Waste Carbon Utilization and Carbon Management

BETO Peer Review

6 March 2019

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U.S. Department of Energy

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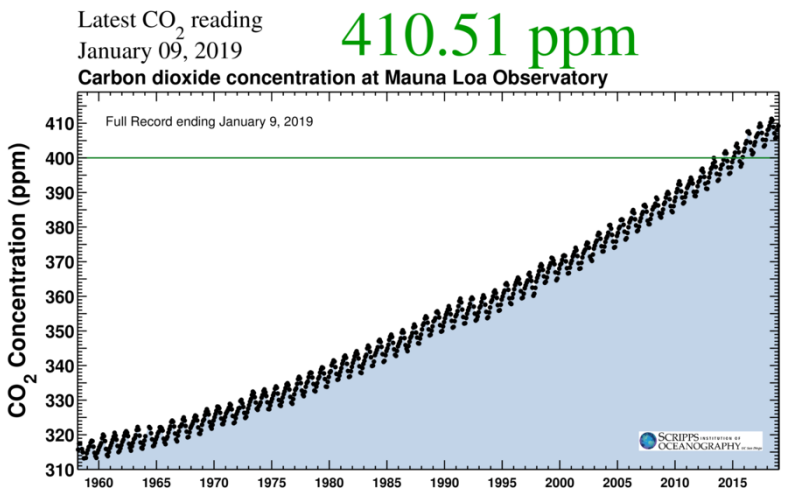
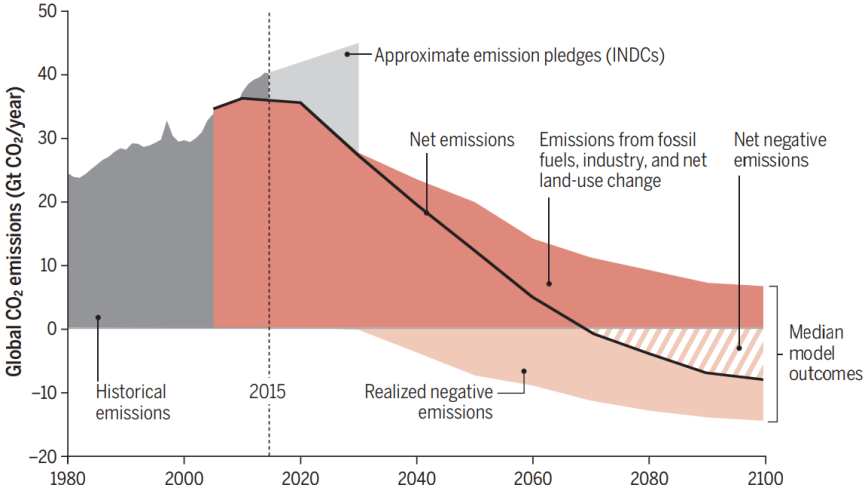
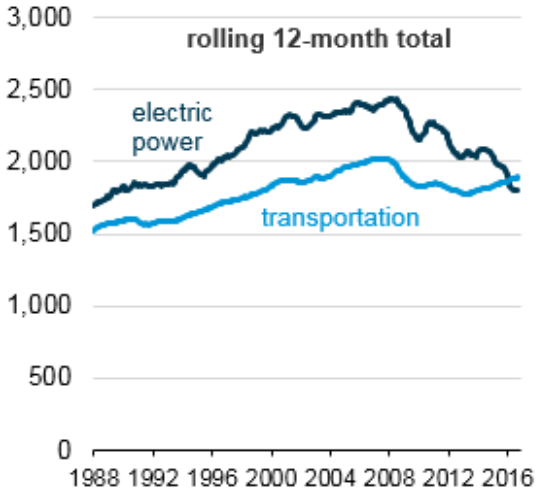
The need for better carbon management







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Can electrification remove the need for carbon?

- A 1-hour flight on a 747-400 uses ~3600 gal (11,000 kg) of jet fuel, which contains approximately 452,000 MJ of energy.
- Tesla Model S battery = ~.75 MJ/kg
- Weight of 747-400: 184,000 kg
- **You'd need over 600,000 kg of battery for a 1-hour flight (over 3X the weight of plane)**

Working gas in underground storage, Lower 48 states

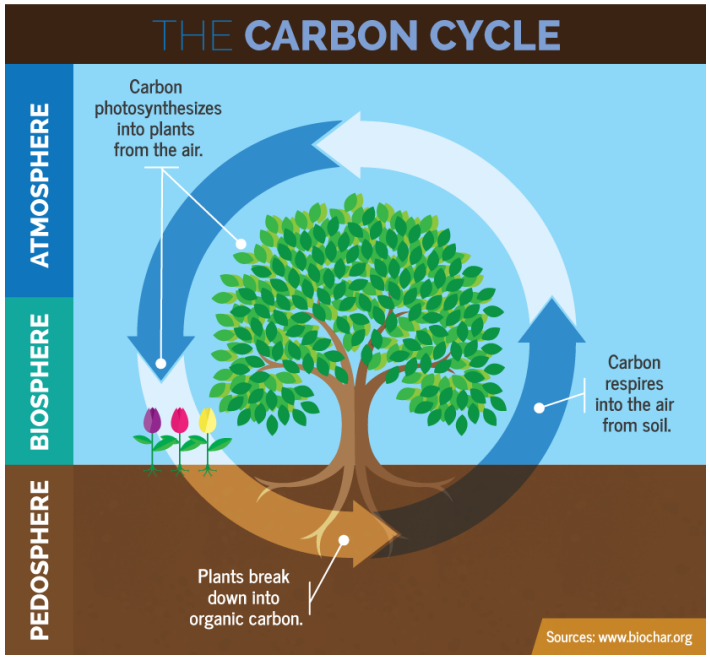
	Stocks billion cubic feet (Bcf)			
Region	02/22/19	02/15/19	net change	implied flow
East	354	395	-41	-41
Midwest	385	436	-51	-51
Mountain	79	87	-8	-8
Pacific	122	138	-16	-16
South Central	598	649	-51	-51
Salt	199	224	-25	-25
Nonsalt	399	425	-26	-26
Total	1,539	1,705	-166	-166

- From 2/15 thru 2/22, the US used 166 Bcf of natural gas from underground storage sites.
- Using the $\Delta_c H$ for CH_4, that's 178 billion MJ
- 1 Tesla Model S battery = 85 kWh = 306 MJ
- **Over 580 million Tesla Model S batteries would be needed to meet this cold-snap demand, assuming they could hold the charge for 6+ months**

The Carbon Based Economy

A more sustainable economy is not a *low-carbon economy* as much as it will be a ***renewable carbon based economy***.

Obtaining and managing renewable carbon



Wet waste: 77M ton/yr

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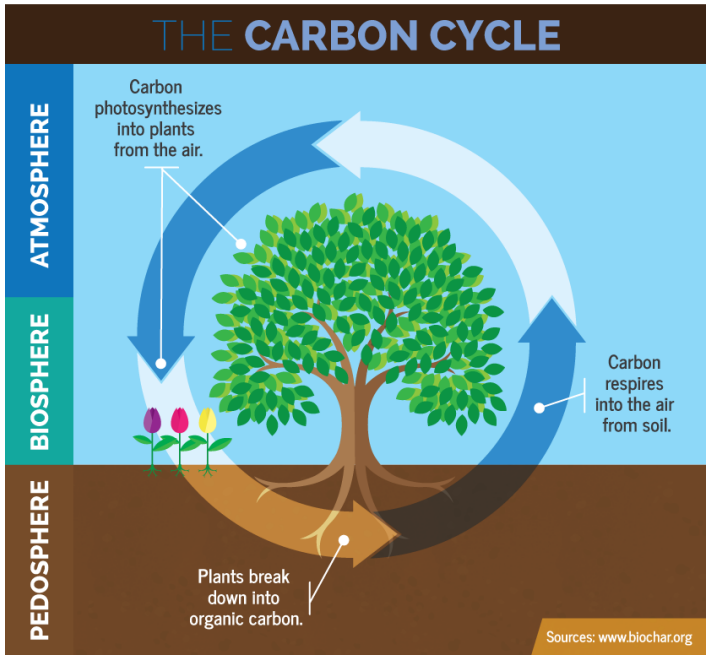
Obtaining and managing renewable carbon



Wet waste: 77M ton/yr

Plastics: 35M ton/yr
<10% recycle rate

Waste CO_2: 5G ton/yr

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Trends in CO_2 management

ADM starts up Illinois CCS project, will capture over five million tonnes of CO2

By Rhea Healy | 10 April 2017

5,903 views | Feb 15, 2018, 08:30am

Tax Credit May Rev Up Carbon Capture And Sequestration Technology

Barrasso: USE IT Act is Important Bipartisan Legislation to Promote Carbon Capture Research and Development

April 11, 2018

CLIMATE

Jerry Brown Orders California to Go Carbon Neutral by 2045. Is That Even Possible?

The New York Times

Scientists Push for a Crash Program to Scrub Carbon From the Air

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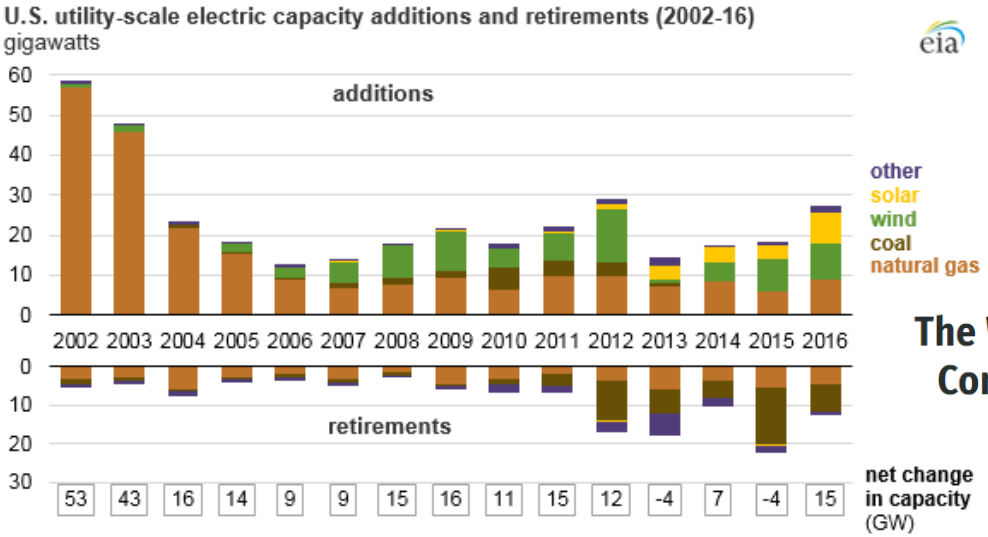
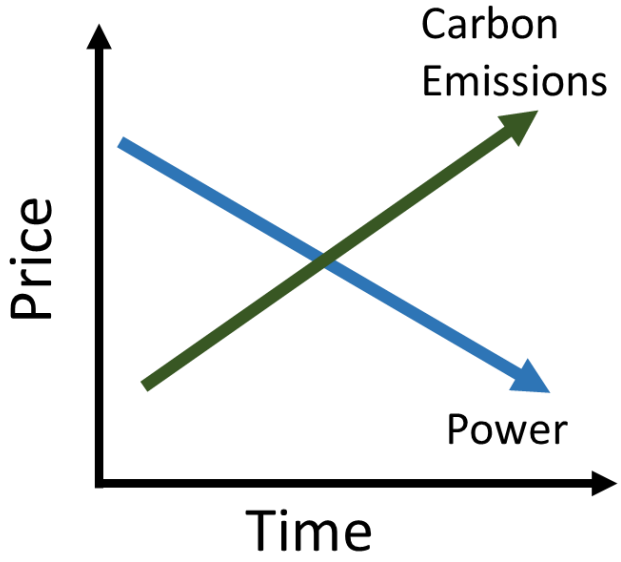
A new paradigm for carbon emissions



The World's Fifth-Largest Economy, California, Just Committed to 100% Carbon-Free Power by 2045



- The price (direct or indirect) of emitting CO_2 will go up
- The price of and C-intensity of electricity will decrease

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CO_2 utilization efforts

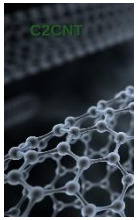
nrg | cosia CARBON XPRIZE

THE CARBON OPPORTUNITY

$20 MILLION

Prize Purse

The $20 million NRG COSIA Carbon XPRIZE is a global competition to develop breakthrough technologies that will convert CO_2 emissions from power plants and industrial facilities into valuable products like building materials, alternative fuels and other items that we use every day.



CARBICRETE

CARBON CURE™

cert

NEWLIGHT TECHNOLOGIES

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ELECTROFUELS: utilizing renewable electricity to make biofuels

- Funding: $50M from 6/2010 thru 12/2014
- Non-photosynthetic microbes convert CO_2 to fuel while using electricity for energy

U.S. DEPARTMENT OF ENERGY Fossil Energy

- Fund $10-15M per year on CO_2 utilization
- Focuses on algae and catalysis

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BIOENERGY TECHNOLOGIES OFFICE

- $30M algae program

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Enabling a Circular Carbon Economy

A future economy that serves as a tool to manage carbon circularly.
Develop technologies to manage carbon throughout its lifecycle, from atmospheric CO_2 through organic products and back to CO_2.
Crosscutting technologies in the land, agricultural, and energy sectors

Three R&D focuses:

- Rewiring Carbon Utilization
- Re-engineering Biomass Conversion
- Enabling Advanced Carbon Management

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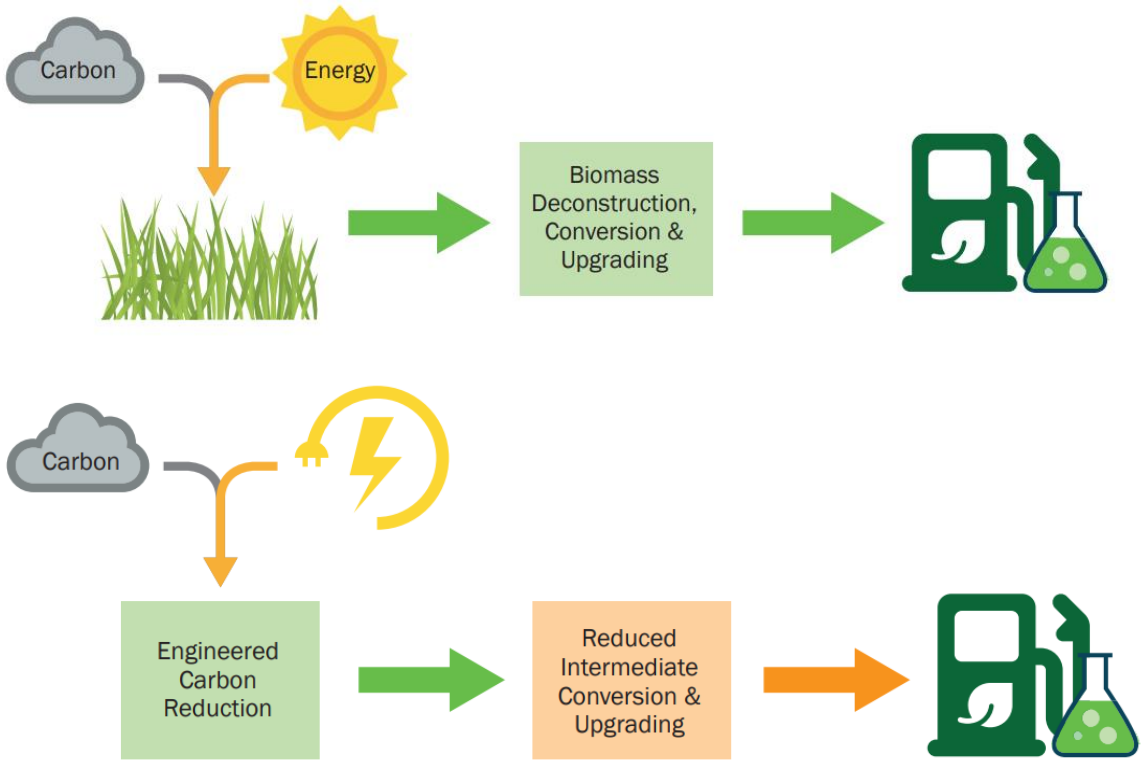
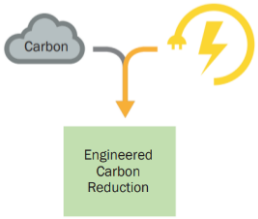
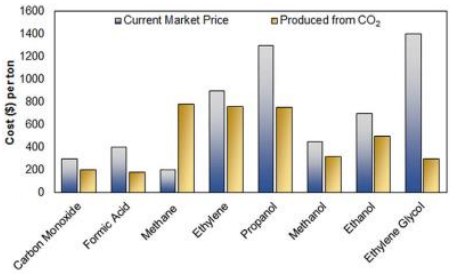
Rewiring Carbon Utilization



Rewiring Carbon Utilization

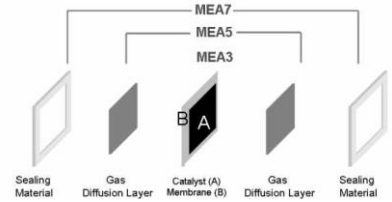


Non-biological CO_2 activation



Enabling Studies:

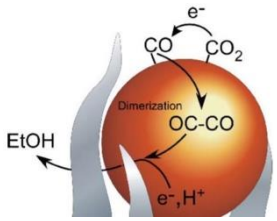
- *Feasibility Study of Utilizing Electricity to Produce Intermediates from CO_2*
- *CO_2 Utilization: Thermo- and Electro-catalytic routes to fuels and chemicals*



Electrocatalysis and thermocatalysis R&D:

- *Electrocatalytic upgrading of CO_2 to fuels and C2+ chemicals*

- *Catalyst Development for Selective Electrochemical Reduction of CO_2 to High-value Chemical Precursors w/Opus-12*



SBIR Phase II - *Utilization of Waste CO_2 to Make Renewable Chemicals and Fuels*

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SBIR Phase I - *Excess Electric Power-Driven Conversion of CO_2 to Chemicals*

ChemCatBio

SBIR Phase II - *Renewables-Driven Production of Organic Acids from Industrial CO_2 Waste Streams*

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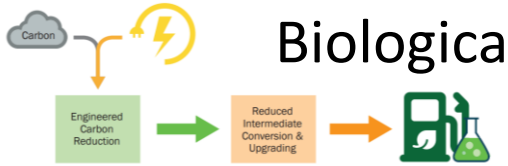
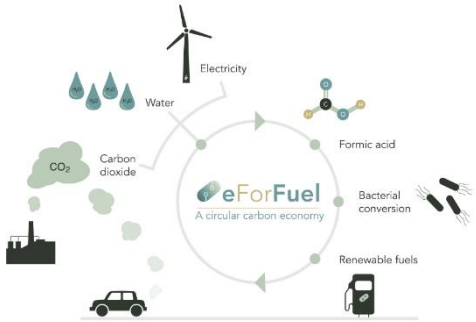
Rewiring Carbon Utilization



Biological upgrading of intermediates derived from CO_2

Engineering microorganisms to upgrade formate/methanol

- *Improving formate upgrading by Cupriavidus necator*
- *Enhancing Acetogen Formate Utilization to Value-Added Products*
- *Synthetic C1 Condensation Cycle for Formate-Mediated ElectroSynthesis*



- ***BEEPS FOA:*** *Integrating Chemical Catalysis and Biological Conversion of Carbon Intermediates for Converting CO_2– Johns Hopkins University*
- ***BEEPS FOA:*** *Electrocatalytic conversion of CO_2 to formic acid via microstructured materials – Montana State University*

CO_2PERATE

Engineering of microorganisms to upgrade carbon monoxide

- ***Agile Biofoundry :****Progress towards a new model chemolithoautotrophic host*
- ***Agile Biofoundry:*** *Data Integration and Deep Learning for Continuous Gas Fermentation Process Optimization*
- ***BRDi:*** *Engineered reversal of the β-oxidation cycle in clostridia for the synthesis of fuels and chemicals*
- ***BEEPS FOA:*** *Production of bioproducts from electrochemically-generated C1 intermediates – Lanzatech*
- ***SBIR Award:*** *Electrochemical conversion of CO_2 to CO for use as a fermentation feedstock*

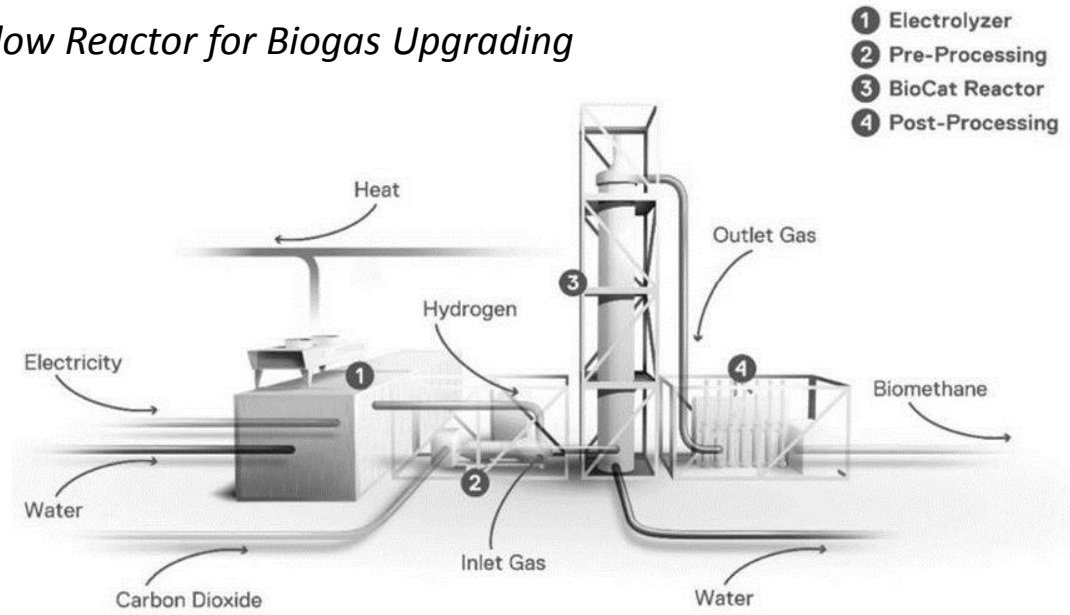
- *Integration of Flue Gas CO_2 Electrolysis with Microbial Syngas Fermentation*

Rewiring Carbon Utilization

CO_2 conversion for grid-scale energy storage:

- *Biomethanation of CO_2 to Pipeline Grade Methane*

- *Modular Microbial Electromethanogenesis Flow Reactor for Biogas Upgrading*



DOE and SoCalGas funding LLNL and Stanford in new power-to-gas research: microbial electromethanogenesis

02 August 2018

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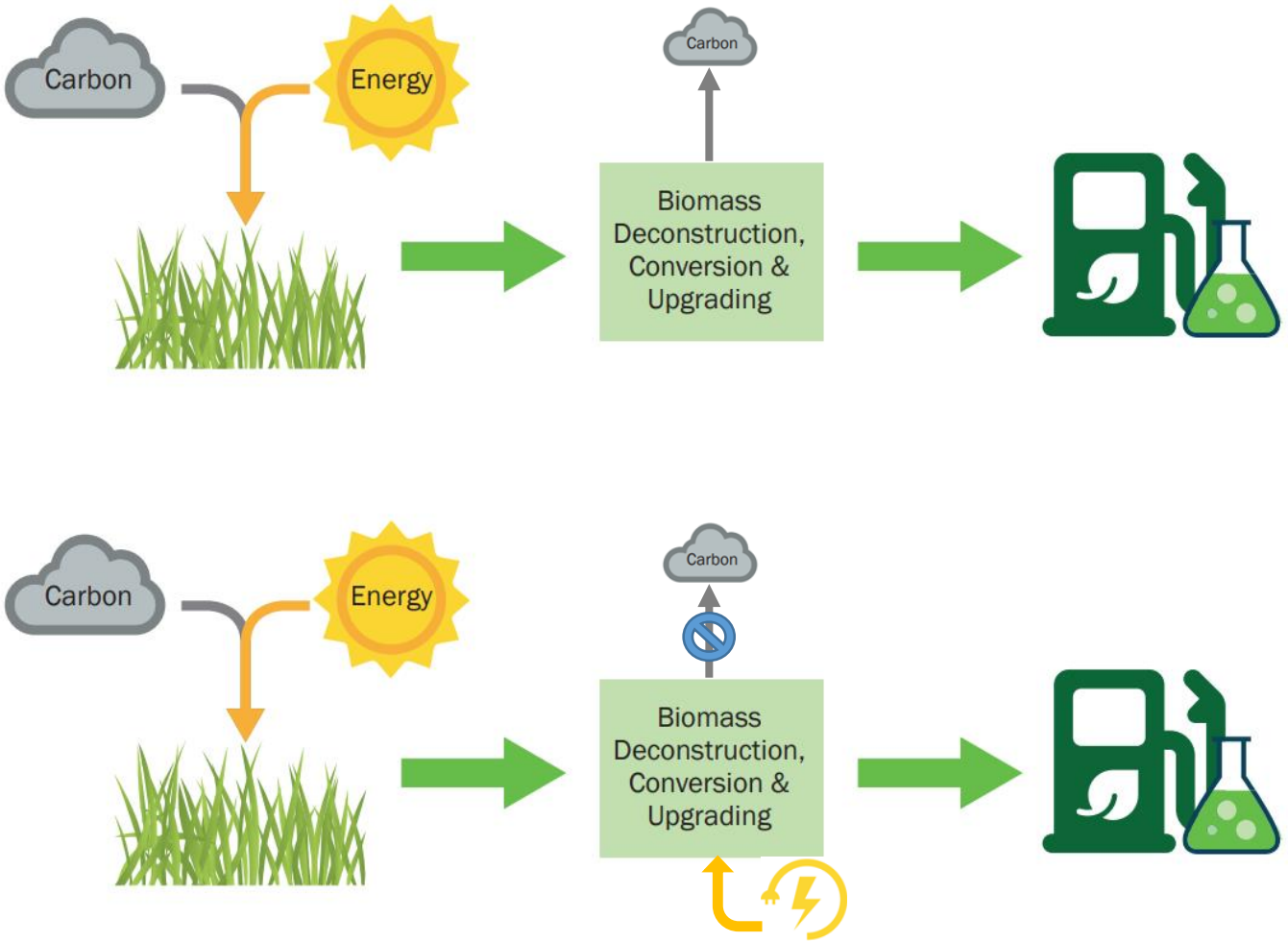
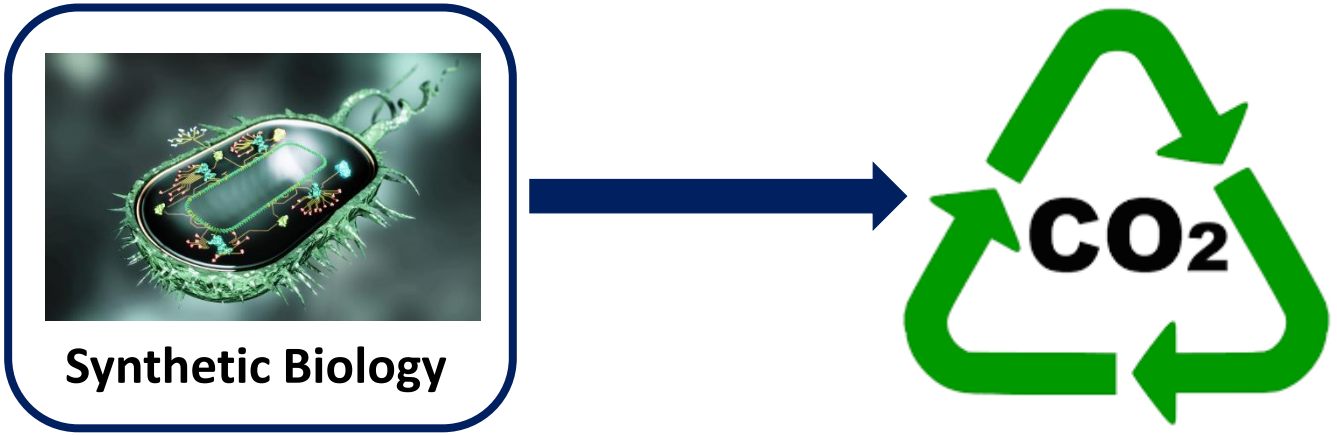
Re-engineering biomass conversion



Re-Engineering biomass conversion: strategies

Whole-cell pathway engineering for optimized carbon utilization (e.g. NOG)



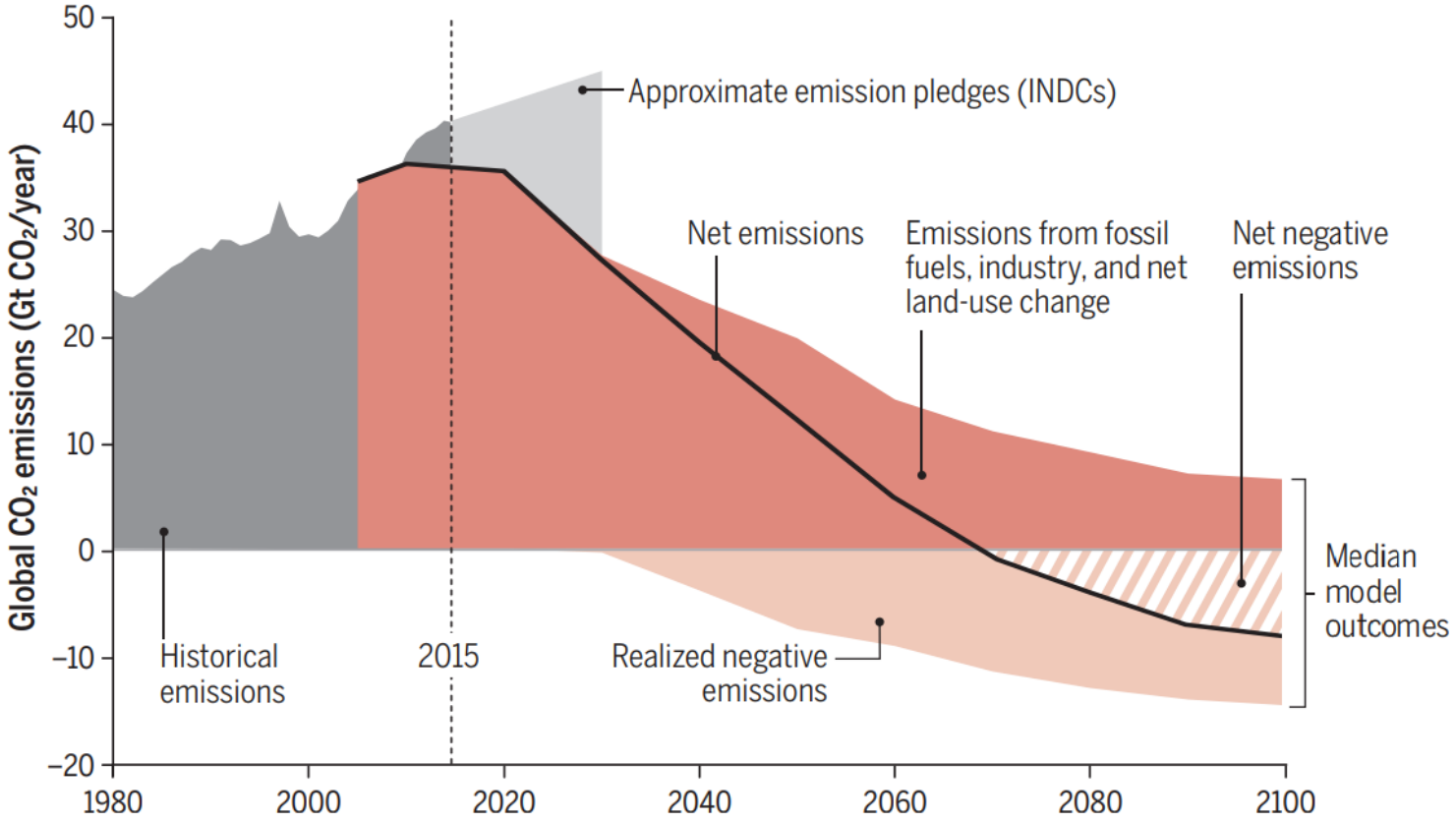
Engineered mixed microbial systems – the carboxylate platform (one example)

$C_6H_{12}O_6 \rightarrow 2\ H_3CCO_2H + 2\ CO_2 + 2\ H_2$	Acidogens
$2\ CO_2 + 2\ H_2 \rightarrow H_3CCO_2H$	Acetogens
$C_6H_{12}O_6 \rightarrow 3\ H_3CCO_2H$	Net

Another opportunity for alternative platform development

Enabling Advanced Carbon Management

Necessary targets rely on huge negative emissions



Integrated Assessment Models for hitting the IPCC target call for an incredible increase in carbon negative pathways

Carbon management as a bioproduct

Tax Credit May Rev Up Carbon Capture And Sequestration Technology

California's Clean Fuels Standard Poised to Get Even Better

United Airlines Plans 50% Emissions Reduction by 2050

CLIMATE

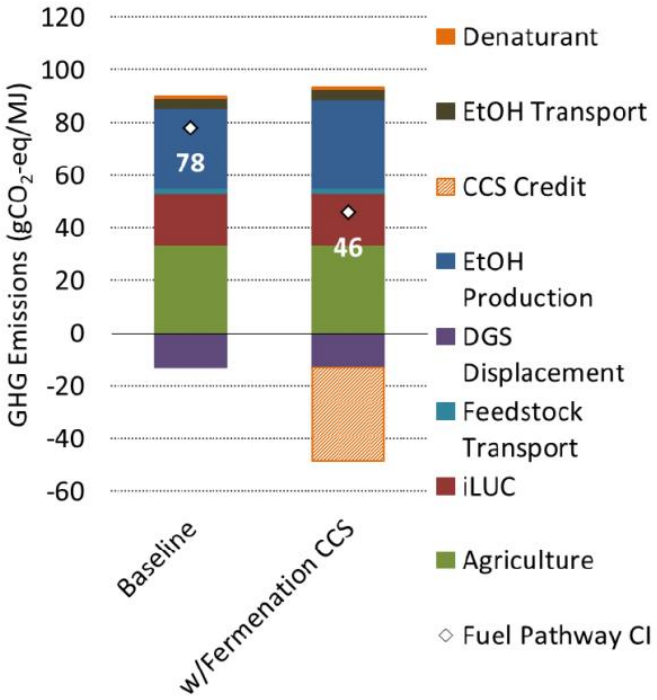
Jerry Brown Orders California to Go Carbon Neutral by 2045. Is That Even Possible?

All Lyft Rides Are Now Carbon Neutral

As Lyft becomes one of the world's largest voluntary purchasers of carbon offsets, every ride will now contribute to fighting climate change.

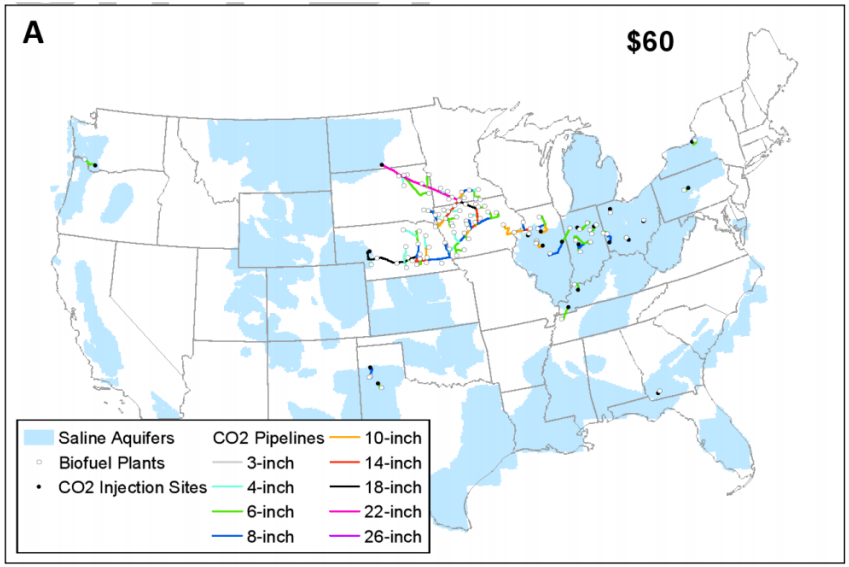
Profit at existing biorefineries

CCS can enable an improved Carbon Intensity at biorefineries



Near-term deployment of carbon capture and sequestration from biorefineries in the United States

Daniel L Sanchez[1], Nils Johnson[2], Sean McCoy[3], Peter Turner[1], Katharine Mach[4]



- Based on the economics of CCS and current EtOH plants, the current 45Q tax credit of \$50/ton CO_2 incentivizes potentially ~30 Mton/yr sequestration at existing biorefineries

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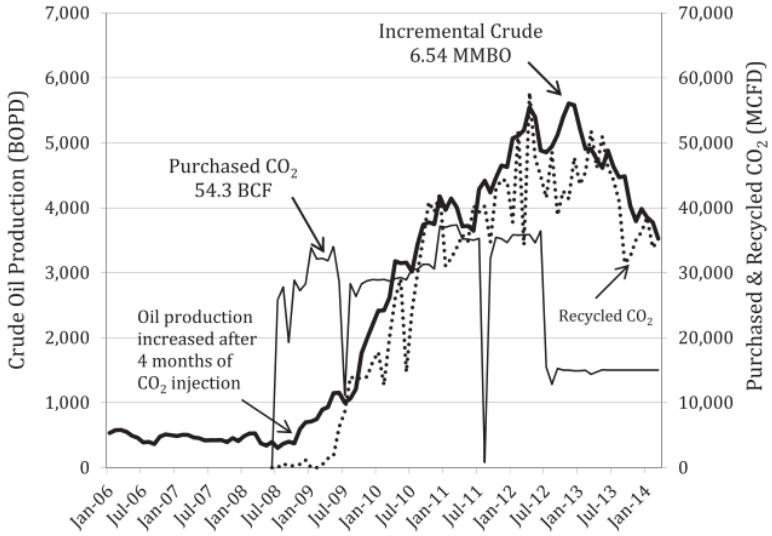
CCS as a tool for new low carbon pathways

Carbon negative oil: A pathway for CO_2 emission reduction goals

Katherine Y. Hornafius [a,*], J. Scott Hornafius [b,c]



CO_2 injection increases oil well production

In the case of the Booker project, the forecast oil recovery is 1.1 million barrels from 11.5 billion cubic feet of CO_2 (Chaparral, 2013b), resulting in a cumulative CO_2 utilization efficiency (ϵ) of about 10.5 Mscf/barrel and a net sequestration ratio (S) of about 1.3, meaning 30% more CO_2 is injected into the subsurface reservoir than the amount of CO_2 that is released into the atmosphere when the produced oil is burned. The resulting oil is carbon negative.

- By using biogenic CO_2, carbon-negative petroleum can be extracted
- Burying 30% more CO_2 through EOR than carbon emitted when the petroleum is burned

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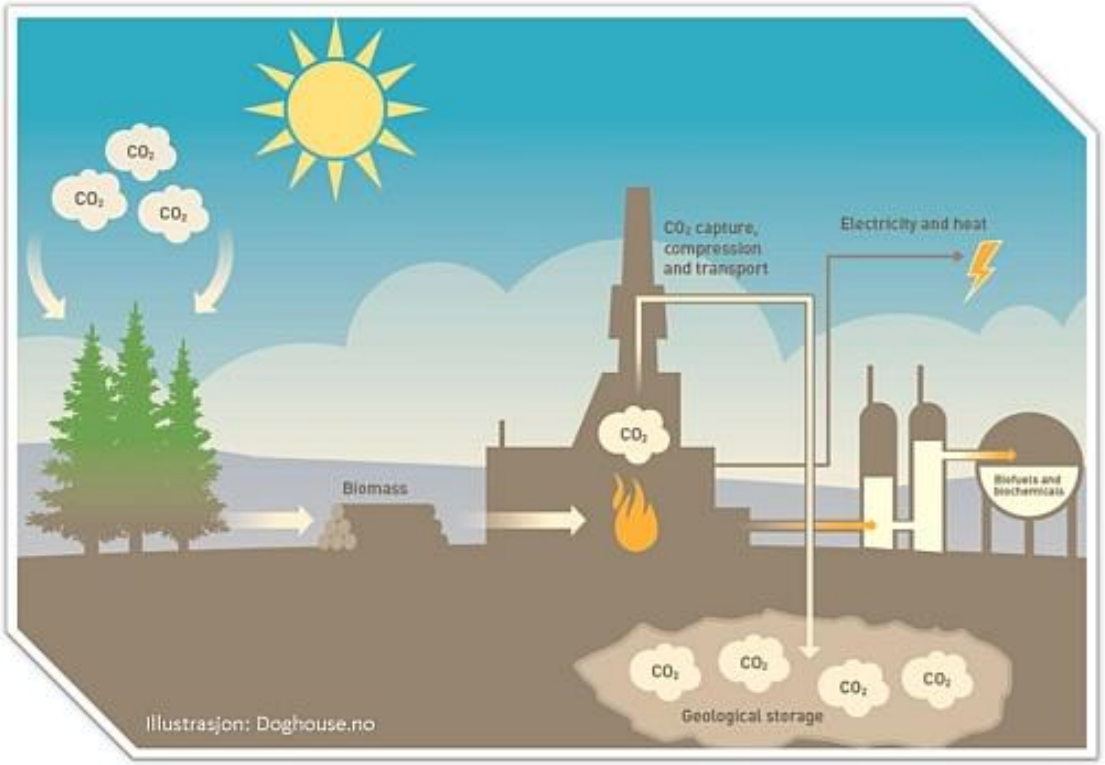
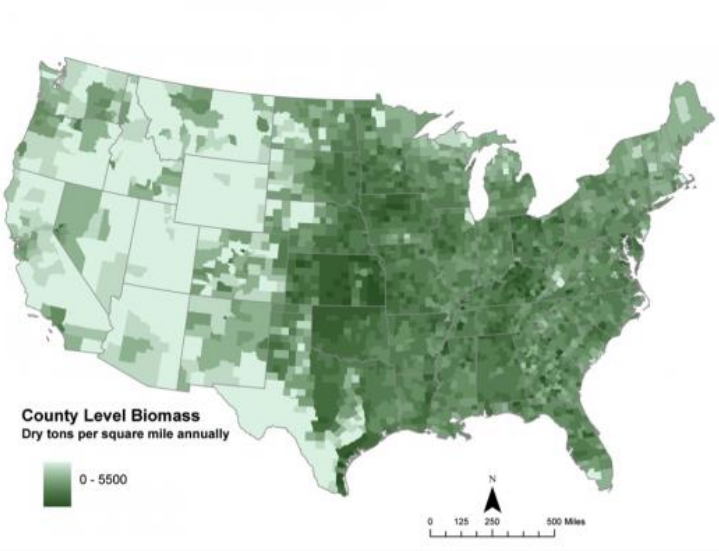
Bioenergy carbon capture and storage (BECCS)





BECCS

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Carbon storage in products and buildings

Bioplastics and chemicals

Biochar

Engineered wood to displace steel and concrete

Carbon fiber

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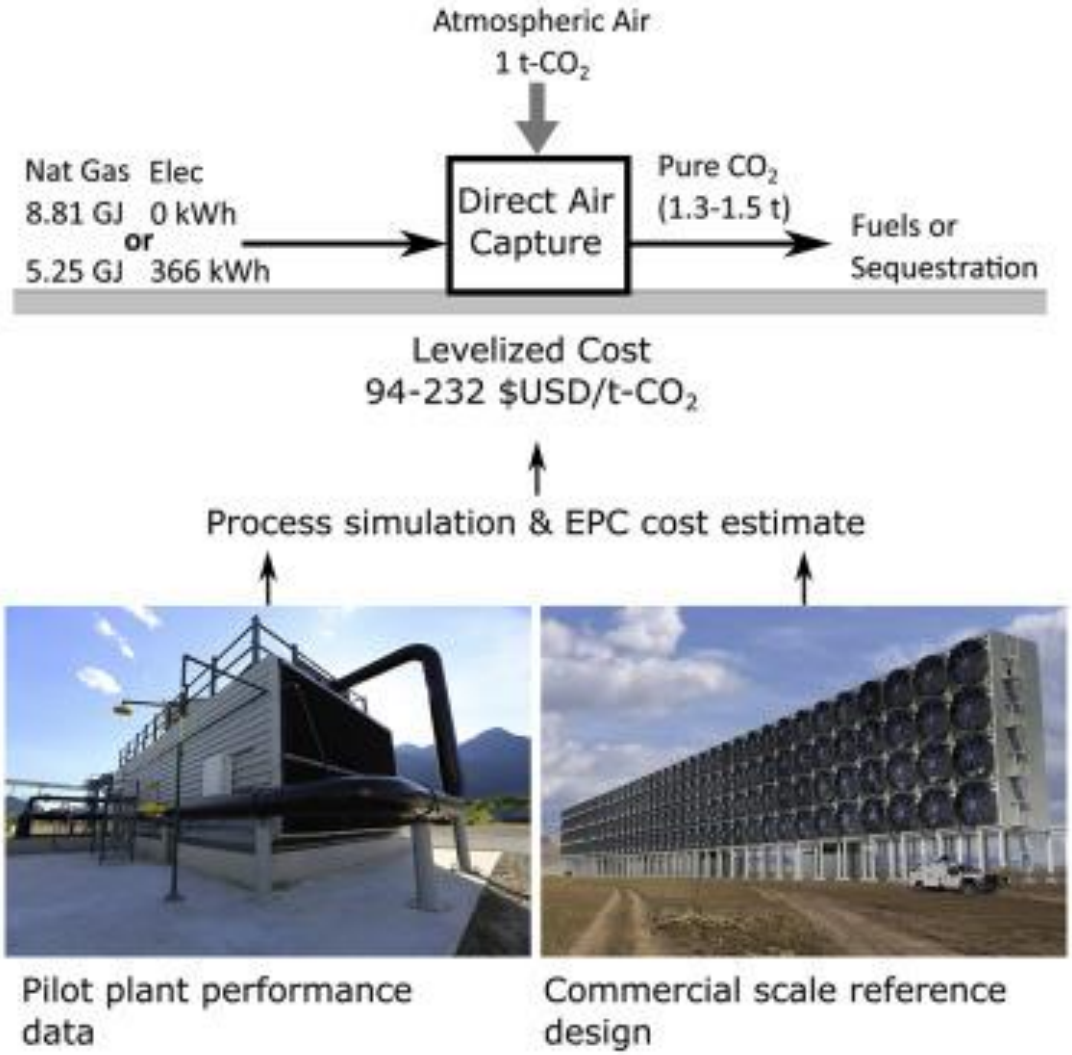
Direct Air Capture



The New Carbon Economy

3.) Valorize carbon

Mechanisms to convert emissions to negative emissions and CO_2U throughout the economy

R&D and Infrastructure Investment

1.) Decarbonize

Drive efficiency improvements and renewable transition throughout all sectors to maximize carbon utilization and minimize carbon emissions

2.) Go Negative

Establish and rapidly expand carbon removal (carbon negative) capacity

Contact us

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