DOE Bioenergy Technologies Office (BETO)

2023 Project Peer Review

Direct Air Capture Algae Cultivation

April 5, 2023

Systems Development and Integration Session B

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Global Algae Innovations

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
- 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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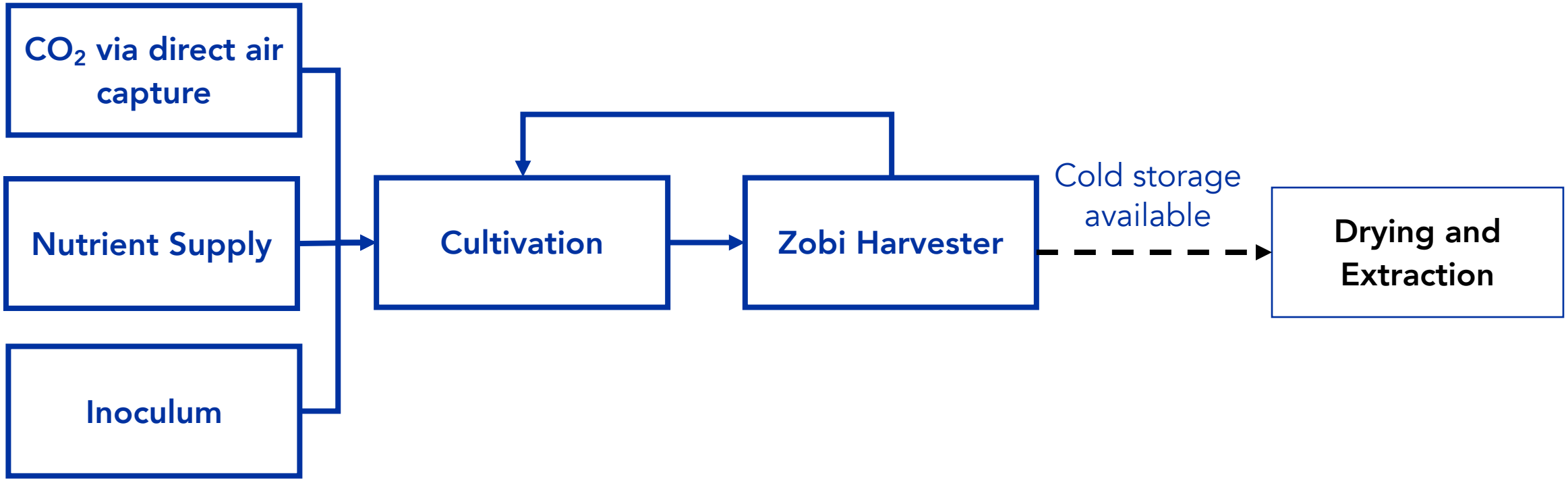
Project Overview – Goals

- **Scale-up Global Algae's cultivation system to 2-acres of raceways**
  - 15 g/m^{2}d average productivity with at least 30% protein content and 35% lipid over 500 hours of operation with at least 100 hours of continuous operation
  - All CO_2 supplied by direct air capture
  - Zobi harvester® and full media recycle
  - Shandon, California in San Luis Obispo County
  - Raceways designed to be initial scaling and cultivation raceways for the 160-acre farm
  - Consistent with overall process that achieves $2.50/gallon of gasoline equivalent (GGE) for biofuel intermediate at 5,000-acres

Project Overview – Context and History

- **Cultivation R&D at Kauai Algae Farm**
  - Farm built in 2011 with best available technology at the time
  - CO_2 supply via slip stream from adjacent power plant stack
  - Current technology has surpassed capability of the original farm
  - Tropical rainforest environment
- **Algal biomass production technology adequate for commercialization**
  - Key performance parameters hold through scale-up: energy use, capital cost, scalability
  - Cultivation: productivity, contamination, product quality and consistency, temperate climate
  - Support: direct air capture CO_2, nutrient supply, media recycle, small inoculum
  - Harvesting: efficacy, concentration

Approach – Overall Algae Process



This Project

Leverage
Concurrent scale-up project

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Approach

- **TEA constrained**
  - Update TEA throughout for decision making and analysis of improved cultivation method
- **Best available strain and methods from ongoing R&D projects**
  - 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
  - Methods:
    - High productivity with up to 50% lipid content in outdoor cultivation
    - Direct air capture CO_2 supply to raceways
    - Contamination control
    - Zobi harvester®
    - Zero liquid discharge

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Approach - continued

- **Design, procure, install**
  - Leverage prior preliminary design and permitting for 160-acre farm
  - Build out first two acres of the farm so eventually incorporated into the full farm
  - Utilize local engineering, procurement, and construction firm
  - On-line instrumentation for all key cultivation parameters, flow rates, and energy use
- **Shakedown**
  - Equipment checkout and instrument calibration
  - Design targets achieved for flows, mixing, and direct air capture CO_2 rate
  - Budget and time included for modifications if scale-up does not meet design targets
- **Demonstration testing**
  - 12 months of demonstration testing using best available strains and cultivation methods
  - Seasonal variations in key performance parameters
  - Product consistency
  - Data for TEA and further scale-up
  - Algae slurry for separate drying and extraction scale-up project

Approach – Challenges and Risk Management

- **Key Technical Challenges**
  - Scale-up of direct air capture CO2
  - Temperature variations greater than prior testing
  - Starting up a cultivation system with a lot of new technology

Risk	Mitigation
CO_2 Scale-up	Time and budget for modifications during shakedown
San Luis Obispo weather has greater impact on productivity than projected	Strain has wide temperature range; improved strains with greater range coming from other directed evolution projects such as PEAK and APEX; detailed thermal model and novel thermal control technology; current smaller-scale test projects on Kauai using San Luis Obispo thermal scripts;
Cultivation system scale-up	Productivity consistent over three orders of magnitude in Kauai; models for cultivation, mixing, and flows provide sound basis for design, interpreting results, and making modifications during shakedown
Inflation and supply chain impact ability to maintain budget	Work closely with engineering, procurement, and construction firm to adjust design as needed to maintain budget and look for alternative suppliers.

Daylight hours and Solar Insulation

Daylight Hours

	Winter	Spring	Summer	Fall
Lihue	11.0	12.5	13.2	11.1
Shandon	10.2	13.1	14.1	10.4
	-7%	5%	7%	-6%

Sunny Hours

	Winter	Spring	Summer	Fall
Lihue	6.4	6.5	8.6	6.4
Shandon	5.3	8.8	12.6	7.0
	-18%	36%	46%	10%

Solar Insulation

	Winter	Spring	Summer	Fall
Lihue	13.1	18.7	21.0	13.8
Shandon	11.4	23.8	29.2	13.1
	-13%	27%	39%	-5%

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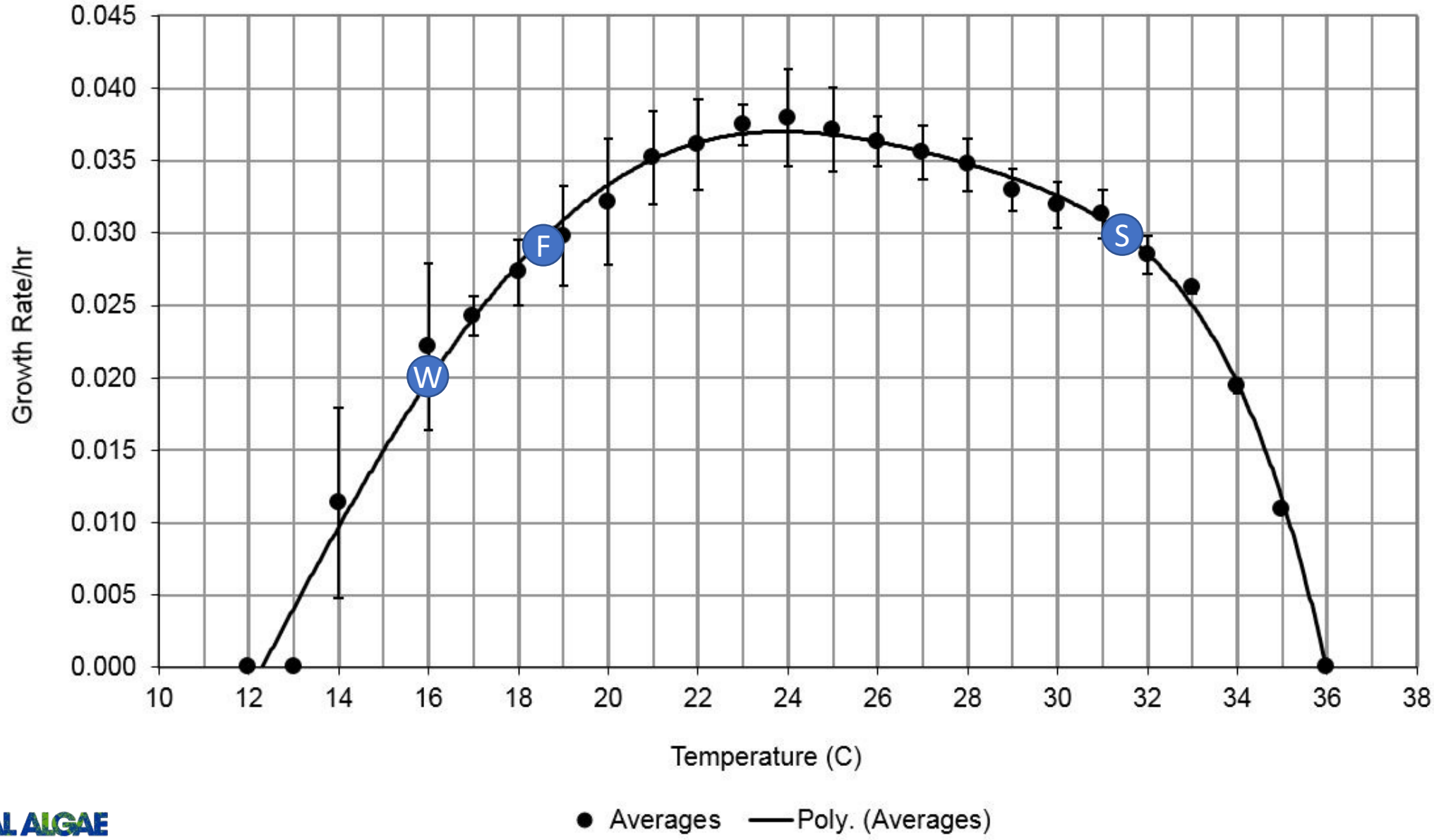
Approach – Strain with wide temperature range



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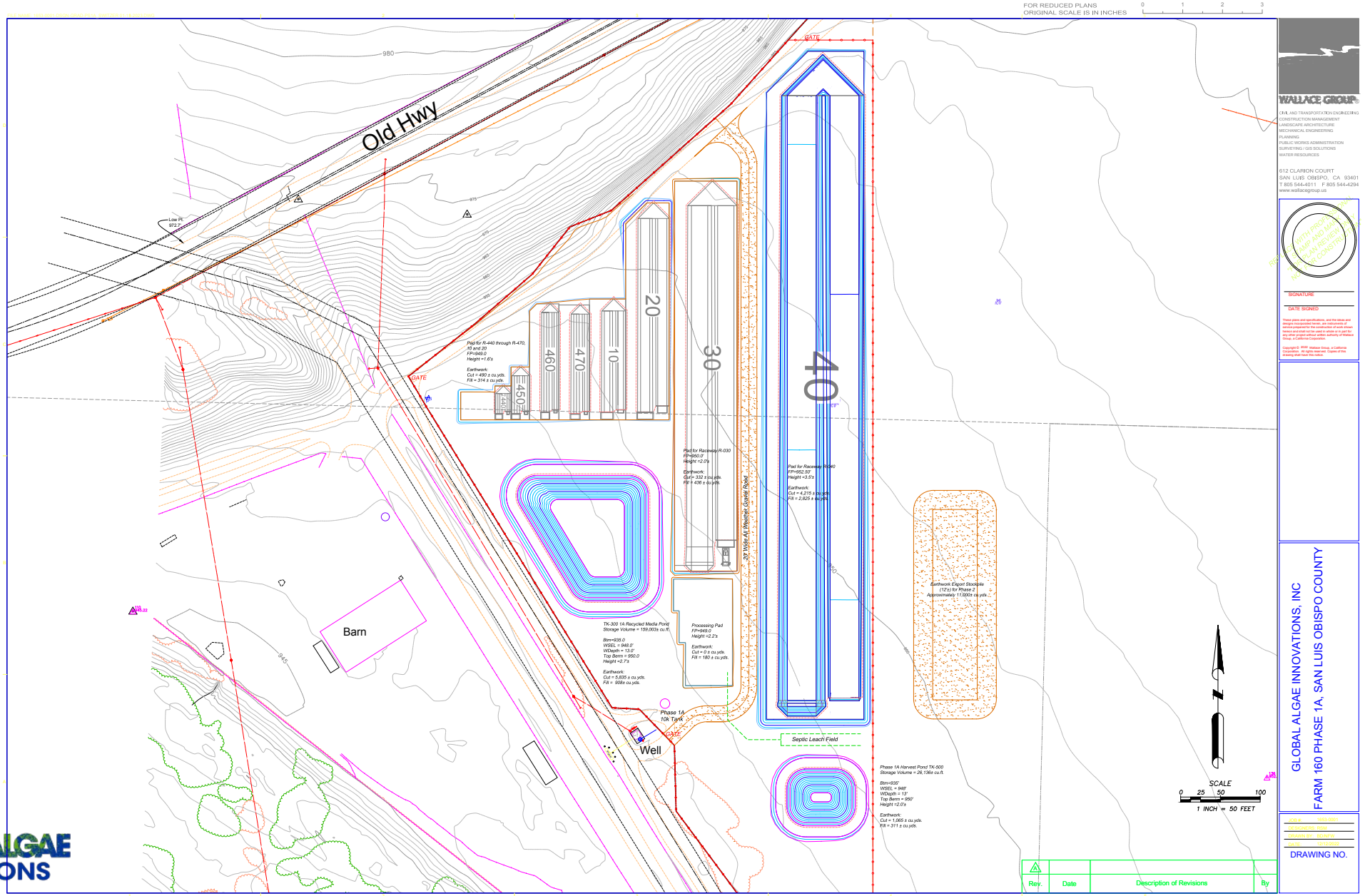
Progress and Outcomes - Overview

- **Project currently in permitting and procurement phase**
  - NEPA approval obtained; mitigations for two endangered species added into plan
  - County agricultural department reversal their original designation of algae as a crop caused an 11-month delay in permitting
  - Revised permitting approach accepted
  - Draft water offset approval letter received
  - Grading permit application revised to incorporate all of the county's comments
- **Verification results**
  - Baseline productivity of 15 g/m^{2}d based on temperature and solar insolation adjustments
  - Scaling factors for all technologies are reasonable based on prior data
- **Re-design of scaling raceways account for inflation**
  - Sacrifice some productivity for longer residence time to reduce number of raceways
  - Rental of some nutrient tanks from suppliers since they would be replaced later anyway
  - Adjusted electrical system approach to reduce costs
  - Smaller total area; system capability range still meets throughput range

Progress and Outcomes - Layouts for Phase 1a



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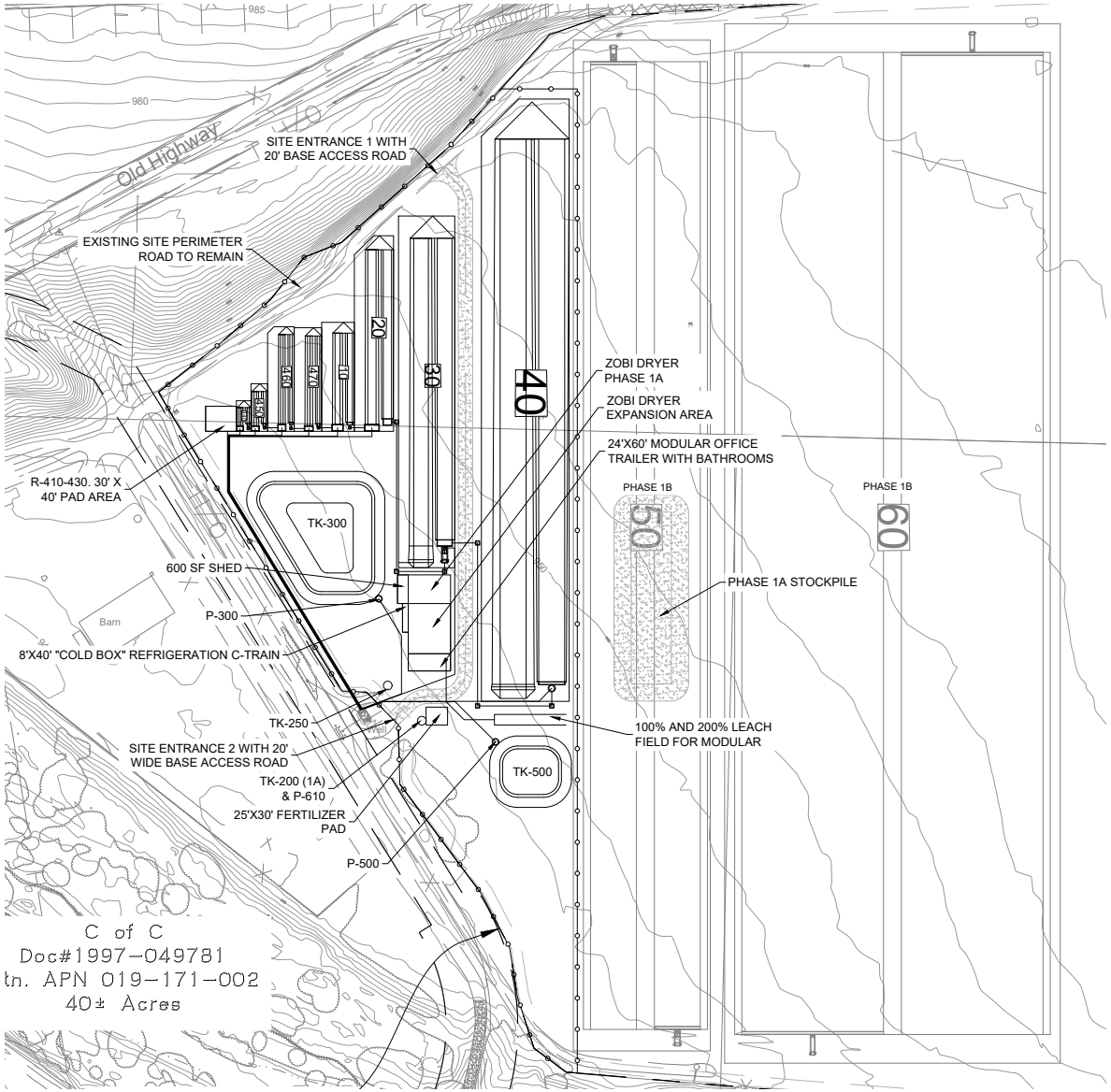
Progress and Outcomes - Layouts for Phase 1a and 1b



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**

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

- Measuring key performance parameters for Nutrients, CO_2 supply, Cultivation and Harvesting at engineering scale

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**

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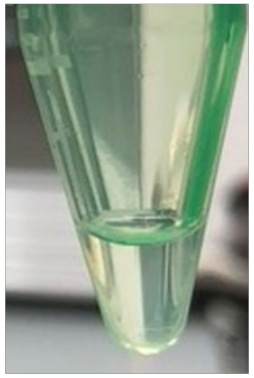
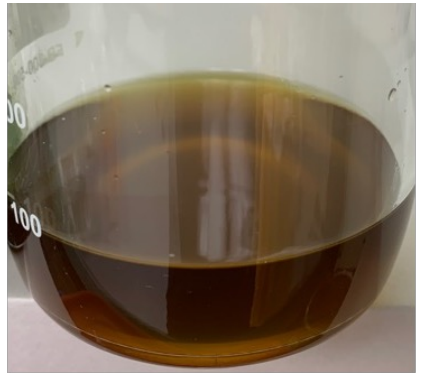
Progress and Outcomes – Products

Protein Meal





Algae Oil

Food Ingredients

Feed Ingredients

Consumer Products

Jet fuel, diesel, and gasoline

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Impact

- Integrated demonstration of Global Algae's suite of advanced cultivation technologies
  - 26 new patent applications on nutrients, cultivation, and harvesting planned this year
  - Technology suite economically competitive for initial 7 billion gallons/year of fuel
  - Scaling data for innovative nutrient supply, cultivation, direct air capture, and harvesting
  - Larger scale productivity data to support BETO state of technology analyses
- Generate larger quantities of biomass to support other DOE R&D projects
- Large risk reduction in advancing technologies toward pilot-scale & commercial scale

Summary

- **Accelerate commercialization**
  - Scale-up of innovative cultivation and harvesting technology suite
  - Technology suite economically viable for algal biofuel if key performance parameters hold through scale-up
  - Automated data acquisition and control to capture key performance parameters
  - Designed to be incorporated in pilot-scale facility after demonstration testing
- **Status**
  - Permitting and long-lead procurement in progress
  - Test program scheduled to start in fall
- **Co-ordination with lab-scale R&D**
  - Using thermal script representative of San Luis Obispo County for some indoor and outdoor R&D at the Kauai Algae Farm

QUAD Chart Overview

Timeline

- *BP2 start date: August 2022*
- *Project end date: June 2024*

	FY22 Costed	Total Award
DOE Funding	$175,000	$4,000,000
Project Cost Share	$44,000	$1,000,000

TRL at Project Start: 4
TRL at Project End: 5

Project Goal

Scale-up Global Algae's innovative suite of cultivation and harvesting technologies to acre-scale raceways with all CO_2 supplied via direct air capture; and validate key performance parameters during one year of demonstration testing.

End of Project Milestones

Acre-scale cultivation and harvesting:

- All carbon supplied via direct air capture
- Full media recycle
- Validate key performance parameters
- Designed for integration into larger pilot plant
- $2.50/GGE biofuel intermediate at 5000-ac

Funding Mechanism

FY21 BETO Scale-up and Conversion FOA

Project Partners:

- Wallace Group
- Specialty Construction

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Additional Slides

Responses to Previous Reviewers' Comments

- **Not previously reviewed**

- **Go/No-Go Review - Verification**
  - Baseline data: ~15 g/m^{2}d anticipated based on Kauai data adjusted for climate and solar insolation
  - Scale-up ratios and basis are reasonable based on prior data

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Publications, Patents, Presentations, Awards, and Commercialization

- None to date
- Technology being scale from multiple current patents and 26 patent planned for submission this year