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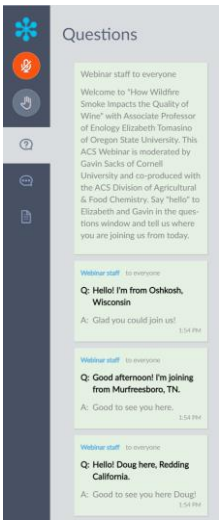

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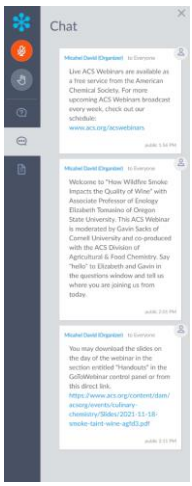

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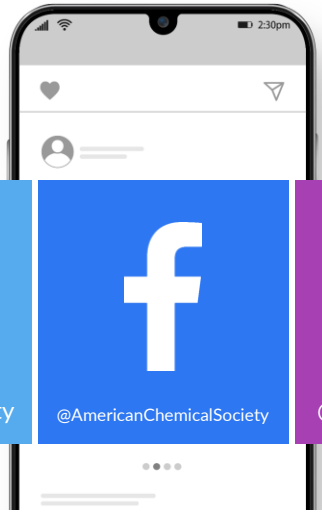

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Where is the Webinar Recording?

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Watch the unedited recording linked in the **Thank You Email for 24 hours.**

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A Career Planning Tool For Chemical Scientists

ChemIDP is an Individual Development Plan designed specifically for graduate students and postdoctoral scholars in the chemical sciences. Through immersive, self-paced activities, users explore potential careers, determine specific skills needed for success, and develop plans to achieve professional goals. **ChemIDP** tracks user progress and input, providing tips and strategies to complete goals and guide career exploration.

https://chemidp.acs.org

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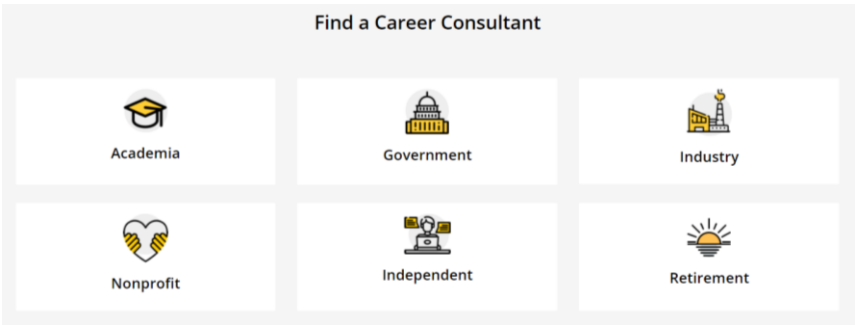
5

Career Consultant Directory



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8

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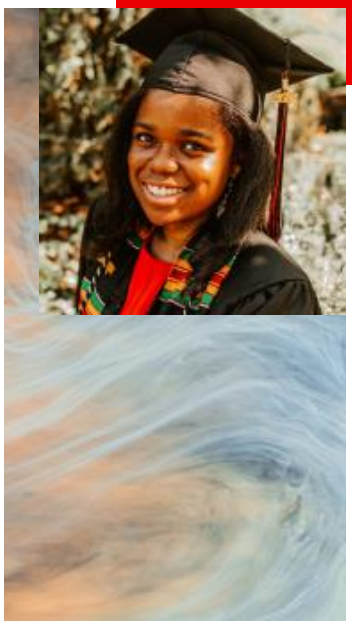

ACS Scholar Adunoluwa Obisesan

BS, Massachusetts Institute of Technology, June 2021
(Chemical-biological Engineering, Computer Science & Molecular Biology)

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Resources

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Designed to help staff and members use language and images that respect diversity in all its forms.

ACS Webinars on Diversity
Covering diversity and inclusion at the workplace

ACS Publications DEIR Hub
See what ACS Publications is doing for fostering inclusivity in scholarly publishing

ACS Volunteer and ACS Meetings Code of Conduct
Fostering a positive and welcoming environment for attendees, volunteers and staff.

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C&EN highlights scientists from different backgrounds who are making an impact in chemistry.

NEW! Download DEIR Educational Resources
Download this educational guide for additional recommendations on videos, articles, books, podcasts, and more on diversity, inclusion, and related topics.

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Learn more about what Inclusion Moments are and see ideas to host them during your meetings.

Quick Guide: How to host inclusive in-person events
Recommendations and best practices to ensure that your events can accommodate everyone.

Diversity, Equity, Inclusion, and Respect
**Adapted from definitions from the Ford Foundation Center for Social Justice:

Equity**
Seeks to ensure fair treatment, equality of opportunity, and fairness in access to information and resources for all. We believe this is only possible in an environment built on respect and dignity. Equity requires the identification and elimination of barriers that have prevented the full participation of some groups.

Diversity**
The representation of varied identities and differences (race, ethnicity, gender, disability, sexual orientation, gender identity, national origin, tribe, caste, socio-economic status, thinking and communication styles, etc.), collectively and as individuals. ACS seeks to proactively engage, understand, and draw on a variety of perspectives.

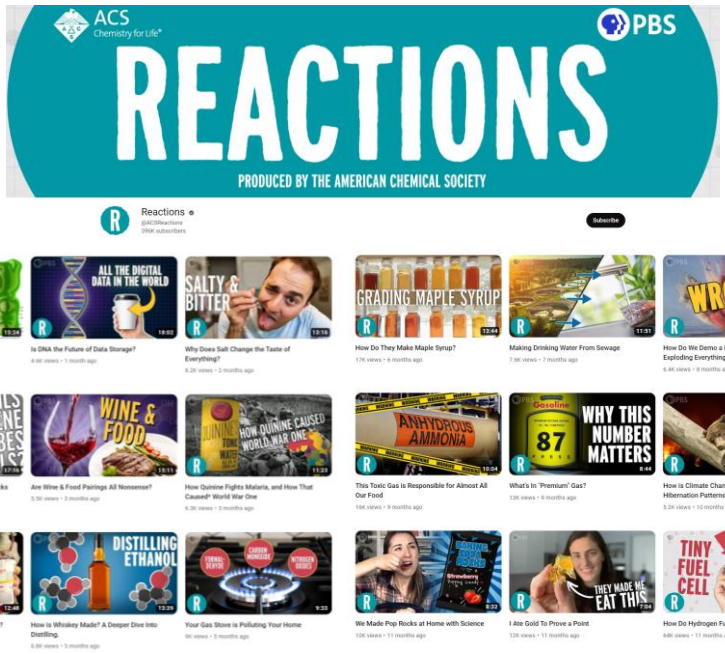
Inclusion**
Builds a culture of belonging by actively inviting the contribution and participation of all people. Every person's voice adds value, and ACS strives to create balance in the face of power differences. In addition, no one person can or should be called upon to represent an entire community.

Respect
Ensures that each person is treated with professionalism, integrity, and ethics underpinning all interpersonal interactions.

https://www.acs.org/content/acs/en/about/diversity.html

10

10



https://www.youtube.com/c/ACSReactions/videos

11

11

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Sam Jones, PhD
Science Writer & Exec Producer

Deboki Chakravarti, PhD
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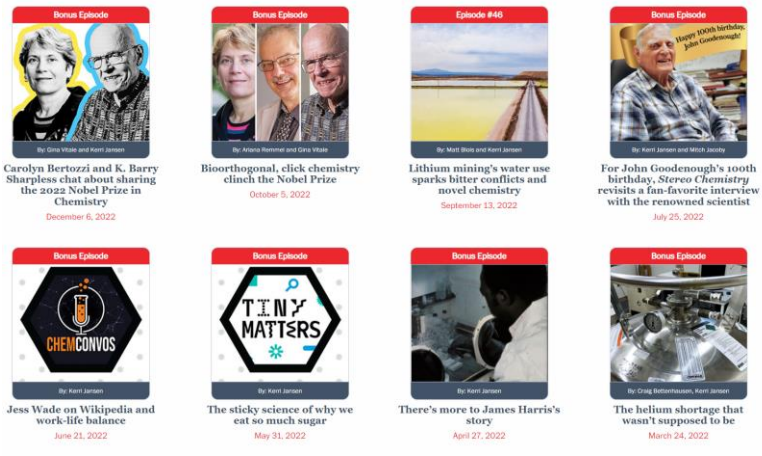
12

12

c&en's STEREO CHEMISTRY



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13

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ACS ON CAMPUS

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16

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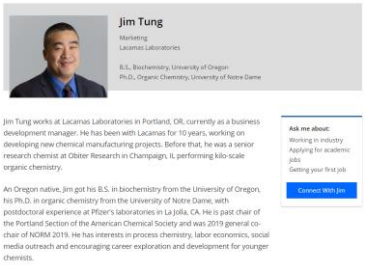

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17

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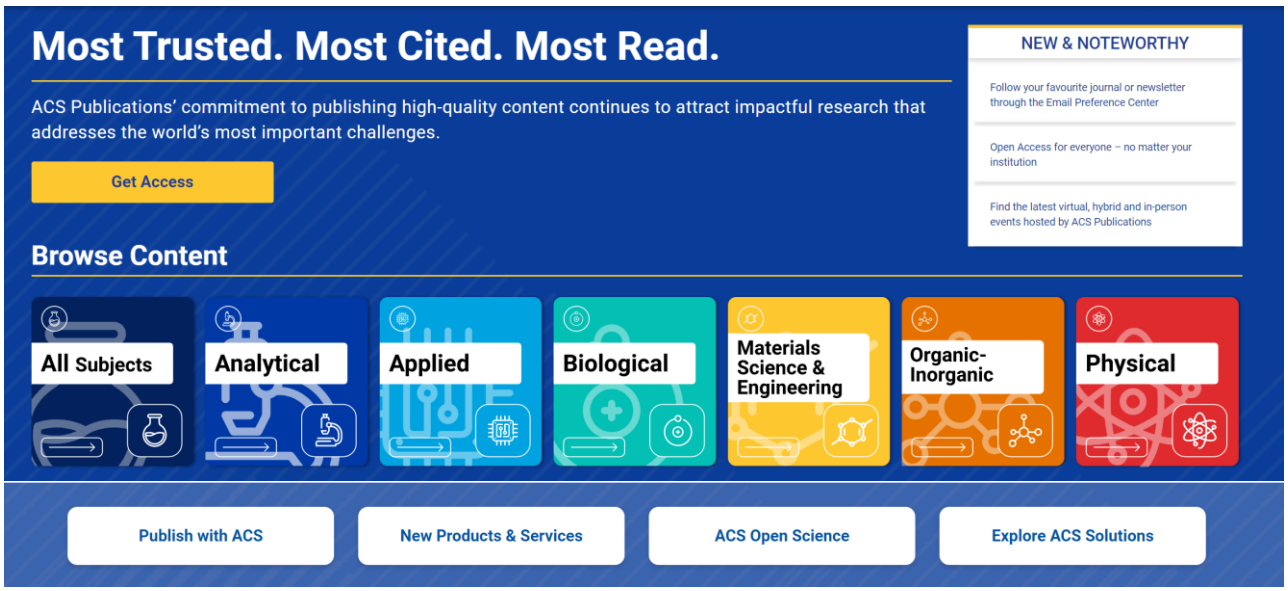

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18

18


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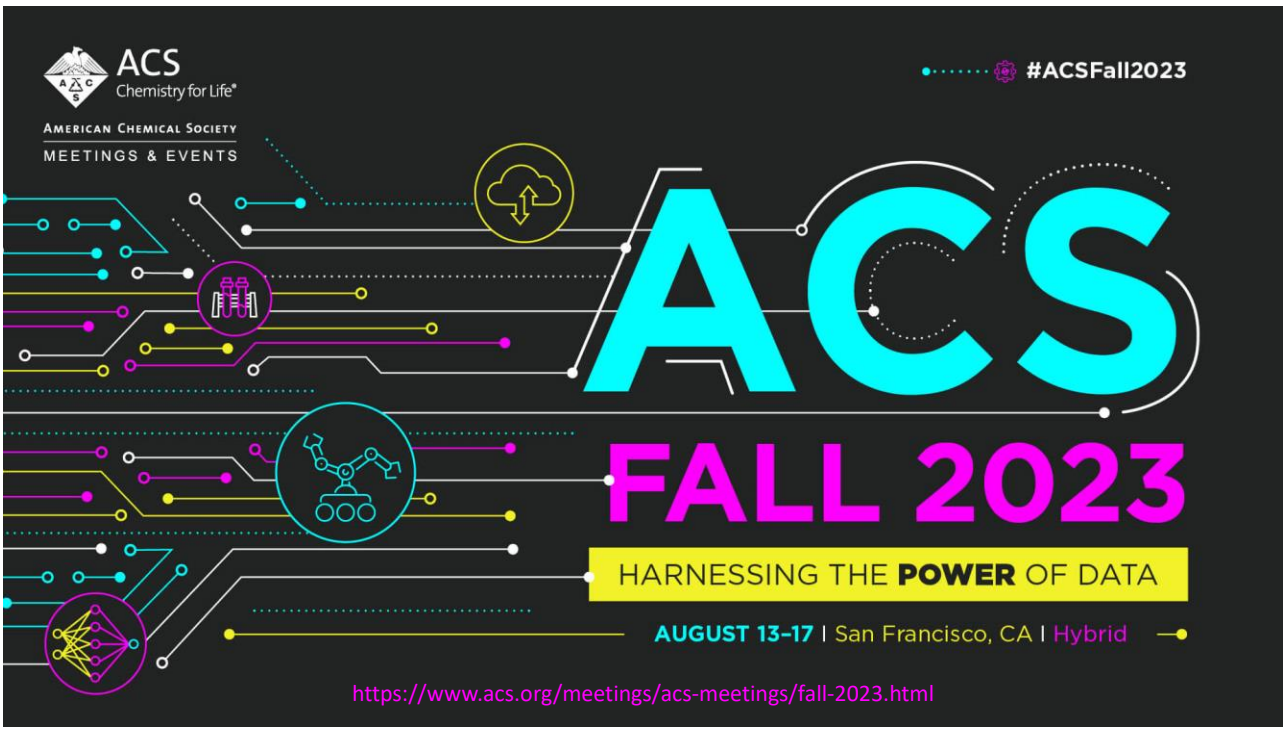
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20

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Wednesday, June 7, 2023 | 2-3:15pm ET

Life Reflections with Nobel Laureate Carolyn Bertozzi

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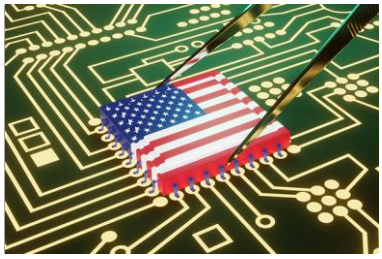
Thursday, June 8, 2023 | 2-3pm ET

Process Chemistry: A Day in the Life

Co-produced with the ACS Office of Career and Professional Education



Thursday, June 15, 2023 | 2-3pm ET

The CHIPS and Science Act: What's in it for the Chemistry Enterprise?

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21

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22

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The Road to Billions of Tonnes of Carbon Sequestration

PAUL DAUENHAUER, PHD

Lanny & Charlotte Schmidt Professor
Department of Chemical Engineering & Materials Science, University of Minnesota
and Co-founder of Carba

MARK JONES, PHD

Creative Director,
MJPhD, LLC

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The Road to Billions of Tonnes of Carbon Sequestration

Paul J. Dauenhauer, Ph.D.
Lanny & Charlotte Schmidt Professor
Co-founder of Carba
University of Minnesota
Department of Chemical Engineering & Materials Science
June 1, 2023

24

PROBLEM

- Global temperatures are rising
- They will continue to rise unless we do something
- Warming >1.5°C will have catastrophic consequences
- The only way to curb warming is through a combination of energy transition (from fossil) and carbon removal

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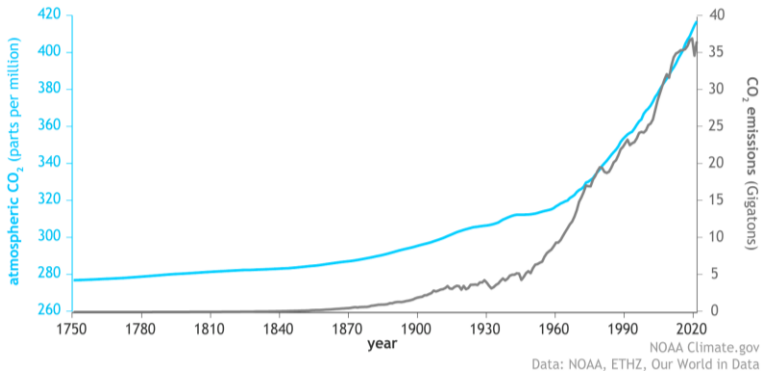
25

Atmospheric CO_2 Composition & Emissions



Atmospheric CO_2 concentration and annual emissions (Source: NOAA)

https://www.climate.gov/media/14596

25

PROBLEM

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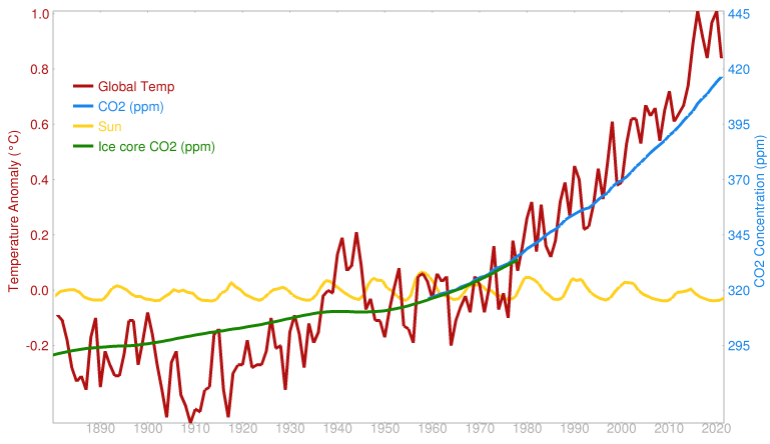
Carbon dioxide emissions and temperature since 1880



[1] https://www.co2.earth

26

PROBLEM

- Global temperatures are rising
- They will continue to rise unless we do something
- Warming >1.5°C will have catastrophic consequences
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What if we do nothing?[1]

U.S. Regional Effects

Below are some of the impacts that are currently visible throughout the U.S. and will continue to affect these regions, according to the Third[3] and Fourth[4] National Climate Assessment Reports, released by the U.S. Global Change Research Program:

Midwest. Extreme heat, heavy downpours and flooding will affect infrastructure, health, agriculture, forestry, transportation, air and water quality, and more. Climate change will also exacerbate a range of risks to the Great Lakes.

"cost of doing nothing could be 15 times greater"[2]

[1] https://climate.nasa.gov/effects/
[2] https://yaleclimateconnections.org/2021/09/can-the-economy-afford-not-to-fight-climate-change/

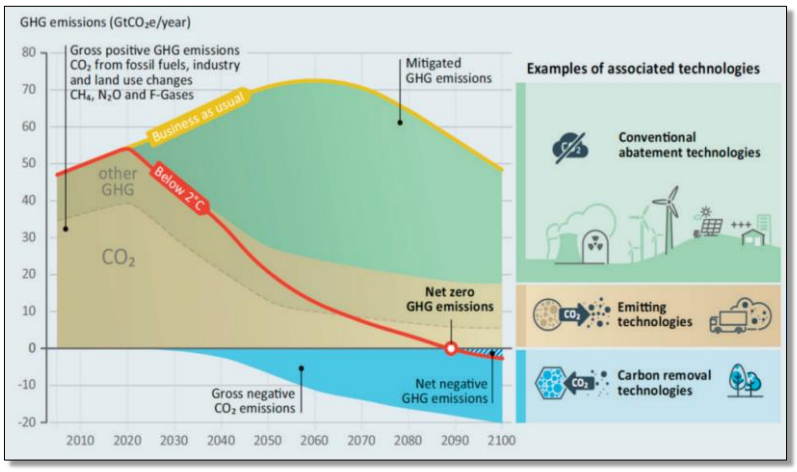
27

SOLUTION

1. Transition energy from fossil-based to zero-carbon
2. Remove CO_2

28

Scenario of the role of negative emissions technologies in reaching net zero emissions

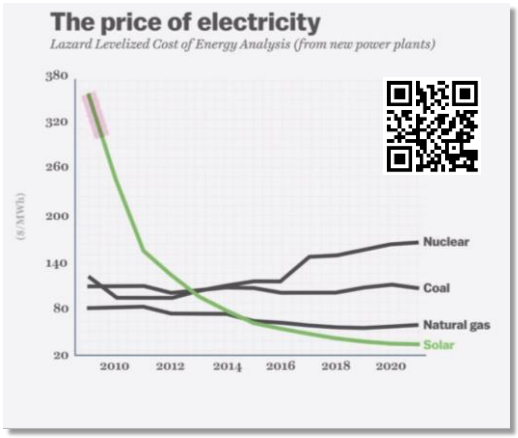


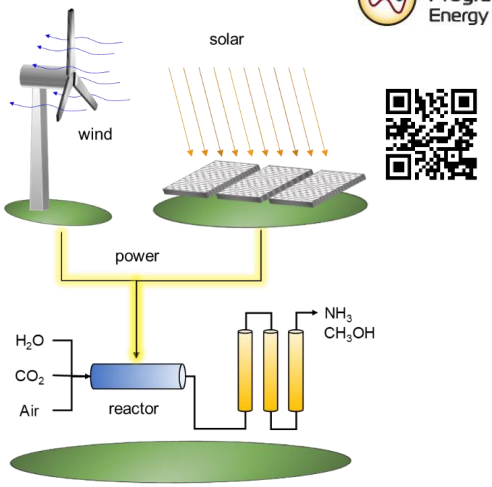
[1] National Academies of Sciences, 2019
https://nap.nationalacademies.org/catalog/25259/negative-emissions-technologies-and-reliable-sequestration-a-research-agenda

28

(1) Decarbonizing power generation

Center for Programmable Energy Catalysis





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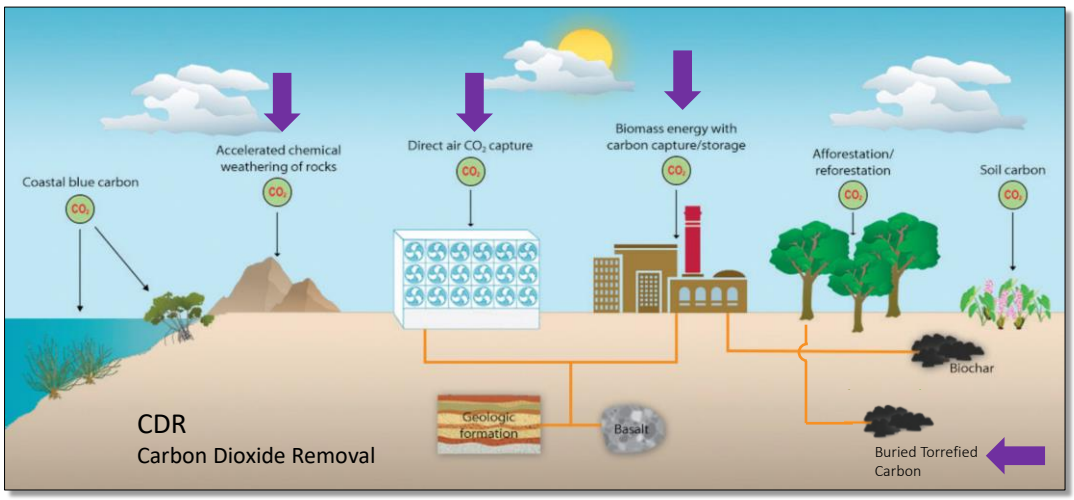
[1] https://www.youtube.com/watch?v=V8Vtb0bn30M [2] https://vimeo.com/641634929?embedded=true&source=vimeo_logo&owner=109060444

29

(2) How do we remove 10 Gt/yr of CO_2?



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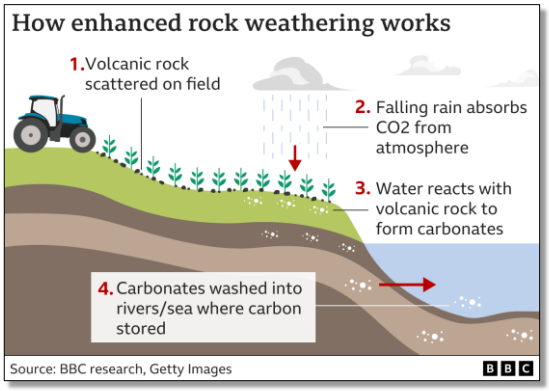
[1] National Academies of Sciences, 2019
https://nap.nationalacademies.org/catalog/25259/negative-emissions-technologies-and-reliable-sequestration-a-research-agenda

30

Enhanced Rock Weathering



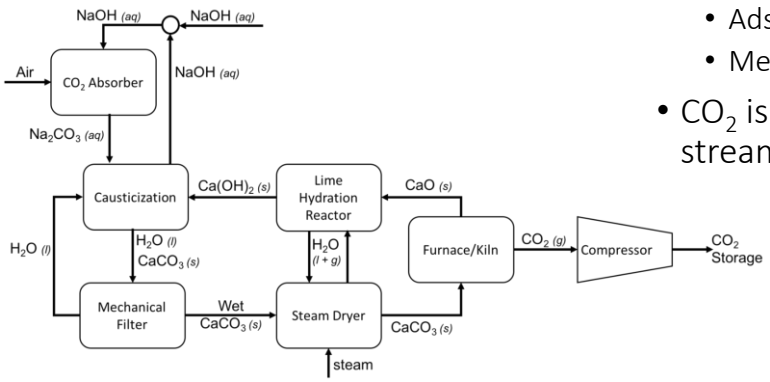
- Carbon dioxide reacts with volcanic rocky materials like basalt to form carbonates
- This process happens naturally with volcanic rock, but spreading basalt enhances the rate of CO_2 capture

[1] https://www.bbc.com/news/science-environment-65648361

31

Direct Air Capture (DAC)

Steam-Driven Caustic Absorber DAC System



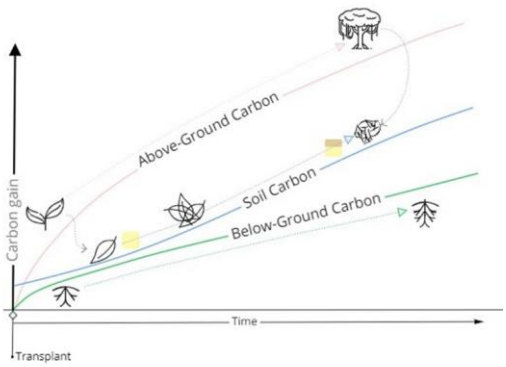
- Air is blown through a unit operation that separates CO_2
  - Absorbers (e.g., caustic)
  - Adsorbers (e.g., MOFs)
  - Membrane
- CO_2 is recovered as purified stream

Challenges:
(1) High capital
(2) High energy usage
(3) Expensive

[1] https://en.wikipedia.org/wiki/Direct_air_capture

32

Reforestation



- Trees are planted in open spaces
- Photosynthesis converts CO_2 to carbohydrates and lignin solid biopolymers
- Carbon accumulates in the soil, below- and above-ground
- Low cost method: planting

Challenges:
(1) Not long term due to the carbon cycle
(2) Difficult to verify

[1] https://www.nature.com/articles/s41598-021-99395-6

33

Underground Bio-Oil Storage

Liquefy wood to a brown 'bio-oil' and pump underground; generate billions of gallons of bio-oil

Challenges

- Pyrolysis oil is *carcinogenic* liquid[5]
- Highly volatile water soluble liquid
- NFPA Health Hazard 3: Extreme danger - "Substance considered highly toxic under OSHA[s Hazard Communication Standard"[2,3,4]

[1] https://images.nrel.gov/MX/Profiles/en/default/#/main/single/6d7e75d4-a643-45e0-ac1f-07c000dd0b2f
[2] https://www.nfpa.org/News-and-Research/Publications-and-media/Blogs-Landing-Page/NFPA-Today/Blog-Posts/2021/11/05/Hazardous-Materials-Identification
[3] See appendix slide [4] https://www.bgsu.edu/content/dam/BGSU/envhs/documents/Lab-Safety/NFPA-Labeling-Information.pdf
[5] https://www.sciencedirect.com/science/article/pii/S0304389412006735?via%3Dihub

34

35

Audience Survey Question

ANSWER THE QUESTION ON BLUE SCREEN IN ONE MOMENT

How much MORE would you pay for a round trip flight from New York to Los Angeles to offset 100% of carbon emissions?

Full ticket price is typically $335 to $520 for a round trip flight (Google flights)
Round trip: ~1 tonne CO_2 emissions[2]

- $25
- $50
- $100
- $250
- Whatever it takes

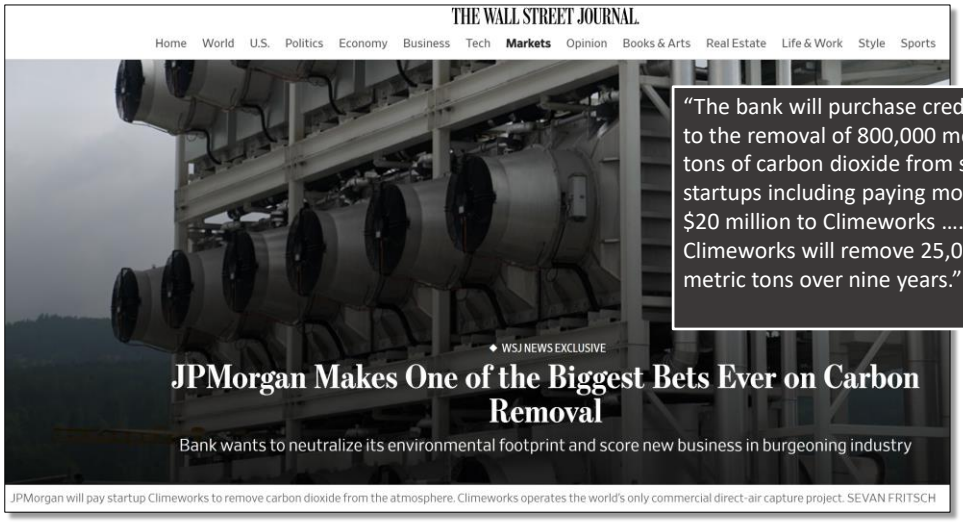
[1] Image: https://www.businessinsider.com/why-flights-from-new-york-city-to-los-angeles-take-longer-than-return-trip-jet-stream-2017-8
[2] https://curb6.com/footprint/flights/new-york-jfk/los-angeles-lax

36

36

Large investments are happening now

$20,000,000
÷
25,000 tonnes
=
$800 / tonne



"The bank will purchase credits tied to the removal of 800,000 metric tons of carbon dioxide from several startups including paying more than $20 million to Climeworks …. Climeworks will remove 25,000 metric tons over nine years."[1]

[1] https://www.wsj.com/articles/jpmorgan-makes-one-of-the-biggest-bets-ever-on-carbon-removal-c7d5fe63

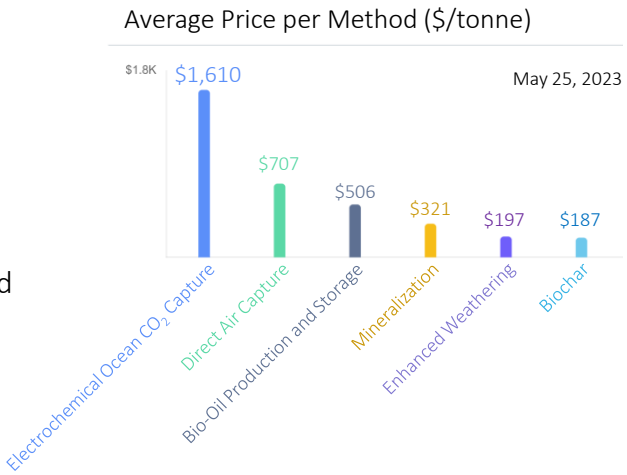
37

37

The costs of CDR are currently too high!

Website: cdr.fyi

- Tracks total CDR
- Announces CDR purchases
- Metrics: total sales, deliveries, price index, transactions, price per method

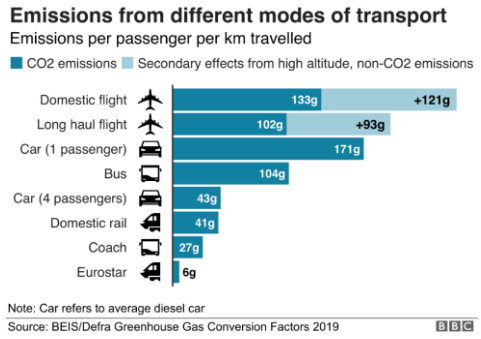


https://www.cdr.fyi

38

38

What carbon price can we afford (or tolerate)?



Consider carbon dioxide removal at prices of $100 to $1,000 per tonne CO_2:

Driving an automobile

- One gallon of gasoline emits 8.8 kg of CO_2
- Adds 10¢ to $1.00 per gallon of gas

https://www.bbc.com/news/science-environment-49349566

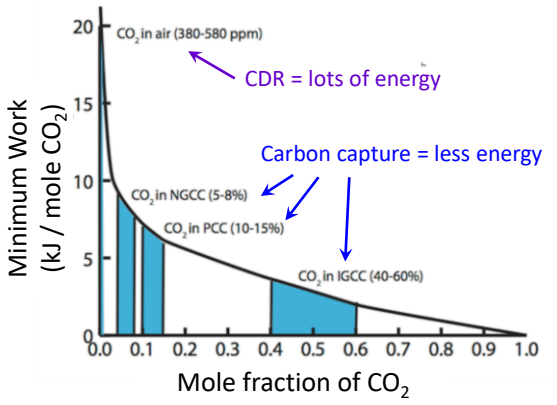
39

39

Atmospheric CO_2 has an "entropy penalty"

- Capture of CO_2 requires more energy as it becomes more dilute
- Carbon capture (CC) in fossil fuel power plants is lower energy and lower cost
- CDR has a significant "entropy penalty"

$$W_{\min} = n_F RT \sum_{i=1}^{N} y_i \ln\left(\frac{y_i}{y_i^0}\right)$$



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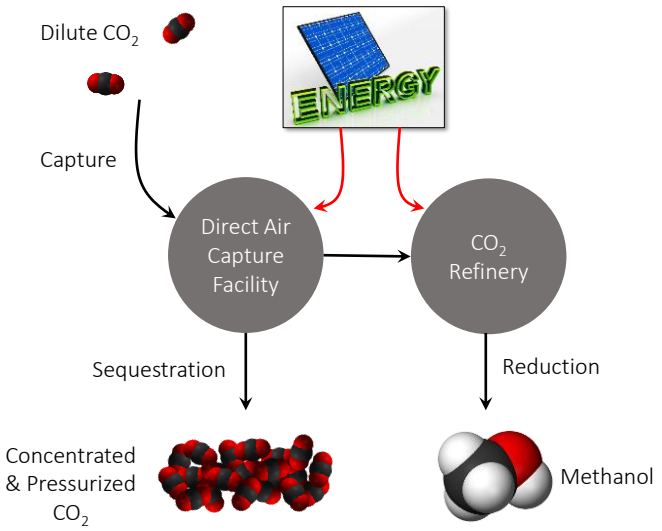
[1] Illustration: Smit et al. (2014) *Introduction to CCS*, Imperial College Press

40

40

Carbon Dioxide Removal Uses Energy

- Capture of CO_2 requires far more energy than minimum amount due to inefficiency of process
- Sequestration of CO_2 as a compressed product uses significant energy
- Conversion of CO_2 to methanol, fuels, or chemicals uses an *incredible* amount of energy



41

The "entropy penalty" is a huge energy problem

Image Source: https://netl.doe.gov/node/11208

To capture 10 Gt/yr with DAC:

- 100 exajoules of energy (at \$0.15/kWh this is \$4.2 trillion/yr) **(1/6 of worlds electrical usage)**[1]
- \$15 trillion capital[1]
- Compressed CO_2 (and water) must be pumped deep underground in unique wells and stay there (cost, transportation, safety, efficacy concerns)

[1] https://www.bbc.com/future/article/20210310-the-trillion-dollar-plan-to-capture-co2

42

An Alternative to Direct Air Capture (DAC)

We want a DAC alternative that:

- Powers itself
- Looks good in the landscape
- Has zero capital cost
- Can generate additional versions of itself
- Goes beyond DAC and reduces CO_2 to some degree

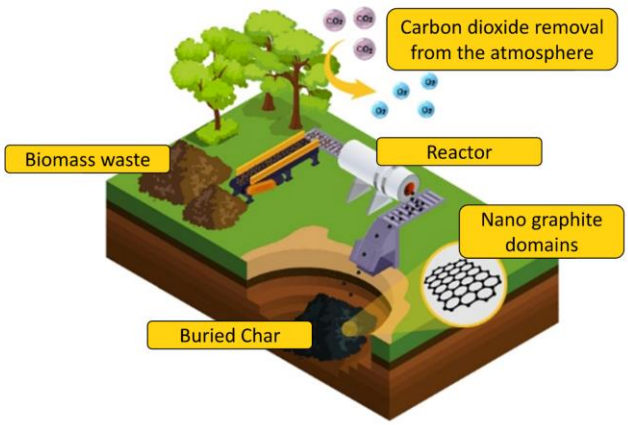
We just described a TREE

Image Source: https://netl.doe.gov/node/11208

43

43

How does Carba get CO_2 out of the air at low cost?



Carba strategy: Let nature do all of the work capturing carbon as trees, then harvest, char, and bury it

4 Key technology characteristics:

(1) Ultra-low capital costs

(2) Distributed and mobile operation

(3) High throughput AND high yield reactor design

(4) Long-term permanence for thousands of years via burial

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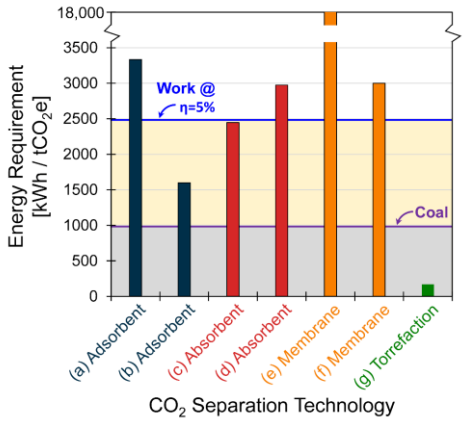
44

44

Energy offset or CO_2 removal?



DAC technologies include adsorbents, absorbents, membranes:

- Use significant energy (>1500 kWh / tCO_2e)
- Low efficiency compared to minimum required amount
- Use more energy than fossil fuel production (e.g., coal) for equivalent amount of CO_2 emissions

Torrefaction (Carba) uses little energy

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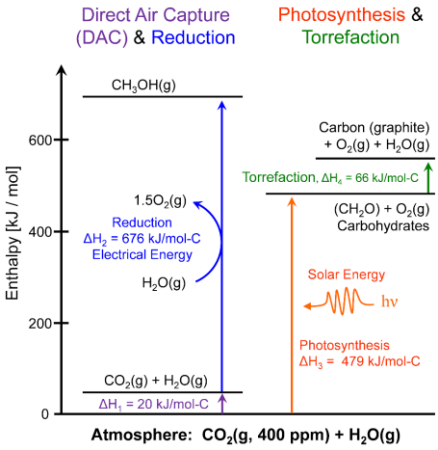
[1] *ACS Engineering Au*. 2023. DOI: 10.1021/acsengineeringau.2c00043

45

Minimum Energy Requirements



- Direct Air Capture + Reduction
  - Requires only 20 kJ/mol-C
  - Massive energy input for reduction of CO_2 to methanol for fuels and chemicals
- Photosynthesis + Torrefaction (Carba)
  - Energy for conversion of CO_2 to carbohydrates is high, but provided directly from sunlight
  - Torrefaction can be exothermic or endothermic depending on the conditions
  - **Carba benefits from natural solar power of photosynthesis**

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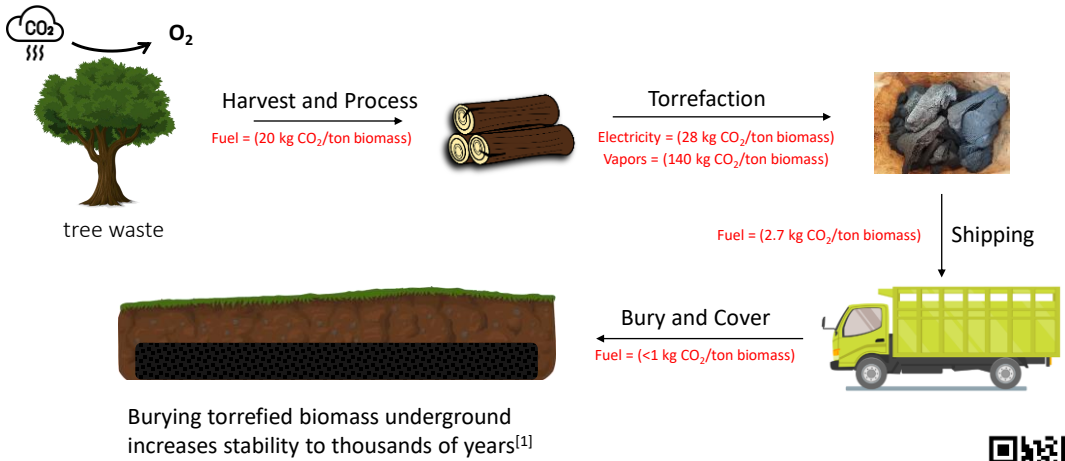
[1] *ACS Engineering Au*. 2023. DOI: 10.1021/acsengineeringau.2c00043

46

CARBA: BIOMASS TORREFACTION & BURIAL (BTB)



Burying torrefied biomass underground increases stability to thousands of years[1]

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[1] *ACS Engineering Au*. 2023. DOI: 10.1021/acsengineeringau.2c00043

47

47

Carba: Startup of Integrated Skills

Paul Dauenhauer
Co-Founder

MacArthur Foundation · SIRONIX · Lakril · arc

Andrew Jones
CEO & Co-Founder

Berkeley · arc · Astronaut Scholarship Foundation

Linda Hofflander
Strategy and Sales

SAMSUNG · SKYKIT

Rob Crane
Operations

Will Langton
Finance

PROTOLABS · CPC

Peter Allbright
Biomass

theWonderfulcompany. · Harris Woolf

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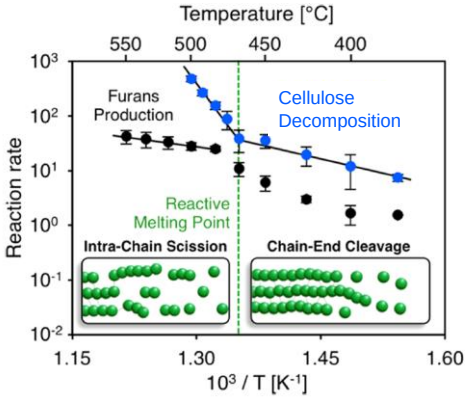
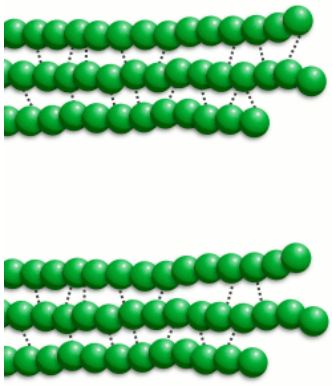
48

48

Technology: Led by Economics & Engineering

Basic research indicates that we want to be close to but not over 467 °C to minimize vapor formation





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Chemistry of Materials 2016, 28(9), 3108-3114. DOI: 10.1021/acs.chemmater.6b00580

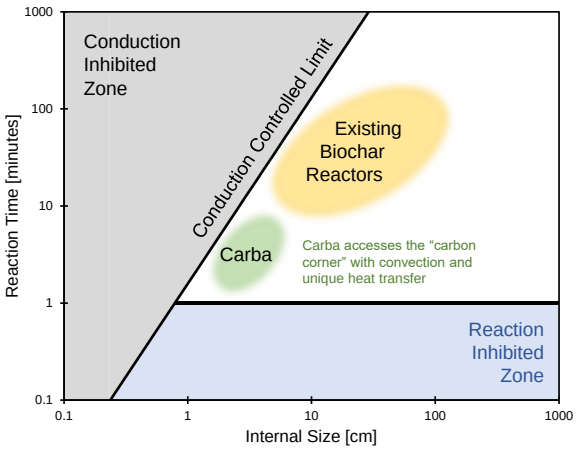
U.S. DEPARTMENT OF ENERGY | Office of Science

49

Technology: Led by Economics & Engineering

The Carba reactor combines multiple design innovations

- Improved heat transfer
- Faster torrefaction rates
- Throughput 1-2 orders of magnitude higher
- Improved yield with mass and energy control



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The Carba Reactor: Performance

Carba Reactor Design:

- 45 tonnes/day biomass
- High throughput, small footprint
- Mobile: can be moved on the back of a truck
- Low capital: payback in <1 yr
- Autothermal design
- Pilot facility: Operating for 8+ months

Torrefied Wood Chips

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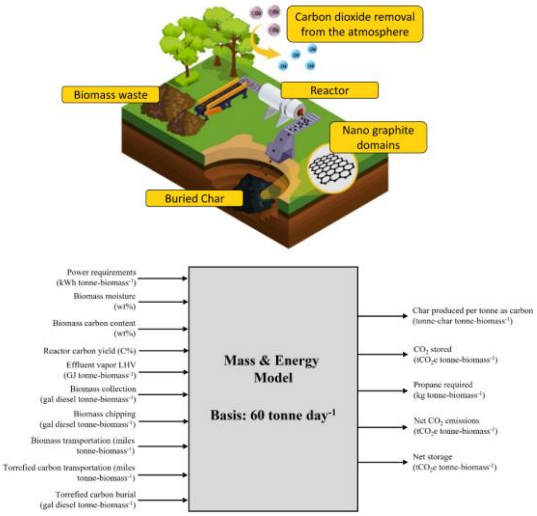
51

BTB: Biomass Torrefaction & Burial

Process Evaluation: A mass & energy model (shown) and an economic model

Monte Carlo Analysis:

- Assign each parameter a probability distribution
- Simulate 10,000 times to determine all possible outcomes
- Identify opportunities



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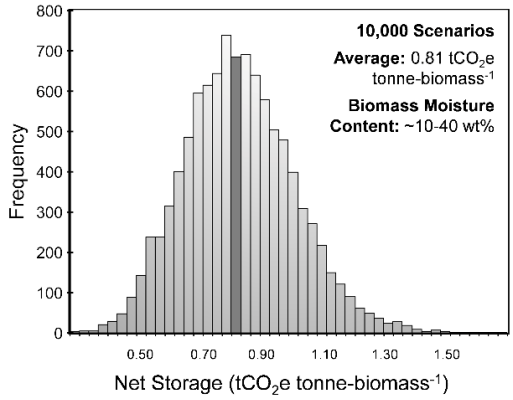
[1] *ACS Engineering Au*. 2023. DOI: 10.1021/acsengineeringau.2c00043

52

Carba: Process Performance



The breadth of carbon inputs and outputs (e.g., fuel, emissions) yield a distribution of carbon net storage

Average:

0.81 tCO_2e tonne-biomass^{-1}

Accounts for variability in biomass composition

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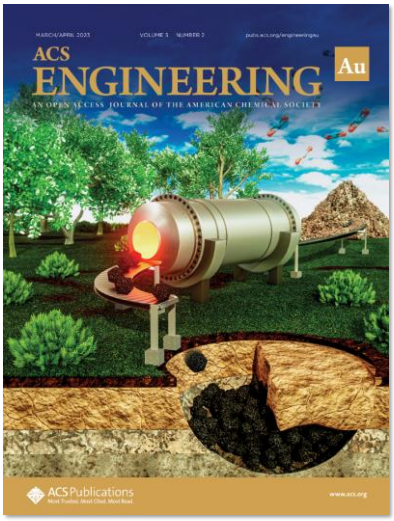
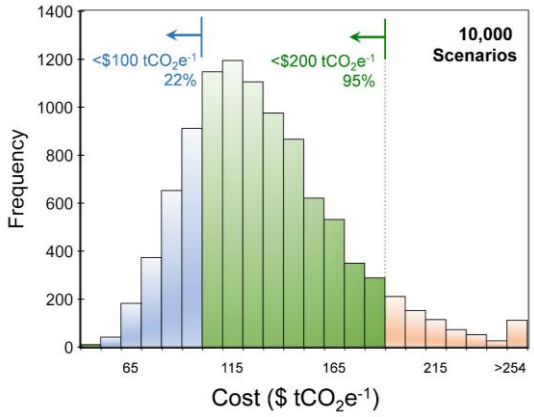
[1] *ACS Engineering Au*. 2023. DOI: 10.1021/acsengineeringau.2c00043

53

Novel Reactor for Carbon Sequestration



The only carbon sequestration technology that can achieve ~$100 / tonne cost of carbon sequestration



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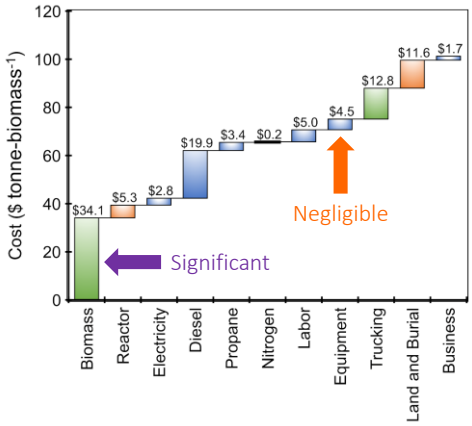
[1] *ACS Engineering Au*. 2023. DOI: 10.1021/acsengineeringau.2c00043

54

Carba: $100 Cost Carbon Sequestration

Consider scenarios that achieve $100 cost carbon sequestration

- Biomass ($34.1 tonne^{-1}) is the largest cost
- Transportation (diesel & trucking) is significant
- Capital costs are small due to reactor design



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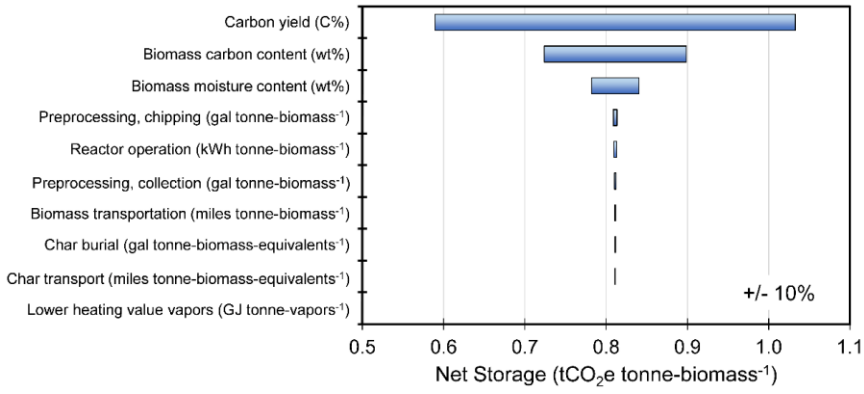
[1] *ACS Engineering Au*. 2023. DOI: 10.1021/acsengineeringau.2c00043

55

Carba: Economics – what matters?

Reactor performance (yield) is most important



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[1] *ACS Engineering Au*. 2023. DOI: 10.1021/acsengineeringau.2c00043

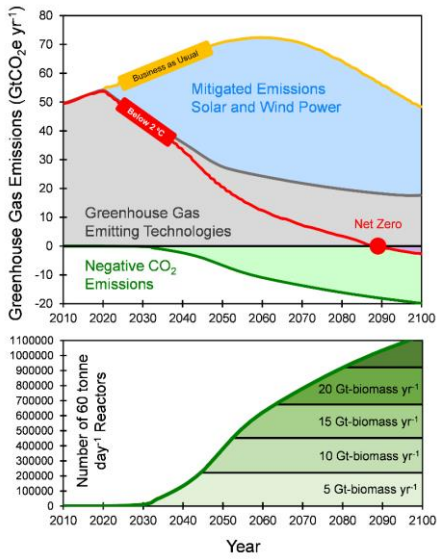
56

Road to Billions of Tonnes of Carbon

By 2050, we need to capture and sequester 10 billion tonnes of CO_2/yr

Need to manufacture 0.5 to 1.0 million reactors in 25 years

- Payback less than a year for each reactor
- Max 40,000 reactors per year



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[1] *ACS Engineering Au*. 2023. DOI: 10.1021/acsengineeringau.2c00043

57

Strategy: Reactors Around the World

Mobile high throughput torrefaction reactors can be placed everywhere

- Waste agricultural residues
- Tree thinning waste
- Waste packaging
- Yard waste
- Carbon crops

Total biomass waste is estimated on the order of 40+ billion tonnes worldwide[1]

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[1] https://pubs.acs.org/doi/10.1021/acsengineeringau.2c00043

https://commons.wikimedia.org/

58

Establishing Credibility in Carbon Markets

CDR: Carbon Dioxide Removal

MRV: Measurement, Reporting, & Verification[1]

- How do customers know how much CO_2 you captured?
- How do you communicate total CO_2 capture?
- How can the amount of captured CO_2 be verified or audited?

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[1] https://www.oecd.org/env/cc/measurementreportingandverificationofghgmitigation.htm

[2] https://twitter.com/_david_ho_/status/1661265764706398209?s=20 (shared with permission)

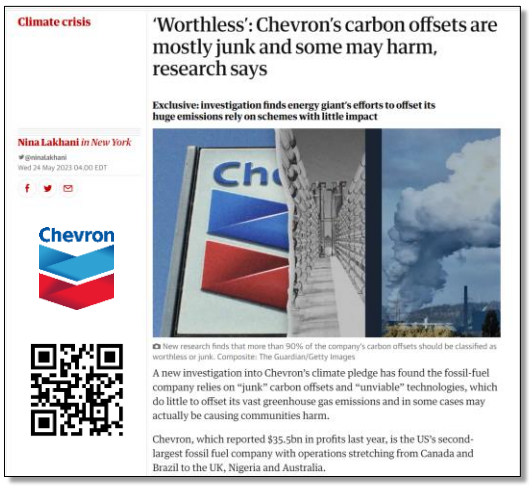
59

The Challenge of Credibility

"A new investigation into Chevron's climate pledge has found the fossil-fuel company relies on "junk" carbon offsets and "unviable" technologies, which do little to offset its vast greenhouse gas emissions and in some cases may actually be causing communities harm."[1]

"Many of Chevron's offset purchases focus on forests, plantations or large dams."[1]

"The report argues that the widespread use of worthless offsets severely undermines Chevron's climate action ambition"[1]


Climate crisis

'Worthless': Chevron's carbon offsets are mostly junk and some may harm, research says

Exclusive: investigation finds energy giant's efforts to offset its huge emissions rely on schemes with little impact

Nina Lakhani in New York

Chevron

New research finds that more than 90% of the company's carbon offsets should be classified as worthless or junk. Composite: The Guardian/Getty Images

A new investigation into Chevron's climate pledge has found the fossil-fuel company relies on "junk" carbon offsets and "unviable" technologies, which do little to offset its vast greenhouse gas emissions and in some cases may actually be causing communities harm.

Chevron, which reported $35.5bn in profits last year, is the US's second-largest fossil fuel company with operations stretching from Canada and Brazil to the UK, Nigeria and Australia.

[1] https://www.theguardian.com/environment/2023/may/24/chevron-carbon-offset-climate-crisis

60

MRV: (Measure, Report, Verify)

Documented certified multi-step process to:[1,2]

- ***measure*** the amount of greenhouse gas (GHG) emissions reduced by a specific mitigation activity, such as reducing emissions from deforestation and forest degradation, over a period of time
- ***report*** these findings to an accredited third party
- third party then ***verifies*** the report so that the results can be certified and carbon credits can be issued

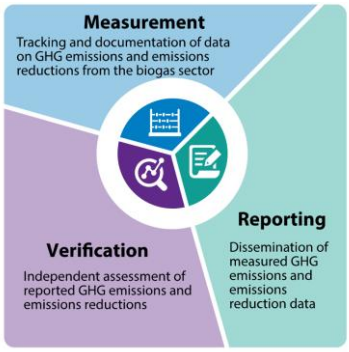


Image source: https://globalmethane.org/mrv

[1] https://www.worldbank.org/en/news/feature/2022/07/27/what-you-need-to-know-about-the-measurement-reporting-and-verification-mrv-of-carbon-credits
[2] https://www.wri.org/research/mrv-101-understanding-measurement-reporting-and-verification-climate-change-mitigation

61

61

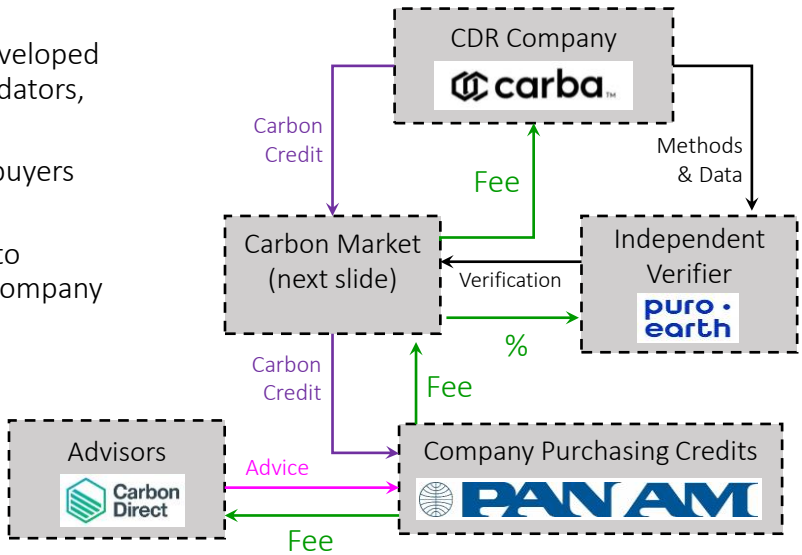
Carbon Dioxide Removal (CDR) Ecosystem

The CDR ecosystem has developed carbon credit creators, validators, markets, and purchasers

Carbon markets: connect buyers and seller

Verifiers: Assess methods to determine quality of CDR company

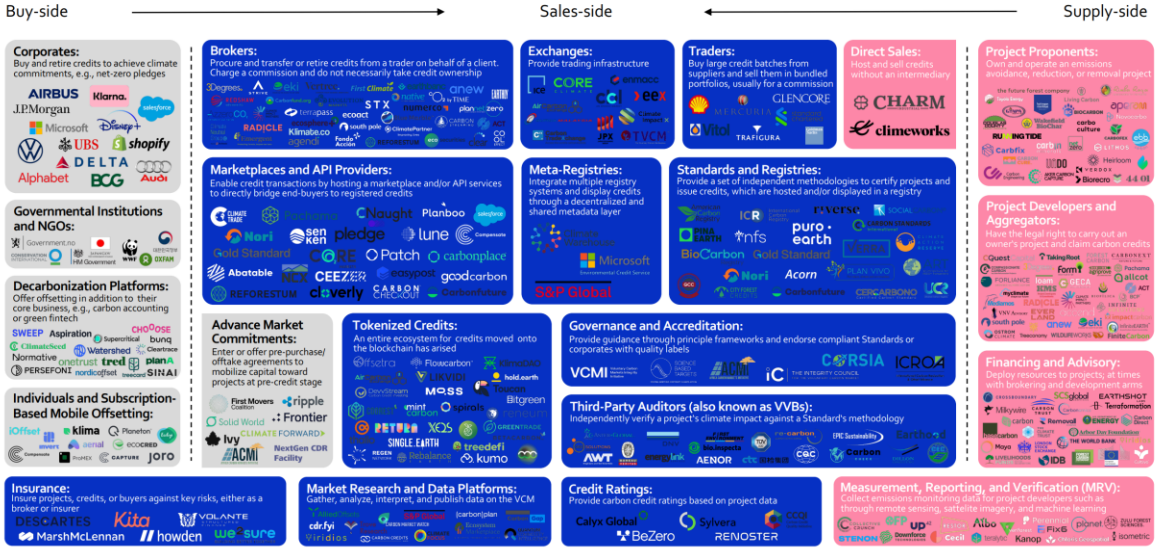
Status: Changing rapidly



62

62

2023 Market Map of the "New" Voluntary Carbon Market



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[1] Image source: https://entrepreneursforimpact.substack.com/p/carbon-prices-are-up-4x-in-2-years

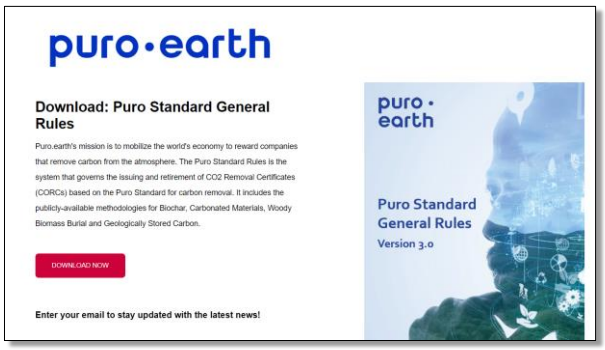
63

63

Independent Carbon Dioxide Removal Standards

Puro Standard Rules

- System that governs the issuing and retirement of CO_2 Removal Certificates (CORCs)
  - Different types and cost of CORCs depending on level of permanence
- Includes publicly-available methodologies for existing methods
- Will work with new producers to create new standards as new methods develop



https://connect.puro.earth/puro.earth.rules

64

64

Carba: Permanent Carbon Storage

Carba utilizes a dual approach to achieve carbon sequestration for thousands of years[2]

- **Torrefaction to char** destroys carbohydrate structure to eliminate conventional biodegradation[1]
- **Burial of char** in soil below the oxygen zone eliminates all other mechanisms of degradation[1]

Carba CEO: Dr. Andrew Jones

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[2] https://www.reversecarbon.com/blog/100-years-and-what#_ftn1 [1] *ACS Engineering Au*. 2023. DOI: 10.1021/acsengineeringau.2c00043

65

65

COMING MARKET OPPORTUNITY

$50B

The United States voluntary carbon credit market is projected to reach **>$50B** by 2030

7.4GT

Scientists estimate **7.4 Gt** of CO_2 per year must be *removed* to limit warming <1.5°C.

$1T

Translating to a **>$1T market** by 2050 at current prices ($50-130/ton)

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66

Conclusions

CDR technologies vary significantly with cost ($100 to $1,000 per tonne CO_2e)

Biomass torrefaction technologies (Carba) have immense promise:

- Low capital modular systems
- Distributed to use plant waste
- Thousand-year permanence with burial

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67

67

Contact us to get started

"Every organization should do its part to reduce their emissions, but if it's not enough then they should think about a carbon removal contract with Carba."

Head of Strategic Innovation
Linda K.

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Image: www.carba.com

68

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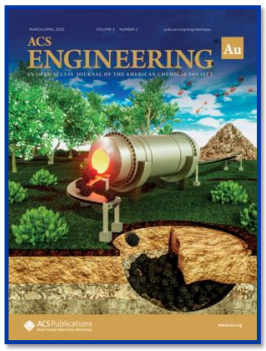

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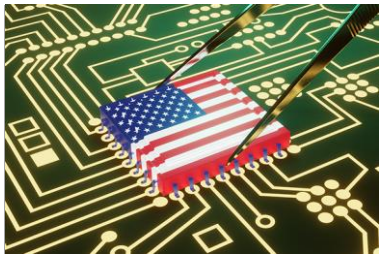

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