# DOE Bioenergy Technologies Office (BETO)

# 2023 Project Peer Review

# Enhanced Algae Productivity in $CO_2$ Direct Air Capture

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Technology Area Session

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# Global Algae Innovations
## *Algae Solutions to Global Dilemmas*

### Vision

Harness the unparalleled productivity of algae to provide food and fuel for the world, dramatically improving the environment, economy, and quality of life for all people

- Founded Dec 2013
- Algae for commodities
- Technology development in 8-acre Kauai Algae Farm
- Radical advances throughout the entire process
- Selected as XPRIZE Carbon Removal milestone award winner in 2022
- Scaling–up suite of novel technologies in new San Luis Obispo County Farm

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# Project Overview – Goals

- **Develop improved strains and cultivation methods for open raceways with all $CO_2$ supplied via direct air capture**
  - 17.8 to 18.9 g/m$^2$d annual average productivity with 35% to 45% lipid content in outdoor cultivation based on quarterly trials
  - Public toolkit for new strain evolution method
  - Public genomic and transcriptomic data sets on wild-type and improved strains
  - Cultivation methods consistent with overall process that achieves
    - $2.50/gallon of gasoline equivalent (GGE) for biofuel intermediate at 5,000-acres
    - 90% GHG reduction for biofuel relative to petroleum fuels
    - 85% reduction in water use relative to soy protein

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# Project Overview – Context and History

- **Multiple prior directed evolution projects with several universities**
  - Achieved remarkable improvements in productivity in indoor photobioreactors
  - Has not yet translated to similar levels of improvement in outdoor cultivation
  - Has not yet been done with strains under direct air capture cultivation conditions
- **Genetic basis of phenotype improvements is very complicated**
  - Limited data sets available for wild-type vs improved strains with higher productivity
  - Many contributing factors, so need broad data set to get full picture
- **Over 100 ways to increase productivity through cultivation methods**
  - Many are too expensive or to energy intensive, such as most  closed photobioreactors
  - All advances must be constrained through detailed techno-economic analysis (TEA)
  - Planning 20 patent applications this year on cultivation advances from other projects

# Approach

- **TEA constrained**
  - Update TEA throughout for decision making and analysis of improved cultivation method

- **High performance starting strain**
  - Global Algae's improved *Nitzschia inconspicua*
  - High productivity under direct air capture cultivation conditions
  - High lipid content in outdoor cultivation
  - Robust outdoor growth with no culture crashes
  - Wide range for pH, temperature, salinity, and dissolved oxygen tolerance

- **Quarterly productivity trials and milestones**
  - Thermal control to match Paso Robles area (where the process scale-up is underway)
  - Best strain and cultivation conditions to-date
  - Generate annual productivity and regular data on progress toward overall goals

# Approach - continued

- **New directed evolution approach**
  - Based on extensive prior experience with universities and national laboratories
  - Focus on improvement in outdoor open raceways
  - Genomic and transcriptomic data for starting and improved strains
  - Cryogenic storage of improved strains
  - Budget period 2 – four individual traits; incremental milestones for each trait
  - Budget period 3 – trait stacking; incremental milestones for productivity and lipid content

- **New cultivation method**
  - Based on observation of previously untapped cultivation productivity with a cultivation method
  - Budget period 2:
    - Nine key variables, 7 week of testing on each
    - 3 weeks optimization, 2 week comparison with control
    - 2 week margin for weather or unanticipated issues
  - Budget period 3: Optimization through combinations of the nine key variables

# Approach – Testing in Outdoor, Open Raceways

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# Approach – Challenges and Risk Management

- **Key Technical Challenges**
  - Translating strain trait improvements to outdoor cultivation
  - Trait stacking
  - Optimization of many variables for the improved cultivation methods
  - Thermal control in raceways to simulate temperature climate

| Risk | Mitigation |
|---|---|
| Translation laboratory strain improvements to outdoor cultivation | A main focus of the project with numerous mitigations that will be tested and reported on when the new stain evolution method is published |
| Inadequate thermal control | Early design support tests to verify control can be achieved |
| Cultivation improvements are not economical | Updated TEA maintained throughout the project for evaluation of results and decision-making on changes in approach |
| Trait stacking cannot be achieved | Work from both directions on the improved stains; maintain pressure for the prior improvement while trait stacking |

# Progress and Outcomes - Overview

- **Project currently in equipment installation and checkout phase**
- **Verification results**
  - Baseline productivity of 15.6 g/m$^2$d with 37% lipid content in Kauai, adjusted: 14.8 g/m$^2$d
  - Solid basis for new strain evolution approach and cultivation methods
  - TEA projects cost and life cycle targets will be met by successful technical results
  - Risk management and mitigation approaches are adequate
- **Equipment design, procurement installation**
  - Systems 90% installed and partially checked out
  - Waiting on final equipment due to arrive in April
- **Preliminary testing with older systems**
  - Promising initial results on cultivation methods with direct air capture
  - 3 patent applications anticipated this year prepared based on initial results

# Progress and Outcomes – TEA Summary

**Production Cost (2023 $)**

| System | Capital ($/mt)* | Operating ($/mt)** | Total ($/mt) |
|---|---|---|---|
| Laboratory | 10 | 0 | 10 |
| Nutrients | 58 | 150 | 207 |
| CO2 supply | 10 | 30 | 40 |
| Cultivation | 310 | 47 | 356 |
| Harvesting | 94 | 40 | 134 |
| Drying & Extraction | 89 | 120 | 219 |
| Fractionation | 171 | 151 | 322 |
| **Total** | **705** | **537** | **1242** |

**Product Selling Price (2023 $)**

| Market | Fraction (% AFDW) | Selling Price ($/mt) | Composite ($/mt) |
|---|---|---|---|
| Biofuel | 17% | 825 | 140 |
| Polymer | 17% | 2300 | 390 |
| Omega-3 feed | 6% | 4200 | 250 |
| Glycerin | 5% | 1100 | 60 |
| Protein Conc. | 12% | 1800 | 220 |
| Aquafeed meal | 43% | 800 | 340 |
| **Total** | **100%** | | **1400** |

* Capital charge factor of 13.27% based on minimum internal rate of return of 8%
** Solar electricity estimated at $0.30/kWh

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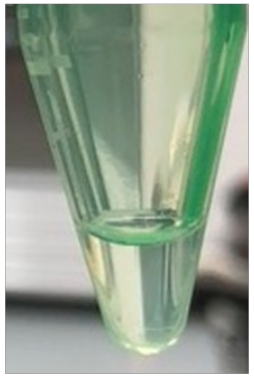
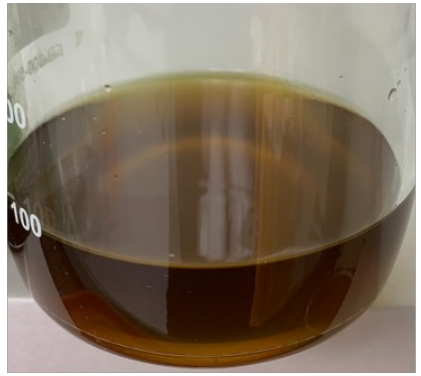
# Progress and Outcomes – Products

**Protein Meal**





**Algae Oil**

Food Ingredients

Feed Ingredients

**Consumer Products**


**Jet fuel, diesel, and gasoline**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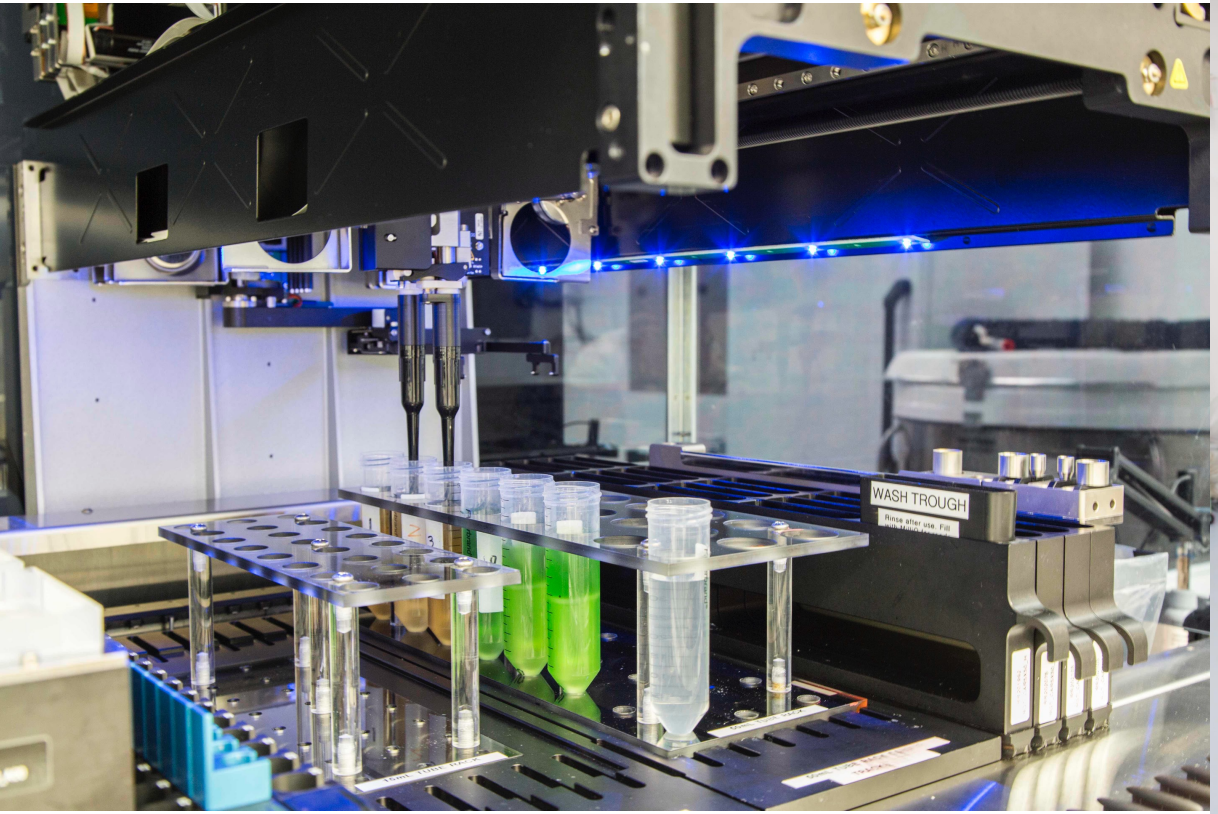
# Progress and Outcomes – Robotic system upgrade

Doubled throughput and added scheduling for additional processing time





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# Impact

- Higher productivity and lipid content will accelerate commercialization of algal biofuels by improving economics and life cycle
- Quarterly productivity data will support BETO state of technology analyses
- New directed evolution toolkit for strain improvement that is more applicable to outdoor, open raceway cultivation
- New cultivation method for improved productivity and lipid content
- Genomic and transcriptomic data sets on improved strains versus wild-types

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# Summary

- **Accelerate commercialization**
  - Improved strains and cultivation methods for higher productivity and lipid content
  - Temperature profiles match scale-up location
  - Improved strains and methods will be used immediately at multi-acre scale
- **New toolkits and data to support algae industry and research**
  - New directed evolution method that generates strains with improved productivity in outdoor, open raceway cultivation
  - Genomic and transcriptomic data sets on wild-type and strains with improved traits
- **Status**
  - Equipment design, procurement, installation and checkout nearly complete
  - Test program will start in late spring or early summer
  - Preliminary testing has resulted in plans for 3 patent applications

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# QUAD Chart Overview

## Timeline

- *BP2 start date: April 2022*
- *Project end date: June 2025*

| | FY22 Costed | Total Award |
|---|---|---|
| DOE Funding | $245,000 | $3,200,000 |
| Project Cost Share | $61,000 | $800,000 |

TRL at Project Start: 3
TRL at Project End: 5

## Project Goal

*Develop improved strains and cultivation methods that increase the productivity by at least 20% with all $CO_2$ supplied by direct air capture and at least 35% lipid content. Measure productivity quarterly in triplicate, two-week tests.*

## End of Project Milestones

- 20-25% increase in productivity (target, stretch)
- 35-45% in lipid content (target, stretch)
- Public genomic and transcriptomic data sets
- Public toolkit for new strain evolution method
- $2.50/GGE biofuel intermediate at 5000-ac
- 90% GHG reduction relative to petroleum
- 85% water use reduction relative to soy protein

## Funding Mechanism

FY21 Feedstock Technologies and Algae FOA

**Project Partners:**

- Hamilton Robotics

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# Additional Slides

# Responses to Previous Reviewers' Comments

- **Not previously reviewed**

- **Go/No-Go Review - Verification**
  - Baseline data: 15.6 g/m$^2$d productivity with 37% lipid
  - Adjusted to 14.8 g/m$^2$d for San Luis Obispo County (greater temperature variation but higher solar)
  - Extensive review of new directed evolution approach and basis for likely translation to improved productivity in outdoor, open raceways
  - Extensive review of cultivation method improvement approach

# Publications, Patents, Presentations, Awards, and Commercialization

- None to date
- Planning 3 patents from preliminary results
- Plan to utilize improved strains and cultivation methods in two separate scale-up projects beginning later this year