DOE Bioenergy Technologies Office (BETO)

2021 Project Peer Review

Algae Cultivation from Flue Gas with High CO_2 Utilization Efficiency

3/10/2021

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

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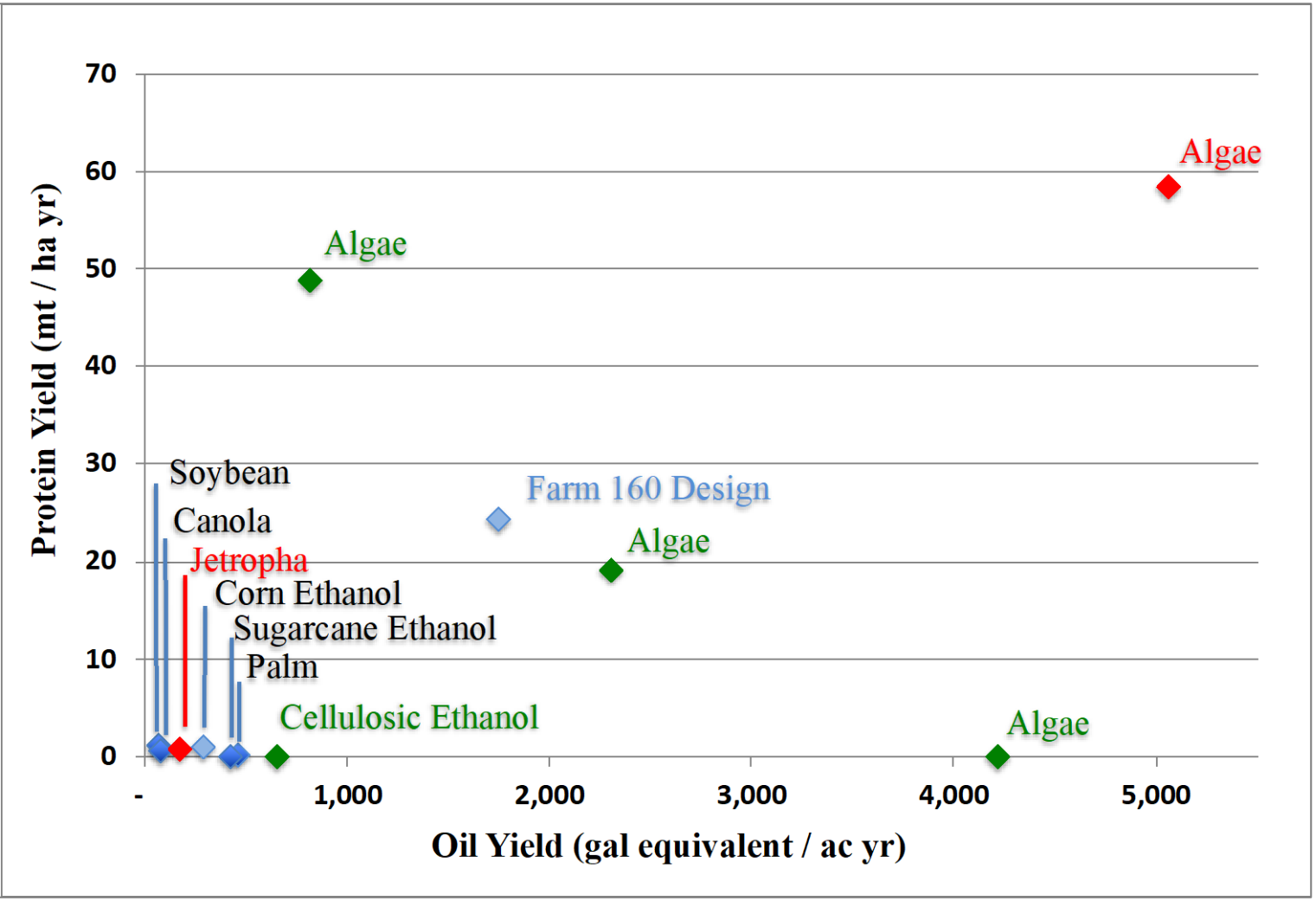
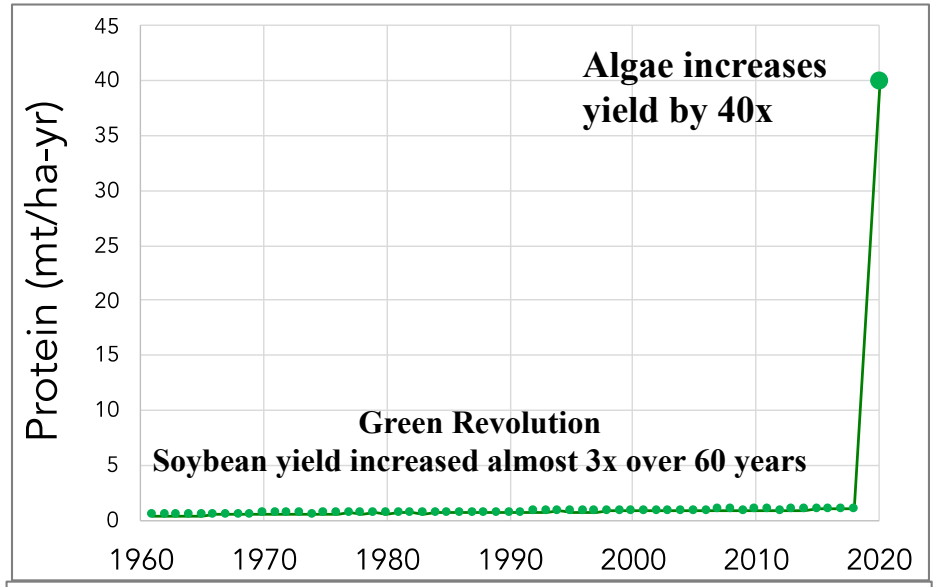
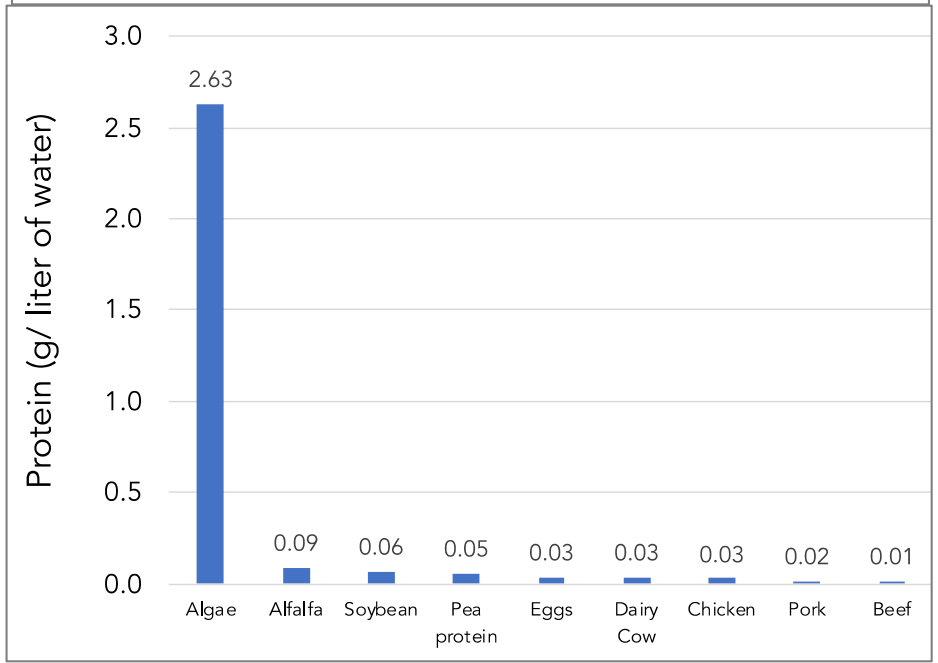
Project Overview

1. **Increase the capture efficiency from flue gas and the utilization efficiency in cultivation for carbon capture and utilization (CCU) from flue gas to biofuel intermediate.**
2. **Integrate algal CCU in a sustainable, economic process for production of algal oil (biofuel intermediate) and algae meal**
3. **Operate the integrated process for a year to obtain long-term operating data on all process steps and product quality**

Economical Algae Commodities Are Important
Unprecedented Productivity Increase







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The IMPACT of ALGAE

CREATE JOBS

IMPROVE HEALTH

RURAL REJUVENATION

SUSTAINABLE FOOD

RESTORE FORESTS

DECREASE POVERTY

MITIGATE CLIMATE CHANGE

PREVENT MASS EXTINCTION

PRESERVE WATER

REPLENISH OCEAN ECOSYSTEMS

GLOBAL ALGAE

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

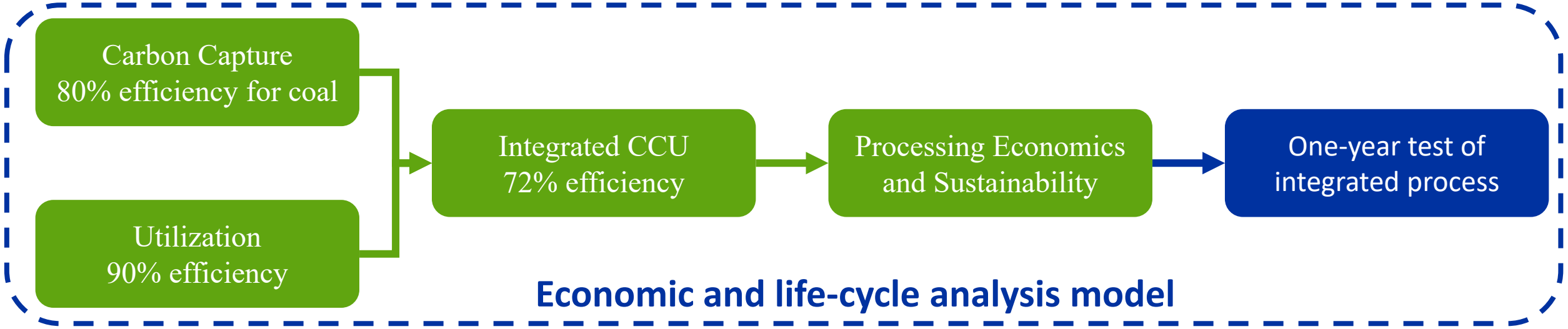
Team

- **Global Algae Innovations**
  - Algae cultivation and processing experts and full technology suite
- **TSD Management Associates**
  - Algae processing expertise, PE

Management

- **Weekly telecoms**
- **Actively manage technical progress and budget**
  - Use techno-economic model to guide the R&D
  - Milestone driven
  - 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
  - Results from this project impact techno-economic model and thus other R&D
  - Look for synergies to increase the bang for the buck on this projectd
- **Formal risk management table**
  - identify risks
  - determine mitigation strategies
  - track through resolution

2 - Approach



Carbon Capture Efficiency

- Systematic test program
- Mass transfer model
- Improved absorber design

Utilization Efficiency

- Improved cultivation methods
- Strain selection and media optimization
- Extended to direct air capture

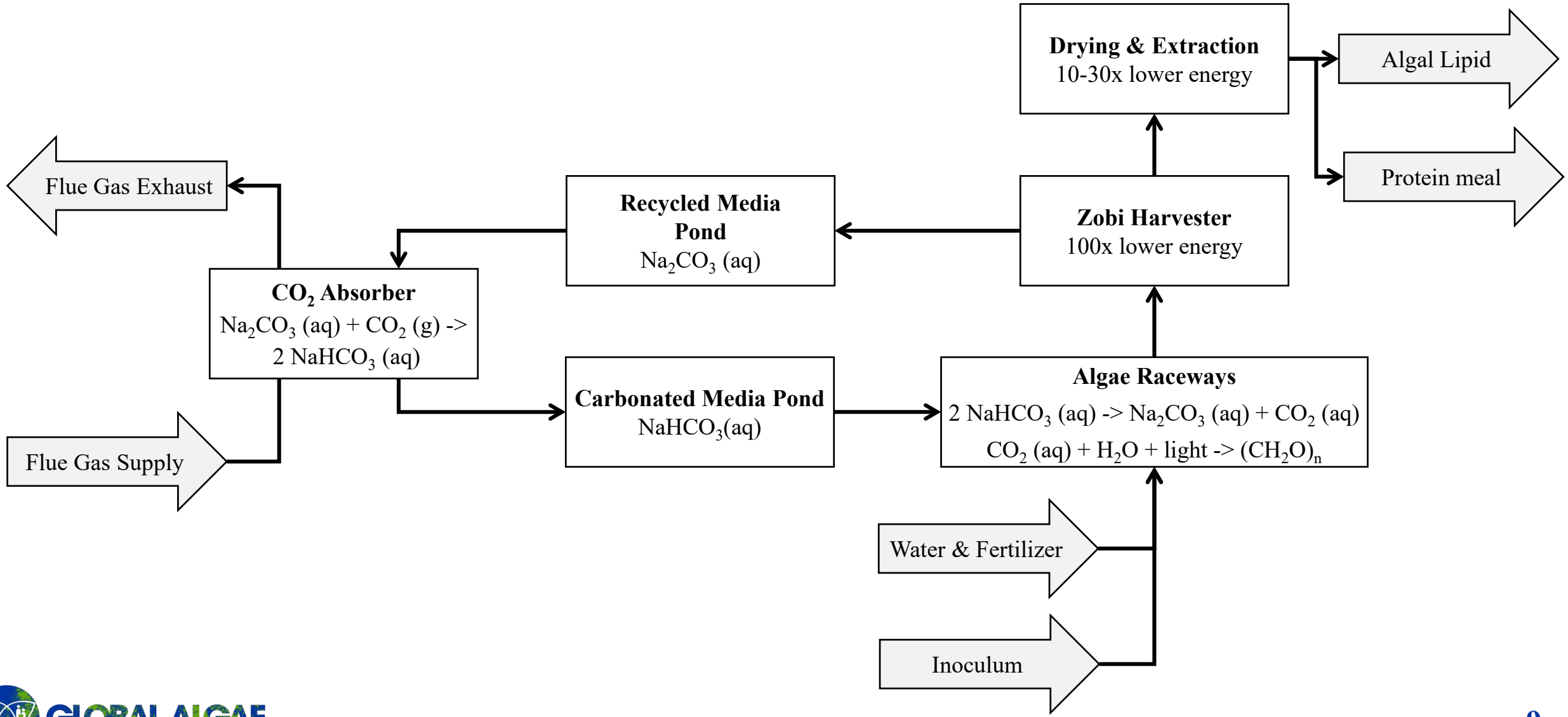
Processing Economics & Sustainability

- Zobi harvester, weekly harvests for drying & extraction tests
- Develop new low energy use, low-cost drying technology
- Develop new low energy use, low-cost extraction technology

One-year integrated test

- Carbon capture, cultivation, harvesting, drying, extraction
- Process parameters, variability, reliability
- Biofuel intermediate and protein meal quality

Block Flow Diagram



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Test Absorber

6” diameter test absorber

- Improved CO_2 capture technology
- Fully instrumented
- Intermediate gas and liquid sampling points

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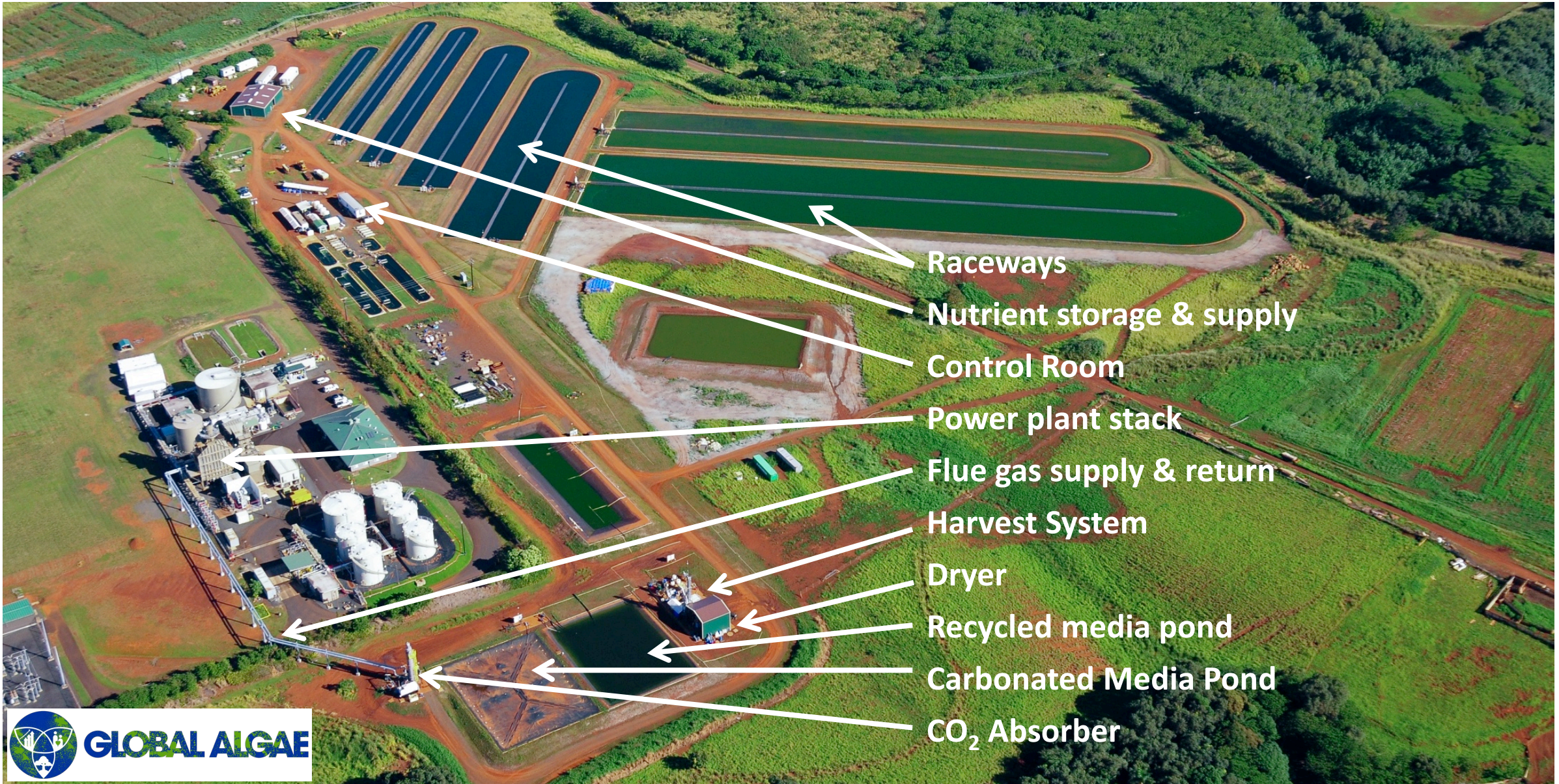
Global Algae Innovations Research and Development Farm
2014 – 2019: CO_2 from power plant flue gas
2019 to present: CO_2 from direct air capture



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3 – Impact, State of the Art Advances

CO_2 is crucial for algae cultivation

- land and water resources near CO_2 point sources is main limitation
- Capture, distribution, and control of CO_2 is makes CCU very expensive, $100-$200/ton

Global Algae previously developed a CCU system for algae production from flue gas

- Inexpensive, $30/ton
- Efficiency was low: 30% capture efficiency and 60% utilization efficiency
- **This project increased capture and utilization efficiency to >90% and reduced cost to $25/ton**
- **This project demonstrated direct air capture for $8/ton**

Drying and extraction are energy intensive, but crucial for protein and oil production

- **This project reduced energy use for drying by 97% and and extraction by 91%**
- **This project achieved production of a much cleaner oil**

Impact - Commercialization

8 invention disclosures (expect more than 8 patents because each cover processes with multiple innovations)

- 1 Direct air capture
- 2 cultivation
- 4 extraction
- 1 Drying

Included in Global Algae's complete technology suite for algae production

- Designing scale-up to160 acres as algae biofoundry so can be used for many products including biofuels
- Plan to franchise/license for specific algae product lines and geographies

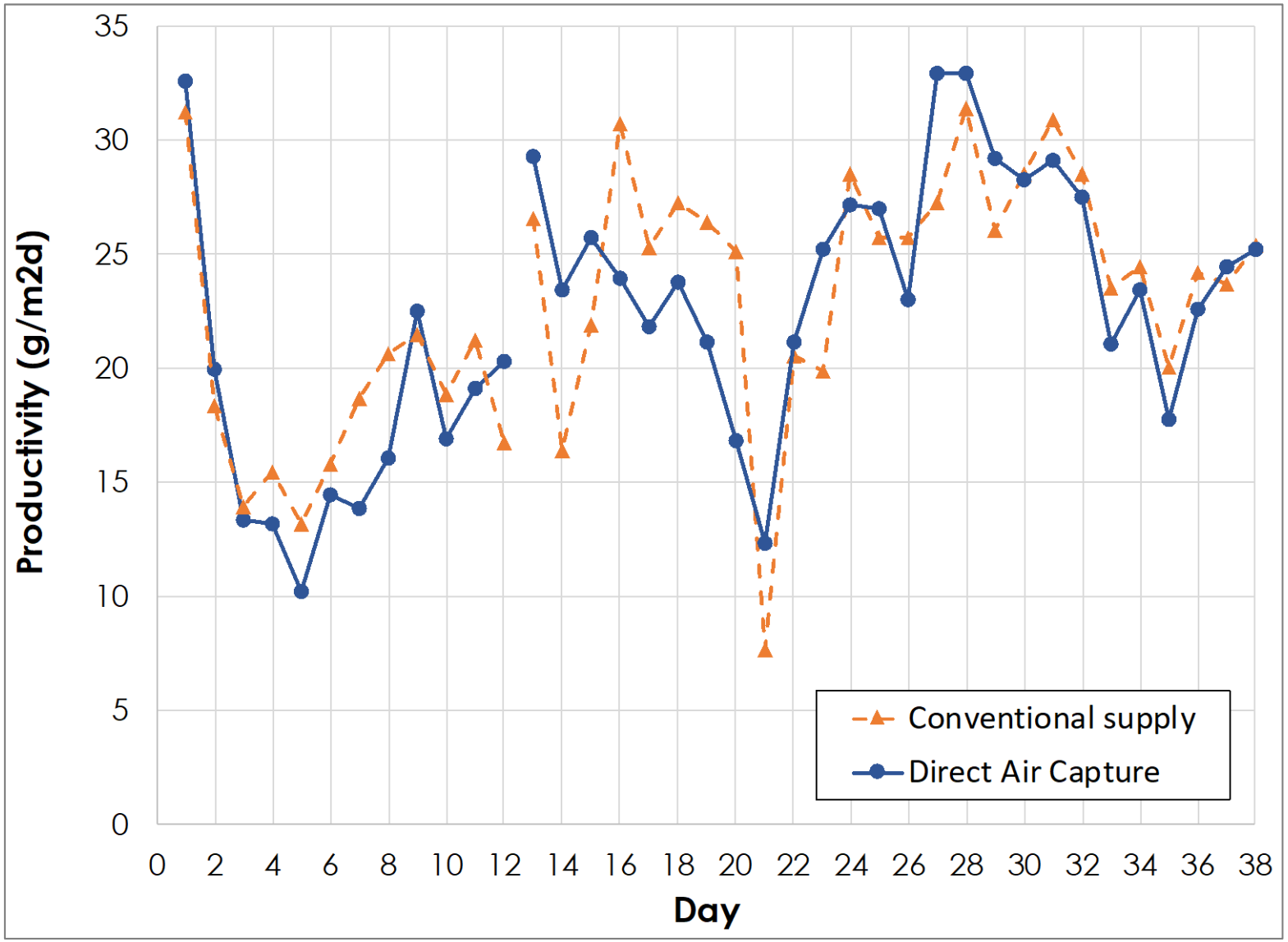
Currently partnering with 18 other organizations

- TEA that guides R&D on all project updated with improvements
- Many of the projects include integrated testing, which uses the best available technology
  - All projects using direct air capture or the improved point source method for CO_2 supply
  - All R&D projects with integrated testing using the new drying and extraction

4 – Progress and Outcomes
Milestones Completed

Metric	Conventional	Starting	Target	Achieved
Carbon Capture efficiency with coal	NA	30%	80%	**98%**
Carbon Utilization efficiency	NA	60%	90%	**> 100%**
Flue gas CCU efficiency	NA	18%	72%	**98%**
Direct Air Capture (% of carbon supplied)	NA	NA	NA	**100%**
Drying energy use	6.5 MJ/kg	1 MJ/kg	0.20 MJ/kg	**0.20 MJ/kg**
Extraction energy use	1.8 MJ/kg	0.35 MJ/kg	0.15 MJ/kg	**0.16 MJ/kg**
Flue gas CCU cost	$100/mt	$30/mt	$30/mt	**$25/mt**
Direct air capture CCU cost	$200/mt	NA	NA	**$8/mt**

Same productivity achieved with direct air capture as with externally supplied CO_2



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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
- **CCU results were very successful for both flue gas capture and direct air capture**
  - High productivity achieved with CO_2 via direct air capture and flue gas capture
  - Exceeded all carbon capture and utilization efficiency and cost metrics
  - Flue gas capture and supply for ~$25/ton
  - Direct air capture and supply for ~$8 per ton
- **New drying and extraction processes achieve 97% and 91% reduction in energy use**

Quad Chart Overview

Timeline

- Project start date: 10-1-18
- Project end date: 12-31-21

	FY20 Costed	Total Award
DOE Funding	1,174.179	2,500,000
Project Cost Share	299,422	625,000

Project Partners

- TSD Management Associates

Project Goal

The goal of this project is to obtain high CO_2 utilization in algae cultivation by increasing the capture efficiency from flue gas and increasing the utilization efficiency and productivity in the cultivation system.

End of Project Milestones

- 72% carbon capture and utilization efficiency (original)
- Direct air capture for 100% of CO_2 supply with full media recycle
- 20 g/m^{2}d productivity average for 1 year
- Projected full-scale minimum selling price o $3/GGE for biofuel intermediate
- Project full-scale 85% reduction in greenhouse gases for algae biofuel relative petroleum-based fuels

Funding Mechanism

DE-FOA-0001908; Topic Area 1; 2018

Additional Slides

Responses to Previous Reviewers' Comments

Not Applicable

Publications, Patents, Presentations, Awards, and Commercialization

- Patents
  - 6 invention disclosures with patent applications planned
- Presentations

  Hazlebeck D. Powering the Future: Transformational Impact of Algae Bioproducts. Innovation X-Lab Biomanufacturing Summit. January 28-29, 2020.

  Hazlebeck D. Pilot-scale algae oil production. California Energy Commission Critical Project Review Meeting. January 27, 2020.
- Commercialization
  - Project is an integral part of Global Algae's plan for deployment of commercial algae facilities
  - Project results are impacting multiple industry leading technoeconomic analyses