U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BETO Advanced Algal Systems Program & DAC investments for FE Peer Review

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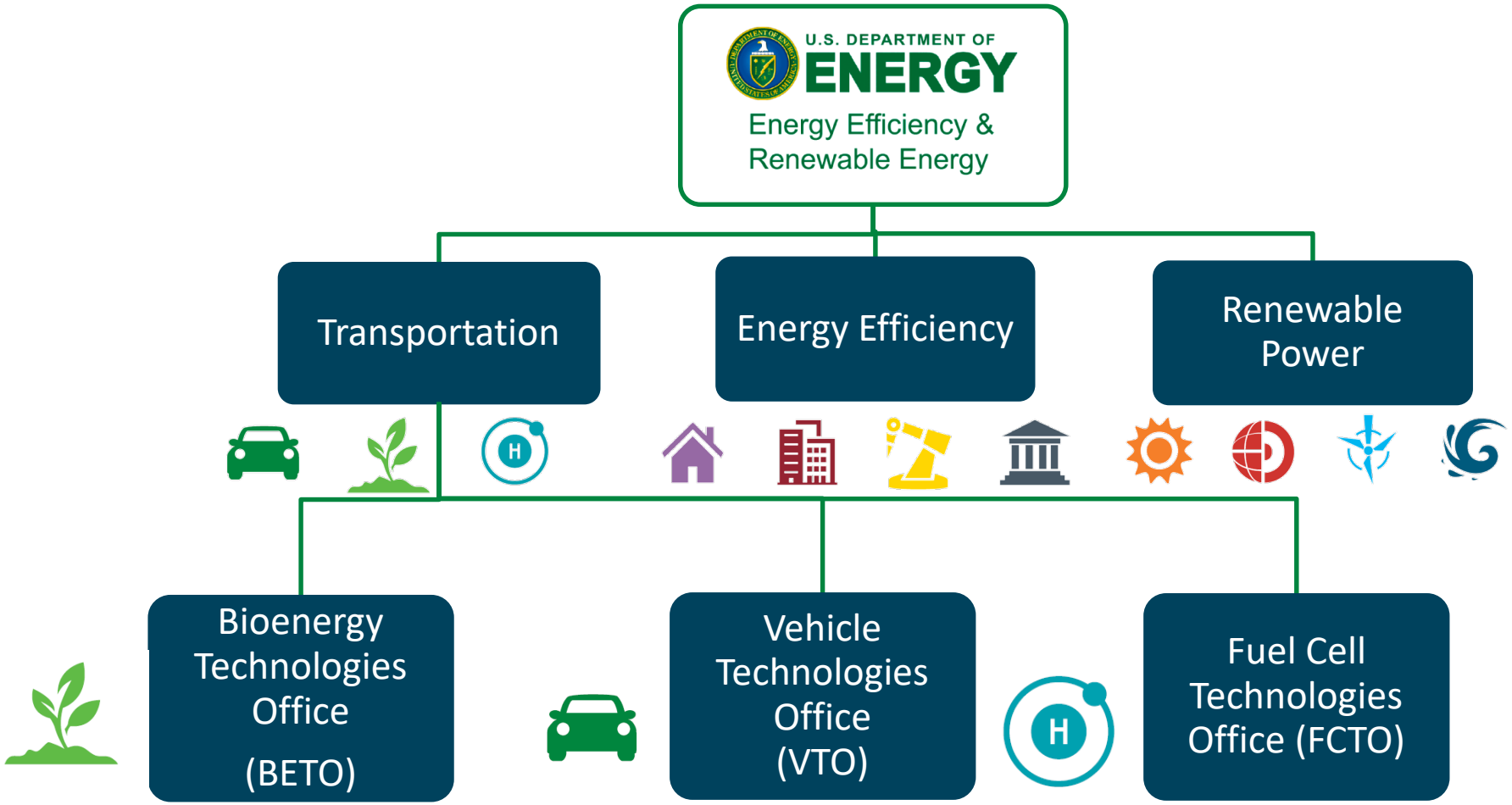
Operations Committee Liaison, Biomass R&D Board

U.S. Department of Energy Transportation Offices



Bioenergy Technologies Office's Critical Program Areas

Production & Harvesting

Feedstock & Logistics
- Reduce cost
- Improve biomass quality
- Increase the volume of sustainable feedstocks for conversion

Advanced Algal Systems
- Lower costs of production
- Improve productivity
- Improve quality

Conversion & Refining

Conversion
- Develops technologies to convert non-food feedstocks into biofuels, bioproducts, and biopower
- Achieve top research impacts by conducting:
  - Feedstock blend testing
  - Separation and materials compatibility evaluations
  - Techno-economic analysis

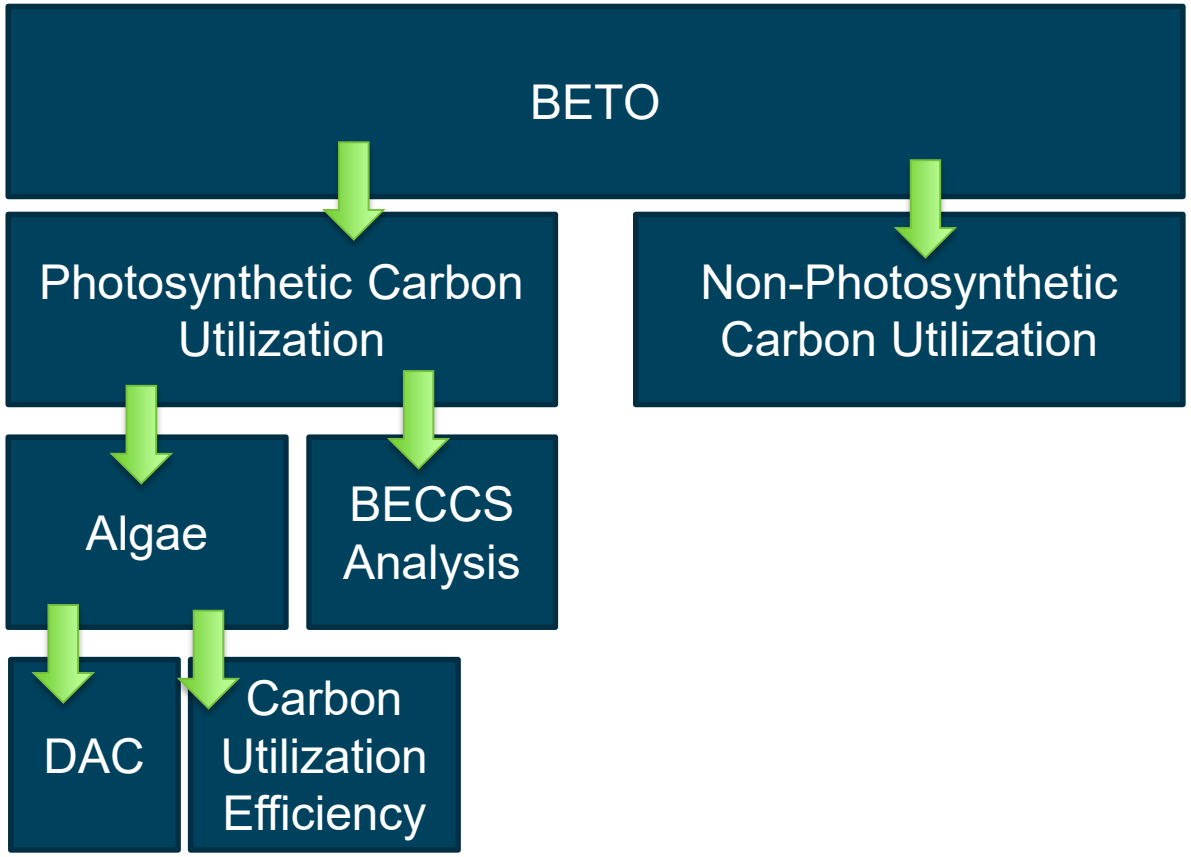
Distribution & End Use

Systems Development & Integration
- Reduce technology uncertainty in bioenergy by:
  - Integrating technologies into a system/process
  - Provide vital knowledge fed back to research programs

Crosscutting

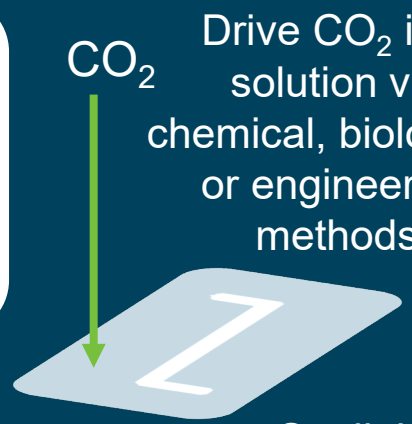
Sustainability and Strategic Analysis
- Supports program decision-making
- Develops strategies to understand and enhance the economic and environmental benefits of advanced bioenergy

BETO's carbon utilization efforts

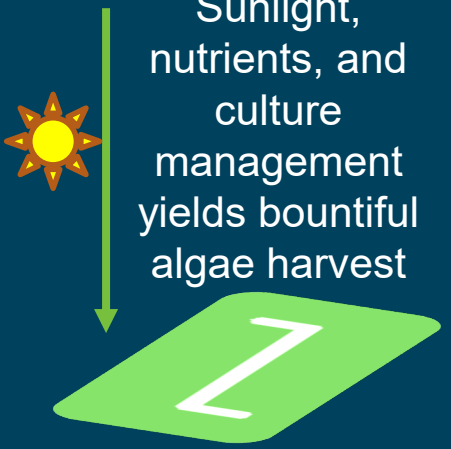


Innovative R&D keeps algae as a forefront technology for the bioeconomy and circular carbon economy.

BETO has a $30-40 million annual R&D program in Advanced Algal Systems.



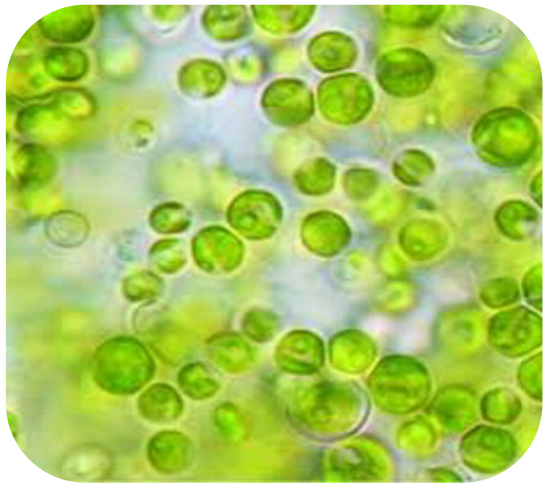
BETO has invested approximately $40 million in R&D directly targeted on photosynthetic carbon utilization of which $23M is on DAC with algae.



Societal challenges which algae can help solve

Today

Better manage carbon, nitrogen, and other resources.



Algae coupled with DAC can capture 1 gigaton of CO_2 a year using marginal lands equivalent to 15% the area of corn.

15 years

Fly a total of 6.9 billion passengers. 3.1 billion more than today.

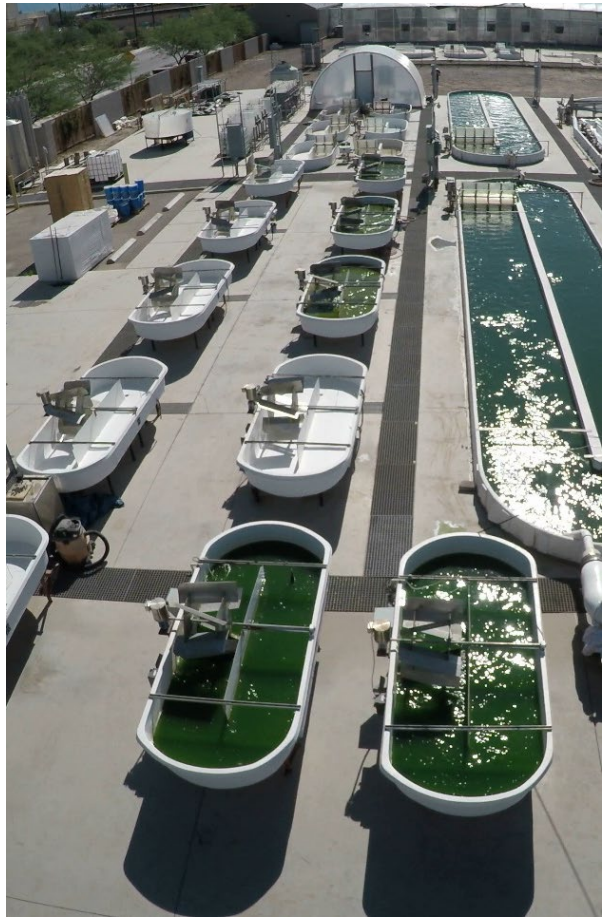
Algae can produce 16% of U.S. jet fuel needs using marginal lands equivalent to 3% of the area of corn.

30 years

Feed a world population that is estimated to reach more than 9 billion people.

Algae grown on marginal lands equivalent to 2% of the area of soy can yield 17 million more tons of protein.

Summary of modeling that informs our program's strategy



***Scenedesmus* cultivation at Arizona Center for Algae Technology and Innovation where DOE SOT work is performed.**

Modeling annual future productivities of 30 tons/acre/year

Over 7 million acres of land with suitable CO_2 access that satisfy land and water sustainability criteria.

30-40% achieves 5 billion gallon goal.

100-270M M tons per year biomass;
Over 5 billion gallons of fuel

Biomass cost averages

$472/ton (freshwater) to $655/ton (saline)

National fuel targets can be delivered at <$2.50/gge when co-produced with high-value commodities like polyurethanes

Pathways achieve 50% GHG reduction

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Summary of modeling that informs our program's strategy

2019 state of technology: 16g/m²/day (21 tons/acre/year)

Summer productivity: 27 g/m2/day

87% improvement in annual average productivity relative to FY15

Biomass cost averages
$670/ton (freshwater) to $866/ton (saline)
$200/ton greater than 2030 target

DISCOVR
Pacific Northwest NATIONAL LABORATORY
NREL NATIONAL RENEWABLE ENERGY LABORATORY
AzCATI Arizona Center for Algae Technology and Innovation
Los Alamos NATIONAL LABORATORY EST. 1943
Sandia National Laboratories

"Advancing the State of Technology thru DOE funded algae cultivation R&D at the Arizona Center for Algae Technology and Innovation" Presentation by Dr. John McGowen on September 19, 2019, at the Algae Biomass Summit;
https://discovr.labworks.org/sites/default/files/McGowen%20DISCOVR%20SOT%20Algae%20Biomass%20Summit%20Presentation%209-19-19.pdf

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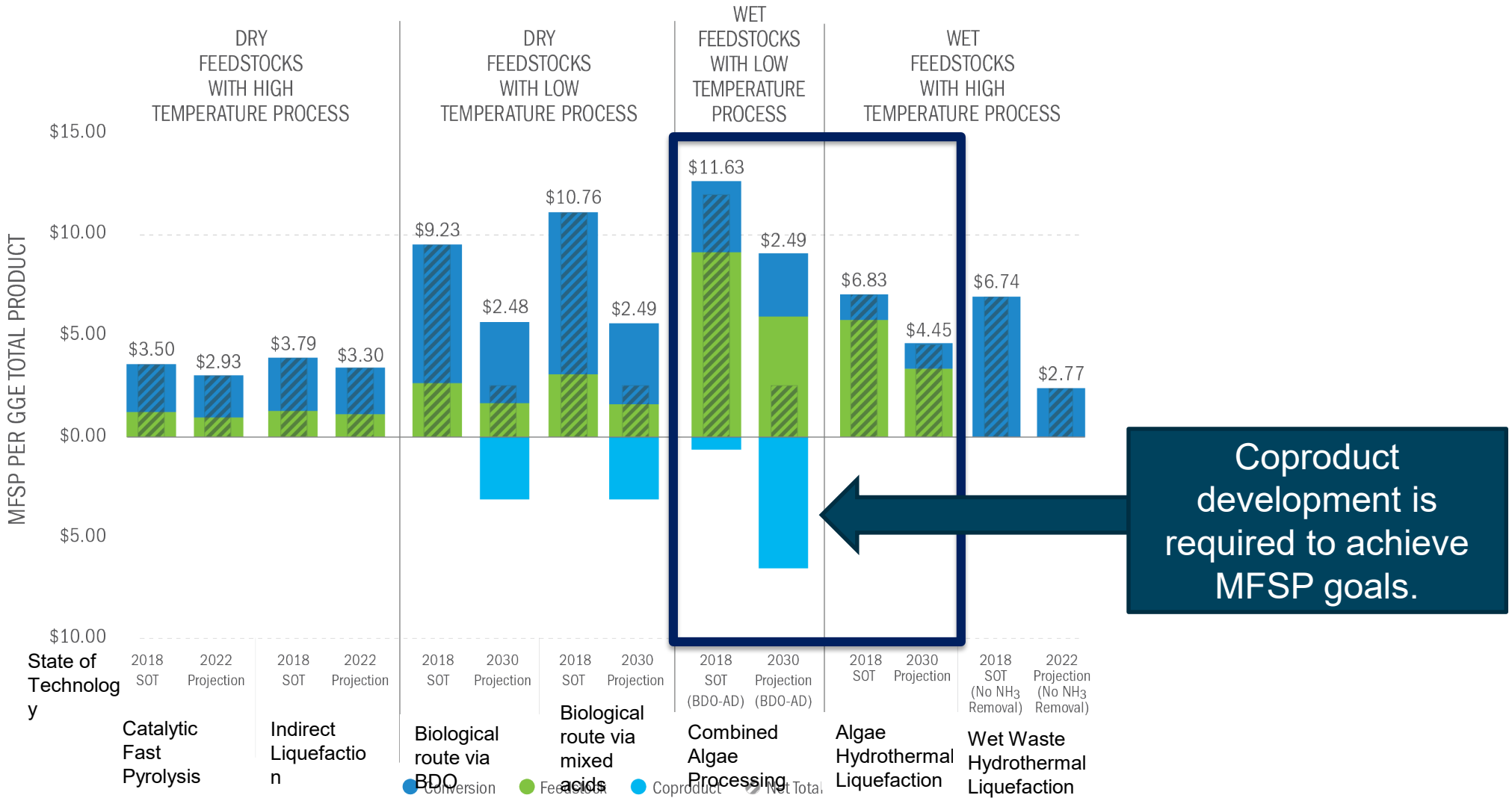
State of Technology Reports: Producing Low Cost, Low GHG Biomass Derived Fuels



Coproduct development is required to achieve MFSP goals.

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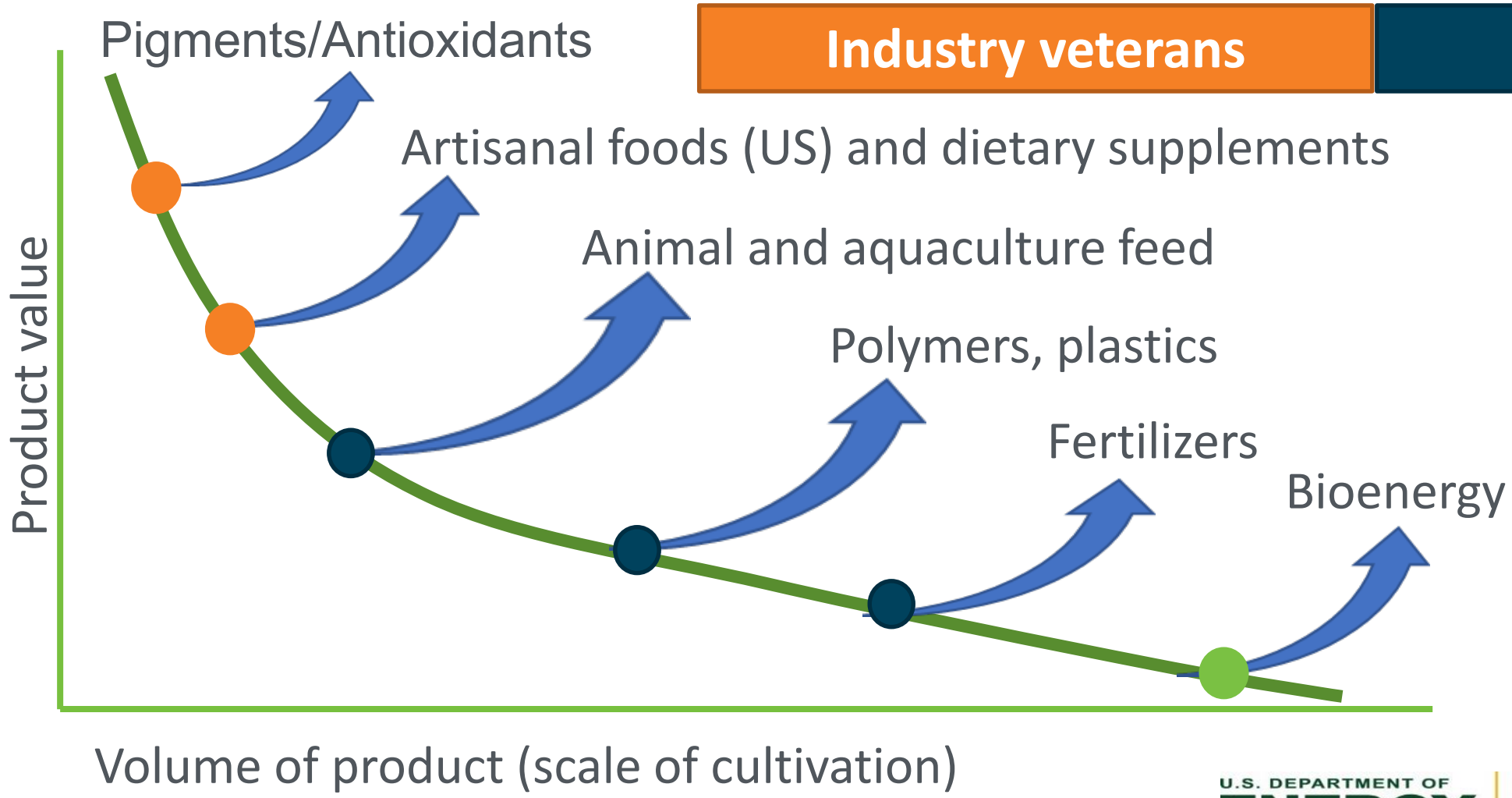
Algae's characteristics make it a versatile feedstock for multiple product markets

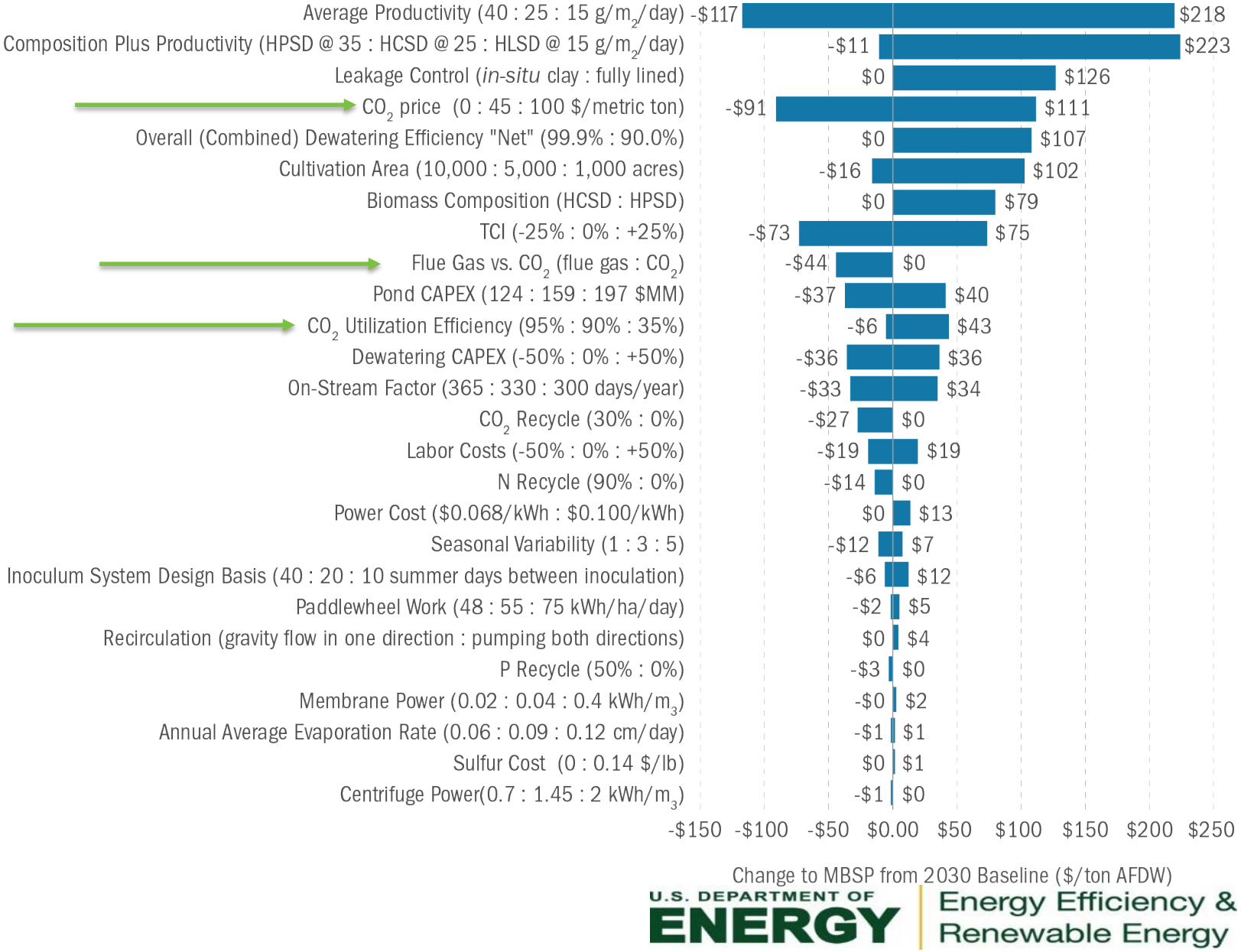
The industry has multiple stepping stones while scaling



Algae companies participating in R&D with biofuel targets; committing cost share.

Carbon Capture and Utilization – Why We Care About This in Our Portfolio

1. We have a tornado plot of variables impacting production costs.
2. Some key factors are algae productivity. We are about 50% off that goal (17 vs. 25)
3. Composition plus productivity. This is an area we are emphasizing more in our work
4. **CO2 price and utilization - this is why we care about CCU and DAC**



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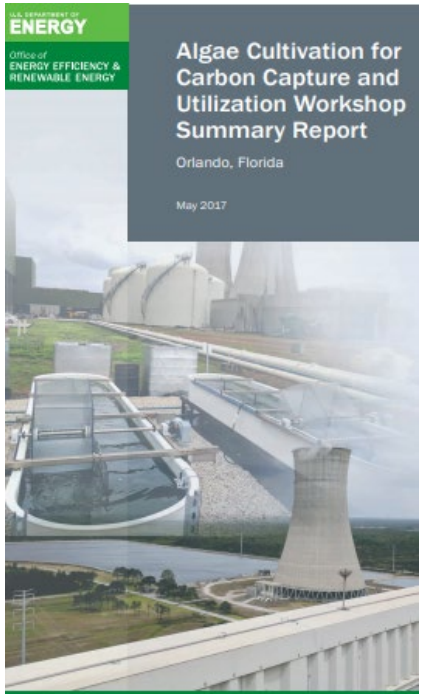
Advanced Algal Systems investment in CCU and partnership with FE

The **algae industry is an early DAC and flue gas capture adopter**
BETO has **partnered with FE on carbon utilization** algae projects to investigate both flue gas capture and direct air capture (DAC) to reduce delivered CO_2 costs and provide added value.

Selection of FOA awards that include carbon utilization from a point source and direct air capture
$2.9M

2015

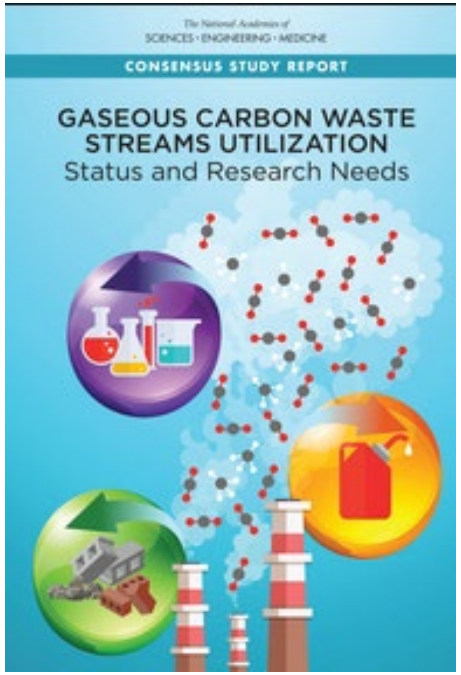


2017

ECUAS
Topic
$6.3M

45Q includes algae as a CCU technology

2018



2017-2019

Algae Bioproducts and CO2 Direct-Air-Capture Efficiency
FOA Topic
$14 Million

The IRS released a new set of regulations for the Section 45Q tax code that can award a federal investment tax credit of up to $35 per ton for carbon utilization with algae.

2020

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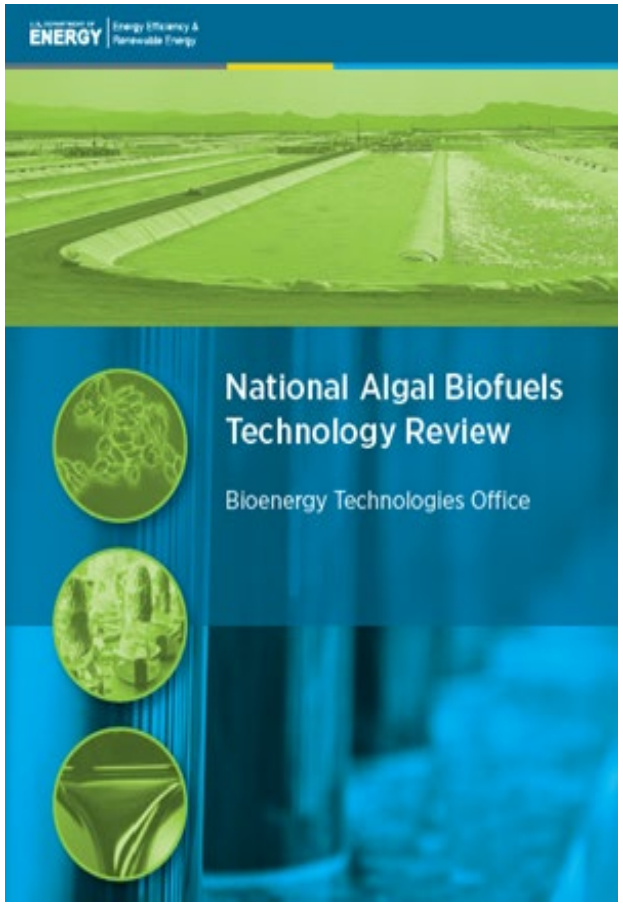
Congressional Language

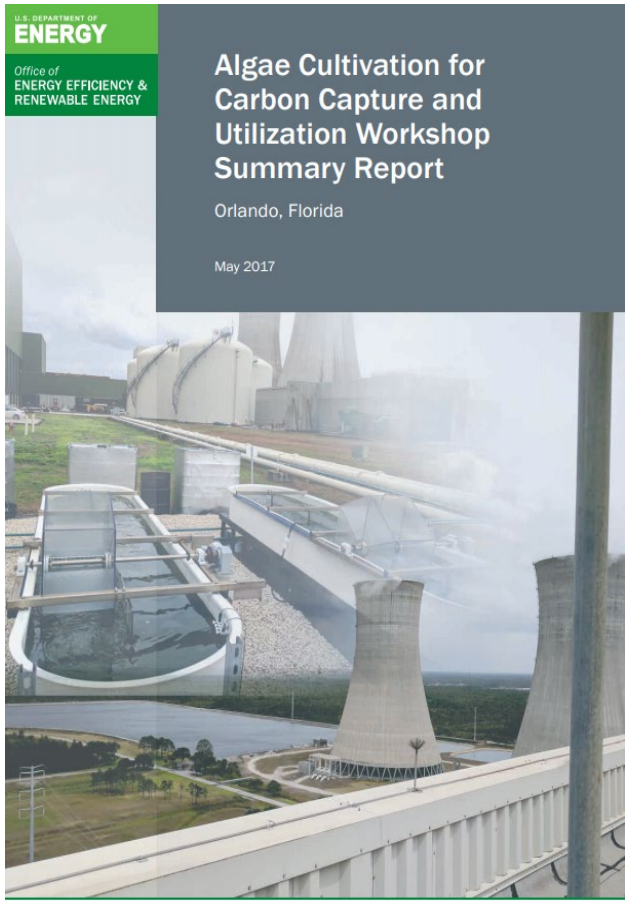
	House	Senate	Conference
FY21	The recommendation provides **$40,000,000** for advanced algal systems.		Short Term CR (Dec 11). Previous year guidance holds.
FY20	The recommendation provides **$35,000,000** for advanced algal systems.	The Committee encourages further research and development activities to support carbon dioxide capture from the atmosphere [ambient air] into highly alkaline solutions using algae-to-energy technologies. Therefore, within funds available, the Committee recommends **$10,000,000** for technology and research and development on direct air carbon capture and removal.	Within available funds, not less than **$40,000,000** is provided for Advanced Algal Systems. (Unless contradicted, House and Senate Report language stands)

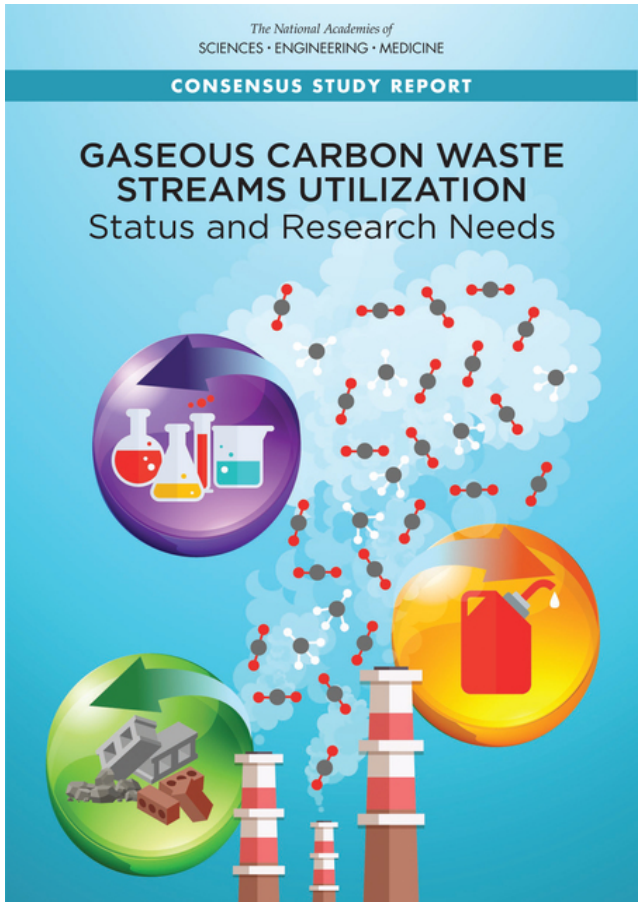
Congressional Language

	House	Senate	Conference
FY19	The recommendation provides **$32,000,000** for algal biofuels, of which **$2,000,000** is for further research and development activities to support carbon capture from the atmosphere (ambient air) using algae-to-energy technologies.	Within available funds, the Committee recommends not less than **$30,000,000** for Advanced Algal Systems to sustain the investment in development of algal biofuels.	**$32,000,000** for algal biofuels, of which **$2,000,000** is for further research and development activities to support carbon capture from the atmosphere (ambient air) using algae-to-energy technologies.
FY18		The Committee encourages FE to collaborate with BETO within EERE to support projects that utilize carbon dioxide in the production of algae and other potentially marketable products. (p84)	**$30,000,000** for algal biofuels.

Support for AAS Carbon Capture and Utilization R&D







Engineering and **biological** solutions are needed to increase the efficiencies of **CO_2 delivery** and **uptake** by the algae, and it is important to show that algae can **thrive** on these emissions while **reducing costs** of production.

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Enabling technology for algae utilization of CO_2 from DAC

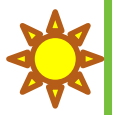
2018 BETO FOA

Technology development approaches for enabling DAC used by FOA awardees

CO_2 concentration in air is about 405ppm. Oxygen in air is **about 500 times** higher than CO_2

CO_2 Drive CO_2 into solution via chemical, biological, or engineering methods

Sunlight, nutrients, and culture management yields bountiful algae harvest



Engineering

Direct Air Capture of CO2 and Delivery to Photobioreactors for Algal Biofuel Production, $2M

Team: Georgia Tech, Global Thermostat, Algenol Biotech, NREL

Use DAC machine with amine-based sorbents to capture CO_2 and deliver to algae cultivation systems

This project will reduce algal biofuel costs and carbon intensity by using 20% or more of CO_2 from DAC and lower the cost CO_2 collection from air by developing DAC technology that utilizes improved sorbents and less intense operating conditions.

Chemically

Air Carbon for Algae Production – AirCAP, $2.2M

Team: MicroBio Engineering Inc , PNNL, Qualitas Health, Global Thermostat

Use pH of the algae cultivation system to convert CO_2 into a more soluble species

Direct mass-transfer of air-CO_2 into algal ponds is limited by diffusion of CO_2 at the air-water interface and the subsequent slow hydration of dissolved CO_2 into carbonic acid. This project will focus on accelerating transfer from air CO_2 into ponds at high pH, as well as biological and physical methods.

Biologically

Enhanced Algal Production of CA for Improved Atmospheric Delivery of CO_2 to Ponds, $2M

Team: J. Craig Venter Institute, Global Algae Innovations, Cal Poly San Luis Obispo

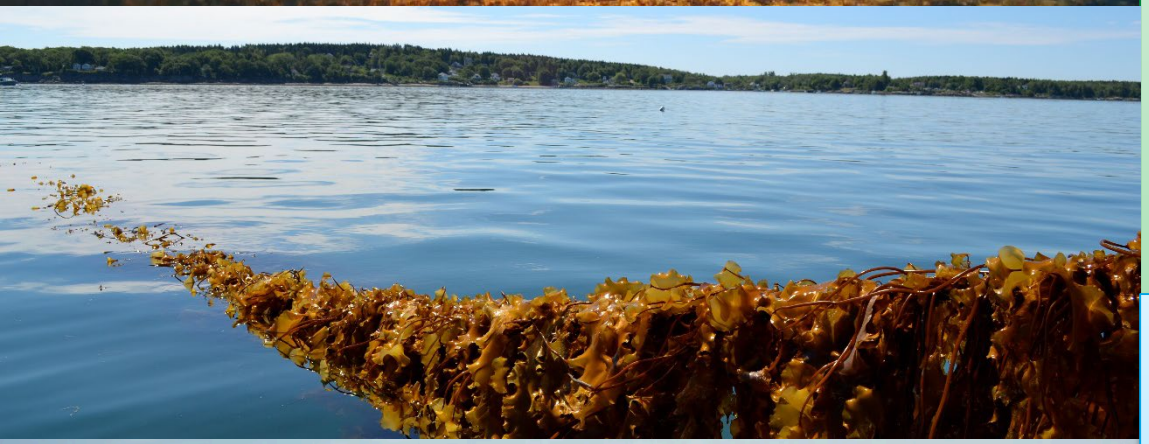
Use a biologically produced enzyme to catalyze CO_2 into a more soluble species

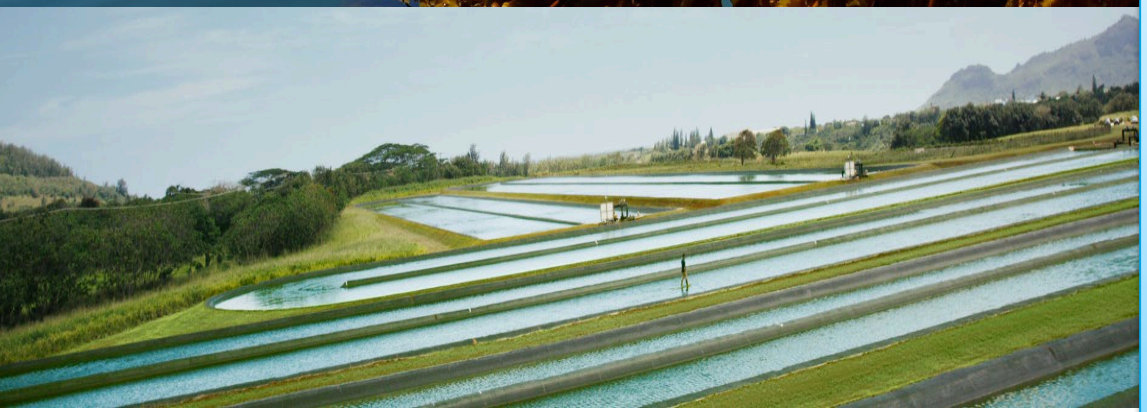
This project will utilize carbonic anhydrase (CA) to catalyze hydration of dissolved CO_2 to bicarbonate, thereby enhancing delivery of atmospheric CO_2 to the growth medium. Commercial CA use is cost-prohibitive at scale, therefore algal-derived extracellular CA production will be evaluated through the generation of transgenic lines.

Enabling technology for algae utilization of CO_2 from DAC

Algae Bioproducts and CO2 Direct-Air-Capture Efficiency FOA Topic Selections	
Production of Algae Biofuel and Bioproducts with CO2 Direct Air Capture	Global Algae Innovations
Transforming High pH/High Alkalinity Cultivation through Beneficial Microbiomes and Improved Pond Design	Montana State University
ASU's Polymer-enhanced Cyanobacterial Bioproductivity (AUDACity)	Arizona State University
Biomolecular Films for Direct Air Capture of CO2	University of California - San Diego
Microalgae Commodities Production with a Direct Air Capture Process	MicroBio Engineering, Inc.
Alkaline Carbon Capture and Expression-Streamlined Spirulina Cultivated in Air for Reliable Bioproducts, Oil, and Nutrition	Lumen Bioscience, Incorporated
Development of High Value Bioproducts and Enhancement of Direct-Air-Capture Efficiency with a Marine Algae Biofuel Production System	Duke University

Thank you, questions?





Useful reports

Federal Activities Report on the Bioeconomy: Algae

2019 BIOENERGY TECHNOLOGIES OFFICE 2019 R&D State of Technology

2017 Algae Harmonization Study: Evaluating the Potential for Future Algal Biofuel Costs, Sustainability, and Resource Assessment from Harmonized Modeling

2016 National Algae Technology Review

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