DOE Bioenergy Technologies Office (BETO)

2023 Project Peer Review

Pilot Scale Algae Oil Production

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

- **Preliminary Design**
  - Conceptual design and trade-off studies
  - Site selection and permitting
  - Preliminary design FEL3 package with -5%/+15% cost estimate
- **Business Assessment**
  - Techno-economic analysis
  - Plan for financing and building pilot-scale farm
  - Plan for moving to commercial-scale

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Project Overview – Context and History

- **Advanced cultivation and harvesting technology ready for scale-up**
  - Demonstrated at engineering-scale at the Kauai Algae Farm
- **Advanced drying and extraction technology at laboratory-scale**
  - Included conventional and novel technology at conceptual design level
  - Engineering-scale demonstration not complete in time to include the advanced technology in the preliminary design
- **R&D portion focused on larger local strain library as risk reduction**
- **Plan for long-term operation of pilot-scale facility**
  - Biofuel with most of capital from grants
  - Produce both biofuel and nutraceutical to provide good ROI since pilot-scale for biofuel is full scale for nutraceuticals

Project Overview – Kauai Algae Farm

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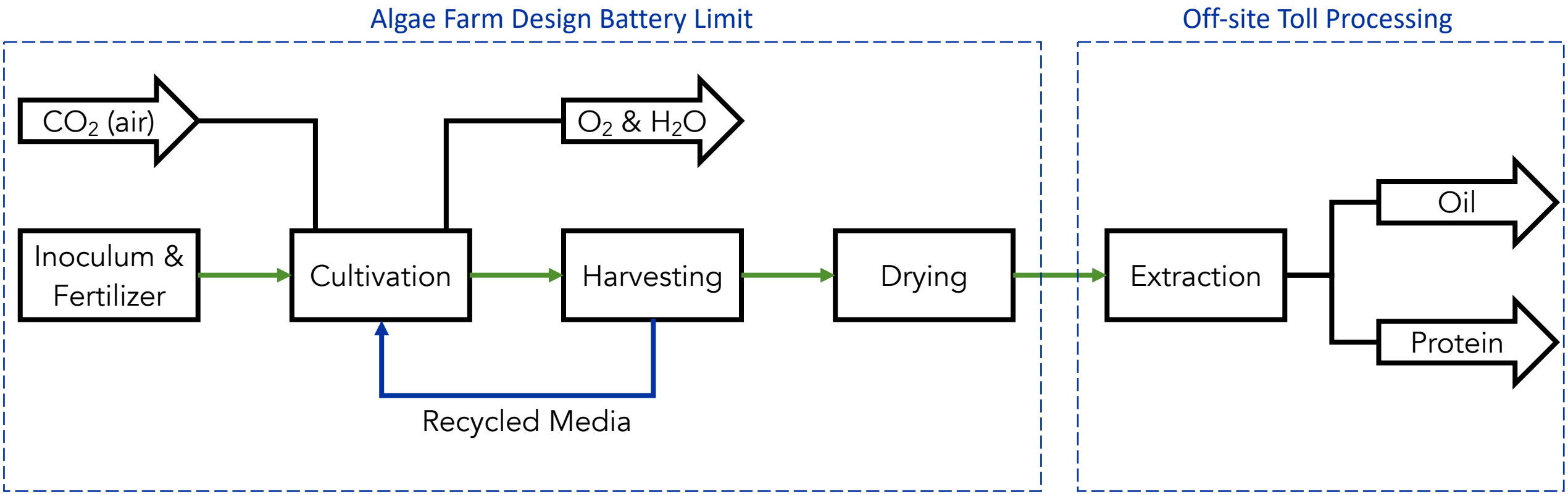
Approach – Overall Algae Process



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Approach – Tasks

1. **Conceptual design & Business assessment**
   - Based on engineering scale data from the Kauai Algae Farm operations
   - Prepared conceptual design documents with updated techno-economic analysis (TEA)
   - Business assessment focused on off-takes, potential partners, financing options
   - Permit planning
   - Technical Advisory Committee review
2. **Site Selection & Trade Studies**
   - Design advances based on engineering trade-off studies and conceptual design results
   - Site selected based on weighted criteria and availability of land for lease or purchase
3. **Preliminary Design**
   - Transitioned design to a local engineering, procurement, and construction company
   - Transitioned permitting to a local permit consulting company
   - Prepared preliminary design documents and cost estimate
   - Updated techno-economic analysis and business assessment
   - Technical advisory committee review
4. **Parallel supporting R&D -** Expanded local strain library (University of California at San Diego)

Approach - Excellent Technical Advisory Committee

Technical Advisory Committee

- Ahma Belay, PhD
  - 40+ years of commercial algae production
- Bill Barclay, PhD
  - 40+ years of commercial algae production
- Ike Levine, PhD
  - 40+ years of algae cultivation and consulting
- Greg Mitchell, PhD
  - 40+ years of algae research & development
- Phil DeDominicis, MBA
  - 30+ years of investment banking experience

Review and Recommendations

- Conceptual design
- Risk Table
  - Other risks
  - Adequacy of mitigation strategy
- Business assessment
- Preliminary Design

Approach – Challenges and Milestones

- **Key Challenges**
  - Re-design of raceways because slope was greater than anticipated in lengthwise direction
  - Site selection and staffing during COVID
  - Unexpected cost increases from post COVID inflation
  - Business approach change from pilot plant operation for oil only to combination of products

- **Milestones**
  - Regular design milestones throughout the project to track progress

Progress and Outcomes - Verification

Raceways during Verification Test

Zobi harvester® (top)
Algae Paste (left)
HEFA Jet Fuel (right)

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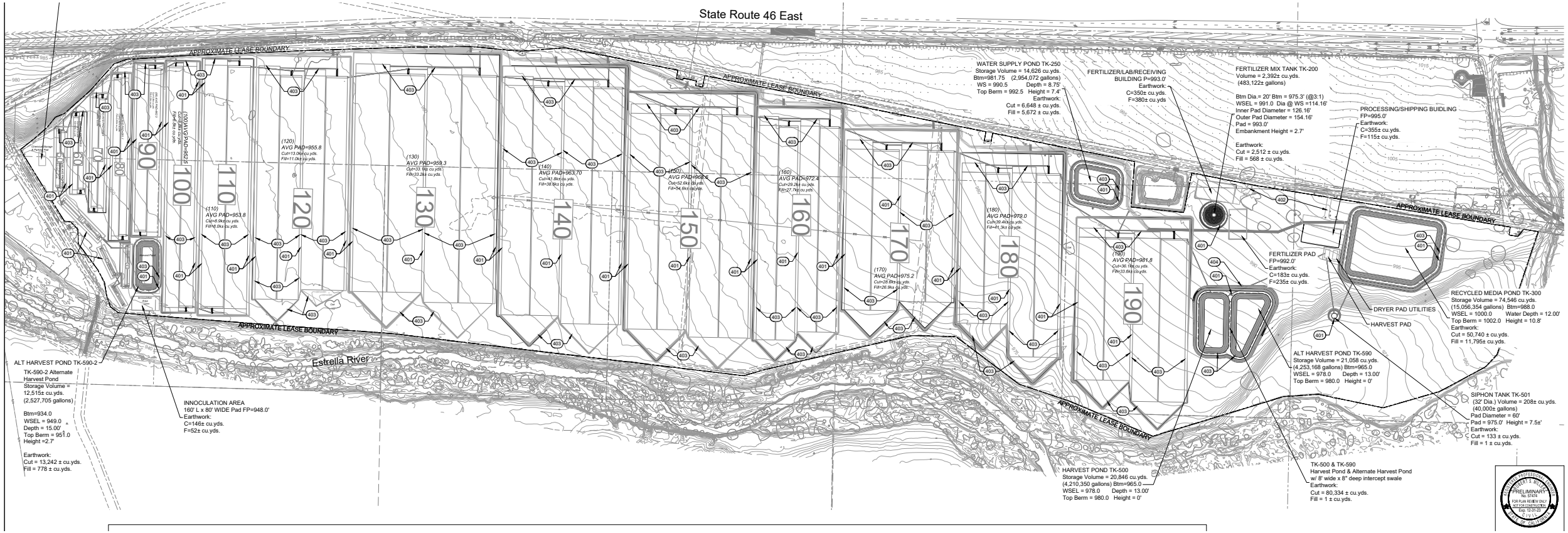
Progress and Outcomes – Cultivation Technology

Item	Conventional Technology	Global Algae Technology	Impact
Raceway	Flat, limited to ~2-acres per raceway	Sloped, scalable to 200-acres per raceway	~30 raceways versus ~2500 raceways for 5000-acre commercial-scale farm
CO_2 Supply	Pure CO_2 piped to and controlled at multiple locations for each raceway	Direct air capture into the raceways (high pH, improved gas-liquid contact)	90% reduction in CO_2 supply cost including distribution and controls
Nutrients	Conventional fertilizers	Novel composition	~25% operating cost reduction
Contamination control	Large inoculum system; chemical treatments	Proprietary technology; no crashes, so small inoculum	Negligible inoculum system vs 5% of the farm dedicated to inoculum system
Productivity	Better strains, higher mixing rates, lower pH/higher CO_2 supply	Proprietary advanced methods: better mixing with lower energy use; better gas-liquid contact; process control and farm design; Strain Improvement in progress	2x higher productivity 10x lower energy use
Lipid formation	Long lipid formation via nitrogen limitation to achieve modest lipid content and low protein	Short lipid formation to 35-50% lipid with high protein content	2x higher productivity and 2x higher value algae

Progress and Outcomes – Harvest Technology

Technology	100% capture Clear recycle	Commercial operations	Feasible today	Energy Use	Capital Cost	Flocculant required	Universal – all algae	Scalable
Zobi harvester	Yes	Yes	Yes	Low	Medium	No	Yes	Yes
Cross-flow filtration / Centrifuge	Yes	Yes	Yes	Medium	High	No	Yes	No
Dissolved air floatation (DAF) / Centrifuge	No	No	No	High	Low	Yes	No	Yes
Settling/Centrifuge	No	No	No	Low	Low	Yes	No	Yes
Settling/ Zobi harvester/ Centrifuge	No	No	No	Low	Low	Yes	No	Yes

Progress and Outcomes – Layout



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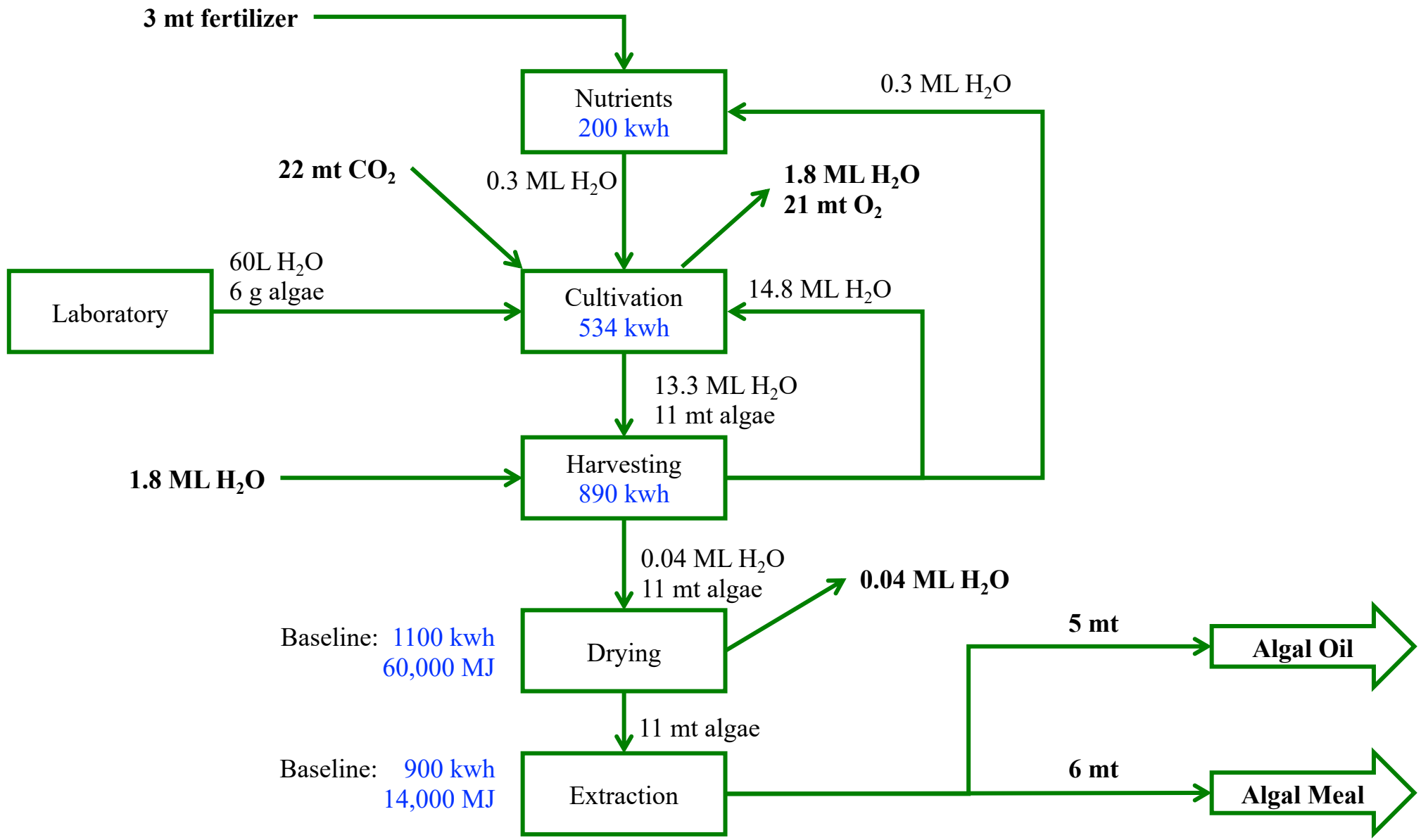
Progress and Outcomes – Mass and Energy Balance



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Progress and Outcomes – 160-acre cost estimate

Item	Installed cost
Mobilization & general conditions	420,000
Earth work	
• Clear and grub	194,000
• 24” over excavation	2,590,000
• Cut and fill	2,820,000
• Fine grading	1,940,000
• All weather gravel roads	897,000
• Security fencing	485,000
Liner	10,040,000
Erosion and sediment control	243,000
Concrete	3,912,000
Major piping	3,766,000
Other piping	5,254,000

Item	Installed cost
Recirculation pumps	10,234,000
Other pumps	1,083,000
Storage tanks	510,000
Electrical distribution systems	4,675,000
Buildings	5,430,000
Other equipment	
• Harvester	5,290,000
• Solar energy	4,400,000
• Dryer with steam system	5,430,000
• Controls and instrumentation	1,930,000
• Laboratory equipment	800,000
• Other	1,545,000
Total	73,887,000

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Progress and Outcomes – Business Assessment

- **Shifted to operational plan to make pilot-scale financially viable**
  - *Nitzschia* for oil 25% of the time and Spirulina 75% of the time
  - Don't need 160 acres

- **Faster path commercial-scale algae biofuel**
  - Data on at least one 12.5-acre raceway so within 16x of commercial-scale raceways
  - Data on integrated operation with harvesting, drying, and extraction to final farm products
  - Expanded product spectrum by further fractionation to double product value
    - Saturated oil for biofuel
    - Mono-unsaturated oil for polymers
    - Polyunsaturated oil for aquafeed
    - 80% Protein concentrate
    - 50% Protein meal
    - Recycle portion of the nutrients
  - Off-takes for all commercial-scale products

Progress and Outcomes – Current Path to Commercial Scale

- Redesign so reach one 12.5-acre raceway with 18-acres of algae (complete)
- Cooperative awards for key next step (2023-2024)
  1. 6-acres or raceways with novel drying and extraction (3 separate projects, breaking ground In Q2 2023)
  2. Spirulina with advanced cultivation and drying (project just started)
- Funding needs (2024-2025)
  1. add product fractionation to 6-acre operations
  2. add one 12.5-acre raceway with larger-scale drying, extraction, and fractionation
- Funding options
  - Scale-up R&D cooperative awards
    - unfunded option on current award for the 12.5-acre raceway
    - New awards needed for fractionation and larger-scale processing
  - Commercial investment or loan, USDA loan (currently greenlit into Phase 2) or state of CA grant
    - Off-take for Spirulina based on product (fully funded)
    - Data from 4-acre raceway (fully funded)
- Off-takes for full-scale products
  - Multiple companies for algal biofuel, biopolymers, and aquafeed
  - Some are currently partnered on current the 6-acre awards
  - Add additional partners and use excess production from testing to validate product quality

Progress and Outcomes – TEA Cost Comparison

Area	This project*	$/mt	Conventional	$/mt	DOE Design Report (Goals)	$/mt
Cultivation	200-acre sloped, 15 g/m^{2}d, 50% oil, 30% protein	230	2-acre paddlewheel, 7.5 g/m2d, 27% oil, ~13% protein	2424	10-acre paddlewheel, 25 g/m2d, 27% oil, ~13% protein	422
Harvesting	Zobi harvester	79	Centrifuge	1943	Settling -> Zobi -> Centrifuge	93
Nutrients	Proprietary	160	Standard	194	Ammonia, phosphate only	29
CO_2 supply	Direct air capture	0	Purchased - $100/t plus distr.	470	Purchased -$45/t very low distr.	110
Inoculum	Very small, ~6 g per day	1	5% of area	240	5% of area	41
Balance of plant	55 raceways to support	181	2500 raceways to support	814	500 raceways to support	49
Total	**Novel cultivation and harvesting**	**651**	**Conventional cultivation and harvesting**	**6085**	**Aspirational cultivation and harvesting**	**745**
Product value	**Protein and oil**	**960**	**Oil and Anaerobic digestion**	**480**	**Oil and Anaerobic digestion**	**480**

All in 2023 dollars

Red text = not feasible today, stated as aspirational goals in the design report

* This project assumes solar energy at $0.30/kWh vs others at $0.10/kWh

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Impact

- **Realistic path to commercial-scale algae biofuels**
  - Team, land, design and permitting for pilot scale algae farm
  - Step-wise plan in place and underway
  - Excellent technology advisory committee to provide guidance during scale-up
- **Lower cost of large-scale algae biofuel production**
  - Solved issues that came up during scale-up
  - Trade-studies identified opportunities for design improvements
  - 11 patent applications planned
- **Higher fidelity techno-economic analysis**
  - Global Algae is a contributor to NREL, ANL, and several university efforts

Summary

- **Preliminary design for pilot-scale algae farm completed**
  - Significant advance over conventional technology
  - Exceeds DOE aspirational design goals
  - Additional innovations developed from design scale-up effort
  - Provides foundation for scale-up – team, design, permitting, land

- **Results used to develop path to commercialization**
  - Updated business assessment
  - Reasonable stepwise path to commercialization
    - 2023-2024 6-acres
    - 2025 – 18 acres
    - 2026-2027 – Design and build commercial scale farm

- **Scale-up underway because of this project**

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QUAD Chart Overview

Timeline

- *BP2 start date: Jan 2017*
- *Project end date: June 2022*

	FY22 Costed	Total Award
DOE Funding	*$300,000*	*$2,235,790*
Project Cost Share	$300,000	$2,235,790

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

Project Goal

Prepare the preliminary design and permitting for scale-up of advanced algal technologies to pilot-scale to facilitate building and scaling algal biofuel technology.

End of Project Milestones

- Preliminary design for 160-acre algae farm with -5/+15% cost estimate
- Business plan assessment and TEA update

Funding Mechanism

FOA: Project Development for Pilot and Demonstration Scale - Manufacturing of Biofuels, Bioproducts, and Biopower (PD2B3)

Project Partners:

- University of California at San Diego
- Kirk Consulting (permitting)

Engineering:

- TSD
- Wallace Group
- Specialty Construction

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Additional Slides

Responses to Previous Reviewers' Comments

Prior comments mainly about presentation, not recommendations for project

- No project change

Verification

- Technology ready for scale-up based on prior engineering-scale data

Technology Selection

System	Conventional Technology	Farm 160 Technology	Improvement
Laboratory	Manual algae and media analysis	Robotic algae and media analyses Microbiota measurements Algae stress measurement	Less labor, greater accuracy, more information about the system
Inoculum	Photobioreactor, ~5% of system area	Mini-raceways, ~0.05% of system area	1000x lower cost and energy use
Nutrients	Fertilizer mix	Lower cost fertilizer formulation	25% cost reduction
CO_2	Purchased CO_2	Direct air capture	95% cost reduction Improved life-cycle analysis
Cultivation	~0.5 ha paddle wheel mixed raceway pond	Scalable, sloped, open raceways Advanced cultivation methods Automated controls Thermal & water management	2-3x higher productivity 10x lower energy use 100x greater scalability 80% cost reduction
Harvesting	Centrifuge	Zobi harvester®	100x lower energy use 90% cost reduction
Drying	Drum or spray dryer	Ring Dryer using waste heat or Global Algae's novel drying process	30x lower energy use 90% cost reduction
Extraction	Extruder & solvent extraction	Extruder & solvent extraction or Global Algae's novel extraction process	10x lower energy use 95% cost reduction

Publications, Patents, Presentations, Awards, and Commercialization

- Patents
  - 11 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