U.S. DEPARTMENT OF ENERGY

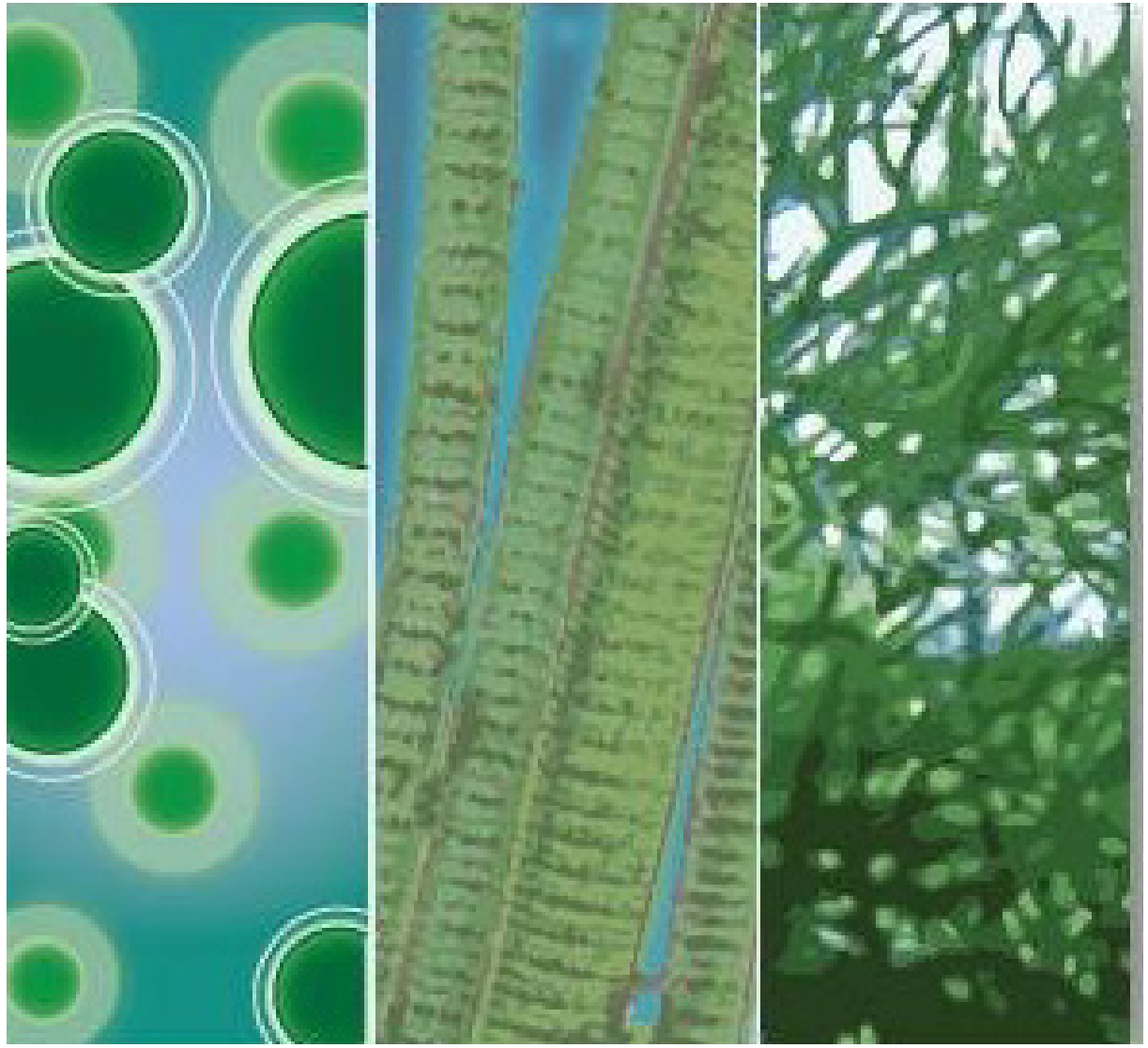
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Advanced Algal Systems

Nichole Fitzgerald, Program Manager

March 8, 2021

Advanced Algal Systems Overview



- The Team
- Why algae?
- Challenges
- Program goals
- Program structure
- Budget
- Funding types
- Key accomplishments
- Engagement
- Reviewers

Advanced Algal Systems Team

Nichole Fitzgerald
Program Manager

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Technology Manager

Devinn Lambert
Technology Manager

Christy Sterner
Technology Manager

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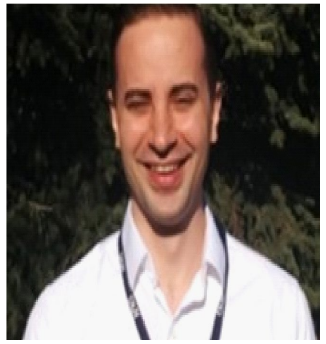
AAAS Fellow

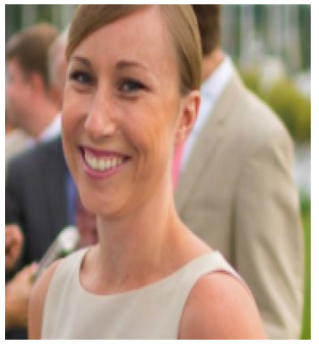
Ty Robinson
Business Support

Phil Lee
Verification Lead
Project Monitor



Evan Mueller
Project Monitor

Jesse Glover
Project Monitor



Colleen Tomaino
Project Monitor

Why Algae?

Productivity 4 times as dense as corn. Biofuel yield 8-13 times larger. Can grow on brackish and saline water.

Corn

Productivity: 4.22 tons/acre;

Conversion quality: 77 GGE/ton

Fuel yield: 326 GGE/ton

Algae

Productivity: 20 (current)- 33 (potential) tons/acre;

Conversion Quality: 85-120 GGE/ton,;

Fuel yield potential: 2,837- 4,000 GGE/acre

45 acres of cultivation on marginal land in Imperial, Texas, with water drawn from a hyper-saline aquifer. Photo: Qualitas

Convert carbon emissions into market opportunities

Demonstration testing of direct flue gas injection into a filamentous algae open system operated by the Orlando Utilities Commission at the Stanton Energy Center and MicroBio Engineering Inc. Photo by MicroBio Engineering Inc. Funding by Office of Fossil Energy.

Improve nitrogen and phosphorous recovery from point and dilute sources

Near term ecosystem services
Credit: Clearas Water Recovery

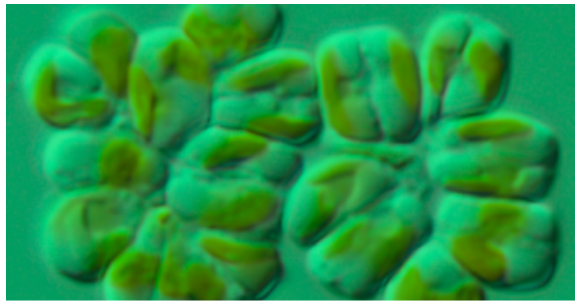
900 foot algae turf scrubber cleaning impaired water in California
Credits SNL

Advanced Algal Systems Program

Strategic Goal: *Develop technologies that enable production of environmentally sustainable algal feedstocks that perform reliably in conversion processes to yield renewable fuel blendstocks, as well as bioproducts and chemical intermediates. Developing algal feedstocks and processes to achieve BETO's goals requires technology breakthroughs along the entire algal supply chain.*

Priorities:

- Develop biology and culture management approaches to increase algal productivity.
- Develop low-cost, scalable cultivation and harvesting systems *that reduce costs and impacts* by minimizing the use of energy, water, land, and nutrients.
- Perform integrative analysis to evaluate impacts on overall yield and identify critical barriers to developments in biology, cultivation, and processing.
- Investigate high-value co-products that can be produced along with biofuels.



Verify laboratory improvements outdoors at increasing scales

Major Goals: FY2021 - FY2030

By 2021, develop strain improvement toolkits and technologies that enable algae biomass compositions in environmental simulation cultivation conditions that represent an energy content and convertibility of 80 GGE of biofuel per AFDW ton of algae biomass.

By 2023, develop technologies that enable mature modeled algae yields of 30 tons ash-free dry weight algae biomass per acre per year with conversion yields of 80 GGE per ton of biomass.

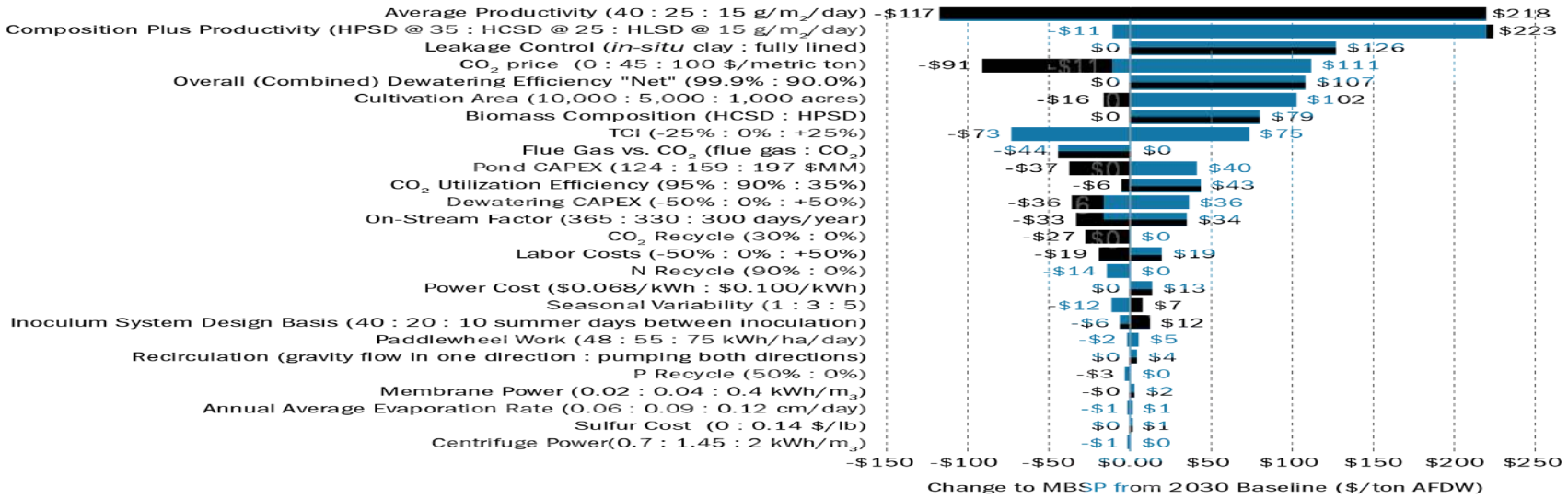
By 2025, increase the summer seasonal areal productivity to 25 grams per square meter per day ($g/m^2/d$) from the 2018 benchmark of 13.3 $g/m^2/d$.

By 2030, deliver technologies that enable the verification of integrated systems research at engineering scale for hydrocarbon biofuel technologies at mature modeled MFSP of $2.50/GGE.

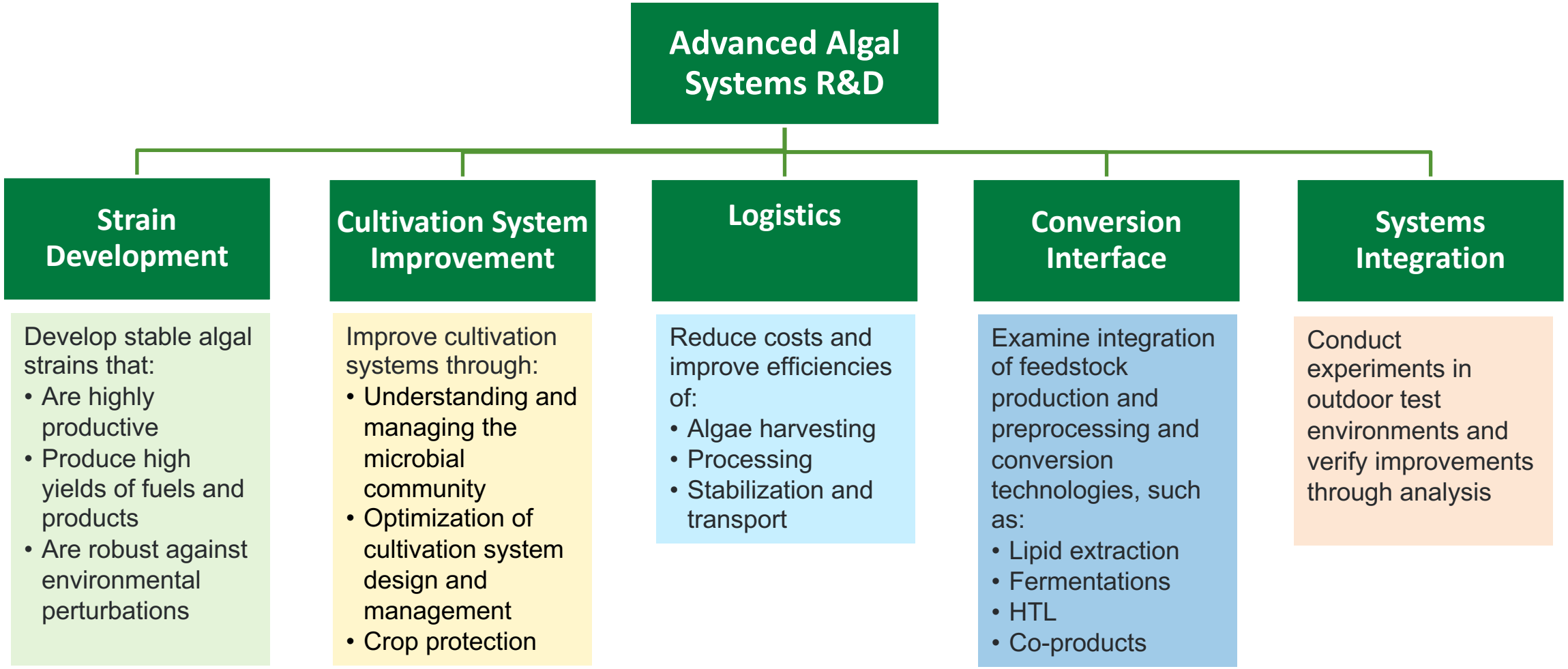
Ruth Spierling from MicroBio Engineering taking samples from outdoor test raceway ponds at a wastewater treatment plant in San Luis Obispo.

Phenometrics ePBRs which allow researchers to simulate outdoor conditions in the laboratory.

Sensitivity Plot for Algae Biomass Costs



Program Structure



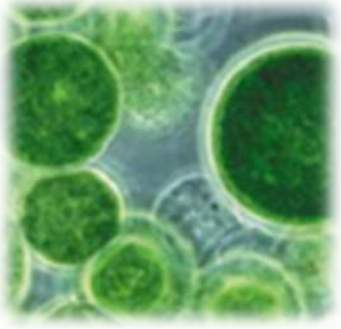
Program Structure: Strain Improvements

Advanced Algal Systems R&D

- **Strain Development**
- **Cultivation System Improvement**
- **Logistics**
- **Conversion Interface**
- **Systems Integration**

Develop stable algal strains that:

- Produce high yields of fuels and products
- Highly productive
- Robust against environmental perturbations



Program Structure: Cultivation System Improvements

Advanced Algal Systems R&D

- Strain Development
- **Cultivation System Improvement**
- Logistics
- Conversion Interface
- Systems Integration

Improve cultivation systems through:

- Understanding and managing the microbial community
- Optimization of cultivation systems and design management
- Crop protection

Program Structure: Logistics RD&D

Advanced Algal Systems R&D

- Strain Development
- Cultivation System Improvement
- **Logistics**
- Conversion Interface
- Systems Integration

Reduce costs and improve efficiencies of:

- Algae harvesting
- Processing
- Stabilization and transport

Utah State University

ASU Arizona State University

INL Idaho National Laboratory

Program Structure: Conversion Interface

Advanced Algal Systems R&D

- Strain Development
- Cultivation System Improvement
- Logistics
- Conversion Interface
- Systems Integration

Examine the integration of feedstock production and preprocessing and conversion technologies, such as:

- Lipid extraction
- Fermentations
- Hydrothermal liquefaction
- Co-products development

μBIO MicroBio Engineering

UC San Diego

Sandia National Laboratories

Duke University

Pacific Northwest National Laboratory

NREL National Renewable Energy Laboratory

LUMEN BIOSCIENCE

Global Algae Innovations

ASU Arizona State University

Montana State University

Photo courtesy of PNNL

Program Structure: Systems Integration

Advanced Algal Systems R&D

- Strain Development
- Cultivation System Improvement
- Logistics
- Conversion Interface
- Systems Integration

New Mexico Consortium

Colorado School of Mines

ASU Arizona State University

Argonne National Laboratory

NREL National Renewable Energy Laboratory

Pacific Northwest National Laboratory

MicroBio Engineering

Duke University

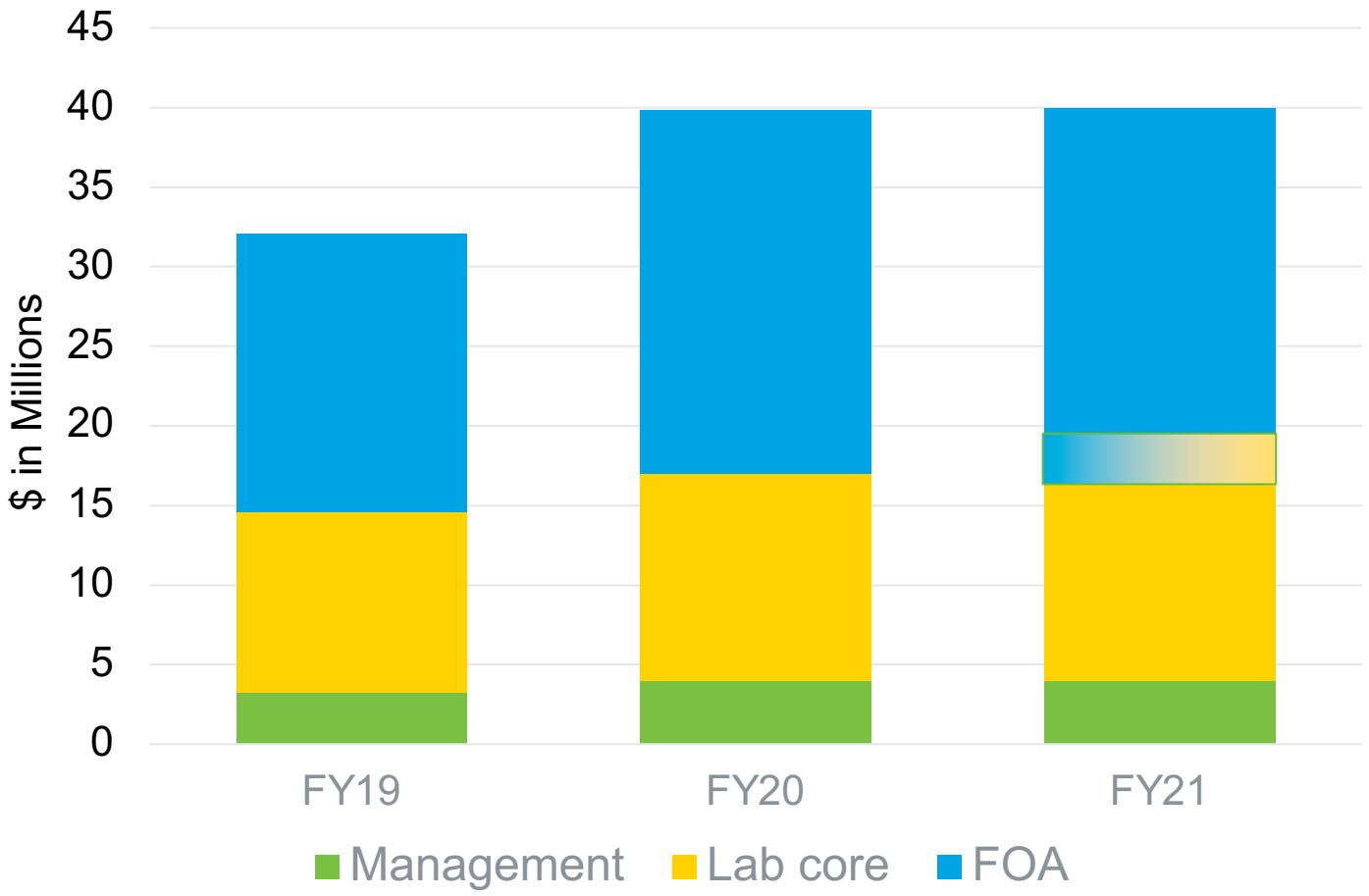
The University of Arizona

University of Illinois Urbana-Champaign

Global Algae Innovations

Conduct experiments in outdoor test environments, as part of an iterative development process, and verify improvements through analysis projects

Budget: FY19 – FY21



National Laboratory Core R&D

- The Program funds **foundational research & development** through its national laboratory partners.
- This funding aligns with national laboratory **core competencies.**
- Labs **collaborate** heavily within this core portfolio, as well as with competitive funding recipients.
- **Novel concepts** can be initiated easily within the “seed” program for minimal initial investment.

Los Alamos NATIONAL LABORATORY EST. 1943

Lawrence Livermore National Laboratory

Berkeley Lab

Sandia National Laboratories

Pacific Northwest NATIONAL LABORATORY

NREL NATIONAL RENEWABLE ENERGY LABORATORY

INL Idaho National Laboratory

Advanced Biology

Algae Cultivation

Conversion Interface

Resource Assessment

Techno-economics

Logistics

Competitive Funding

- The Program annually supplements Core R&D with open and competitive funding through EERE Funding Opportunity Announcements (FOAs)
- Relatively large awards encourage partnership within the algal biofuels community
- Multi-year project work allows for research during multiple growing seasons
- This funding allows for robust outdoor validations at commercially-relevant scales

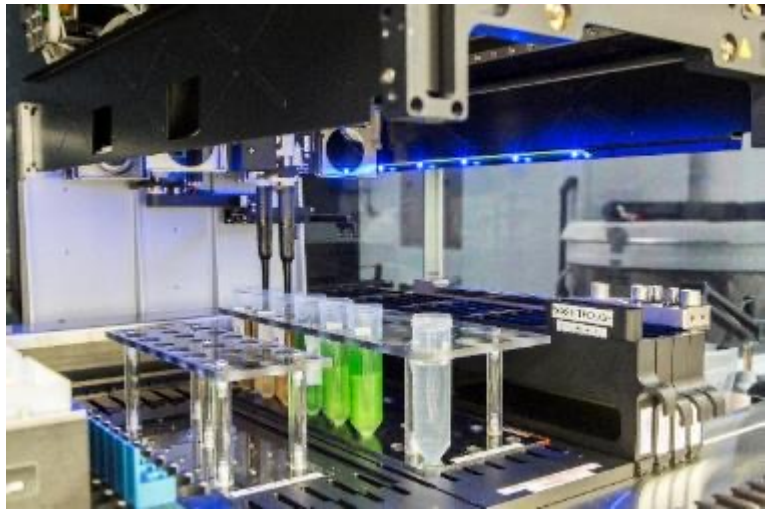
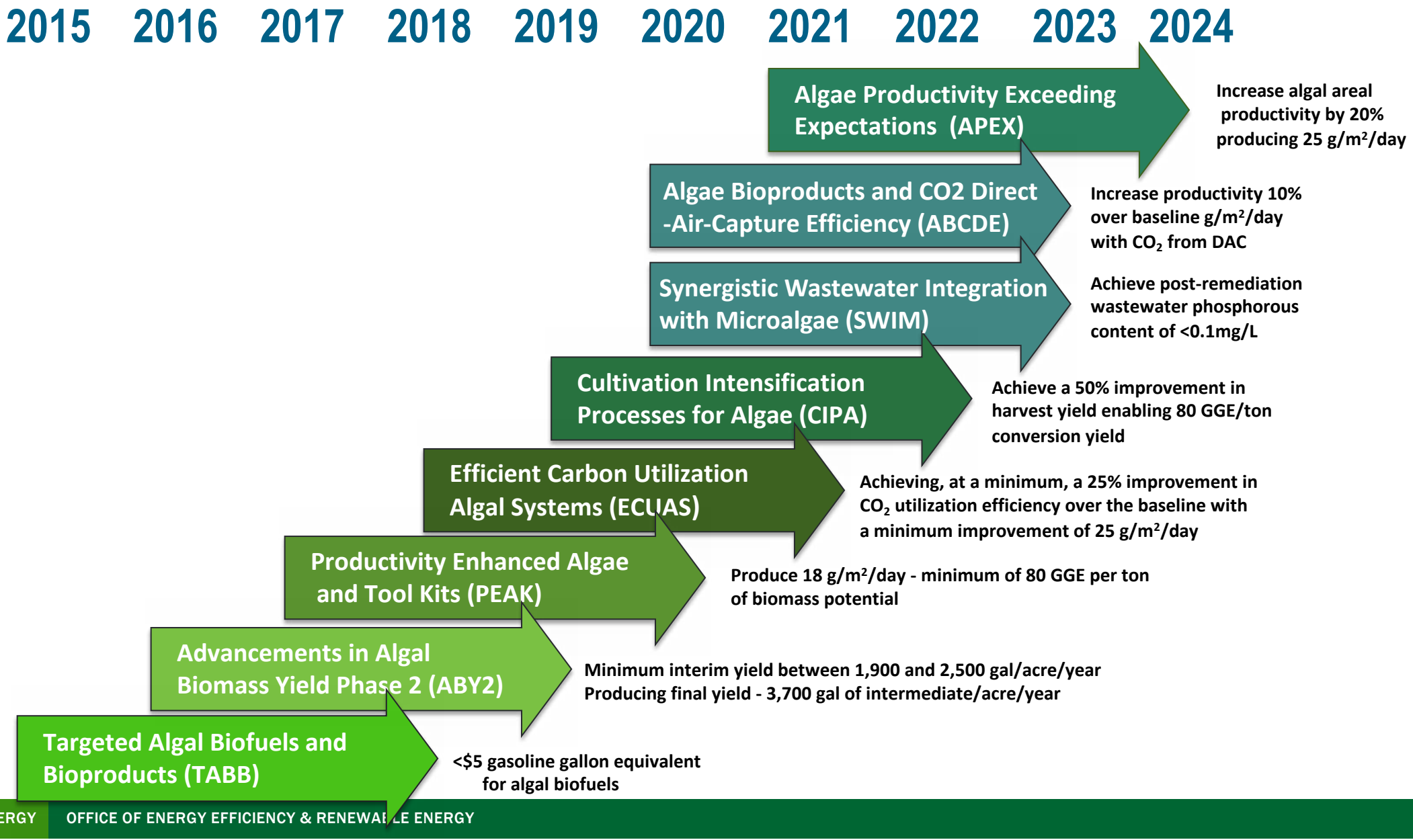


Photo courtesy Global Algae Innovations

University of Arizona's RAFT testbed in Tucson, AZ

Funding Opportunity Announcements



Key Accomplishments

Global Algae Innovations

- Direct air capture supports 20-30 g/m^2/d for \$8/ton CO_2
- Open raceway contamination control with 99.95% reduction in area and cost for inoculum
- Zobi harvester produces up to 20% algae slurry and crystal clear permeate using 0.05 kWh/m^3

Zobi Harvester at Qualitas Facility; picture courtesy of Global Algae

DISCOVR

- Fall 2020 (FY21) formal SOT seasonal average was 19.3 g/m^2/day compared to 15.0 g/m^2/day for Fall 2019 (FY20), **an increase of 28.7%.**
- Demonstrated improvement of greater than 20% in simulated AZ summer season biomass productivity of *P. celeri*

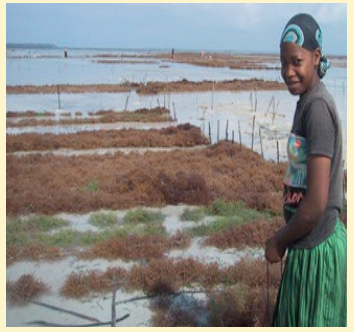
Scenedesmus cultivation; Arizona Center for Algae Technology and Innovation

Key Accomplishments

31% higher outdoor productivity by an improved *Scenedesmus obliquus* vs. wild type.

- New isolate *Tribonema minus* monoculture had higher productivity than a native polyculture (prior leading producer). *T. minus* is filamentous; harvested by screens.
- In g/m^2/d annual average: **17.1** *Tribonema,* **13.3** polyculture, vs. **9.1** BETO 2016 SOT.

Covid-19 Pivot
Conversion of Algae Academy (K-12) to online; for 2020-2021 more than 250 schools and 35,000 students to be served; conversion of college face to face courses to online lectures and intensive face to face laboratories



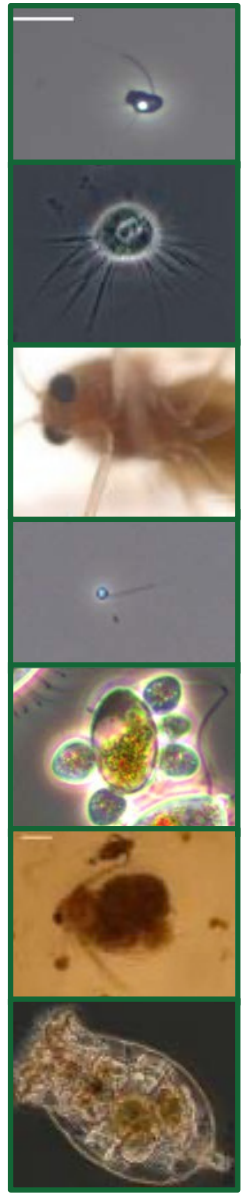
Massive Open Online Courses (MOOCs): MOOC #1 Introduction to Algae > 16,500 enrollees. MOOC #2 Introduction to Algae Biotechnology > 500 enrolled (3 weeks on Coursera.org platform)

Established partnership with the Future Farmers of America (FFA) and its 760,000 members to introduce algae as a crop and STEM curricula

Examples of Stakeholder Engagement

Barriers to Scale: Algae Crop Protection Workshop

- AAS is seeking stakeholder input on crop protection, a significant barrier to scaling the algae industry
- Register for free now! Event will be virtual, April 20-21, 2021
- Keynote, Panel Presentations + Q&A, Breakout Sessions, Networking
- Day 1, 11:00 – 4:30 (ET)
  - Keynote Presentation – Barry Goldman, Pluton Biosciences
  - Session #1 – Current State of Crop Protection
  - Session #2 – Alternative Crop Protection Approaches to Chemicals and Pesticides
- Day 2, 11:00 – 4:30 (ET)
  - Session #3 – Pest Models: Understanding Pest Life Cycles and Infection Mechanisms
  - Session #4 – Current and Future Pest Monitoring Practices
  - Session #5 – Developing Scalable, Economic, and Consumer- Accepted Pest Management Practices



The Advanced Algal Systems Peer Reviewers – Thank You!

Jaime E. Moreno, PE
Managing Principal
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Rumley Assoc. Prof.
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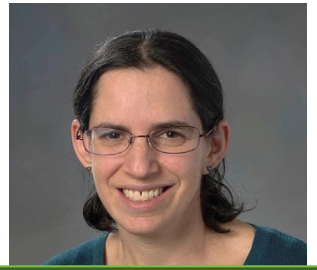

Linda Rauch, Process
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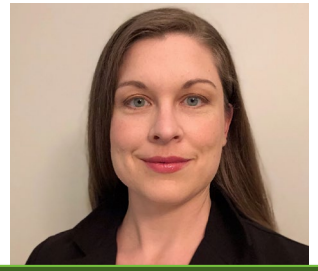
Next Rung Technology



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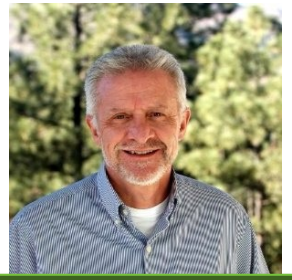

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Project Manager
Pebbles Lab

Ify Oranugo
Associate Director
Homology Medicines, Inc

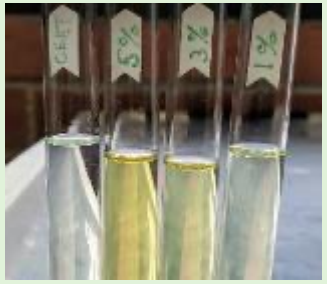
Lora Cameron-Landis
Sr Technical Lead Strategic Growth
Initiatives, Lonza Biologics


Thank you!

Key Accomplishments

Producing Algae for Coproducts and Energy Algal Biofuel from Field to Engine

Reliance Industries Ltd. Algal Ponds – largest raceway ~1 km.
Average annual productivities during PACE project ~23 g/m^2/d



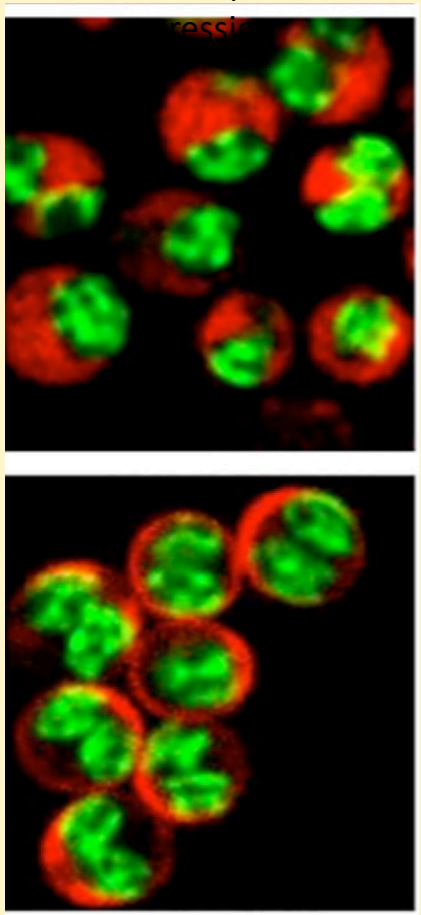
Biocrude produced by RIL was hydrotreated at Pacific Northwest National Laboratory (*Anderson Laboratory*) but NOT fractionated. Blended up to 5% with certification diesel.

Diesel Engine Testing at Colorado State University (Marchese Laboratory). Undistilled, hydrotreated HTP fuel produced from algal biomass can be blended to 5% without negatively affecting engine performance. Higher levels not yet tested.

Algae Biotechnology Partnership

- *Picochlorum renovo* is a robust algae strain with high growth rate, salinity, and temperature tolerance
- Strain isolation, genome sequencing, transformation tools developed through DOE funded projects
- Genome analysis identified native signal peptides
- Robust protein secretion tools are now being applied to other projects in the portfolio

Intracellular mCherry fluorescent protein



Secreted mCherry fluorescent protein

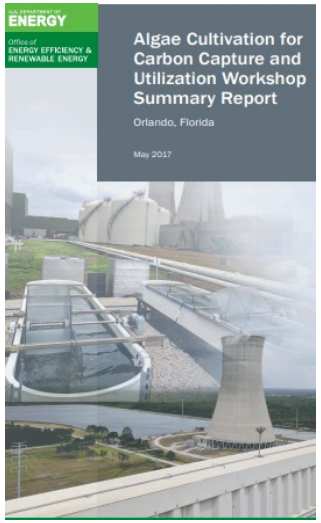
Advanced Algal Systems Investment in CCU and Partnership with FE

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

2015

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

2017

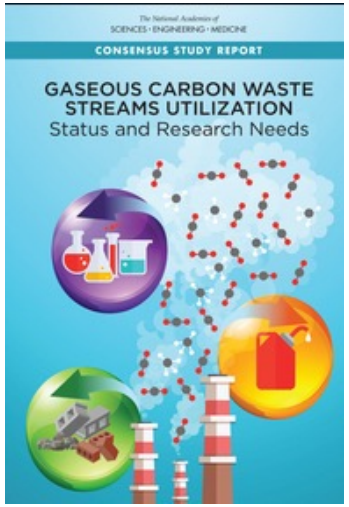


2018

ECUAS Topic language developed with input from FE

45Q includes algae as a CCU technology

2017-2019



2020

ABCDE
Scoping on FOA discussed with FE
FE reviewer
FE Federal Consensus Board

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.