DOE Bioenergy Technologies Office (BETO) 2021 Project

Peer Review

Pilot-Scale Algal Oil Production

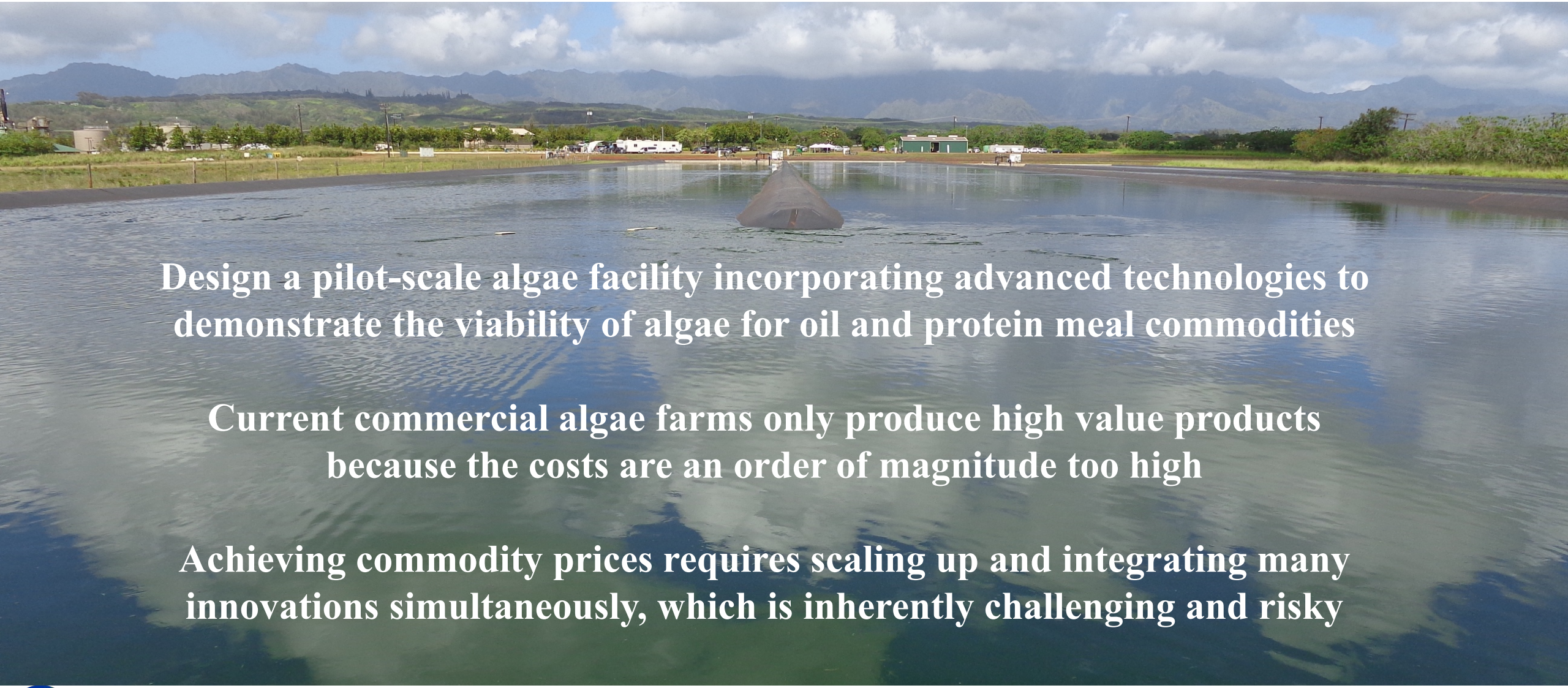
3/26/2021

SDI

Dave Hazlebeck
Global Algae Innovations

GLOBAL ALGAE

Project Overview

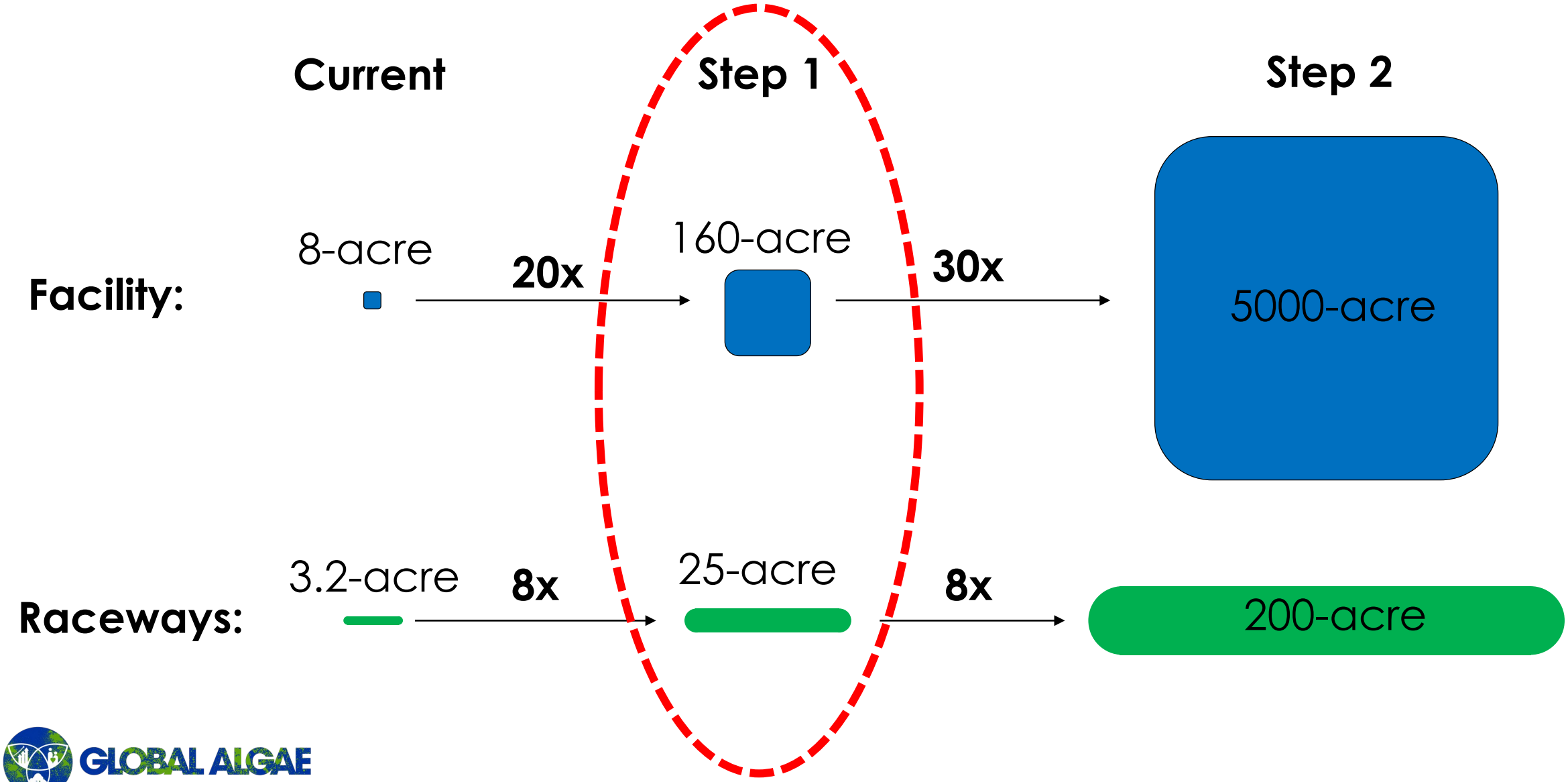


Design a pilot-scale algae facility incorporating advanced technologies to demonstrate the viability of algae for oil and protein meal commodities

Current commercial algae farms only produce high value products because the costs are an order of magnitude too high

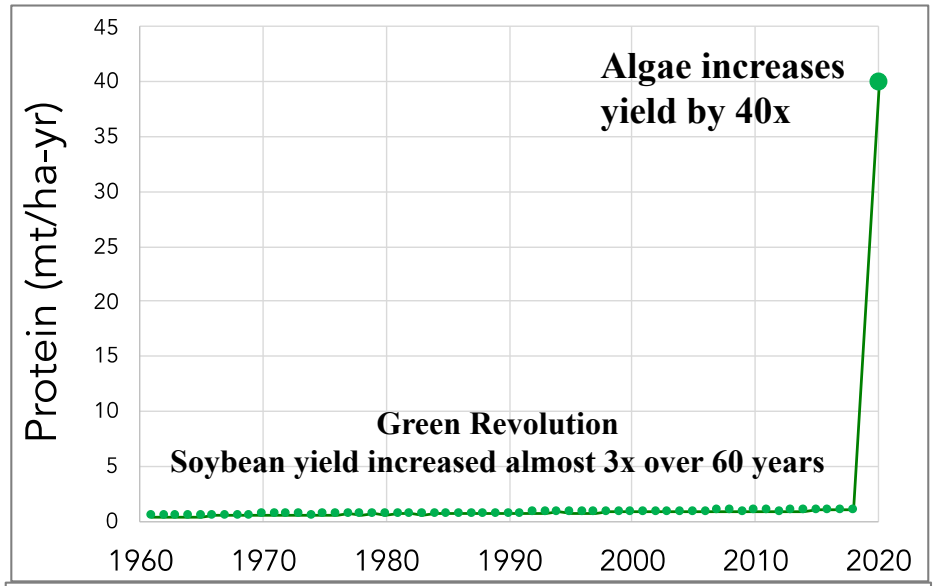
Achieving commodity prices requires scaling up and integrating many innovations simultaneously, which is inherently challenging and risky

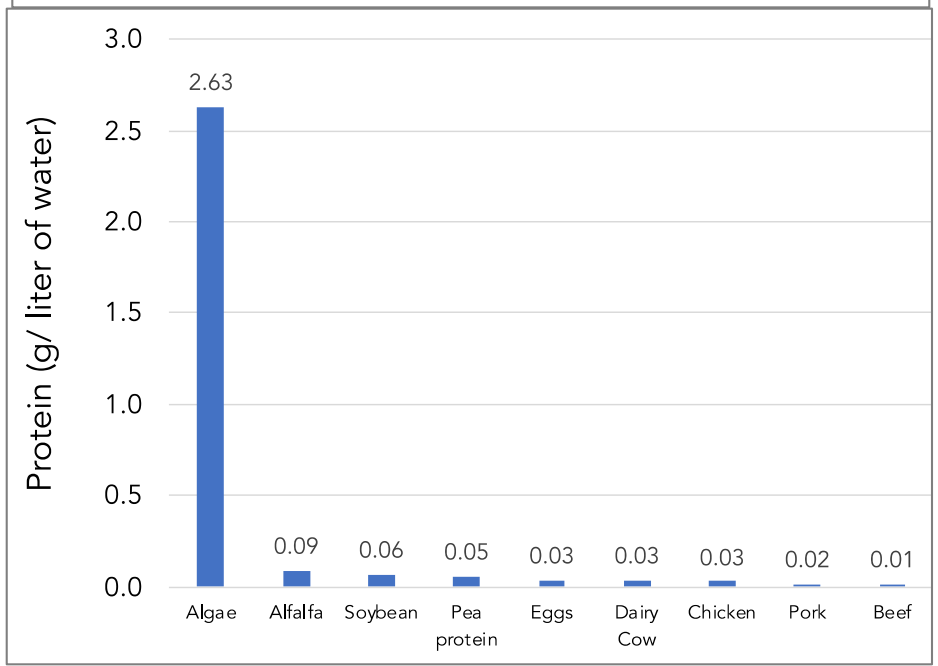
Two Step Scale-up

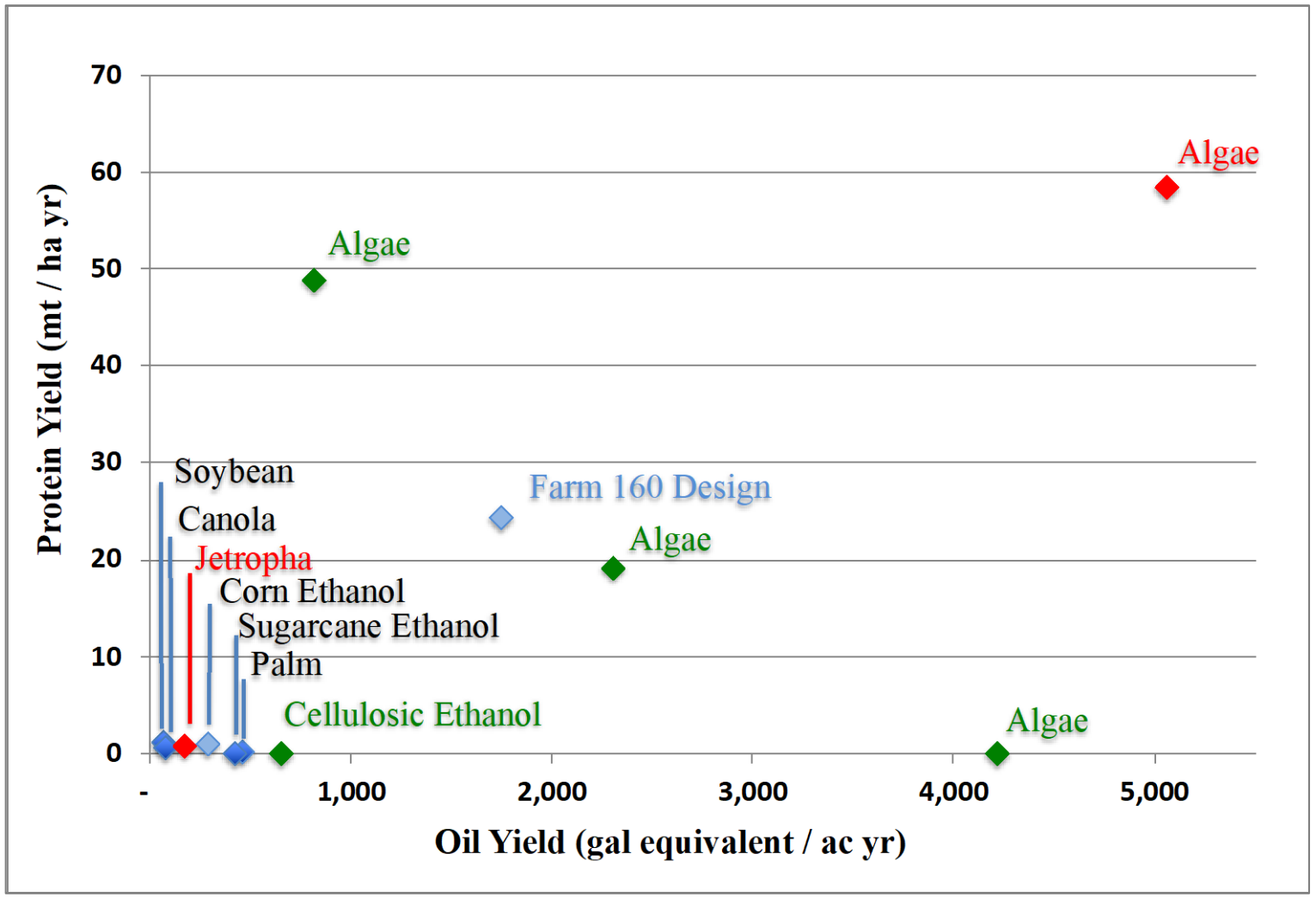


GLOBAL ALGAE

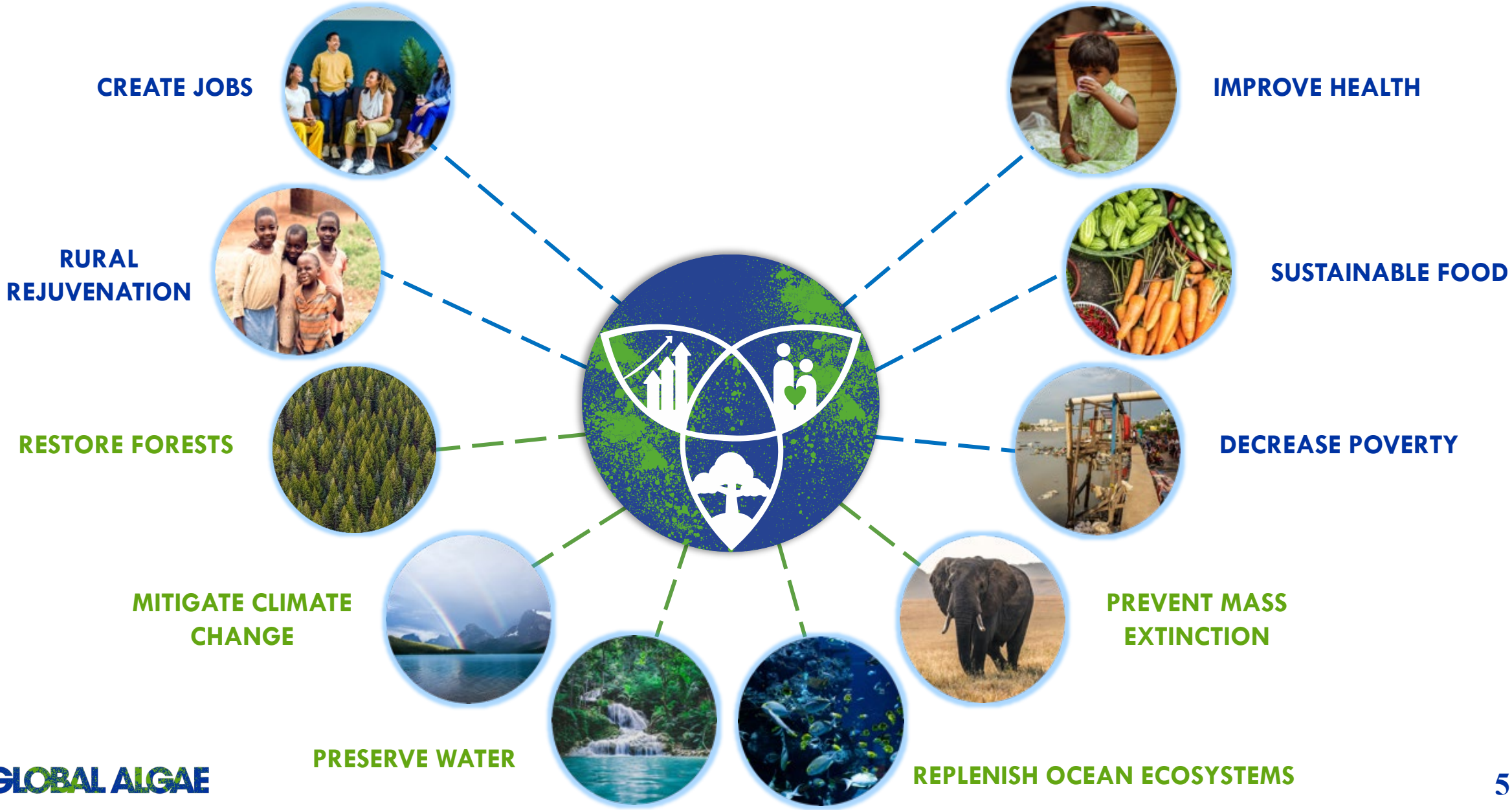
Economical Algae Commodities Are Important Because Algae Offers an Unprecedented Productivity Increase







The IMPACT of ALGAE



GLOBAL ALGAE

Large-scale algae for feed and fuel: 13.3 Gt/year in reduced CO_2 emissions

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
- **University of California at San Diego**
  - Algae strain library, design review
- **TSD Management Associates**
  - Algae processing expertise, PE
- **Permitting Consultant – TBD**
  - Best Best & Krieger LLP
- **Engineering, Procurement, and Construction (EPC) firm – TBD**
  - Specialty Construction

Management

- **Weekly telecoms**
  - Business assessment, permitting, and site selection
  - Design
  - Strain library
- **Actively manage technical progress and budget**
  - Microsoft project schedule
  - Track critical path and near critical path
  - Regular meetings with DOE project team and independent engineer
  - Quarterly reports
- **Integration with ongoing R&D in other projects**
  - 18 partner organizations (universities, national labs, commercial, non-profit)
  - Results that have implications on design and techno-economic analysis
  - Results from this project that impact techno-economic model and R&D targets
- **Formal risk management table**
  - identify risks
  - determine mitigation strategies
  - track through resolution

Excellent Technical Advisory Committee

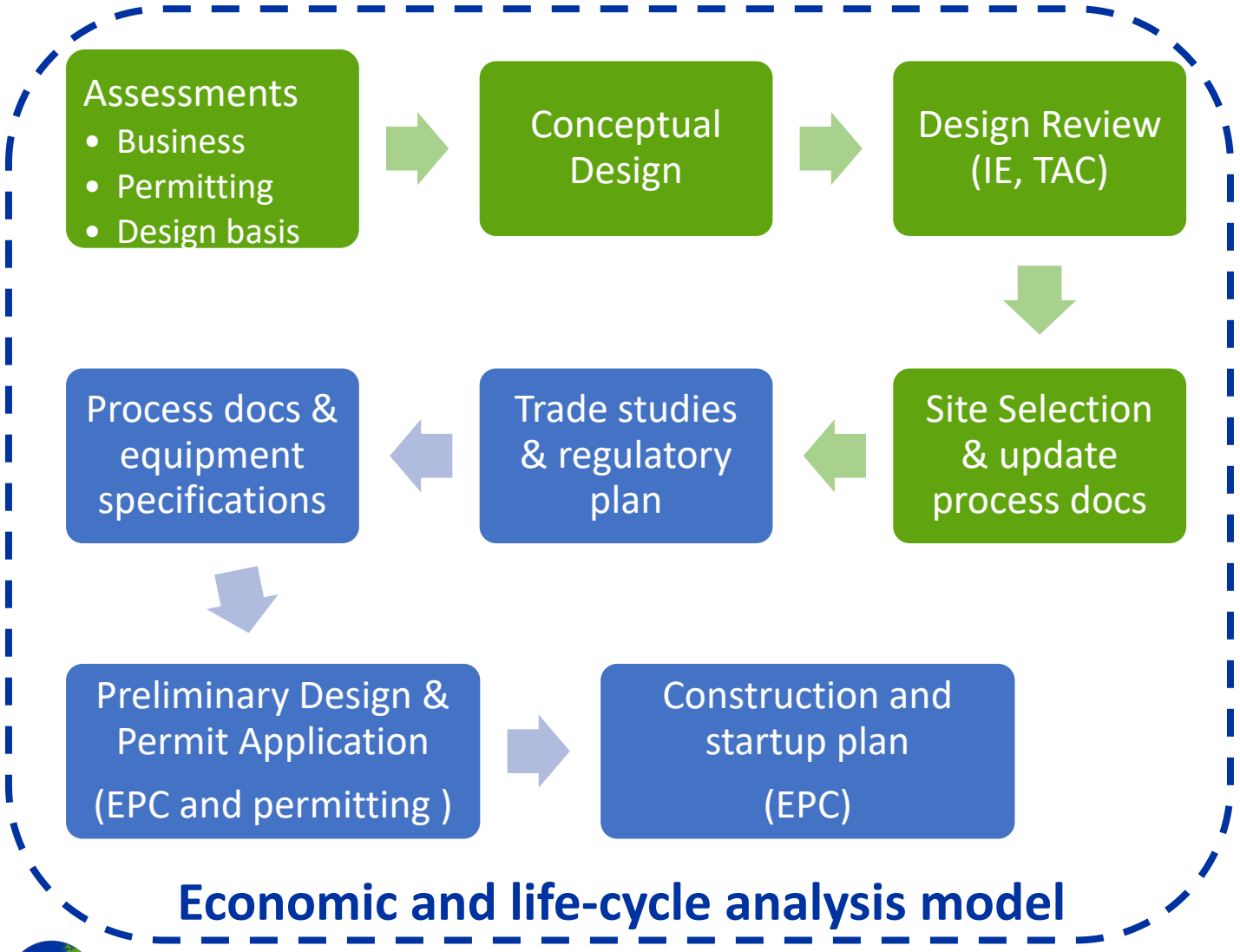
Technical Advisory Committee

- **Ahma Belay, PhD**
  - 40+ years of commercial algae production
- **Bill Barclay, PhD**
  - 40+ years of commercial algae production
- **Greg Mitchell, PhD**
  - 40+ years of algae research & development
- **Ike Levine, PhD**
  - 40+ years of algae cultivation and consulting
- **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

2 - Approach



Integration into Pilot-Scale Design

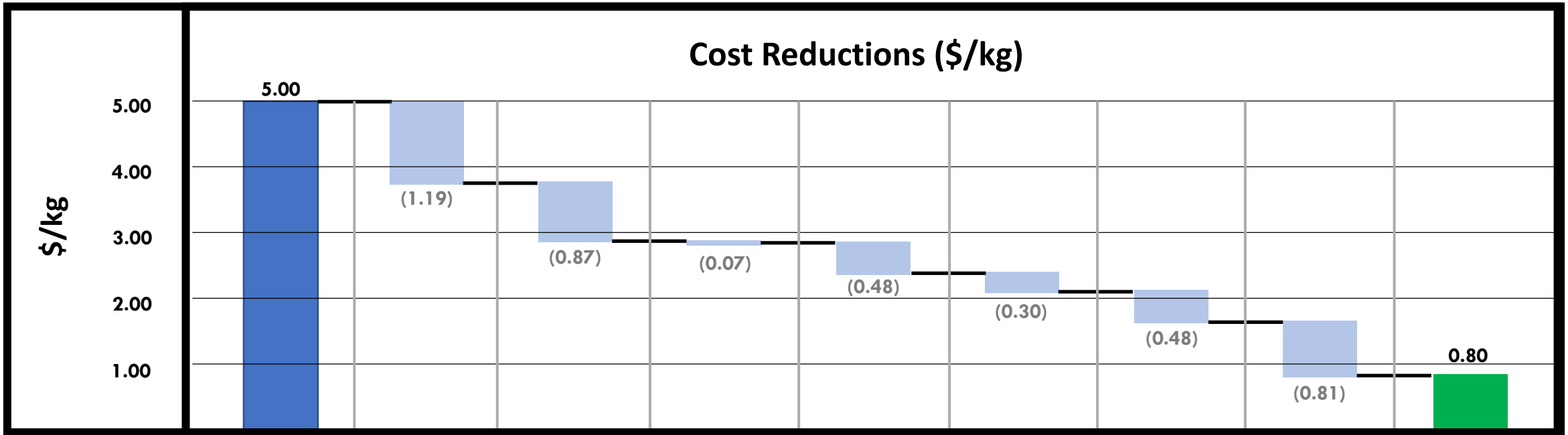
- Breakthroughs & innovations
- Commercial production environment
- Local weather variations
- Site constraints
- Business assessment
- Permitting assessment

Preparatory R&D

- Photobioreactor testing for inoculum
- California Strain Library

Schedule

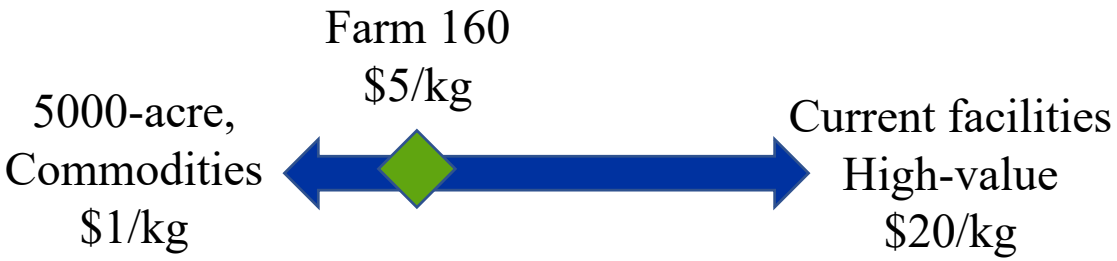
Integrate Many Breakthroughs and Innovations into the Pilot-Scale Design



	Conventional	Cultivation	Harvesting	Nutrient Supply	Stability & Inoculation	CO_2 Supply	Extraction	Drying	Global Algae
Major Break-throughs	–	3	2	0	1	2	1	2	**11**
Other Key Innovations	–	19	7	1	14	4	4	5	**54**
R&D in progress		37	7	8	13	9	9	2	**85**

GLOBAL ALGAE

Business Assessment



- Algae oil - validate economics and quality
  - ¼ of time, ~1wk per month
  - Oil for polymers, fuel, omega-3
  - Protein meal for feed trials and testing to support regulatory approvals
- High value product / biofoundry – pay the freight
  - ¾ of time
  - repay loans and/or ROI
  - support long-term operation

Parallel financing routes

- Commercial investment
  - Future off-take rights
  - Rotate high value product/biofuel so can leverage with USDA guaranteed loan
  - Financial partner
- Non-profit grants/loans/investments
  - Solutions to environmental/societal dilemmas needed now
  - Move to pilot & commercial-scale faster
  - Spur algae industry: biofoundry, regulatory approvals, proof of viability
- Federal and state grants/loans

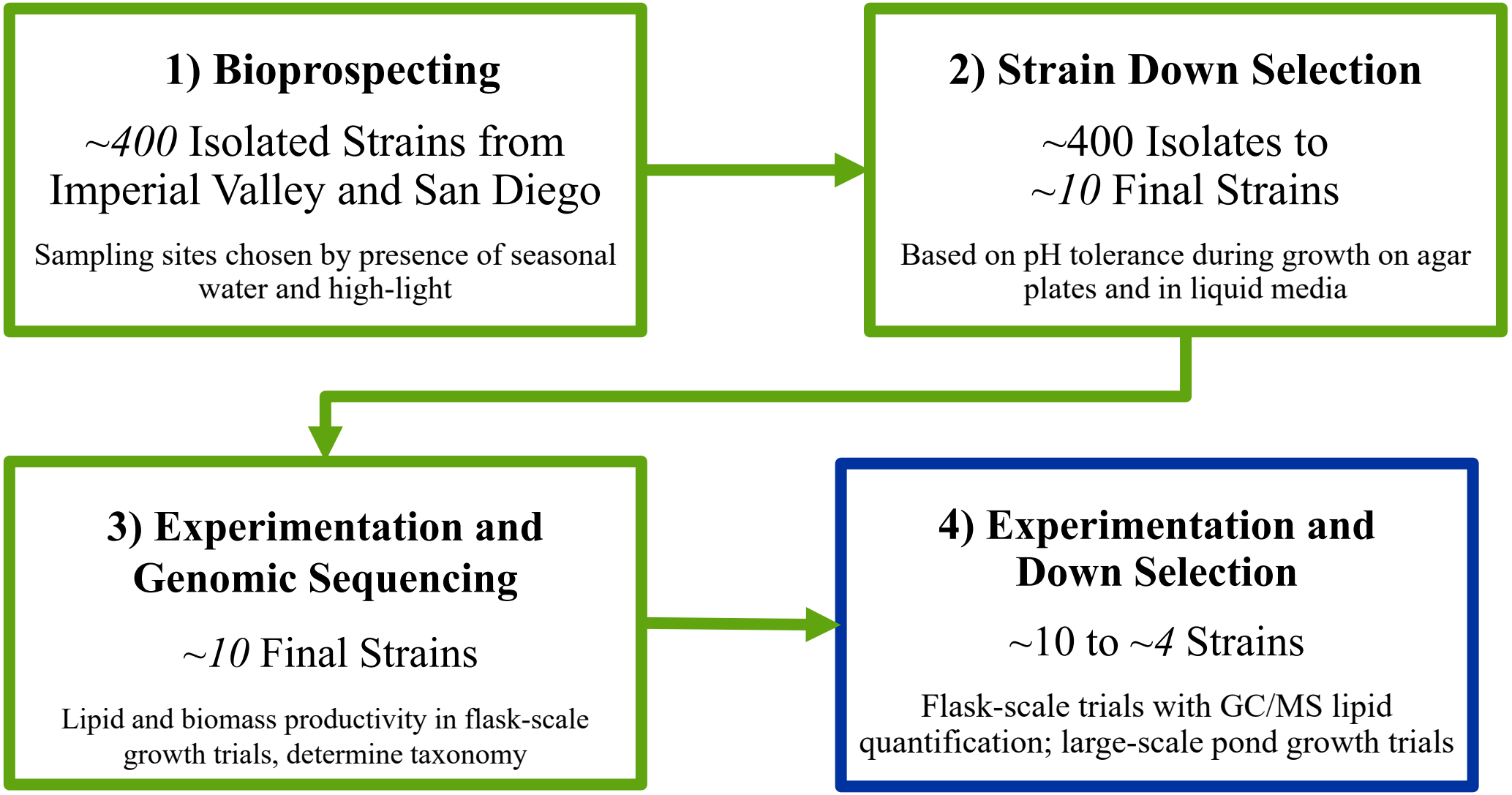
3 - Impact

- Facilitate financing of pilot-scale algae oil facility through completion of design and permitting
- Integration and scale-up design for 65 innovations including 11 major breakthroughs
- Patents based on the design and scale-up work (6 invention disclosures from conceptual design effort)
- 12 trade studies each advance state-of-the-art through evaluation of options and optimization, e.g.
  - Water management – rain, evaporation, cleaning, recycle, blowdown, evaporation pond, etc.
  - Raceway pumping and circulation
  - Harvesting configuration and operational mode/time
- Scale-up and cost estimates
  - Validate economic and sustainable attributes of the advanced algae process
  - Higher fidelity economic model will benefit general industry through our partnerships
  - Better R&D because the techno-economic model is used to guide all of our research projects
- Once built and operating
  - Plan to finance plant and then licensing/franchise model for dissemination
  - Biofoundry will spur industry
  - Existence proof for lower cost algae production will invigorate investment

4 – Progress and Outcomes
Milestones Completed

- Strain collection, isolation, initial down selection and characterization
- Photobioreactor validation
- Permitting and regulatory assessment
- Business assessment
- Risk assessment
- Conceptual design
  - Design basis, block flow diagram, mass and energy balance
  - Technology selection, process description, control and operating plan
  - Major equipment sizing, site layout, technoeconomic model update, cost estimate
- Conceptual design review
- Site selection
- Process document updates (block flow diagram, mass and energy balance, techno-economic model)

UC San Diego Strain Library Progress

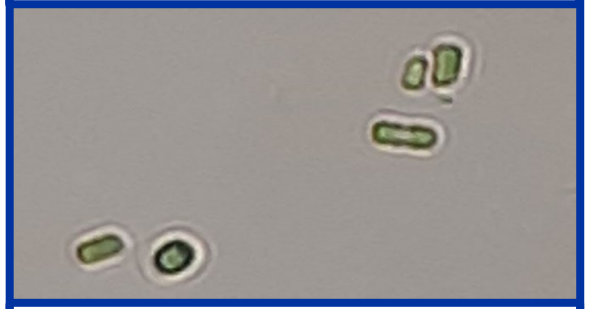


Strain Collection and Isolation

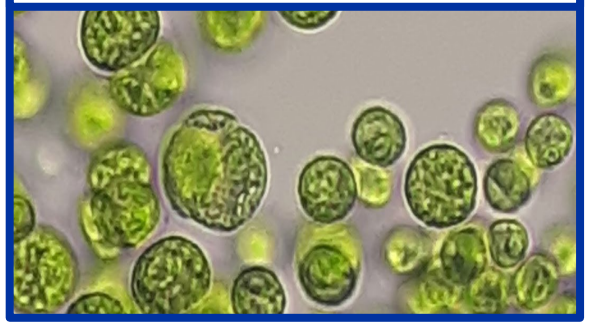
Sample Site IV-03

Plated Environmental Sample

IV-003(Stichococcus)



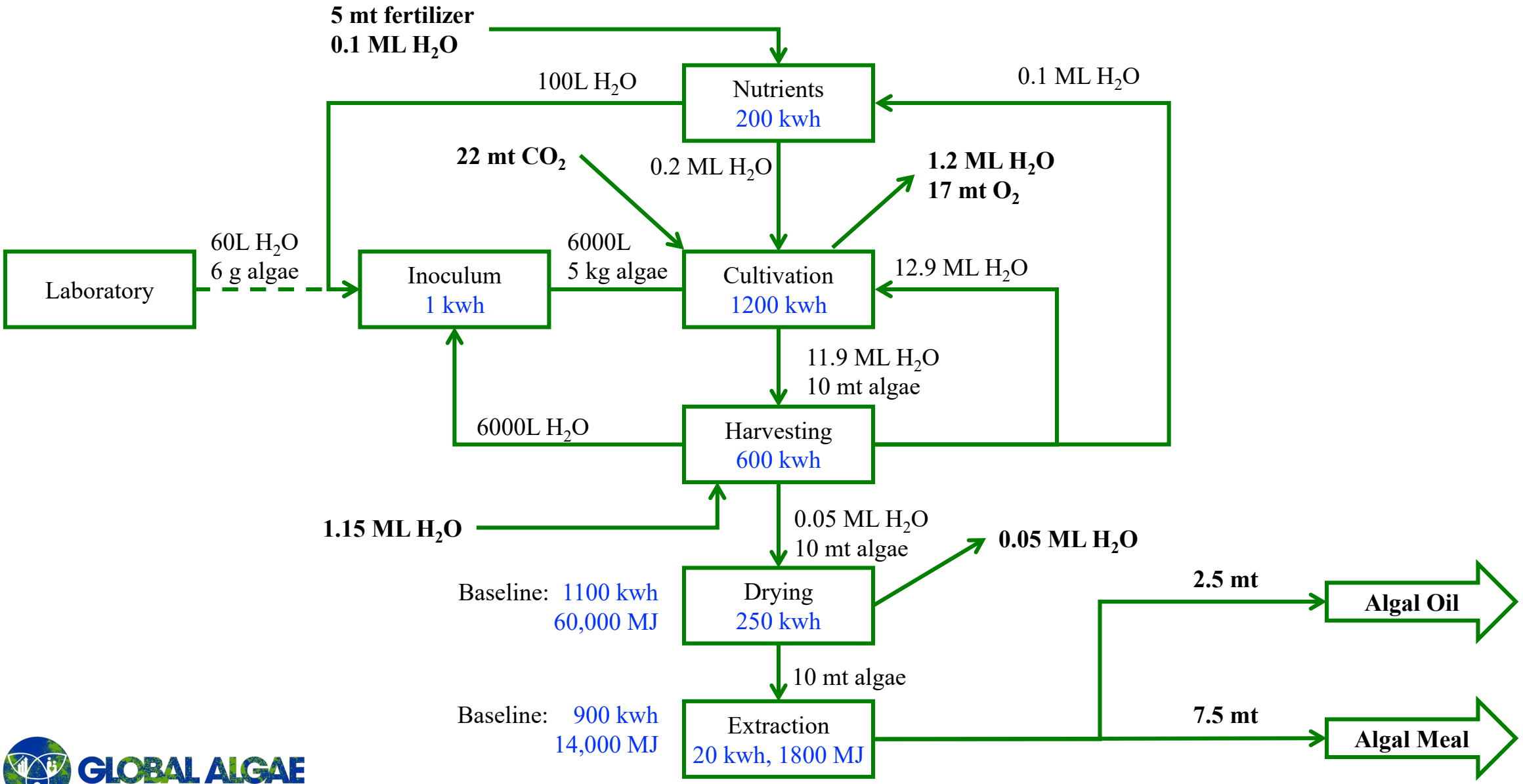
IV-023(Tetracystis)



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	99.9% 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

Mass and Energy Balance (average daily flows)



Site Selection Matrix

Location	Access Support	Temp range	Days of Sun	Water	Topo	Permit & Reg	Fert. Supply	Oil & Feed Use	CO_2	Total
Weight factor	8	8	8	6	4	2	1	1	2	120
San Diego: Tijuana valley	3	3	1	3	2	3	2	2	2	96
San Diego: San Pascal	3	3	1	2	3	3	2	2	1	92
San Luis Obispo: Shandon	**2**	**2**	**2**	**3**	**3**	**3**	**3**	**2**	**1**	**91**
San Luis Obispo: Huasna	2	3	2	2	2	3	3	2	1	89
Imperial Valley: El Centro	1	1	3	3	3	3	3	2	2	85
San Diego: Campo	2	2	1	3	3	3	2	2	1	82
Kern: Bakersfield	1	2	1	3	3	3	3	3	3	74

Summary

- **Large-scale algae production for commodities is essential to mitigate climate change**
  - Stopping and reversing deforestation is pivotal in the IPCC pathways to achieve our climate change goals
  - Algae is the only solution to deforestation that meets the world's protein requirements
- **The design and trade off studies are advancing the state-of-the art for algae oil production**
  - Integrating many innovations to achieve an order-of-magnitude reduction in costs and energy
  - First scale-up design of an open-algae cultivation system with advanced technologies
  - Identifying and addressing the challenges and opportunities in commercial application of these innovations
  - Design effort has resulted in 6 invention disclosures to-date
  - Better scaling and cost estimate will improve algae R&D programs through technoeconomic model fidelity
  - R&D advances in other projects are being tracked for incorporation of results into the design
- **Technical advisory board has wealth of experience and expertise to help ensure the pilot is successful**
- **On-track for completion of the preliminary design, permitting, and execution plan this year**
- **Construction and operation of this pilot facility will hasten development of the algae industry**

Quad Chart Overview

Timeline

- Project start date: 1-15-17
- Project end date: 12-31-21

	FY20 Costed	Total Award
DOE Funding	211,097	2,235,790
Project Cost Share	190,018	2,235,790

Project Partners

- TSD Management Associates
- University of California at San Diego
- California Energy Commission
- Engineering, procurement, construction - TBD
- Permitting consultant - TBD

Project Goal

The goal is to scale-up an open-raceway algae biofuel process that is economically viable and sustainable

- Preliminary planning and design
- High fidelity technoeconomic analyses for a full-scale facility that verify the process is economically viable and sustainable
- Business plan for financing and operation that enables long-term algal oil production

End of Project Milestones

- FEL-3 design documents with -5% / +15% cost estimate accuracy.
- Business plan including technoeconomic analysis results.
- Project management plan for detailed design, construction and start-up.

Funding Mechanism

DE-FOA-0001232; Topic Area 1; 2016

Additional Slides

Responses to Previous Reviewers' Comments

2019 Peer Review Questions/Comments	Project Changes
Not clear that project advances the state-of-the-art.	Added more information into the 2021 presentation about how the project advances the state-of-the-art.
Need alternative financing plans	Pursing five financing approaches: • Commercial investment for future off-take rights • Commercial investment & USDA loan for high value product & biofuel • Financial partner for Global Algae • Non-profit grants/loans for environmental and societal benefits • Government grants/loans
Pilot plants are too small to be profitable	160-acres is pilot-scale for algae biofuels but is commercial-scale for higher value algae products. Design basis already included strain rotation to improve contamination control. Added rotation between high value product ($20/kg) and algae oil ($1/kg) so composite sales revenue is commensurate with pilot-scale costs.

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