DOE Bioenergy Technologies Office (BETO)

2021 Project Peer Review

Innovations in Algae Cultivation

3/11/2021

Advanced Algal Systems

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Global Algae Innovations

Global Algae Innovations

Algae Solutions to Global Dilemmas

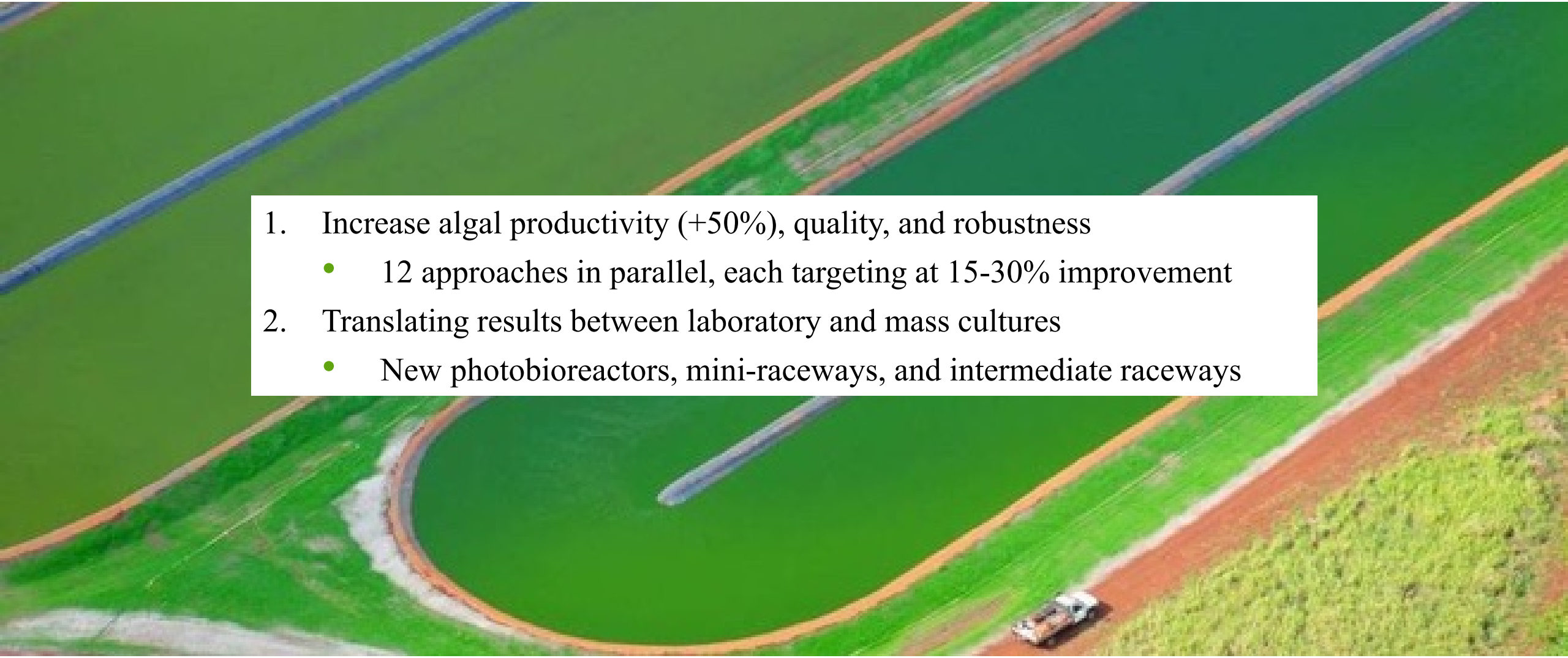
Vision

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
- Radical advances throughout the entire process
- Successful technology development in 8-acre farm
- Scaling –up now with design for 160-acre farm

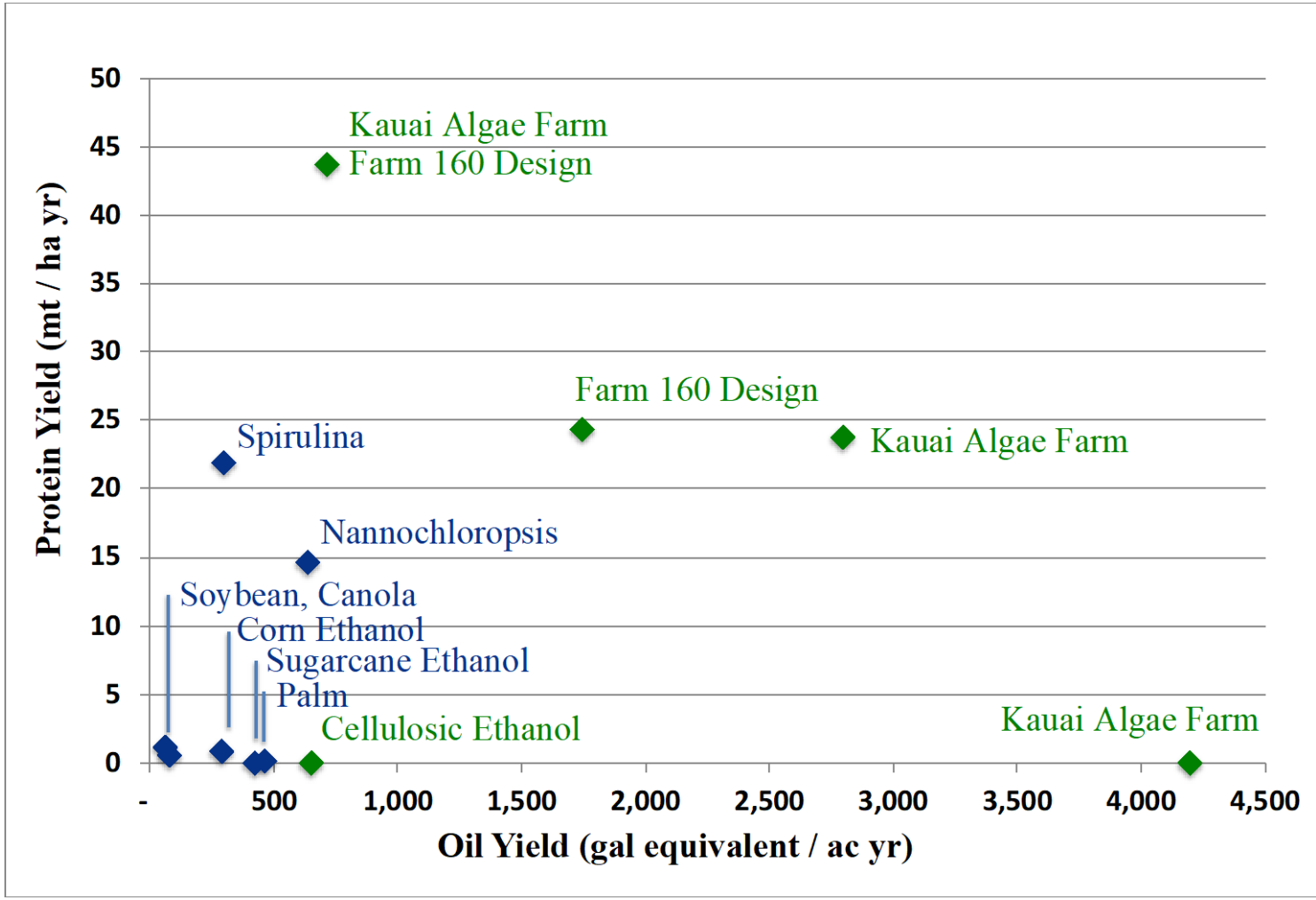
GLOBAL ALGAE

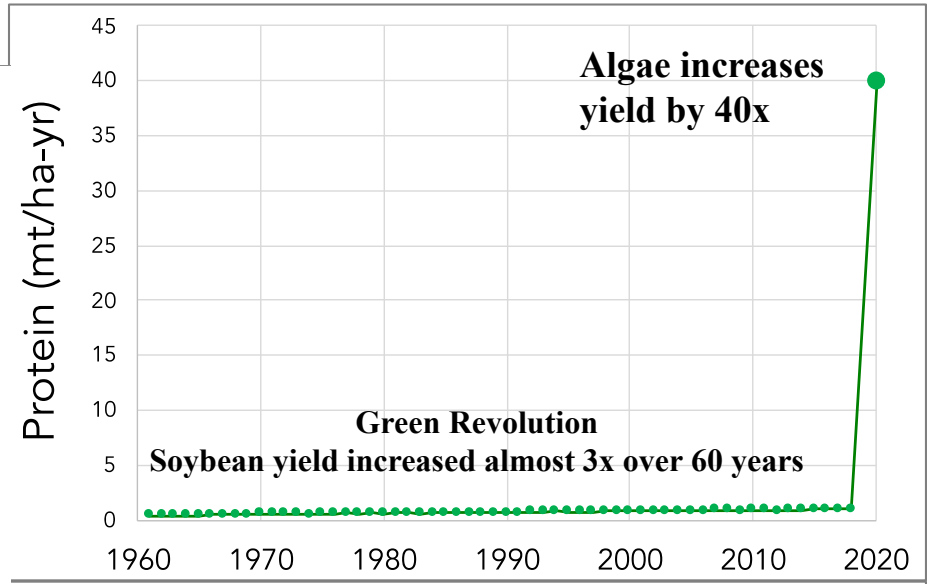
Project Overview

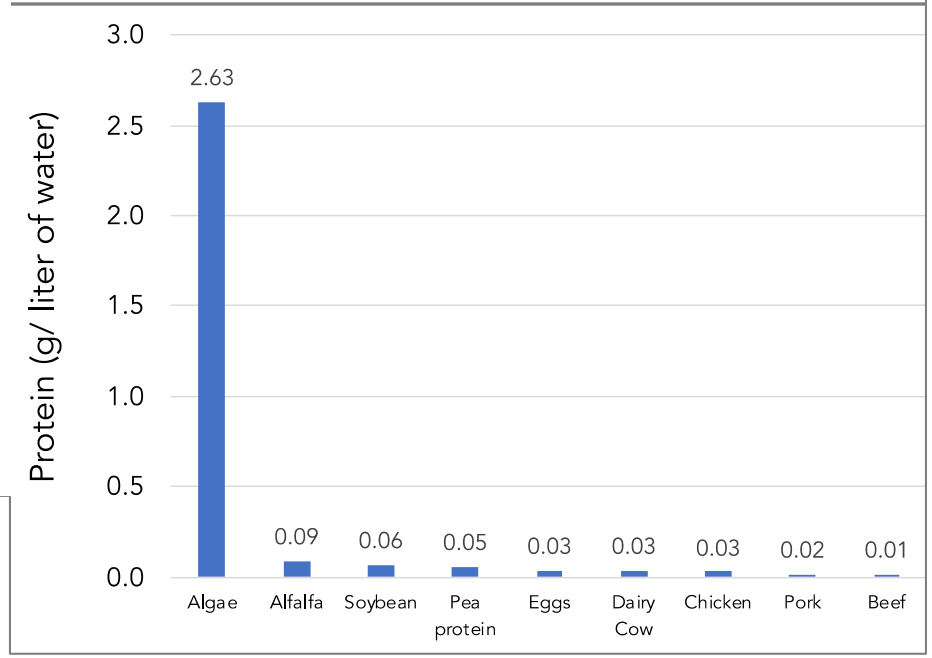


1. Increase algal productivity (+50%), quality, and robustness
   - 12 approaches in parallel, each targeting at 15-30% improvement
2. Translating results between laboratory and mass cultures
   - New photobioreactors, mini-raceways, and intermediate raceways

Economical Algae Commodities Are Important Because Algae Offers an Unprecedented Productivity Increase







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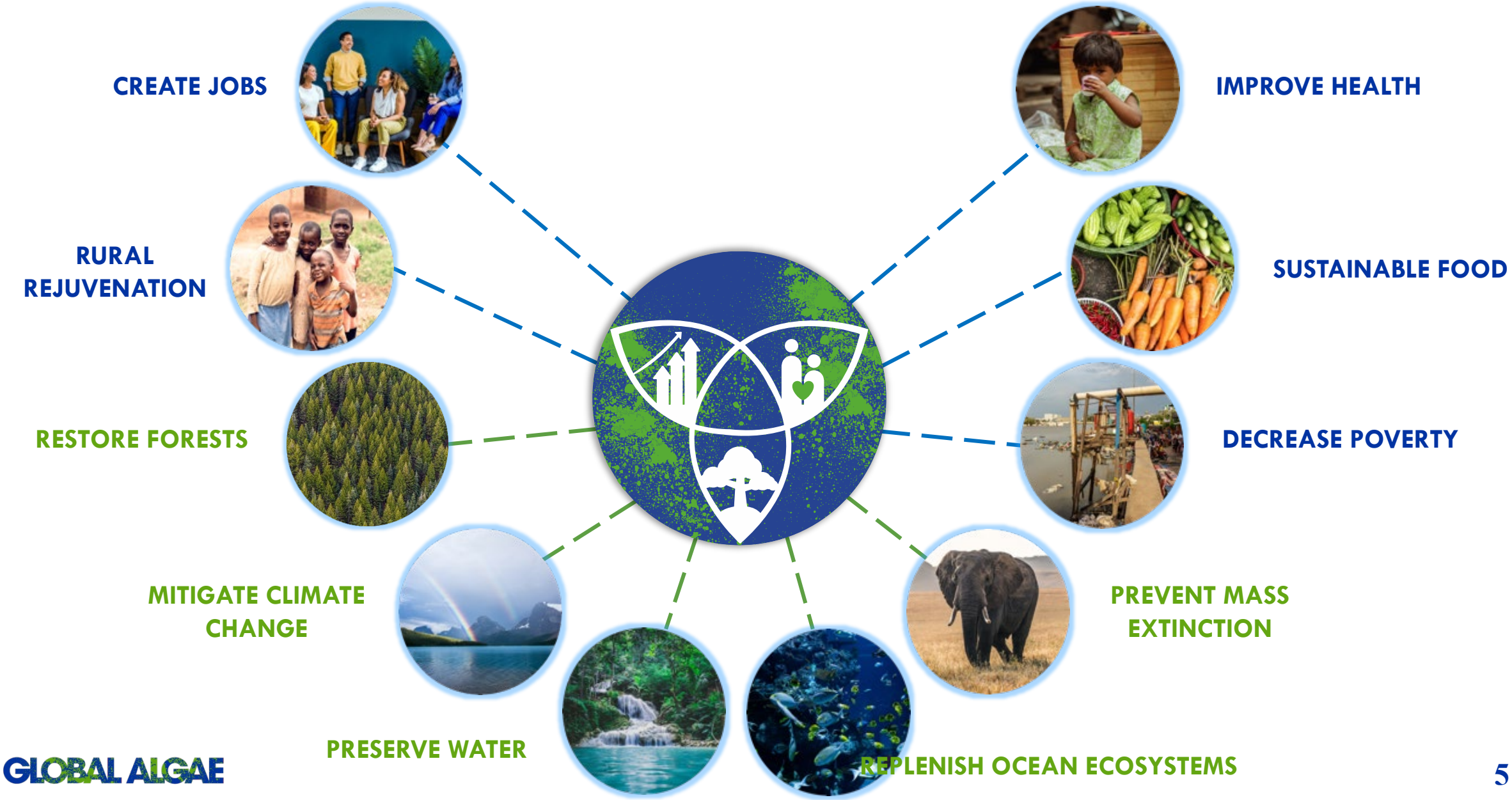
The IMPACT of ALGAE



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Large-scale algae for feed and fuel could reduce Global CO_2 emissions by 13.3 Gt/year

Algae for animal feed and biofuels:

- Agriculture – 5.4 Gt/y, 32% with algae, 60% GHG reduction = 1 Gt/y
- Fuels - 12 Gt/y, 20% with algae biofuel, 94% GHG reduction = 2.3 Gt/y
- Stopping deforestation = 5 Gt/y
- Restoring forests = 5 Gt/y

Eventually replace all fuels for 20 Gt/y total

Greene, C. H., M. E. Huntley, I. Archibald, L. N. Gerber, D. L. Sills, J. Granados, C. M. Beal, and M. J. Walsh, Geoengineering, marine microalgae, and climate stabilization in the 21st century, Earth's Future, 5 (2017).

Walsh, B.J., Rydzak, F., Palazzo, A. et al. New feed sources key to ambitious climate targets. Carbon Balance Manage 10, 26 (2015).

GLOBAL ALGAE

1 – Management
Team and Communications

Team

- **Global Algae Innovations**
  - Algae analysis, strain collection, cultivation and processing expertise; and full technology suite
- **National Renewable Energy Laboratory**
  - Compositional, spectral analysis, and machine learning expertise

Management

- **Weekly telecoms**
- **Actively manage technical progress and budget**
  - Use techno-economic model to guide the R&D
  - Milestone driven, parallel paths
  - Regular meetings with DOE
  - Quarterly reports
- **Integration with ongoing R&D in other projects**
  - 18 partner organizations (universities, national labs, commercial, non-profit)
  - Utilize results from other projects that improve the integrated process, strains, or cultivation technology
  - Results from this project impact the tools and correlations for R&D, the productivity options, and the techno-economic model
  - Look for synergies to increase the bang for the buck on this project
- **Formal risk management table**
  - identify risks
  - determine mitigation strategies
  - track through resolution

2 - Approach

Goals

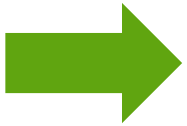
- overcome the challenge in translating results between laboratory and mass cultures;
- increase algal productivity, quality, and robustness while achieving cost and LCA targets

Project Objectives

- Correlations of parameters from microplate through mass-culture
- 50% reduction in time below 75% of target productivity or lipid content
- 50% increase in productivity
- 20% increase in lipid content

R&D on 12 parallel advances (15-30% improvement each)

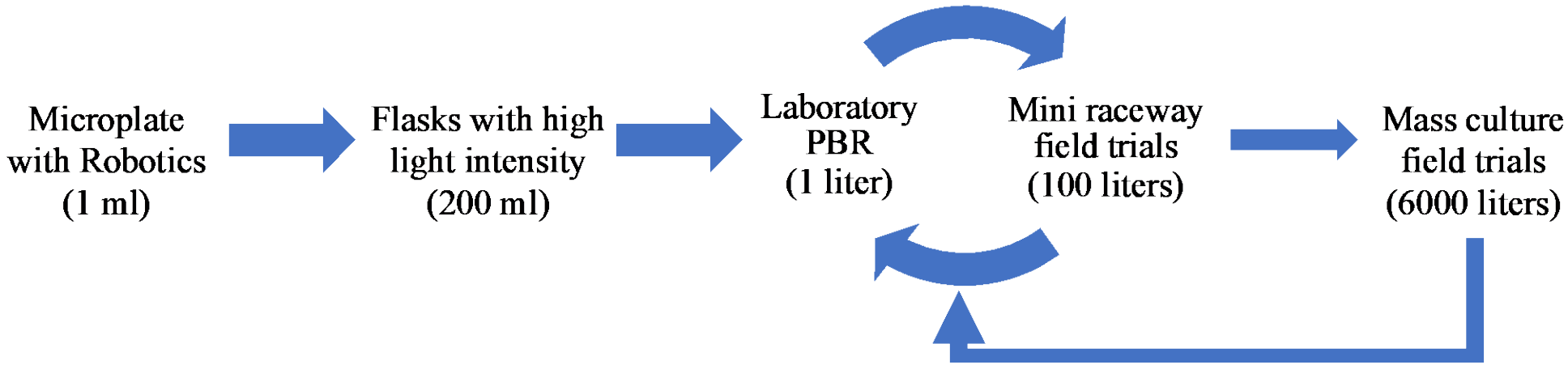
- Cultivation control and operation (4)
- Respiration and nighttime losses (2)
- Lipid accumulation rate (2)
- Strain improvements (2)
- Microbiota control (2)



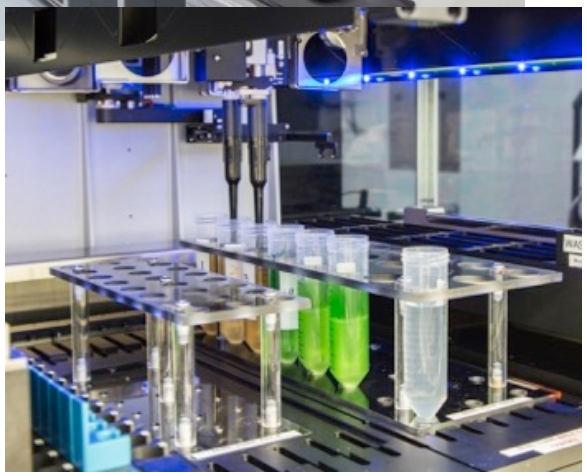
Down-select to ~3 for detailed development

2 – Approach Tools

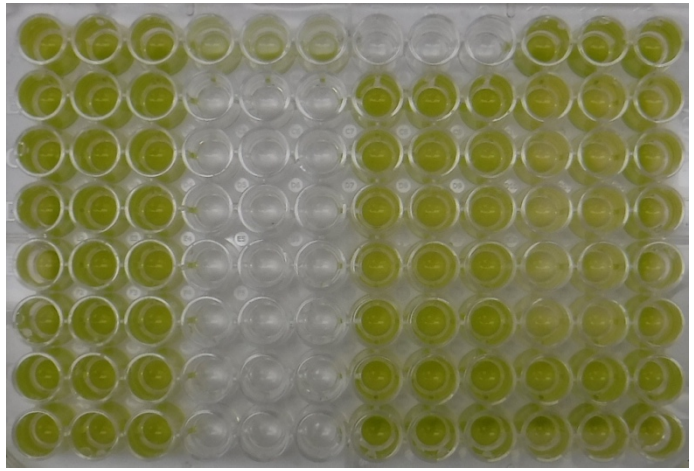
- **Economic and life-cycle analysis model to guide R&D**
- **Develop rapid, near real-time compositional analysis**



Microplate & flask testing



- 96-well microplate format for growth experiments
- Screen algae for OD based specific growth rate and final OD as indicator of biomass produced



- Grow in 1-liter flasks in incubator on stir plates
- High light (>1000 umol/m^2s) during part of the day
- Daily samples for analytical testing
- Transfer every 48 hours

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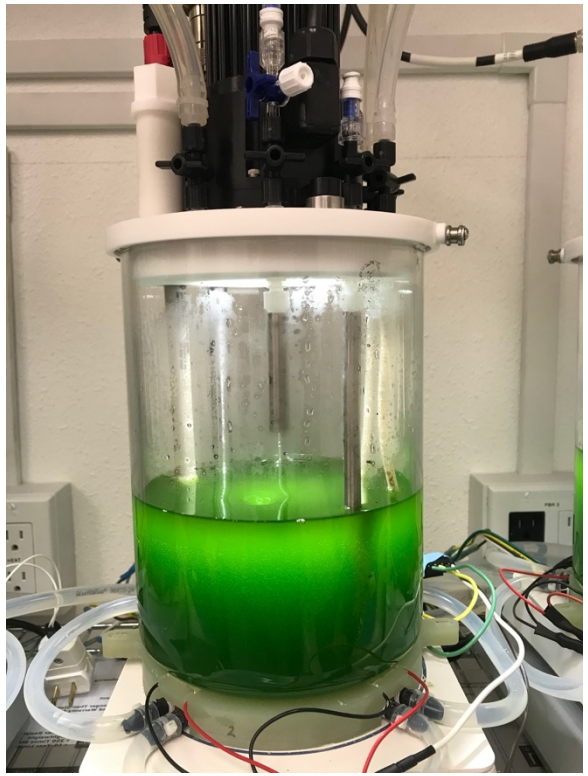
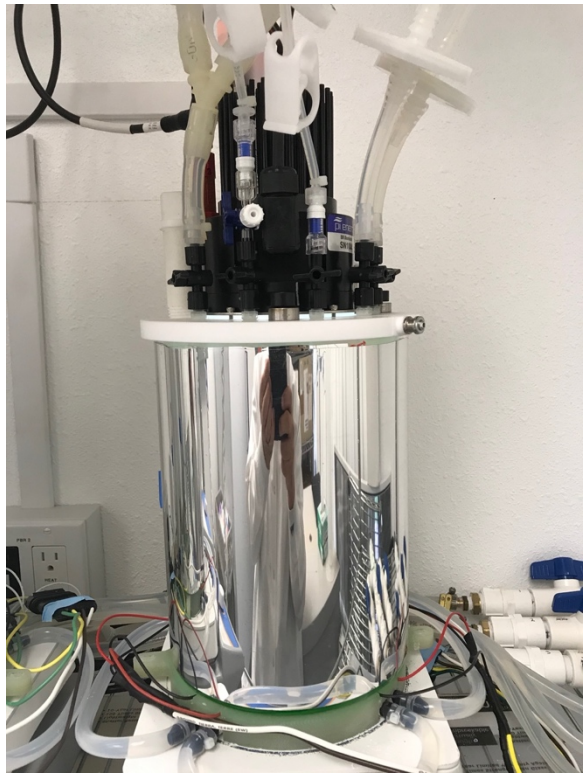
Laboratory Photobioreactors





PLC controlled growing system

- 6 reactors dedicated to this project enable triplicate experiments
- LED illuminator to simulate natural sunlight including seasonal and daily scripts
- Heater and thermoelectric coolers
- Peristaltic pumps for media and harvesting
- Variable mixing rate
- Filtered N_2/O_2 and CO_2 additions to control pH and dissolved oxygen
- Monitors temperature, pH, DO, OD, and conductivity

2m^2 sloped raceways

- Depth control from 2.5 – 16.5 cm
- Automated concentrated media feed
- Automated recycled or fresh media feed
- Automated controls for pH, dissolved oxygen, and temperature
- Continuous instrumentation monitoring via sondes
  - Temperature
  - Dissolved Oxygen
  - Conductivity
  - pH
- Volume monitoring via pressure sensor

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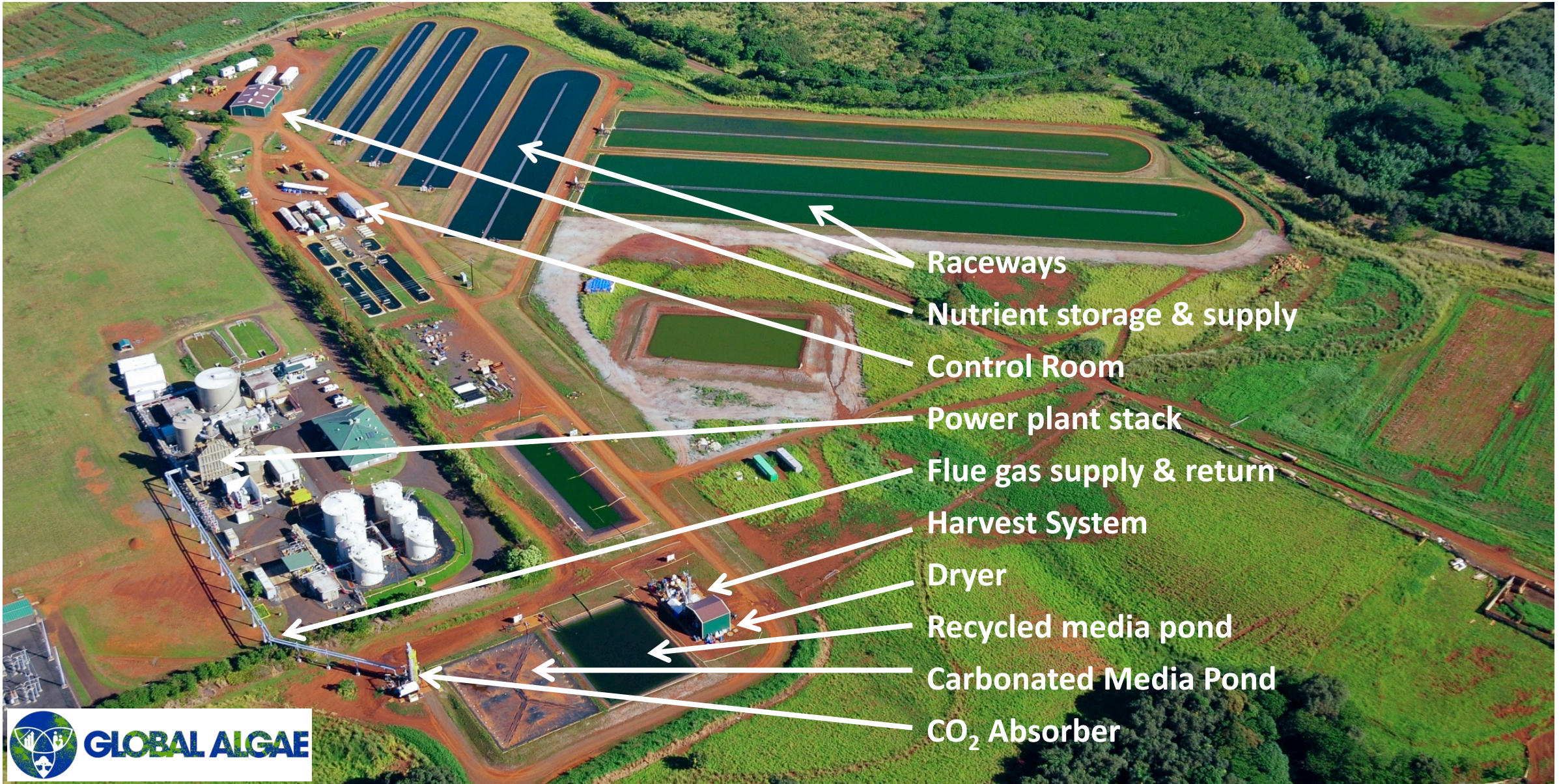
Triplicate Intermediate Scale Raceways - 60 m^2

- Automated concentrated media feed
- Automated recycled or fresh media feed
- Automated controls for pH, dissolved oxygen, and temperature
- Continuous instrumentation monitoring via sondes
  - Temperature
  - Dissolved Oxygen
  - Conductivity
  - pH
- Volume monitoring via pressure sensor
- Goal: Good correlation with full-scale raceways

Global Algae Innovations Research and Development Farm
2014 – 2019: CO_2 from power plant flue gas
2019 to present: CO_2 from direct air capture



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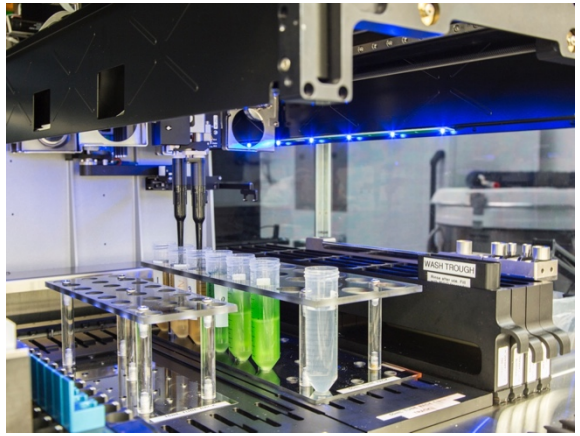
Quantitative Spectroscopic Phenotyping

Goals

- Real time monitoring of algae cell density and health
- Rapid compositional analysis by spectroscopic prediction

Approach

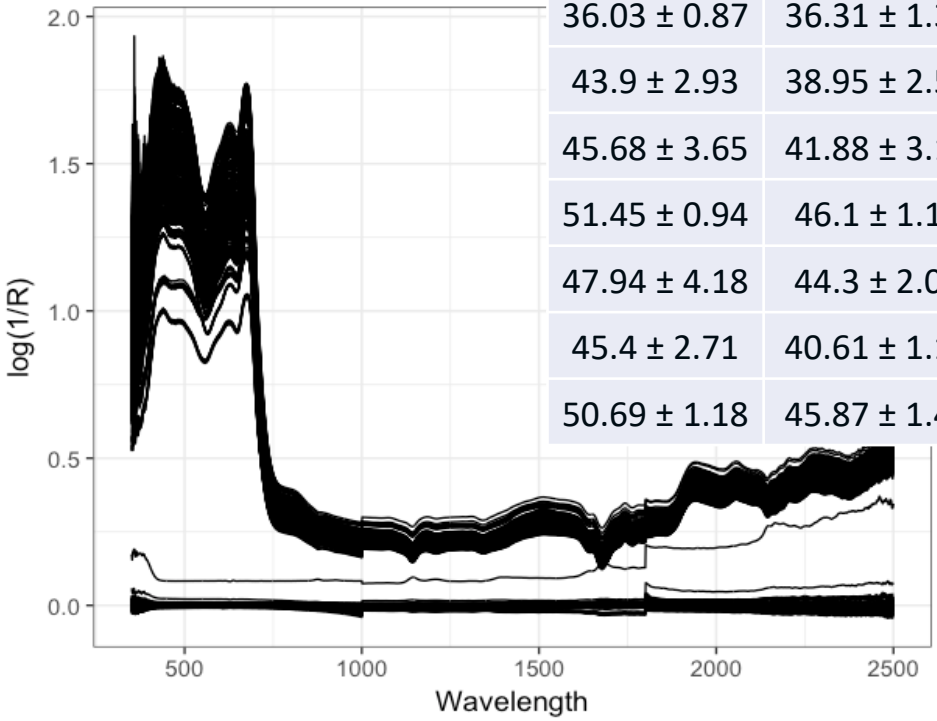
- Multivariate spectroscopy, robotic processing and data collection, sample presentation, configuration
- Novel machine learning algorithms on complex spectra



- Partial Least Squares linear regression analysis
- Artificial Neural Networks (ANN)

Example multivariate prediction of protein content in Spirulina

Protein measured (%AFDW)	Protein predicted (%AFDW)	% deviation
48.92 ± 0.48	46.55 ± 0.91	4.8
40.19 ± 0.38	40.07 ± 0.28	0.3
36.03 ± 0.87	36.31 ± 1.36	0.8
43.9 ± 2.93	38.95 ± 2.59	11.3
45.68 ± 3.65	41.88 ± 3.11	8.3
51.45 ± 0.94	46.1 ± 1.12	10.4
47.94 ± 4.18	44.3 ± 2.07	7.6
45.4 ± 2.71	40.61 ± 1.18	10.6
50.69 ± 1.18	45.87 ± 1.49	9.5



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Impact

Significantly reducing the projected selling price of algal biofuel

- All R&D guide by techno-economic analysis (TEA), so only economical approaches are studied
- Successful advances will increase productivity, one is the most important factors in attaining economical, sustainable algal biofuel production

New R&D tools will be available in Global Algae Equipment's commercial product line

- rapid compositional analysis system
- photobioreactor systems

Advances will be included in Global Algae's complete technology suite for algae production

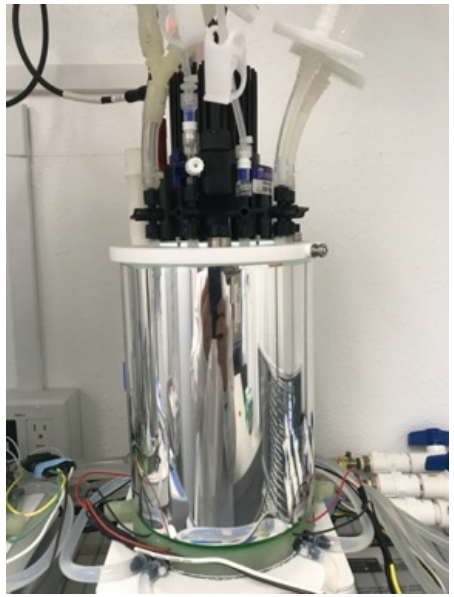
- Currently designing scale-up to160 acres as algae biofoundry for biofuels and other products
- Plan to franchise/license for specific algae product lines and geographies

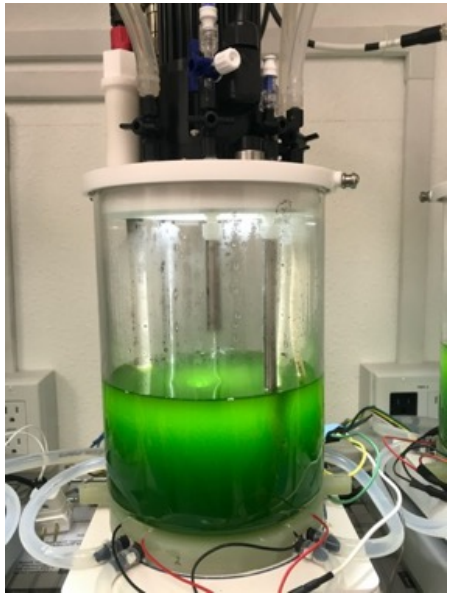
Currently partnering with 18 other organizations

- TEA that guides R&D on all projects updated with the cultivation system improvements and data
- Many of the projects include integrated testing or productivity improvements which will benefit from
  - R&D pipeline and correlations developed from microplates through mass cultivation
  - New rapid compositional analysis system

4 – Progress and Outcomes

- PBR, intermediate and mini raceways installed
- Validated operating parameters, pH, mixing, dissolved oxygen, temperature, and light
- Initial tests in-progress





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Initial Spectroscopic Samples and Data collection

Spectroscopic methods & configuration

- Sample Matrix - 5,022 spectra
  - 23 Algae cultivation conditions
  - 3 Methods of sample preparation
  - 6 Method/configuration of spectra collection
  - Triplicate for all samples
  - Quadruplicate measurements for all spectra
  - 3 different types of controls

Sample preparation

- Sample Matrix – 2,100 spectra
  - 4 algae cultivation conditions
  - 35 sample preparation conditions
  - 5 methods of spectra collection
  - Triplicate for all samples
  - Quadruplicate measurements for all spectra

- Compositional measurements
  - Ash-free dry weight, ash content
  - CHN
  - Protein
  - Carbohydrate & profile
  - Lipid & profile
  - Chlorophyll/pigments in-vivo fluorescence

Summary

- **Large-scale algae production for commodities is essential to mitigate climate change**
  - Stopping and reversing deforestation is pivotal to achieve our climate change goals
  - Algae is the only solution to deforestation that meets the world's protein requirements
- **Structured approach to improve R&D tools and apply the tools to increase productivity**
  - Correlations, methods, and equipment from microplate to flasks to photobioreactors to $2m^2$ raceways to $60m^2$ raceways to full-scale raceways
  - Rapid compositional analysis method
  - 12 parallel approaches to improve productivity with down select to the most promising
- **Project started last summer**
  - installation and validation of the new reactor systems at various scales
  - initial testing in progress, so no conclusions to report other than the new systems are working well

Quad Chart Overview

Timeline

- Project start date: 10-1-19
- Project end date: 12-31-23

	FY20 Costed	Total Award
DOE Funding	0	4,500,000
Project Cost Share	0	1,125,000

Project Partners

- National Renewable Energy Laboratory

Project Goal

The goals of this project are to

(i) overcome the challenge in translating results between laboratory and mass cultures;

(ii) increase algal productivity, quality, and robustness while achieving cost and LCA targets

End of Project Milestones

- 50% increase in productivity
- 20% increase in lipid content
- 50% reduction in time below 75% of target productivity or lipid content
- Correlations of parameters from microplate through mass-culture

Funding Mechanism

DE-FOA-0002029; Area of Interest 1; 2019

Additional Slides

Responses to Previous Reviewers' Comments

Not Applicable

Publications, Patents, Presentations, Awards, and Commercialization

- Patents
  - None to date

- Presentations

  None to date

- Commercialization
  - Project is an integral part of Global Algae's plan for deployment of commercial algae facilities
  - Tools developed on the project will be marketed through Global Algae Equipment's product line