kiewit to be located at an Ormat geothermal facility in California. Image: Ormat

DAC coupled to steel plant waste heat: $4.3m ($3.5m federal) FEED study led by Univ. Illinois to be integrated with US Steel's Gary Works in Indiana, with CO_2 to be trucked to a ready-mix concrete plant to be mineralized into calcium carbonate.Photo: Adobe 296734139

Bipartisan Infrastructure Law

> $10 billion in new carbon management funding over 5 years through the Infrastructure Investment and Jobs Act (Bipartisan Infrastructure Law).

Carbon Dioxide Removal - Direct Air Capture
Regional Direct Air Capture Hubs: $3.5 billion
DAC Technology Prize Competition: $115 million

Carbon Dioxide Utilization and Storage
Carbon Storage Validation and Testing: $2.5 billion
Carbon Utilization Program: $310 million

Front-End Engineering Design Studies
Pipeline Infrastructure: $100 million

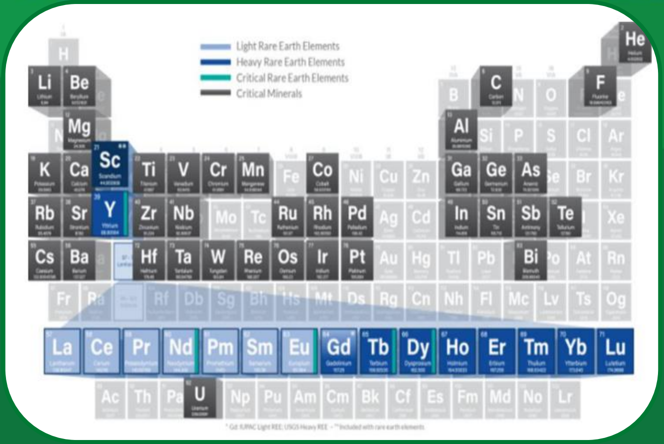
Carbon Dioxide Transportation Infrastructure
Loan Programs Office: $2.1 billion

Carbon Capture Demonstrations and Large Pilots
Integrated Systems: $3.5 billion

U.S. DEPARTMENT OF
ENERGY
Fossil Energy and
Carbon Management

Questions?





ASSESSING IMPACTS OF DAC TO ENABLE RESPONSIBLE SCALING

EESI Briefing on Direct Air Capture

May 25, 2022

KATIE LEBLING, WORLD RESOURCES INSTITUTE

WHY FOCUS ON RESPONSIBLE SCALING?

- We will likely need DAC at a large scale
- DAC is a new industry, unfamiliar to most
- Like all infrastructure, need to consider local impacts beyond DAC's needed carbon removal
- To not repeat historical inequities related to infrastructure development

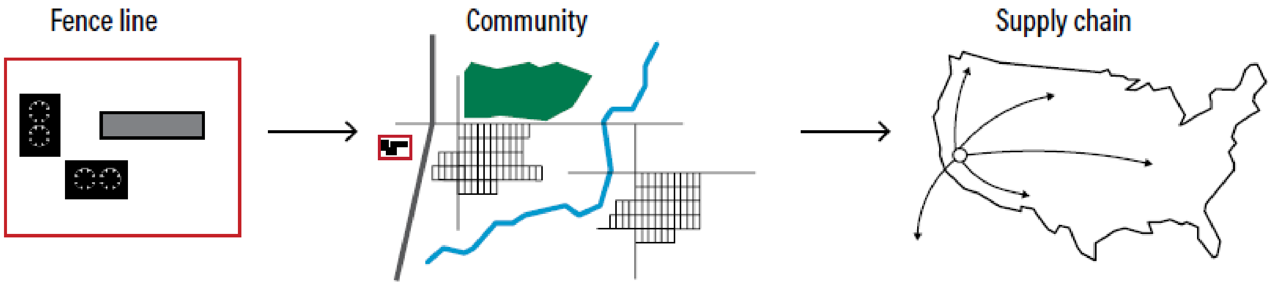
Explore further at: wri.org/research/direct-air-capture-impacts

Photo by Climeworks

KEY TAKEAWAY

WRI research finds that overall, DAC plants are expected to produce zero or almost zero onsite emissions that could negatively impact human health or the environment

CATEGORIZING IMPACTS



	Local	Distributed
One time: Pre-plant	Construction of plant (one time), construction material production, transport, labor	Production of capture media, production of select construction materials, production of energy infrastructure
Ongoing	Energy usage (fossil), chemical leakage or drift, transport of materials to/from plant, energy production, CO_2 use-related activities,* management of captured CO_2,* end-treatment of plant materials	Distant supply chain stresses; production of capture media; production of electricity, transport, and management of captured CO_2,* end-treatment of materials*
One time: Post-plant	Decommissioning, destruction, post-site maintenance and remediation, destruction and disposal transport, economic loss, discontinuation of CO_2 use-related activities,* end-treatment of materials, residual infrastructure, post-management site care	Economic loss, end-treatment of plant materials, residual infrastructure, post-management site care

IMPACTS ARE PROJECT SPECIFIC

DAC system and energy source	DAC plant (km^2)	Energy source (km^2)	Total for 1 $MtCO_2$/yr scale plant (km^2)
Sorbent: geothermal	0.5	7.0	7.5
Sorbent: solar PV	0.5	34.2	34.7
Sorbent: wind	0.5	65.6	66.0
Sorbent: NG with CCS	0.5	-	0.5
Solvent: NG with CCS + geothermal	0.4	1.5	1.9
Solvent: NG with CCS + solar PV	0.4	7.1	7.5
Solvent: NG with CCS + wind	0.4	13.6	14.0
Solvent: NG with CCS	0.4	-	0.4

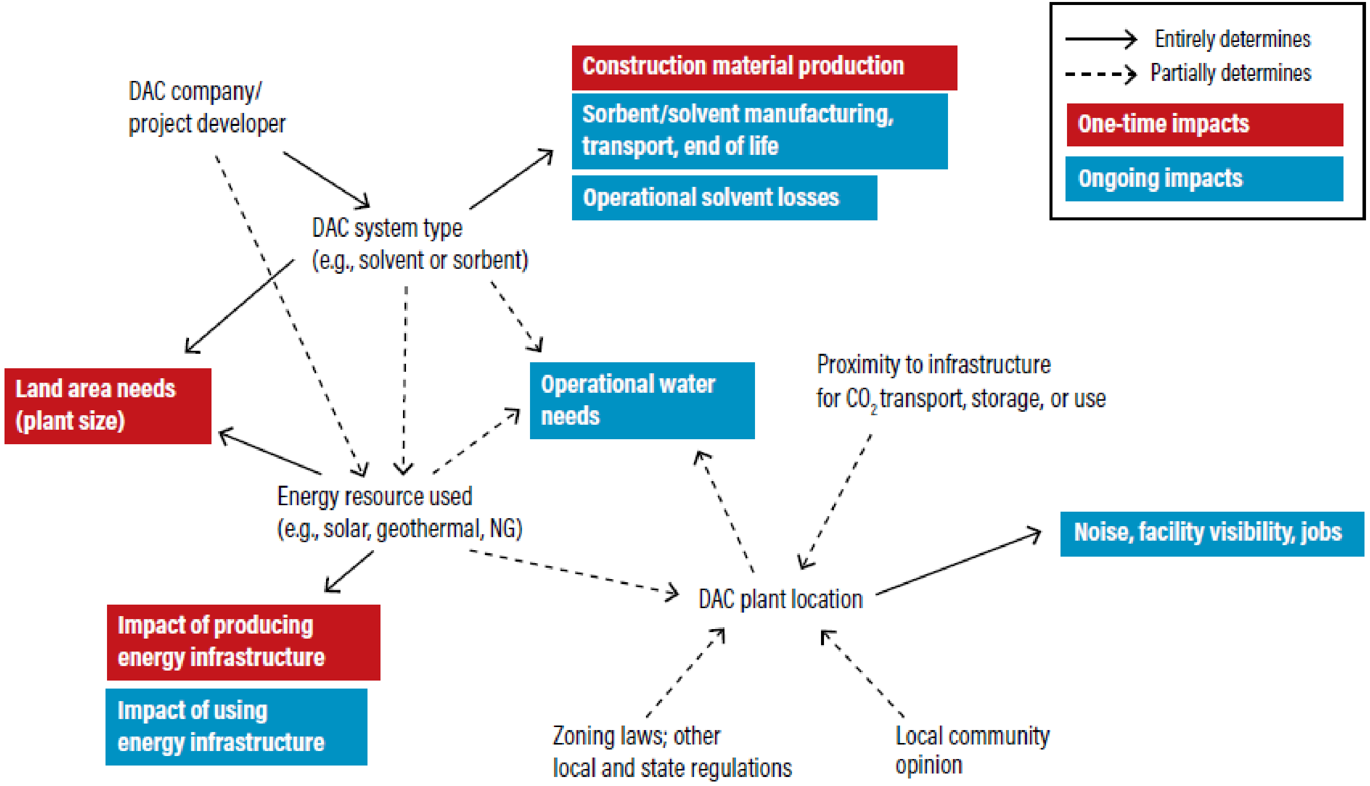
Note: Numbers may not add up due to rounding

EXPECTED IMPACTS AT SCALE

DAC at a half-billion tonne scale would be expected to use:

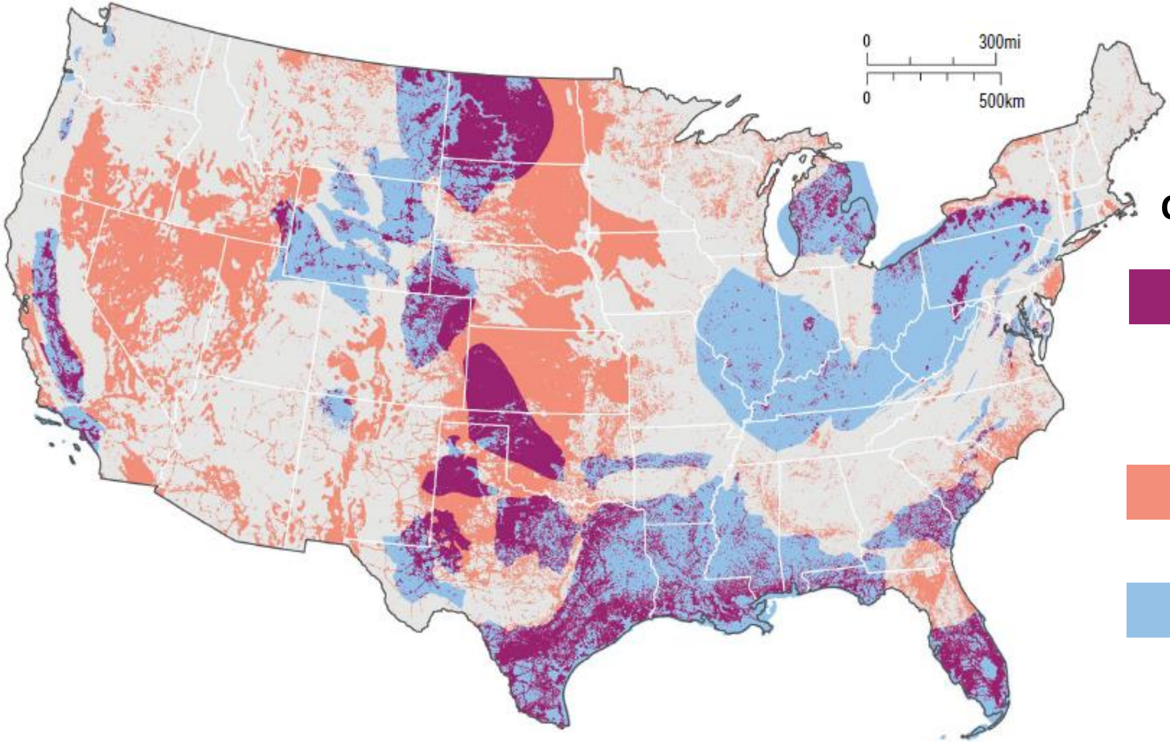
Resource/ material	Share of	U.S. or global total
Energy	4.4%	U.S. primary energy supply
	3.8%	U.S. projected 2050 energy supply (EIA reference case)
Construction materials	Up to 3%	U.S. annual cement production (for concrete)
	Up to 4%	U.S. annual steel production
	Up to 8%	U.S. annual PVC production
Chemicals	19%	Global annual solvent (KOH) production
	37%	Global annual production of chemicals used in sorbents

IMPACTS ARE INTERCONNECTED



Explore further at: wri.org/research/direct-air-capture-impacts

DAC IMPACTS & SITING PROCESSES



Carbon dioxide removal (CDR) systems

- Complete CDR system: potential for deployment of energy (solar, wind, geothermal) and geologic sequestration co-located
- Incomplete CDR system: potential for deployment of energy only
- Incomplete CDR system: potential for deployment of geologic sequestration only

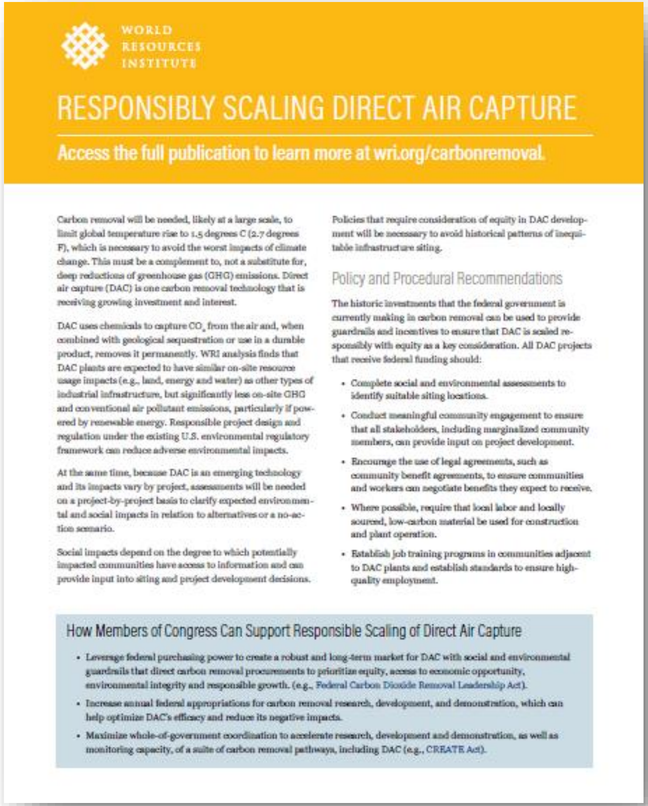
EQUITABLY DISTRIBUTING BENEFITS

- Global benefit: CO_2 removal
- Potential local benefits:
  - High-quality employment opportunities
  - Job training and apprenticeship programs
  - Other local investment tailored to community needs

Photo by Climeworks

RECOMMENDATIONS

- Procedural
  - Social impact assessment (SIA)
  - Legal benefit and workforce agreements
- Policy
  - Meaningful community engagement
  - Local labor, local low-carbon materials
  - Encourage use of SIAs and legal agreements with communities



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RESPONSIBLY SCALING DIRECT AIR CAPTURE

Access the full publication to learn more at wri.org/carbonremoval.

Carbon removal will be needed, likely at a large scale, to limit global temperature rise to 1.5 degrees C (2.7 degrees F), which is necessary to avoid the worst impacts of climate change. This must be a complement to, not a substitute for, deep reductions of greenhouse gas (GHG) emissions. Direct air capture (DAC) is one carbon removal technology that is receiving growing investment and interest.

DAC uses chemicals to capture CO_2 from the air and, when combined with geological sequestration or use in a durable product, removes it permanently. WRI analysis finds that DAC plants are expected to have similar on-site resource usage impacts (e.g., land, energy and water) as other types of industrial infrastructure, but significantly less on-site GHG and conventional air pollutant emissions, particularly if powered by renewable energy. Responsible project design and regulation under the existing U.S. environmental regulatory framework can reduce adverse environmental impacts.

At the same time, because DAC is an emerging technology and its impacts vary by project, assessments will be needed on a project-by-project basis to clarify expected environmental and social impacts in relation to alternatives or a no-action scenario.

Social impacts depend on the degree to which potentially impacted communities have access to information and can provide input into siting and project development decisions.

Policies that require consideration of equity in DAC development will be necessary to avoid historical patterns of inequitable infrastructure siting.

Policy and Procedural Recommendations

The historic investments that the federal government is currently making in carbon removal can be used to provide guardrails and incentives to ensure that DAC is scaled responsibly with equity as a key consideration. All DAC projects that receive federal funding should:

- Complete social and environmental assessments to identify suitable siting locations.
- Conduct meaningful community engagement to ensure that all stakeholders, including marginalized community members, can provide input on project development.
- Encourage the use of legal agreements, such as community benefit agreements, to ensure communities and workers can negotiate benefits they expect to receive.
- Where possible, require that local labor and locally sourced, low-carbon material be used for construction and plant operation.
- Establish job training programs in communities adjacent to DAC plants and establish standards to ensure high-quality employment.

How Members of Congress Can Support Responsible Scaling of Direct Air Capture

- Leverage federal purchasing power to create a robust and long-term market for DAC with social and environmental guardrails that direct carbon removal procurements to prioritize equity, access to economic opportunity, environmental integrity and responsible growth. (e.g., Federal Carbon Dioxide Removal Leadership Act).
- Increase annual federal appropriations for carbon removal research, development, and demonstration, which can help optimize DAC's efficacy and reduce its negative impacts.
- Maximize whole-of-government coordination to accelerate research, development and demonstration, as well as monitoring capacity, of a suite of carbon removal pathways, including DAC (e.g., CREATE Act).

WORLD RESOURCES INSTITUTE

THANK YOU!

Links to: Paper, article, 2-pager

Questions or comments: katie.lebling@wri.org

Scaling Up-Direct Air Capture (DAC): Learnings From Traditional Capture Projects

Kevin C. OBrien, PhD
Director, Illinois Sustainable Technology Center
Director, Illinois State Water Survey

Briefing Panel: Environmental and Energy Study Institute
May 25, 2022

ILLINOIS
Prairie Research Institute

EESI
Environmental and Energy Study Institute

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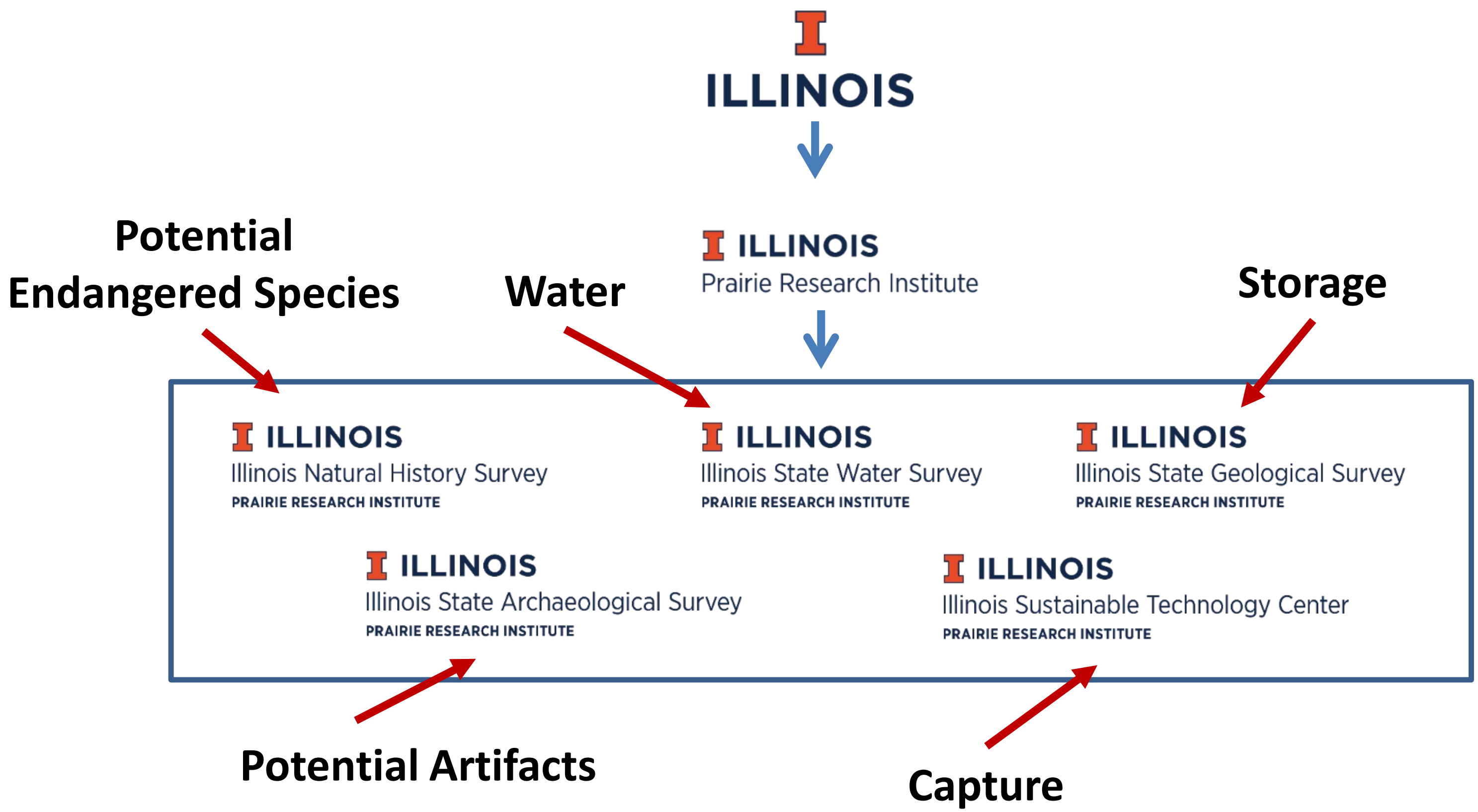
Skilled in transitioning from lab scale to build/operate scale

UNIVERSITY OF ILLINOIS / PRI: LEADER IN CAPTURE R&D

Prairie Research Institute (PRI): Addressing Societal Issues

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN



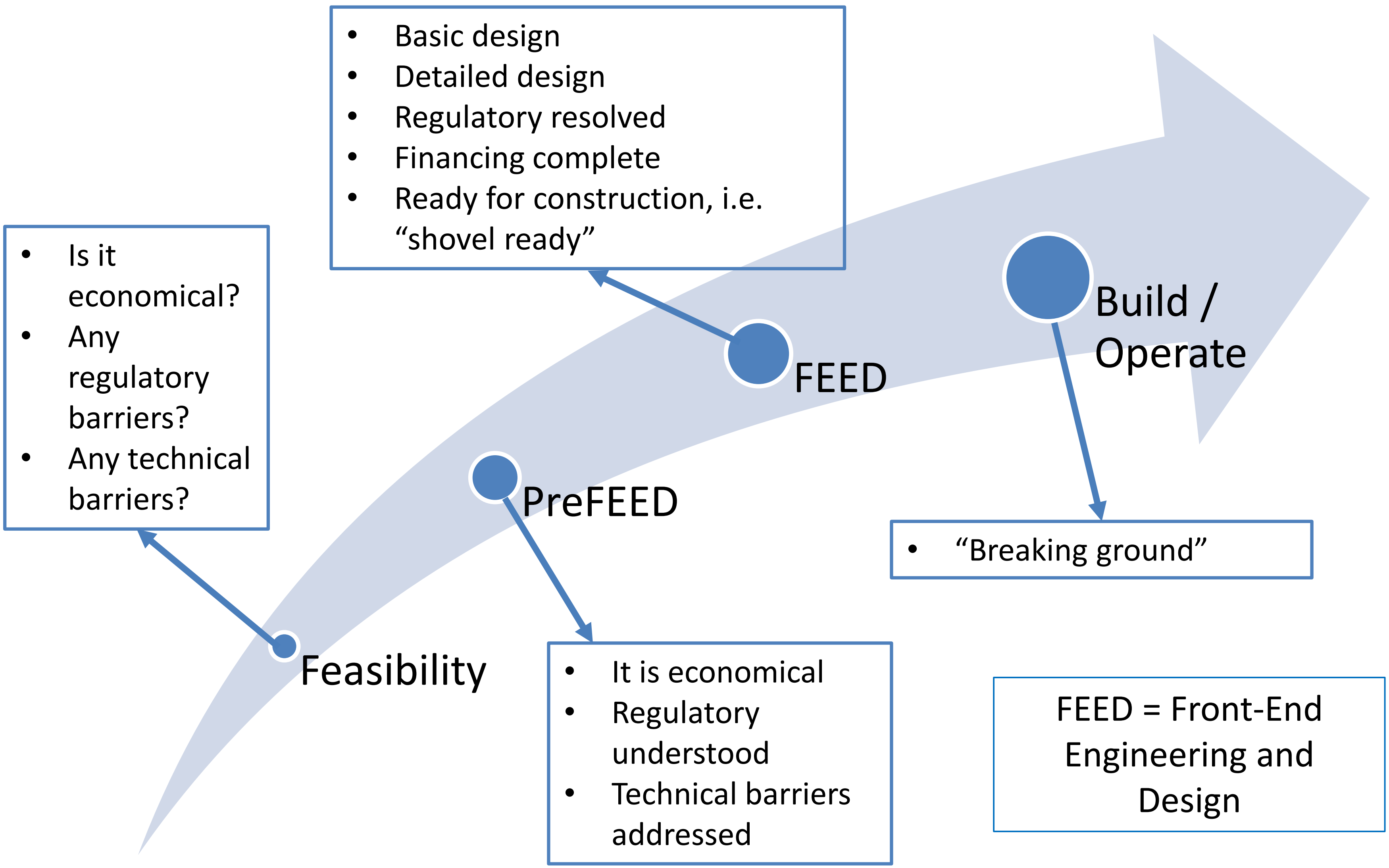
UIUC / PRI Network

Multi-organizational team is required

- Relationships and access to host sites in the region / US
- Network of Engineering Procurement and Construction (EPC) firms, OEMs, etc.
- Infrastructure in place (financial, project management, etc.) to meet US Department of Energy (DOE) requirements
- Typically functions as "prime" for projects
- "Agnostic" approach to technology, i.e. willing to work with any technology as long as it works

Pathway to Scaling-Up Capture Technologies

Traditional Capture Provides Good Lessons Learned for DAC scale-up



UIUC Project Portfolio

Color code: Complete / In Process

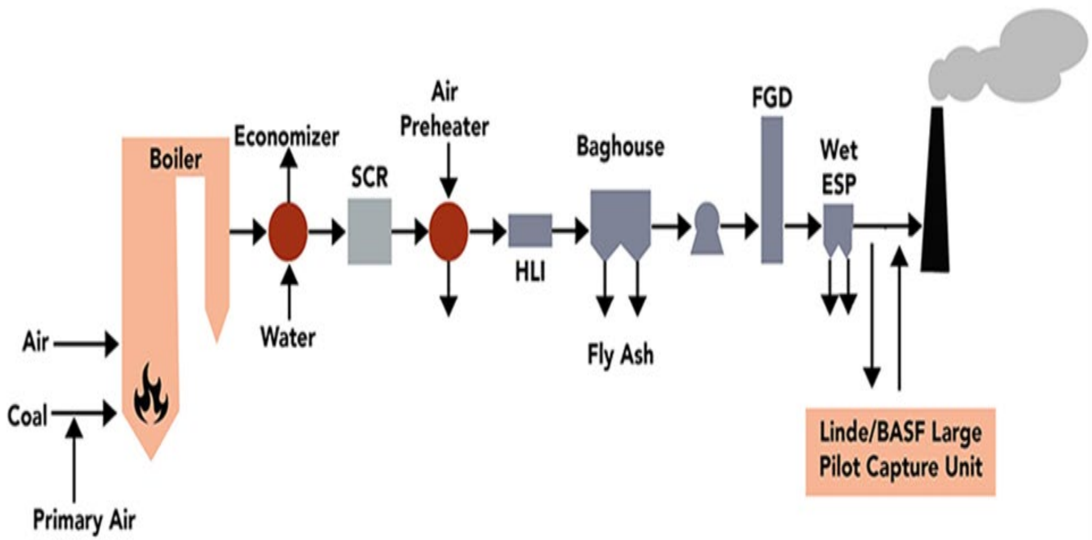
Lab	Small Pilot	Large Pilot / Full Scale
Next generation DAC materials	0.5 MW Capture w/Mixed Salts	816 MW capture plant (largest capture FEED in the world)
	40 kW – Biphasic Capture System	10 MW – Build / Operate (largest capture pilot in the world)
	0.5 MW aerosol reduction technologies	350 MW –Capture, energy storage, algae, hybrid coal/NG
	FGD blown-down water recycle	1 MW- Build/operate Utilize CO2 from flue gas for algae growth
		Capture from Cement Plant (largest single kiln in North America)
		Direct Air Capture (DAC) + renewables 100,000 tCO2/yr, 3 sites
		Direct Air Capture (DAC) + geothermal 5,000 tCO2/yr.
		Direct Air Capture (DAC) + nuclear 5,000 tCO2/yr.
		DAC + excess heat from steel plant+ utilization of CO2 for cement applications (DACU) 5,000 tCO2/yr.
		400 MWh energy storage using NG

Scale-up studies and considerations

DIRECT AIR CAPTURE (DAC)

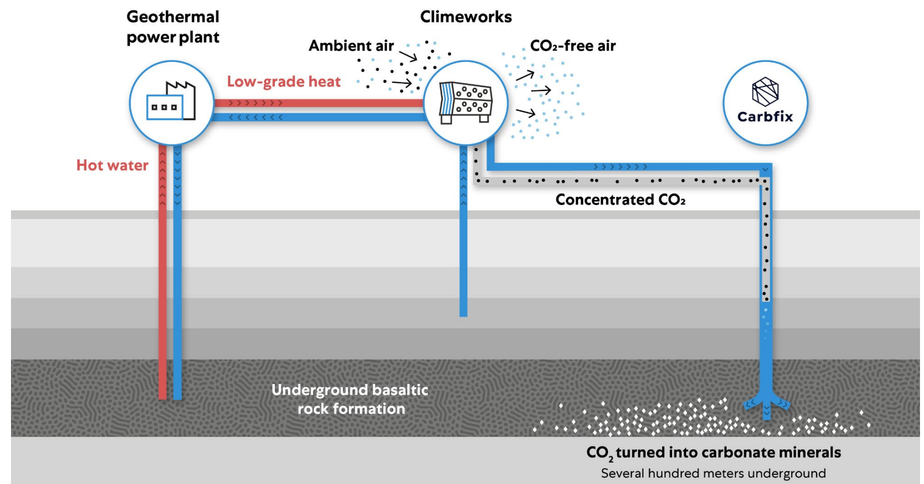
Some Engineering Scale-Up Considerations

Post combustion vs DAC



- Capture unit located before stack
- Heat / power from plant drives capture unit
- Capture CO_2 from flue gas
- CO_2 levels ~11% in flue gas
- Residuals could be present: NOx, SOx, etc.
- Industrial > 100,000; power generation >1,000,000 tCO2/yr. captured

- Capture unit location flexible
- Heat / power can be from multiple sources
- Capture CO_2 from atmosphere
- CO_2 levels in ppm range
- Residuals seen in post combustion not present



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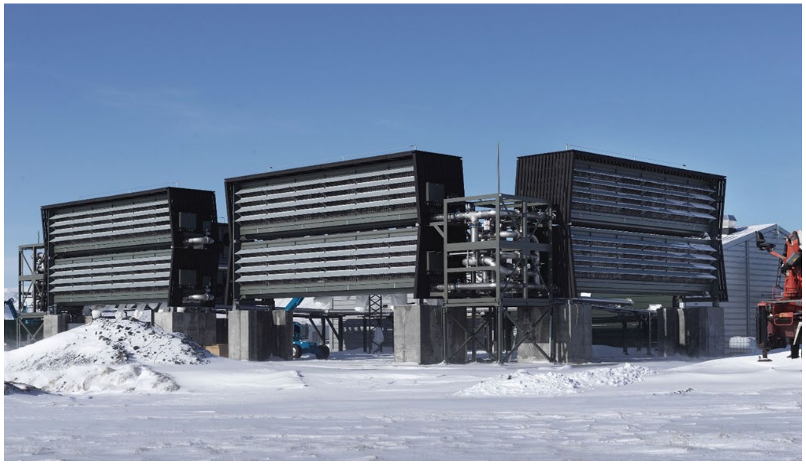
Direct Air Capture-Based Carbon Dioxide Removal with Low-Carbon Energy and Sinks

US Department of Energy (DOE) Funded Project



Louisiana

California

Wyoming

climeworks
Kiewit
GULF COAST SEQUESTRATION
ORMAT
SUNPOWER
SENTINEL PEAK RESOURCES
north shore energy, llc
Lawrence Livermore National Laboratory

Goals:

- Initial engineering design for system that captures 100,000 tCO_2/yr..
- Evaluate effect of various climates within the US on engineering design for three sites
- Estimate cost and timeline for construction of facility
- Technoeconomics, Life Cycle Analysis, and Business Case at all three host sites

Total Project Funding: $3.1 MM
Project Duration: 18 months

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Effect of Power Source and Climate on DAC Design

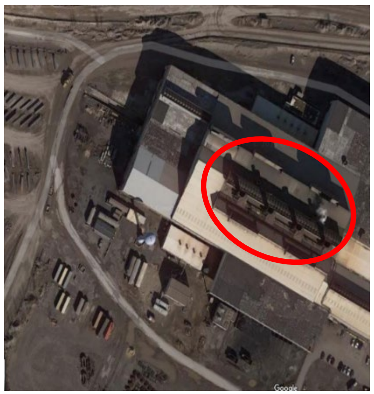
Evaluates impact of various factors on scale-up

Site Location	Volume CO_2 Captured (tCO_2/yr.)	Power Source	Existing vs New Power Source	Operator	Climate	Storage Site	Transport to Storage Site
Louisiana	100,000	Solar (SunPower)	New	Gulf Coast Sequestration	Hot & Humid	Deep Subsurface Rock	Co-located with DAC
California	100,000	Geothermal	Existing	Ormat	Hot & Dry	Saline Aquifer	Rail / Pipeline
Wyoming	100,000	Waste Heat (Gas plant) & Wind	Existing	North Shore Exploration & Production, LLC	Warm & Dry / Cold & Dry	Depleted Oil & Gas Reservoir	Co-located with DAC

Direct Air Capture + Utilization = DACU

Waste heat from Steel plant and utilize captured CO_2 for cement

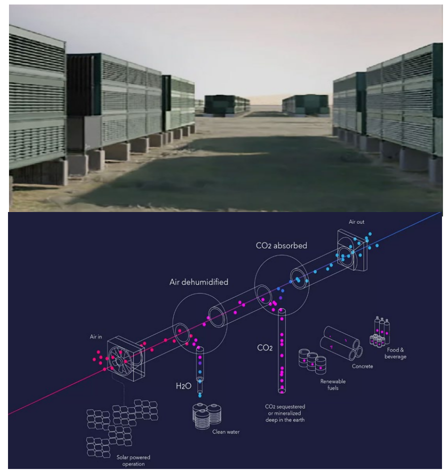
USS



US Steel Gary Works Facility Host Site Aerial View

Waste Heat

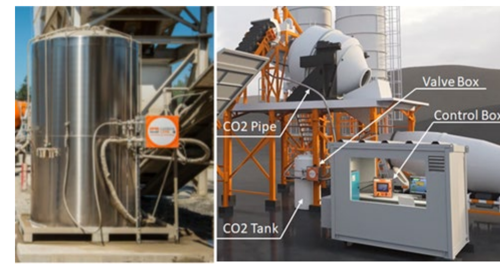
Carbon Capture



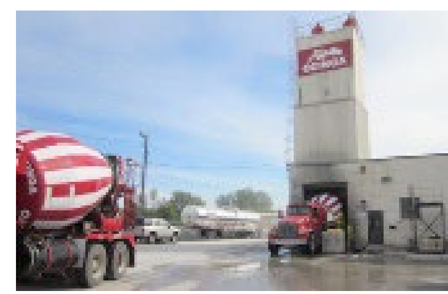
Captured CO_2

CARBONCURE
SIMPLY BETTER CONCRETE

CarbonCure's CO_2 Dosing Tank and Utilization System



CO_2 incorporated into cement



OZINGA

5,000 tCO_2/yr.

Total Project Funding: $ 3.5 MM
Project duration: 18 months

Strategies / Tools to Assist in DAC Scale-up

Many under development by NETL / DOE

- Use FEED study results to drive R&D funding
  - Uncover the technology "gaps" that inhibit scale-up
- Build pilot scale systems to accelerate learnings
  - Building systems has demonstrated for many energy technologies the ability to transition on the "learning curves[1,2] "
- Technoeconomic Analysis (TEA) standards for DAC
  - Patterned after those established for Post Combustion Capture[3]
- Standardized scale-up pathway
  - Equivalent for post combustion: bench-scale / lab-scale / small pilot / large pilot / demonstration

[1] Edward S. Rubin; Margaret R. Taylor; Sonia Yeh; David A. Hounshell, Learning curves for environmental technology and their importance for climate policy analysis, Energy 29 (2004) 1551-1559
[2] T. Wiesenthal, P. Dowling, J. Morbee, C. Thiel, B. Schade, P. Russ, S. Simoes, S. Peteves, Technology Learning Curves for Energy Policy Support, ISBN 978-92-79-25676-9, 2012
K. Schoots, M. Londo
[3] COST AND PERFORMANCE BASELINE FOR FOSSIL ENERGY PLANTS VOLUME 1: BITUMINOUS COAL AND NATURAL GAS TO ELECTRICITY (Sept. 2019, NETL-PUB-22638)

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