USEA

United States Energy Association

TECHNOLOGY SERIES

MEMBERSHIP BRIEFING

November 4th, 2014

Washington, DC

REMOVING CARBON FROM THE ATMOSPHERE:

What the Emergence of "Carbon Negative" Strategies Means for Industry & Government

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Background:

Carbon Dioxide Removal (“CDR”) techniques are gaining increased attention in the climate change debate.

The latest IPCC report:

"The large majority of scenarios produced in the literature that reach roughly 450 ppm CO_2eq by 2100 are ***characterized by concentration overshoot facilitated by the deployment of carbon dioxide removal (CDR)*** technologies."

IPCC: Fifth Assessment Report (WG3 -Chapter 6), 2014

The Climate Institute: Science:

EDITORIAL

Negative-emissions insurance

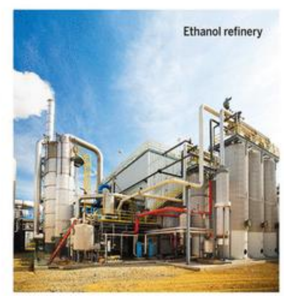
SCIENCE sciencemag.org 27 JUNE 2014 • VOL 344 Issue 6191 1431

In its April 2014 report, the Intergovernmental Panel on Climate Change (IPCC) recognized that reducing greenhouse gas (GHG) emissions by 40 to 70% by mid-century will require more than just implementing emission-free solutions. Many scenarios for stabilizing GHG concentrations that were evaluated by the panel included removing carbon dioxide (CO_2) from the atmosphere: so-called "negative emissions" or carbon dioxide removal (CDR). Among the most promising CDR methods are reforestation, afforestation (planting new forests), and bioenergy with carbon capture and storage (BECCS). However, for BECCS strategies to succeed, major hurdles must be overcome.

All BECCS approaches rely on removal of CO_2 from the atmosphere by plants during photosynthesis. In nature, as a plant decays, it releases CO_2 back into the atmosphere. But with BECCS, CO_2 is captured and permanently stored underground, resulting in a net negative reduction in atmospheric carbon. At least three BECCS technologies are being investigated today. CO_2 released during the microbial fermentation of plant sugars to ethanol can be captured. CO_2 can also be captured during the gasification of biomass to synthetic gas for conversion to transportation fuels, chemicals, or electricity generation. And CO_2 from the combustion of biomass, either with or without coal, can be captured.

Since 2009, a consortium supported by the U.S. Department of Energy has successfully operated a BECCS test facility in Illinois. CO_2 emitted during the fermentation of corn is captured and stored in a sandstone formation about 7000 feet underground. The project removes 300,000 metric tons of CO_2 per year from the atmosphere—the equivalent of removing about 70,000 cars from the road annually. But that's just a fraction of the amount of CO_2 that will have to be removed to curb global warming, and of the estimated 2 to 10 gigatons (Gt) of CO_2 per year that could be removed from the atmosphere with BECCS by 2050.*

For either conventional CCS or BECCS, the cost must come down. Right now, CCS costs range from about $30 to $140 per ton of CO_2, depending on the source from which it is captured, the capture technology, and the form of storage.† Improving energy-conversion efficiency would address the cost hurdles, but this requires further research and development. Increased confidence in long-term geological storage security is also needed to better understand the risks of BECCS strategies. Capturing and storing 1 Gt of CO_2 from the atmosphere using BECCS would require about 0.5 to 1 Gt of biomass (equivalent to 10 to 20 exajoules of primary energy). Concerns about whether this much biomass could be practically and sustainably harvested, dried, and collected at this scale without interfering with food production or negatively affecting other ecosystem services must be examined.



"This approach still leaves unanswered questions, but to not consider it carefully would be too risky."

Combined with sustainably managed reforestation and afforestation, the potential co-benefits of habitat creation, carbon mitigation, and renewable energy make BECCS an attractive choice. Rigorous research and development are needed so that the potential of BECCS is clear to scientists, policy-makers, and the public.

Negative-emissions technologies such as BECCS can be thought of as part of an insurance policy for climate change mitigation. This approach still leaves unanswered questions, but to not consider it carefully would be too risky.

– Sally M. Benson

Sally M. Benson is director of the Precourt Institute for Energy and the Global Climate and Energy Project, and a professor in the department of Energy Resources Engineering, at Stanford University, Stanford, CA. E-mail: smbenson@stanford.edu

Key questions about CDR addressed in this briefing:

1. The Basics	2. The Need	3. The Approaches	4. The Implications
What is CDR?	Why might we need it?	What are the different approaches to remove carbon from the atmosphere?	What are the implications of CDR for industry and government?

Three key conclusions:

1. CDR techniques provide complementary options to mitigating climate change
2. CDR brings more stakeholders to the table to discuss a wider range of strategies to fight climate change
3. All stakeholders need to start prioritizing and fostering CDR strategies with greater urgency

Part 1: The Basics of CDR

1. The Basics

2. The Need

3. The Approaches

4. The Implications

What is CDR?

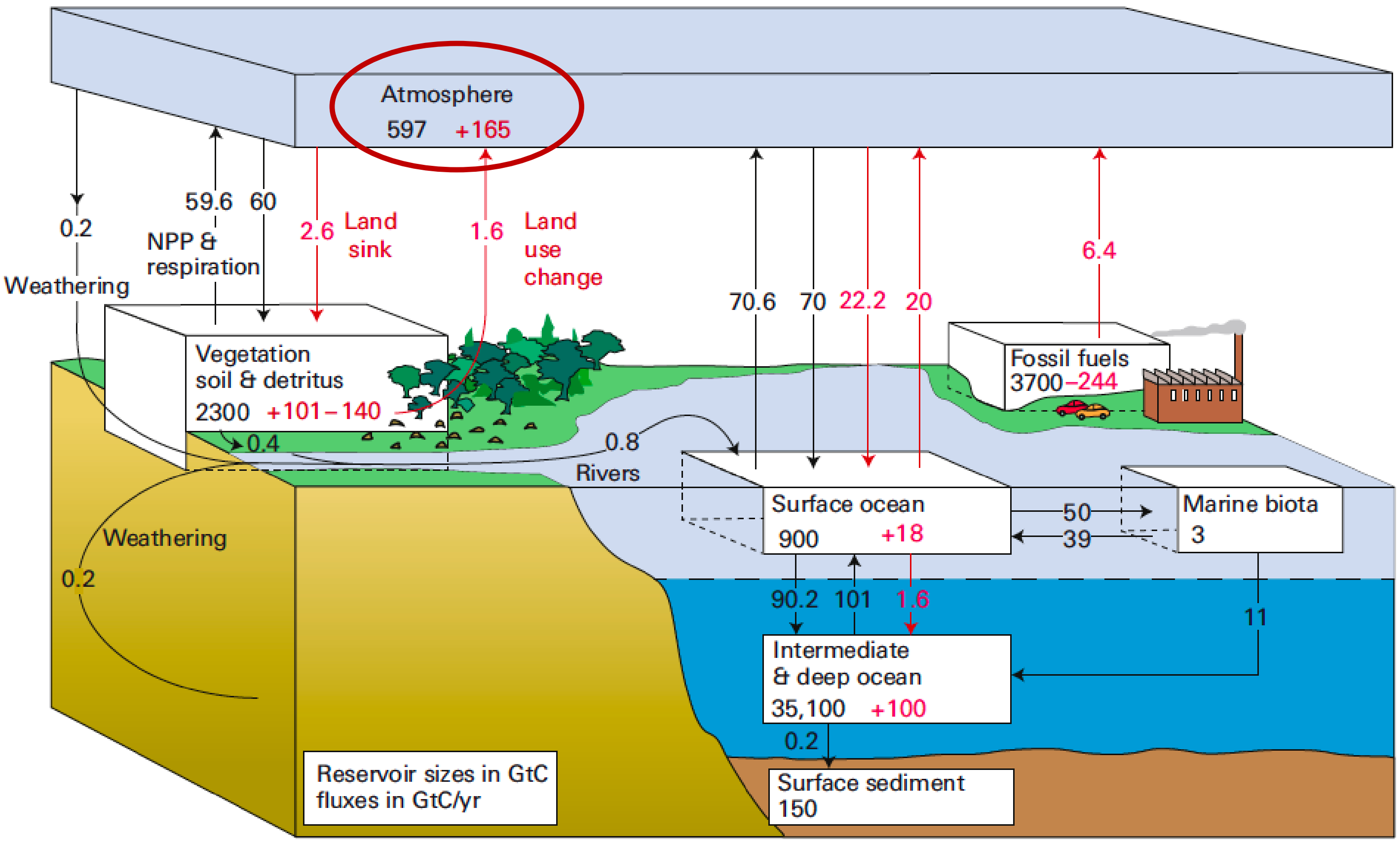
Why might we need it?

What are the different approaches to remove carbon from the atmosphere?

What are the implications of CDR for industry and government?

The Carbon Cycle

The carbon that the planet doesn't sequester remains in the atmosphere:



Humans emit a net ~8 B tonnes C (red arrows)

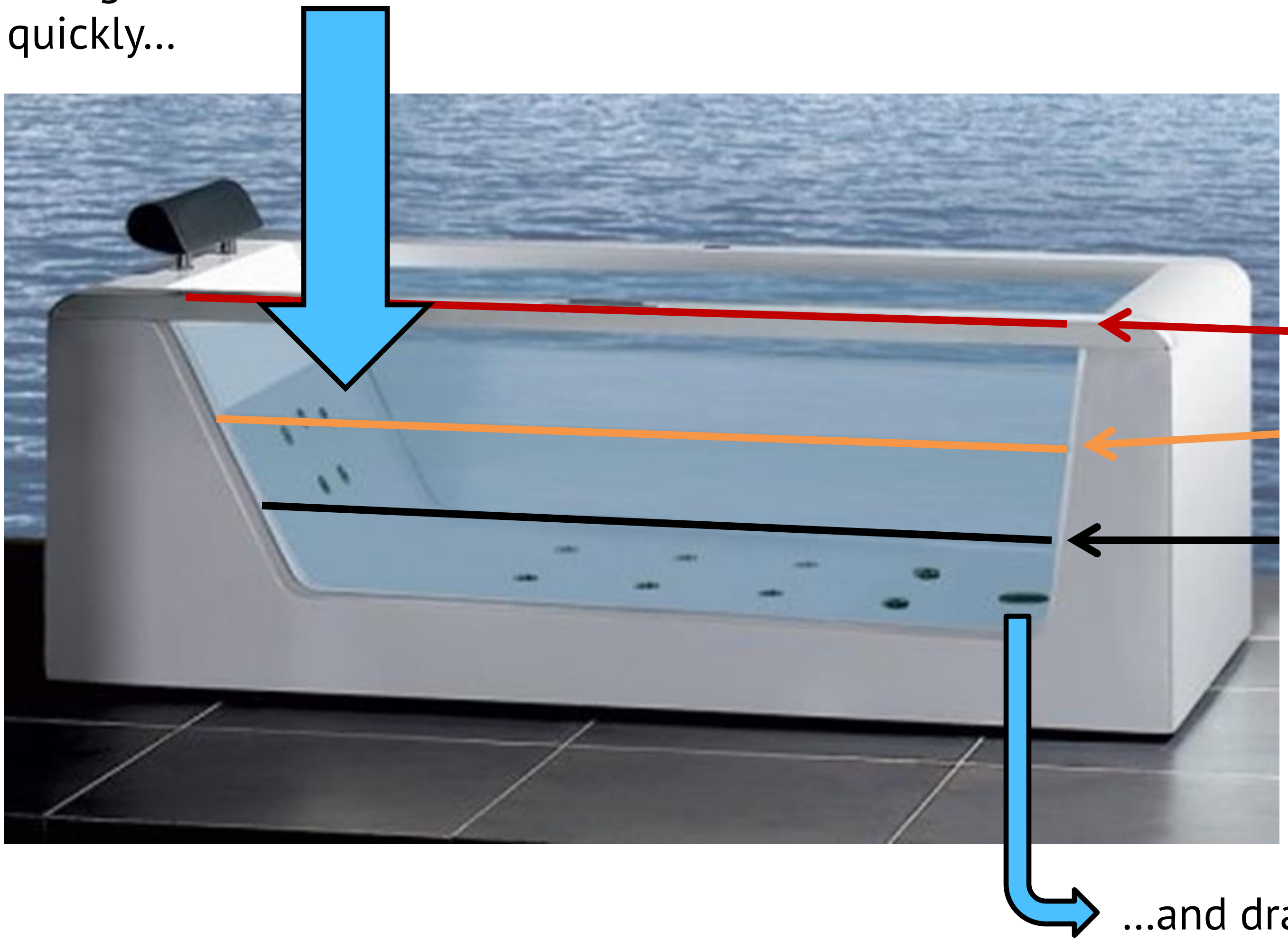
The planet's ecosystems pull out about half – ~4 B tonnes C – of human emissions (black arrows)

[1] Royal Society, 2009

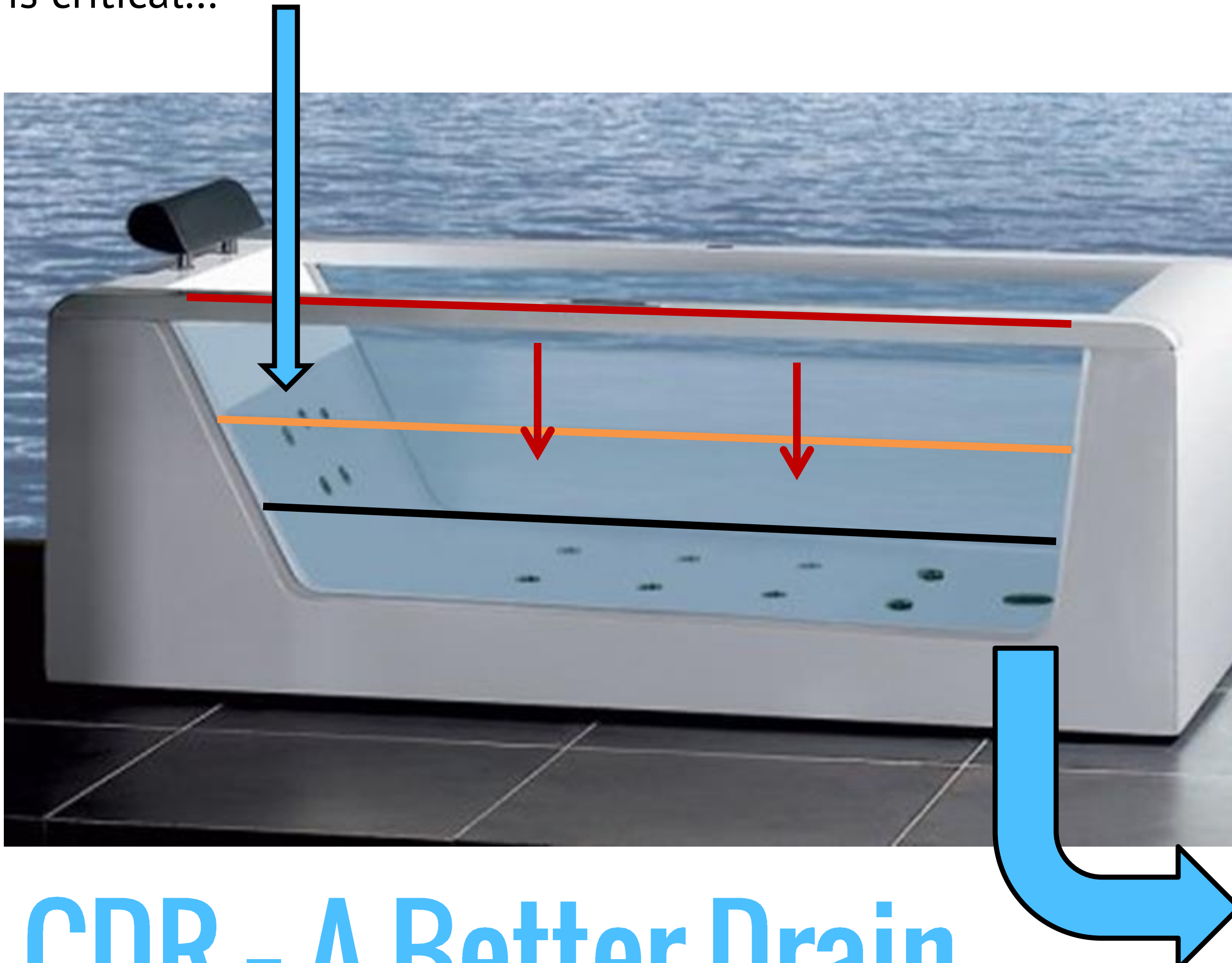
> "The removal of human-emitted CO_2 from the atmosphere by natural processes will take a few hundred thousand years **(high confidence)**"

IPCC, Climate Change 2013, The Physical Science Basis (p. 469)

CARBON DIOXIDE REMOVAL



Reducing emissions is critical...



CDR = A Better Drain

...as is increasing the capacity of the drain

Key Conclusion #1:

1. CDR techniques provide complementary options to mitigating climate change

2. CDR brings more stakeholders to the table to discuss a wider range of strategies to fight climate change

3. All stakeholders need to start prioritizing and fostering CDR strategies with greater urgency

Part 2: The Need for CDR

1. The Basics
2. The Need
3. The Approaches
4. The Implications

1. The Basics: What is CDR?

2. The Need: Why might we need it?

3. The Approaches: What are the different approaches to remove carbon from the atmosphere?

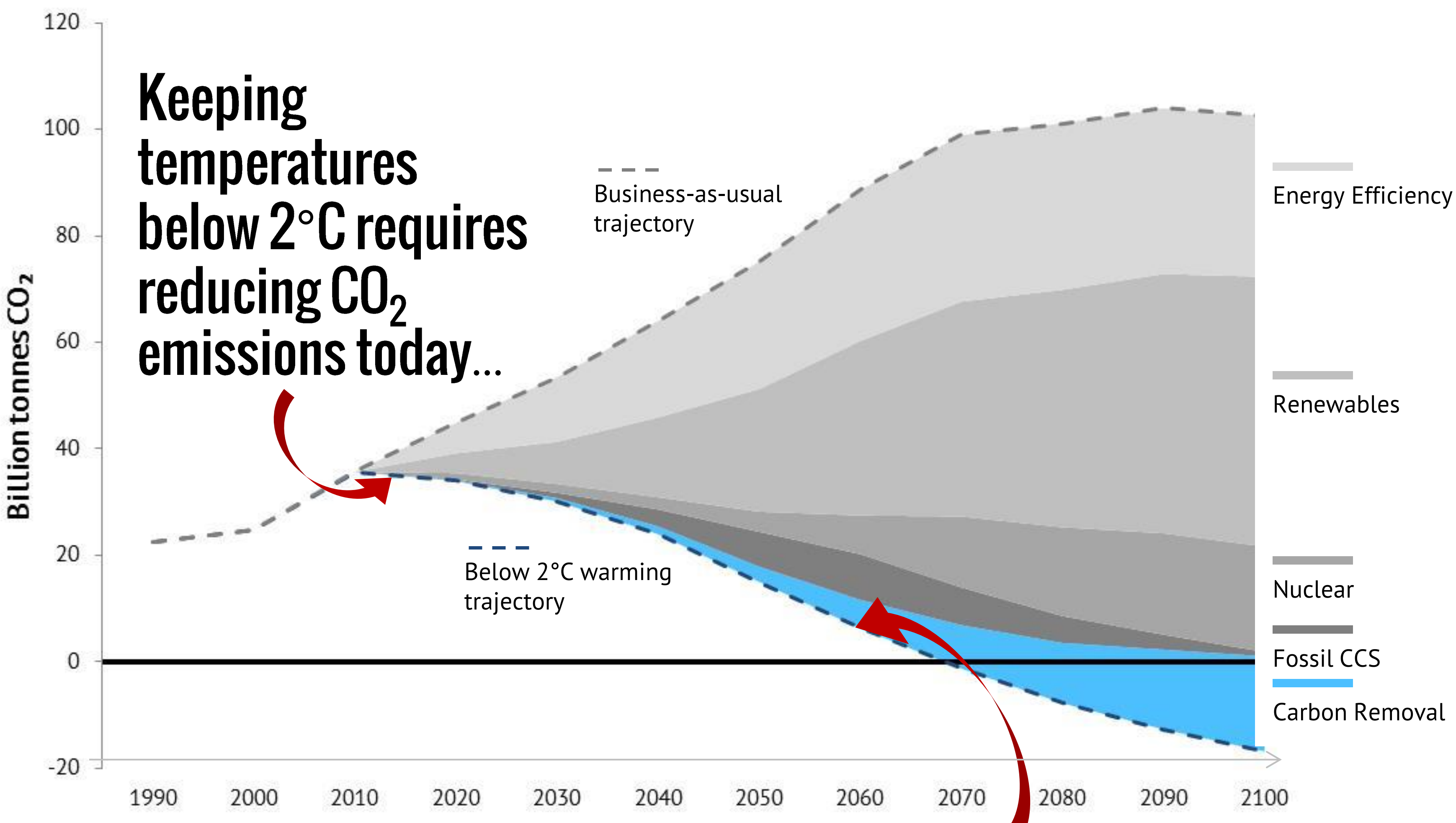
4. The Implications: What are the implications of CDR for industry and government?

CDR in context:

- Conservation
- Efficiency
- Low carbon energy
- Carbon dioxide removal
- Adaptation

Ideally, we could focus only on GHG emission abatement…

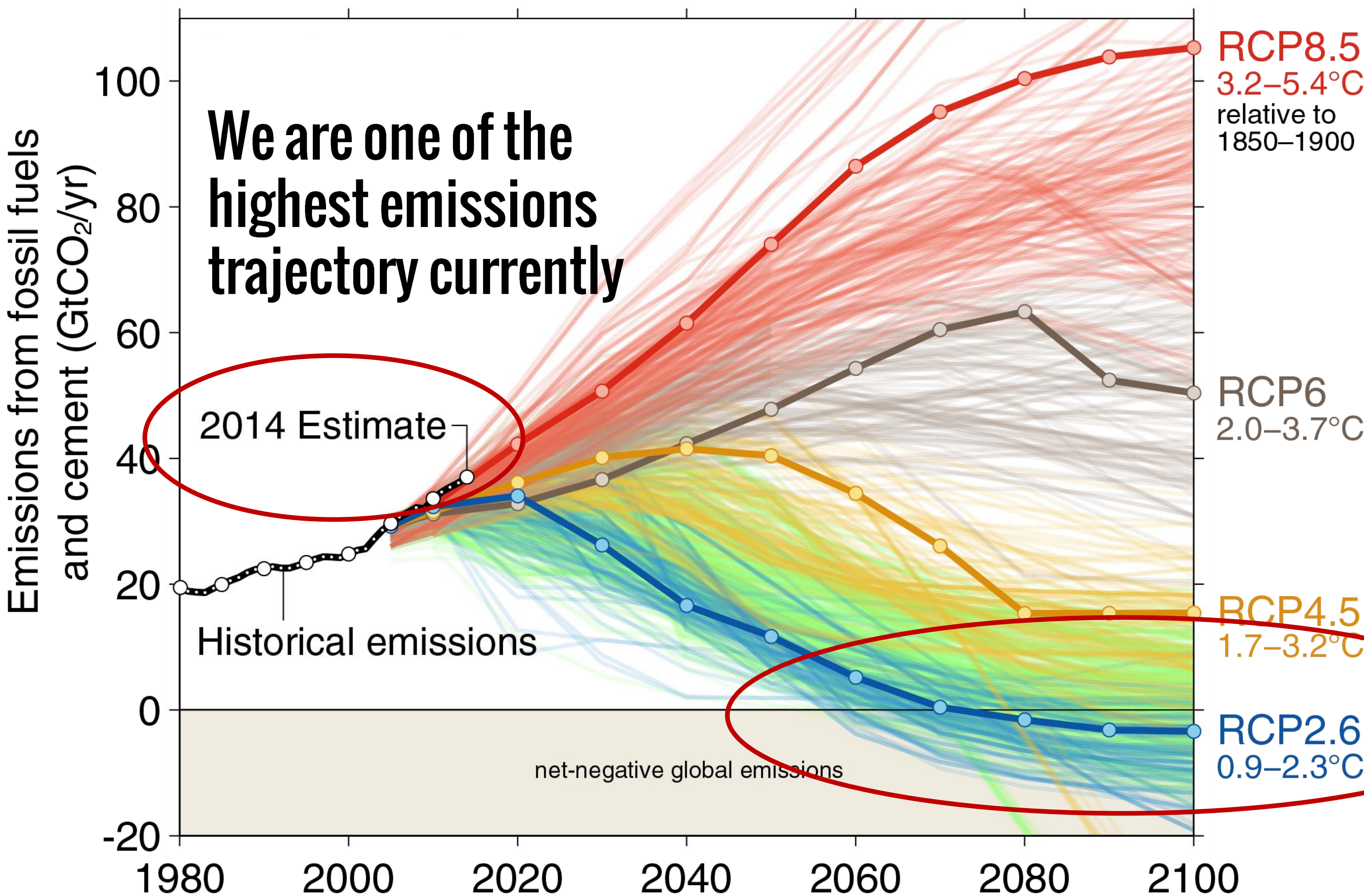
...but the situation we face is far from ideal:



...AND large-scale CDR by midcentury

Source: Clare Pinder (The Climate Institute)

CARBON DIOXIDE REMOVAL



Most <2°C scenarios involve negative emissions

Source: Fuss et al 2014; CDIAC; Global Carbon Budget 2014

And 2°C might even be too much warming:

sign in search jobs edition: US

theguardian
Winner of the Pulitzer Prize

home › environment development cities US world opinion sp ≡ all sections

environment Guardian Environment Blogs

Sorry policy-makers, the two-degrees warming policy is likely a road to disaster

As we approach the New York climate summit, there are serious questions about whether the two degrees of warming limit is acceptable.

What might prevent rapid decarbonization?

Part 3: CDR Approaches

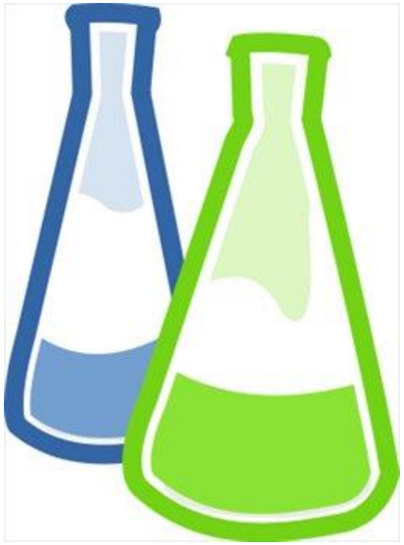
1. The Basics	2. The Need	3. The Approaches	4. The Implications
What is CDR?	Why might we need it?	What are the different approaches to remove carbon from the atmosphere?	What are the implications of CDR for industry and government?

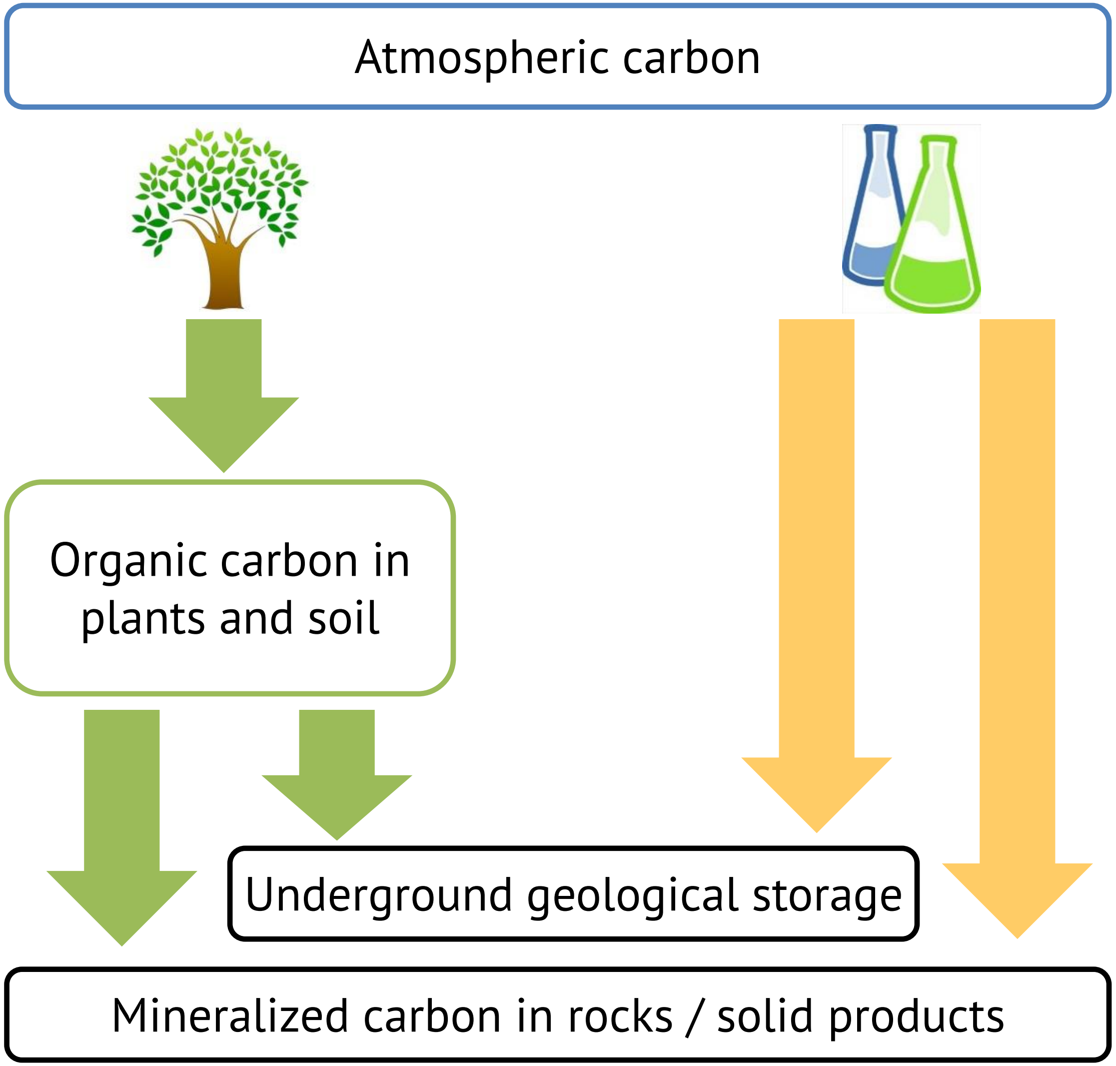
CDR is an outcome: many different approaches can achieve CDR

Carbon Removal Pathways:

Biological Removal

Chemical Removal





CDR approaches can take advantage of existing carbon flows

Adapted from: Negatonnes (Duncan McLaren for Friends of the Earth, 2011)

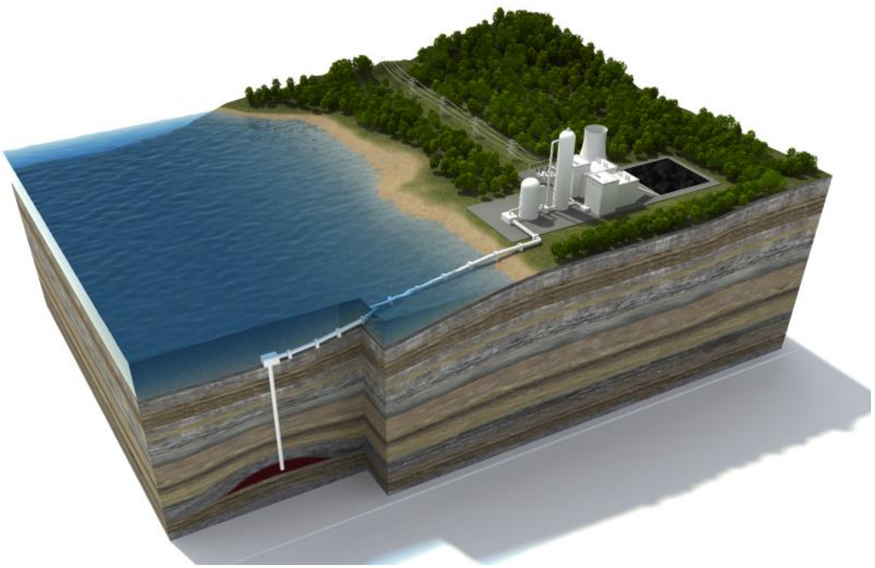
Bioenergy with CCS (Bio-CCS)

Process: plants remove CO_2 from the air; when biomass is burned, CO_2 is captured and stored.

Key prerequisite: sustainable source of biomass

A double benefit: each unit of energy produced through Bio-CCS can displace fossil fuel in addition to capturing the carbon from biomass

Embedded options: Bio-CCS can be developed alongside existing bioenergy and fossil CCS development programmes



Carbon capture and geological storage; Credit: Bellona

Pathway: Biological

Cost: \$60-200/tCO_2

Limiting factors: Availability of sustainable biomass, availability of geological storage

Biochar

Process: Slow pyrolysis (burning without oxygen) of biomass to a char that can be added to soil

Co-benefits: improves soil quality and resilience, reduces other fertilizer use

Scale: can operate at scales from small household to small commercial plants

State: Numerous early commercial ventures are starting to sell either biochar or small pyrolysis units

Biochar produced from woodchips; Credit: Black Carbon

Pathway: Biological

Cost: \$0–60/tCO_2 depending on feedstock

Limiting factors: Availability of sustainable biomass, size of market for biochar products

Afforestation

Process: The establishment of forests on land that has either not been recently forested or has been cleared of forest

Key prerequisite: For long term carbon storage, new forests must be protected and any products managed sustainably

An early CDR leader:
Afforestation and reforestation are already contained within traditional mitigation approaches and carbon offsetting

Pine forest in the Netherlands; Credit: ®DS / Foter.com

Pathway: Biological

Cost: \$20–100/tCO_2

Limiting factors: Suitable land area, saturation of forest sinks

Land Management

Process: intentional changes in agricultural land management that enhances or restores soil carbon sinks and reduces GHG emissions from soils

Benefits: enhance soil carbon often improve productivity and resilience, reduce environmental impacts and decrease the need for agricultural inputs, enhance productivity

Scale: these approaches do not require new land to be brought under management, so a very large land area is potentially available

Cattle grazing in Ghana; Credit: ILRI / Foter.com

Pathway: Biological

Cost: Most methods <$100/t$CO_2$

Limiting factors: Suitable land area, saturation of soil sinks, identification and diffusion of appropriate practices

Direct Air Capture

Process: concentrate ambient CO_2 directly from the atmosphere into a pure stream for subsequent utilisation and/or storage

Scale: 1B+t scale potential– constrained only by available storage and investment costs

State: CO_2 captured from the air is already starting to be used in as a primary feedstock for high-performance synthetic hydrocarbon fuels and polymers

Impression of a 'dry' amine-based sorbent CO_2 air capture system; Credit: Climeworks

Pathway: Chemical

Cost: $20-1000/tCO_2$

Limiting factors: Availability of geological storage in long term, energy and capital requirements in short term

Carbon Negative Products

Process: products – e.g. plastics and cement – that are derived from carbon sourced from the atmosphere

Benefits: storage of carbon in materials with a long intended lifespan; could replace existing products if cost effective or if performance is greater

State: research activity in plastics; early commercial ventures in cement

Plastic made out of atmospherically sourced carbon. Credit: Newlight Technologies LLC

Pathway: Chemical

Cost: Goal is cost parity or better

Limiting factors: Limited most fundamentally by markets for materials produced

Enhanced Weathering

Process: accelerate natural weathering processes that currently draw down CO_2 over geological timescales through carbonation reactions with silicate minerals

Benefits: no additional energy input required for the capture process itself, though energy required for mining and transport

The reaction of CO_2 and silicate minerals is irreversible, thus guaranteeing the **permanent** removal of CO_2.

A bag of olivine sand on the market for CO_2 removal; Credit: greenSand

Pathway: chemical

Cost: $25-125/t$CO_2$

Limiting factors: Land area where sufficiently high reaction rates can be attained; logistical and industrial capacity in the short term

Part 4: Implications of CDR

1. The Basics	2. The Need	3. The Approaches	4. The Implications
What is CDR?	Why might we need it?	What are the different approaches to remove carbon from the atmosphere?	What are the implications of CDR for industry and government?

Key Conclusion #2:

1. CDR techniques provide complementary options to mitigating climate change

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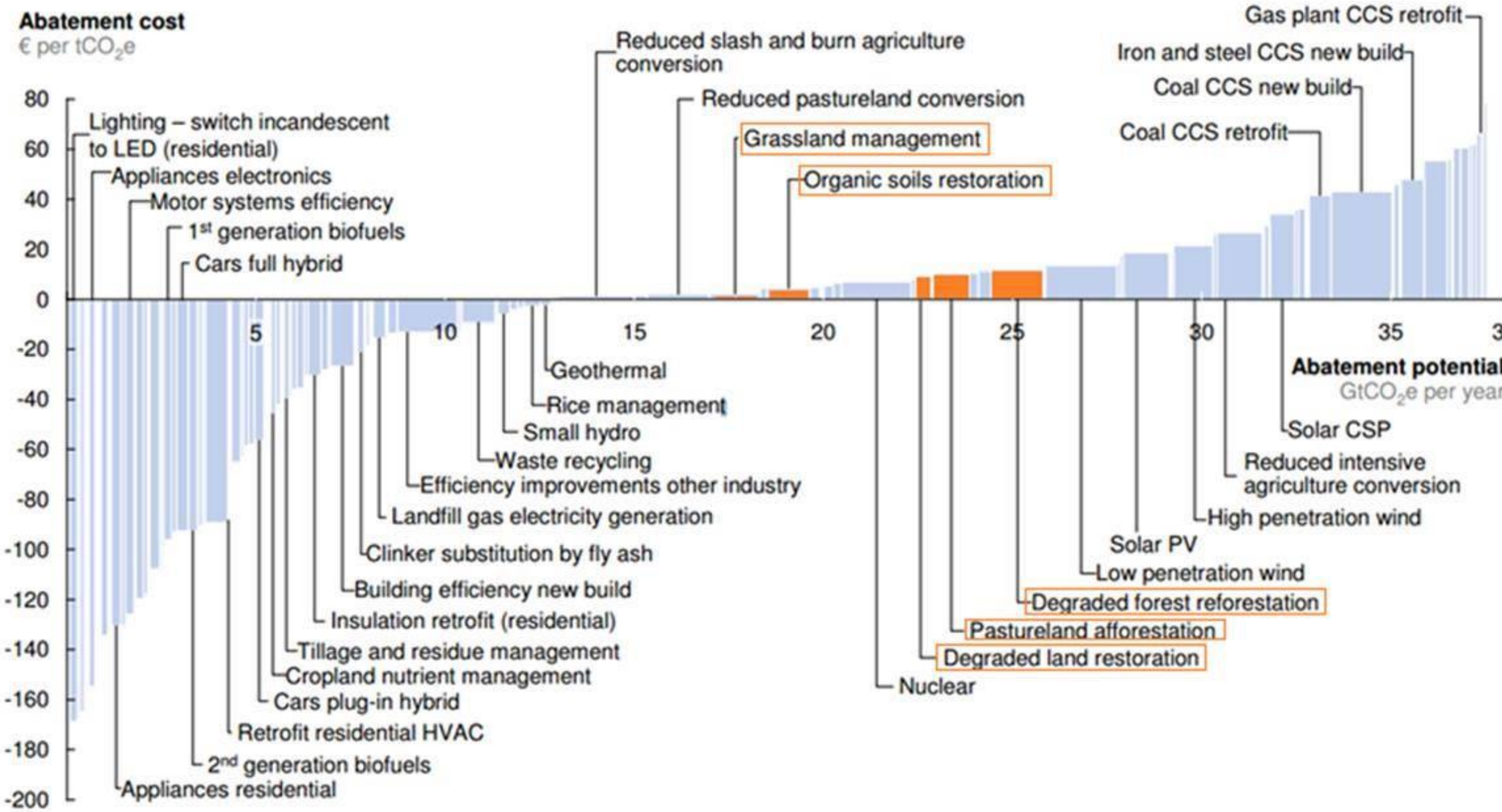
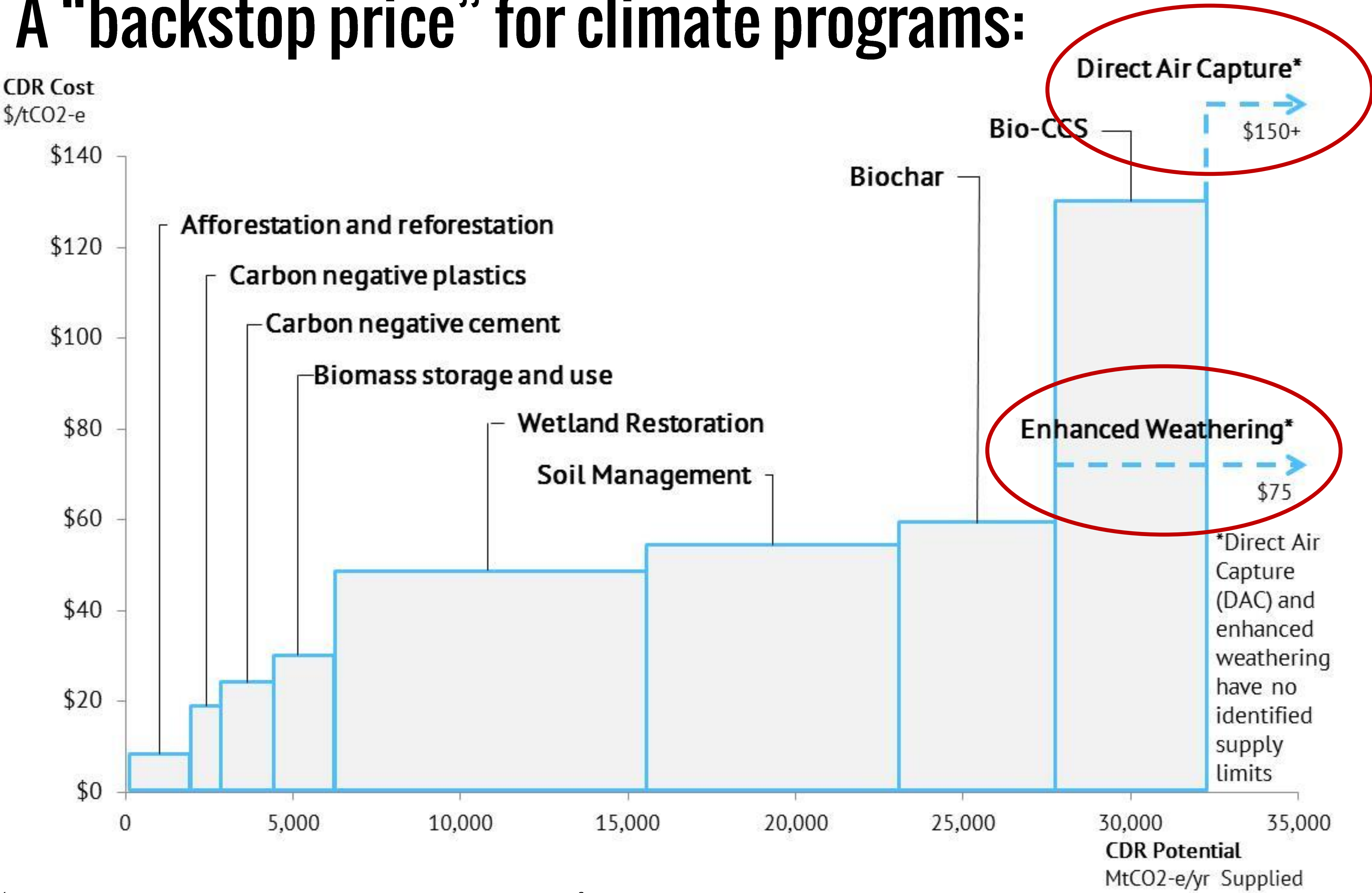
3. All stakeholders need to start prioritizing and fostering CDR strategies with greater urgency

CDR helps reduce overall cost of climate change:



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €80 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.
Source: Global GHG Abatement Cost Curve v2.1

A "backstop price" for climate programs:



[1] Lomax and Addison (Virgin Earth Challenge)
Curve assumes midpoint estimates for costs and supply levels

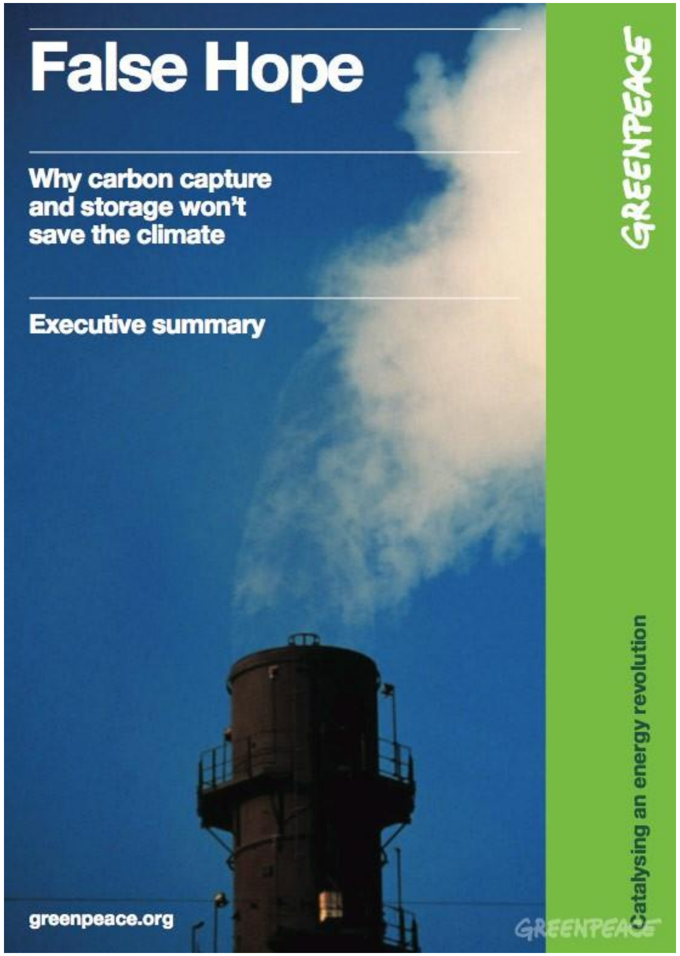
[2] Ciais, et. al. (UN IPCC).
[3] Fouquet and Pearson. (Energy Policy)

Strange, but ultimately necessary, bedfellows:

Environmental interests…

… collaborating with fossil interests

CARBON DIOXIDE REMOVAL



The old story:

> "Carbon capture and storage (CCS) aims to reduce the climate impact ***of burning fossil fuels*** by capturing carbon dioxide (CO2) from power station smokestacks and disposing of it underground."

The new story: a pathway to carbon removal

Uncontrolled fossil fuels → Fossil fuels + CCS / EOR → Bio + CCS

Carbon Negative Ethanol?

ADM

Decatur, IL Ethanol + CCS demonstration

Carbon Negative Agriculture?

Sink of CO_2

Source of CO_2 emissions

Carbon Negative…

Cement

Plastics

Timber

When we start to analyze opportunities for CDR, tricky climate problems start to look more solvable

Conclusion:
What’s next for CDR?

Key Conclusion #3:

1. CDR techniques provide complementary options to mitigating climate change
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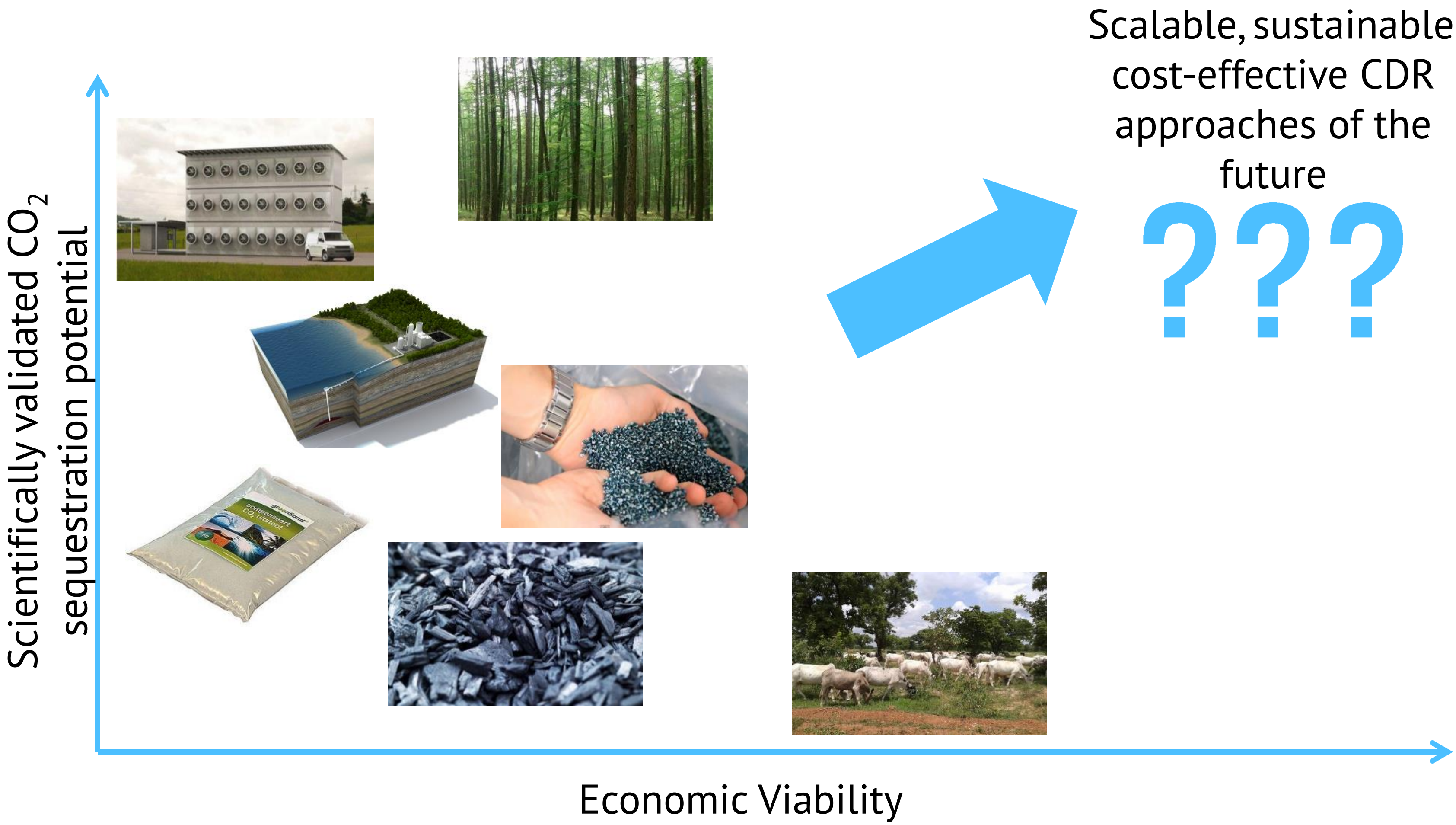
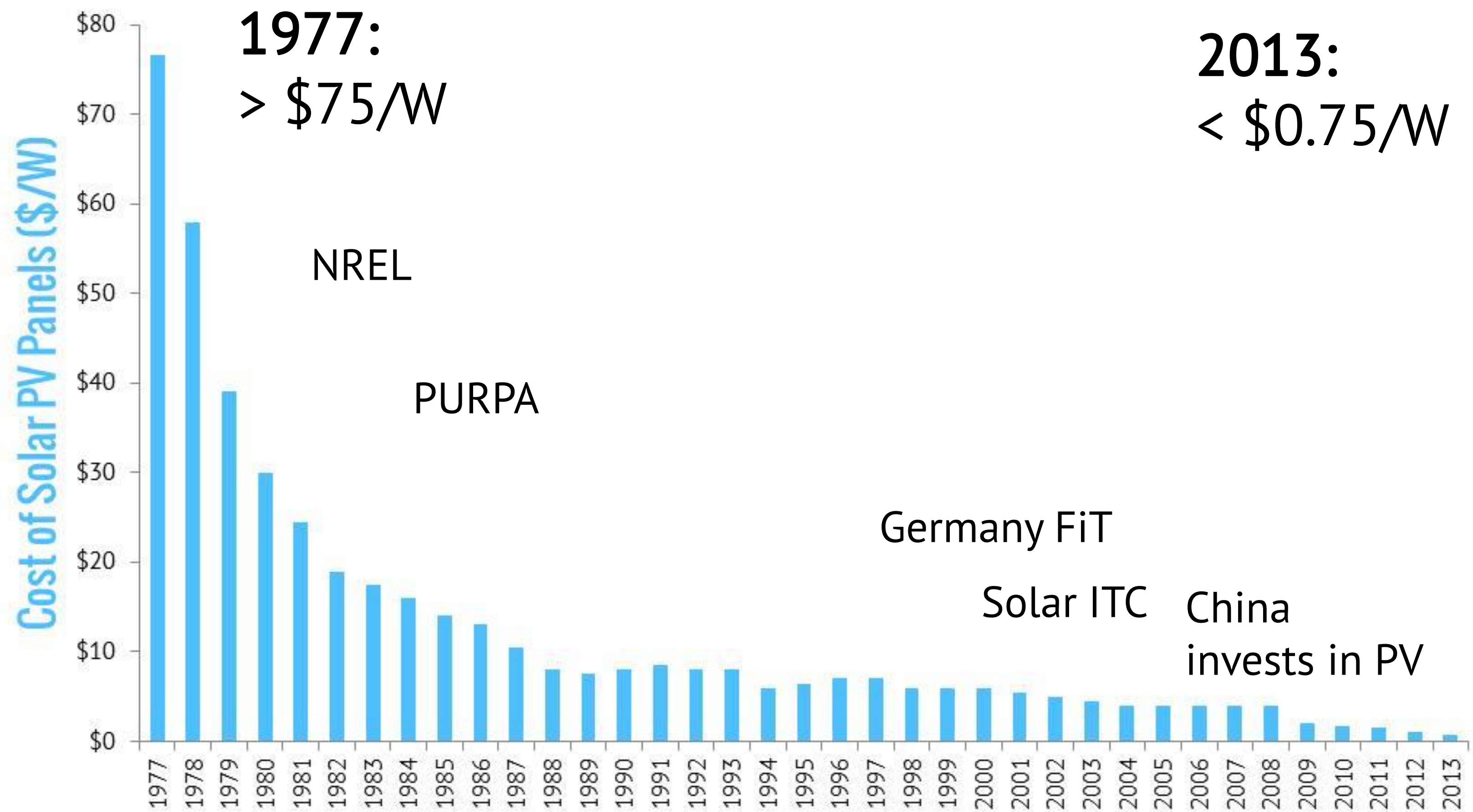
What is holding back large scale CDR project deployments?



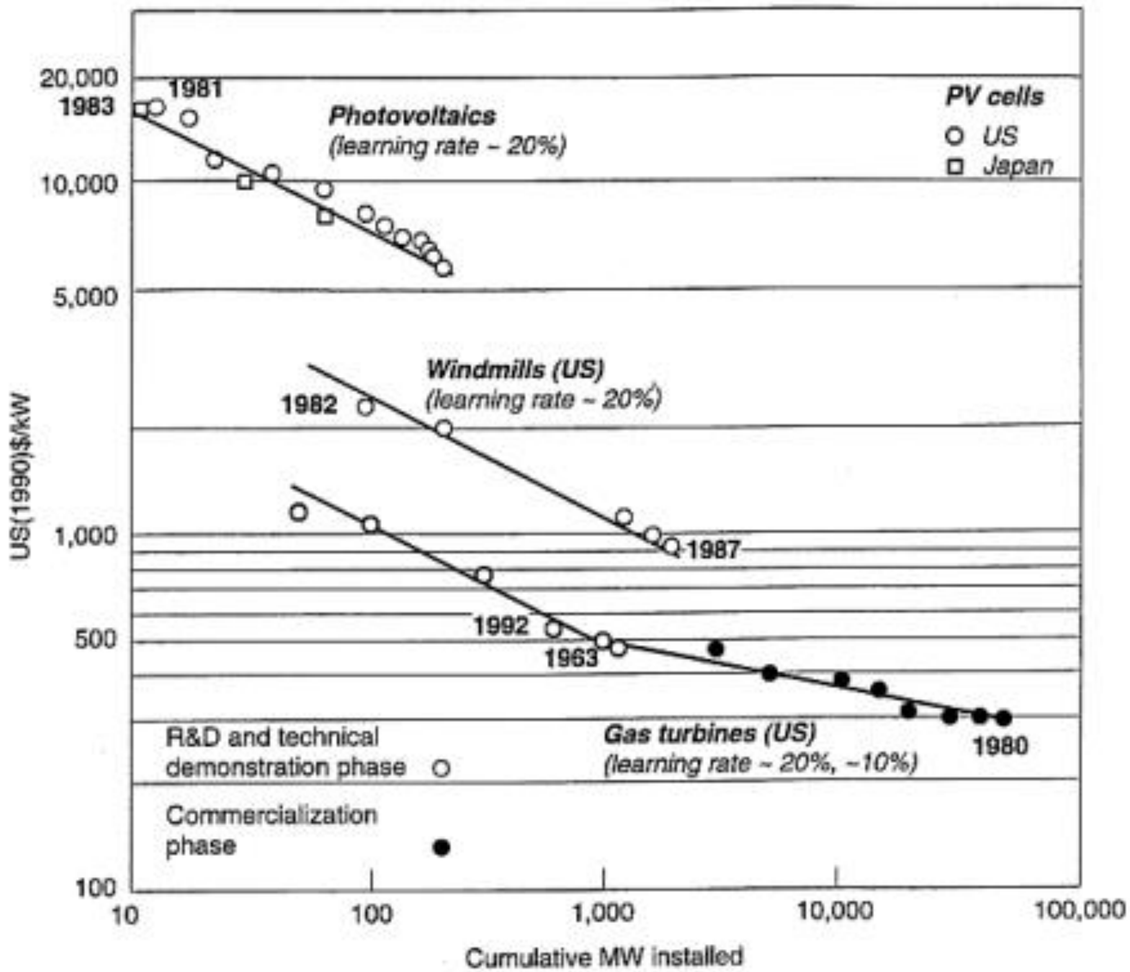
Energy technologies take decades to develop:



Source: Bloomberg New Energy Finance

Large-scale deployments correlate with cost reductions

The CDR field today



Source: Dan Kammen, UC Berkeley

The field is still figuring out what to call itself:

- Negative Emission Technologies (NETs)
- Greenhouse Gas Removal (GGR)
- Enhanced Carbon Sinks
- Carbon Drawdown

A handful of early leaders in the CDR field have emerged:

CDR Focused Organizations

Biochar
the BIOCHAR company
coolplanet ENERGY SYSTEMS
CARBON GOLD

Land management
SAVORY INSTITUTE
SLM

Direct Air Capture
Carbon Engineering
CLIMEWORKS
globalthermostat

Carbon-Negative Materials
NEWLIGHT TECHNOLOGIES
Skyonic
Solidia Technologies
CARBONCURE SIMPLY BETTER CONCRETE

Bio-CCS
MGSC
ADM

Established Industry
EARTH CHALLENGE
SUMMIT POWER

On the radar for some insurers, IOCs, utilities, auto manufacturers

Investors
High Net Worth Angels

National Regulators
Australian Government Department of Agriculture

Government Banks
World Bank funding land restoration projects, but not doing so primarily for CDR potential

NGOs
The Nature Conservancy
The Climate Institute
friends of the earth see things differently
International Biochar Initiative
BELLONA

On the radar at IEA, major green groups in the US / UK

Media
Handful of recent articles on CDR in mainstream publications, but no dedicated publications / units

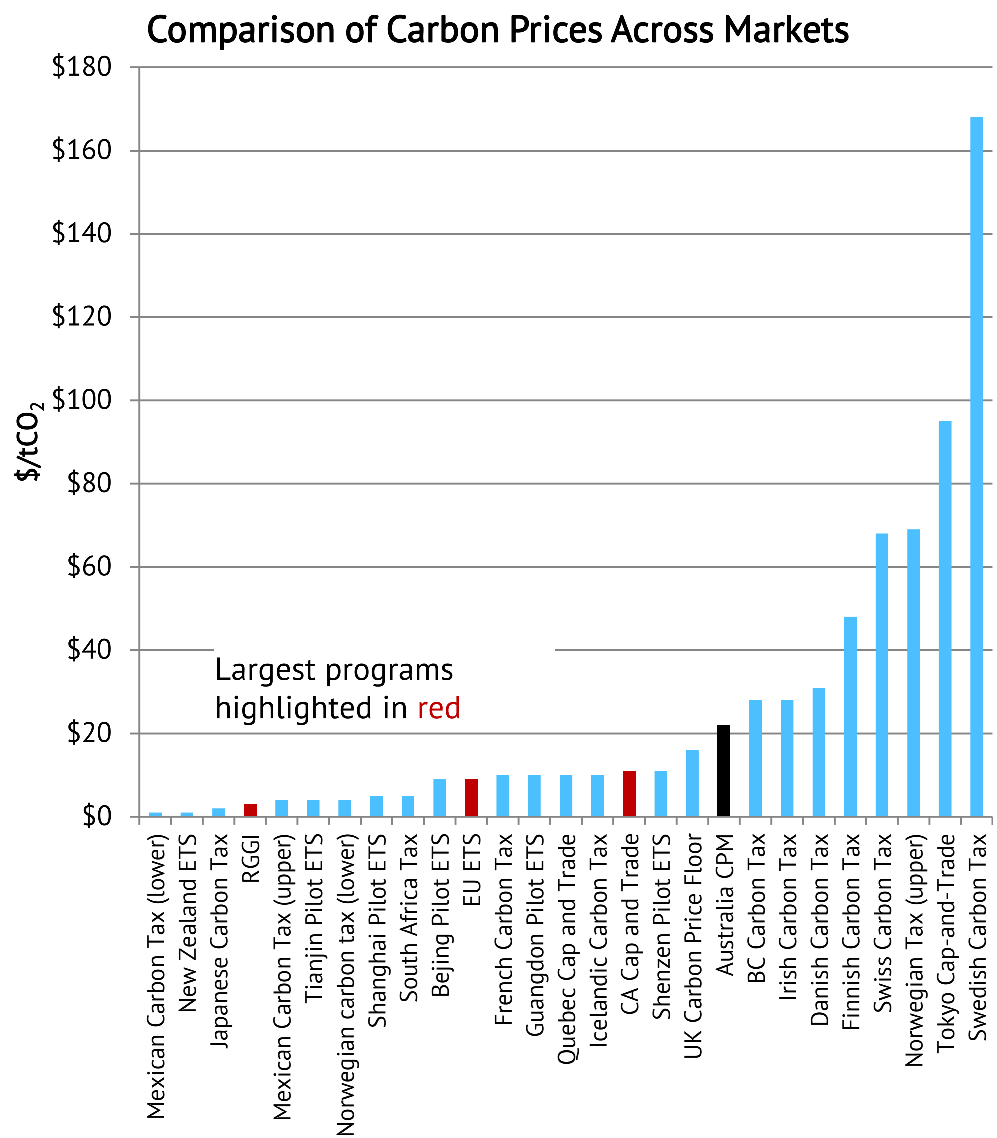
Academic / Scientific Institutions
OXFORD MARTIN SCHOOL UNIVERSITY OF OXFORD
National Aeronautics and Space Administration Goddard Institute for Space Studies
STANFORD UNIVERSITY GLOBAL CLIMATE & ENERGY PROJECT
Cornell University Department of Crop and Soil Sciences
THE ROYAL SOCIETY
IIASA
ipcc INTERGOVERNMENTAL PANEL ON climate change

Note: logos link to websites

Early leaders in the general CDR field highlighted in red outline

Carbon markets are failing to catalyze development of CDR solutions

- Only 12% of global emissions are capped today
- Carbon prices average <$10
- Few CDR projects can even access carbon markets



[1] World Bank (2014).

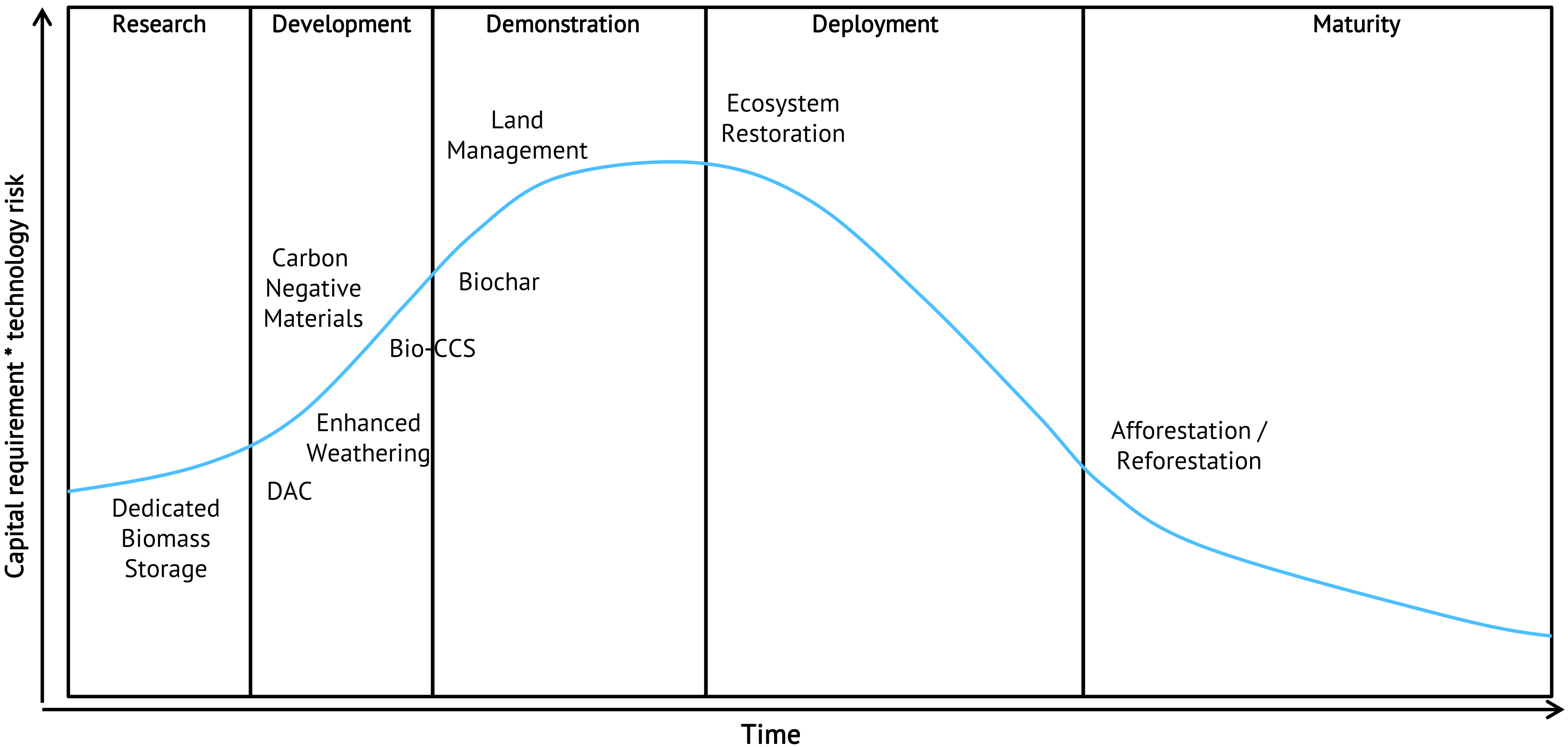
"Utilizing" CO_2 at scale presents serious challenges:

> "Each person in the US is responsible for over 100 lbs *per day* of CO_2 emissions"

Ken Caldeira, Stanford University

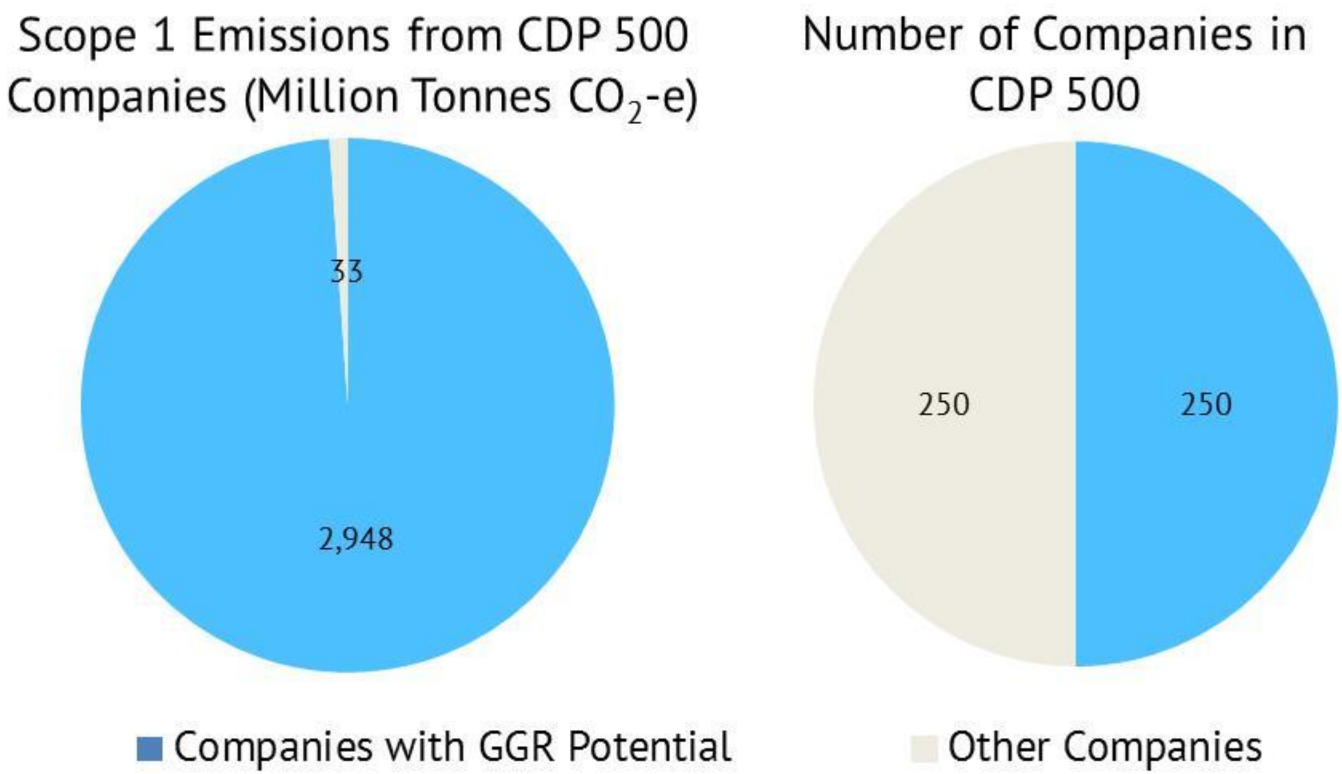
Global CO_2 consumption is less than 1% of global CO_2 emissions

Basic science research and funding for viable early stage ventures are critical



Set favorable regulations and policies that pave the way for negative emissions

Corporate R&D groups and supply chains have opportunities for negative emissions



[1] CDP (2012).

Set standards

Three key conclusions:

1. CDR techniques provide complementary options to mitigating climate change

2. CDR brings more stakeholders to the table to discuss a wider range of strategies to fight climate change

3. All stakeholders need to start prioritizing and fostering CDR strategies with greater urgency

If you can do one thing to advance the field of CDR, then…

- **Policy makers:** fund demonstration projects and research initiatives
- **Regulators**: incentivize projects that pave the way for CDR projects in the future (e.g. CCS/CO_2 transport and storage, EOR projects utilizing anthropogenic CO_2)
- **Industry:** research the potential for strategic CDR opportunities that enhance profitability while offering significant external upside
- **Project developers:** search for ways that revenue streams from CDR co-products can enhance energy and agricultural projects
- **Equity investors:** seek to invest in viable CDR projects today – especially in the forestry and land management areas, and monitor emerging CDR techniques for investments in the future
- **Government Banks:** fund/guarantee first-of-a-kind commercial projects to pave way for follow-on investment
- **Institutional / Sovereign Investors:** encourage public equities to incorporate CDR into business plans
- **Insurers:** estimate climate change related claims costs to provide ballpark willingness-to-pay for CDR
- **Carbon / CSR standards organizations:** start developing protocols for measuring, reporting, and monetizing CDR projects
- **NGOs:** further research CDR and raise awareness by leveraging convening power
- **Universities:** devote greater resources to CDR research across technical and social scientific fields
- **Concerned citizens:** increase awareness and understanding of CDR in personal and professional circles; then buy products aiming to be carbon negative when possible: e.g. biochar for gardens, plastics/cement made from atmospheric CO_2, etc.)

Appendix

CDR and GHG emission mitigation are two sides of the same coin in the fight against climate change:

	Avoiding climate change			Avoiding impacts of climate change	Responding to climate change
Aim	Avoiding a given level of atmospheric GHG concentration		Avoiding global average temperature increases	Ensuring that rising temperatures do not impact upon core interests	Providing redress for injuries to core interests
Strategy	**Mitigation** Reducing GHG emissions	**CDR** **Drawing GHGs out of the atmosphere**	**SRM** Increasing albedo	**Adaptation** Improved irrigation, flood defenses, protection against disease	**Rectification** Financial compensation, symbolic reparation

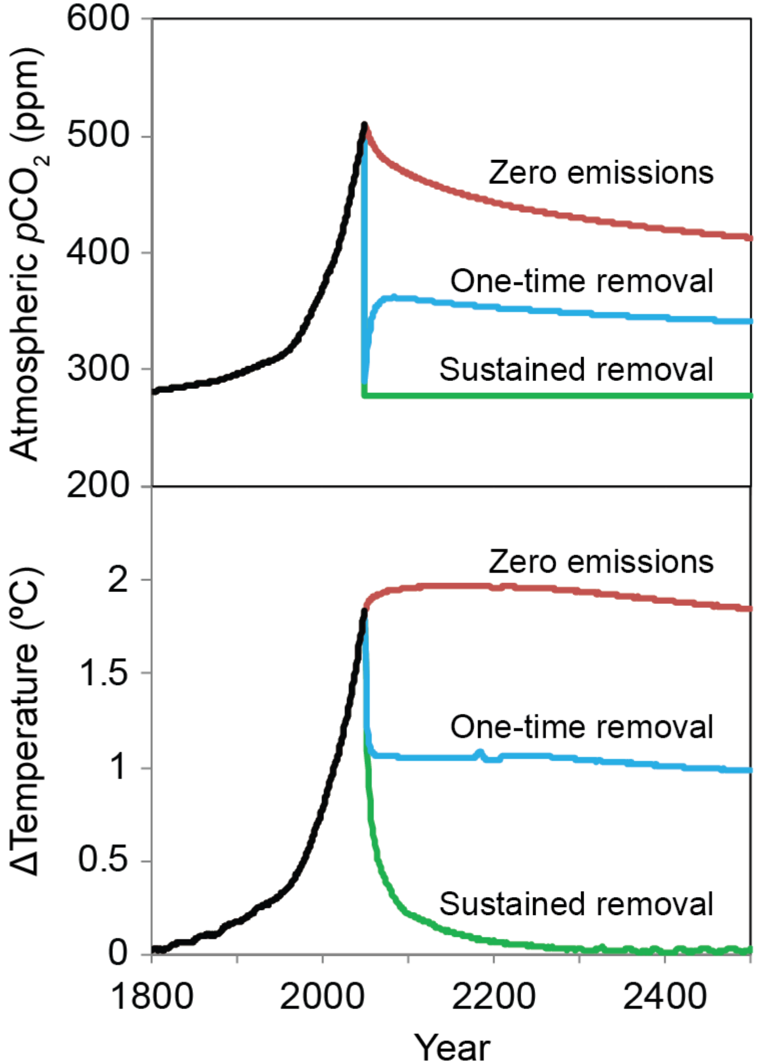
Source: Clare Heyward (Oxford)

Estimates of Likely CDR Required

The graphs to the right show what happens once CO_2 emissions stop: temperatures go down slowly along with atmospheric CO_2 concentrations.

To get temperatures/atmospheric CO_2 concentrations to come down more quickly, sustained carbon removal is required.

The carbon cycle mitigates the impact of a one-time removal, as oceans and plants would release stored carbon back to the atmosphere



Source: Ciais, et. al. (2013). UN IPCC.

Resources to learn more about CDR

Blog: Everything and the Carbon Sink
(https://carbonremoval.wordpress.com/cdr-resources/)

Email: Noah Deich
noah.deich@berkeley.edu