# DE-FE0032187

# Spirulina Production on Flue Gas

Global Algae Innovations

08/6/2024

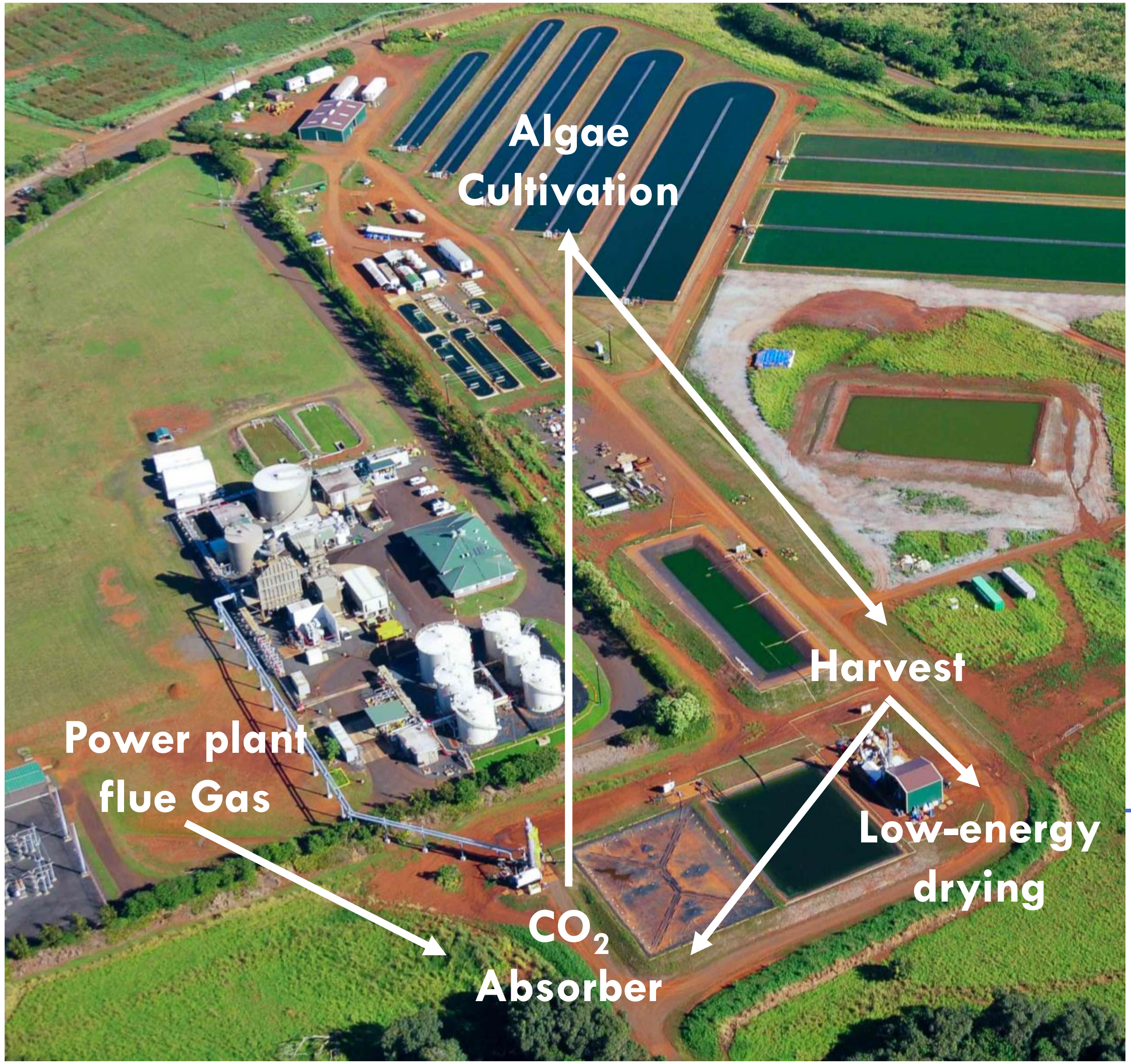
NATIONAL ENERGY TECHNOLOGY LABORATORY

## Creating an abundant & sustainable world

**Founded in 2013 with the Vision to:**

***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. .***

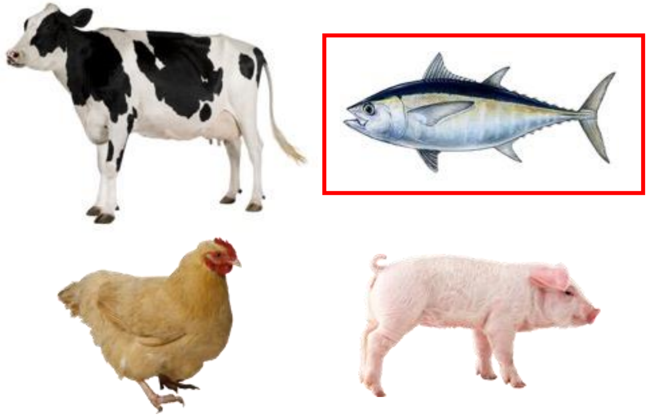
# Project Summary




Spirulina


Harvest Paste

Feed Ingredients



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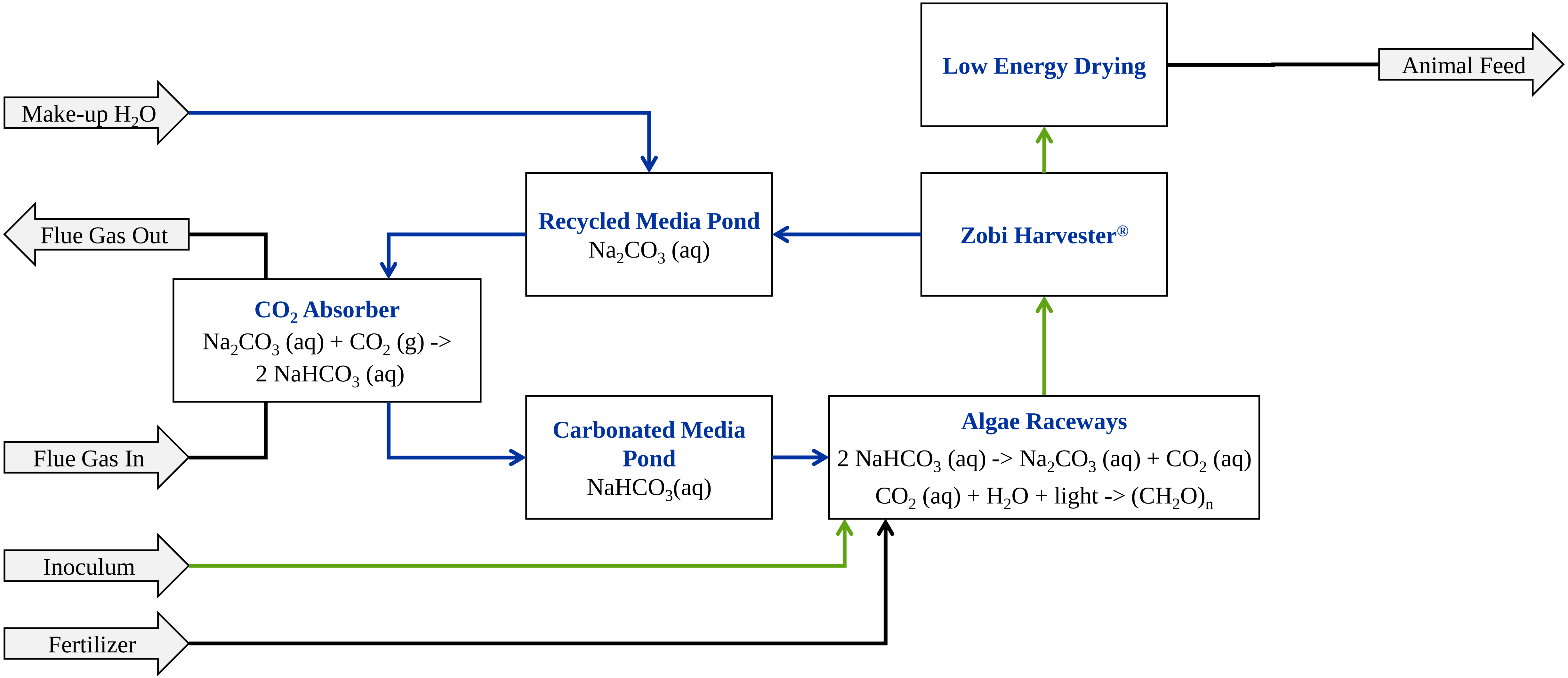
# Simplified Block Flow Diagram

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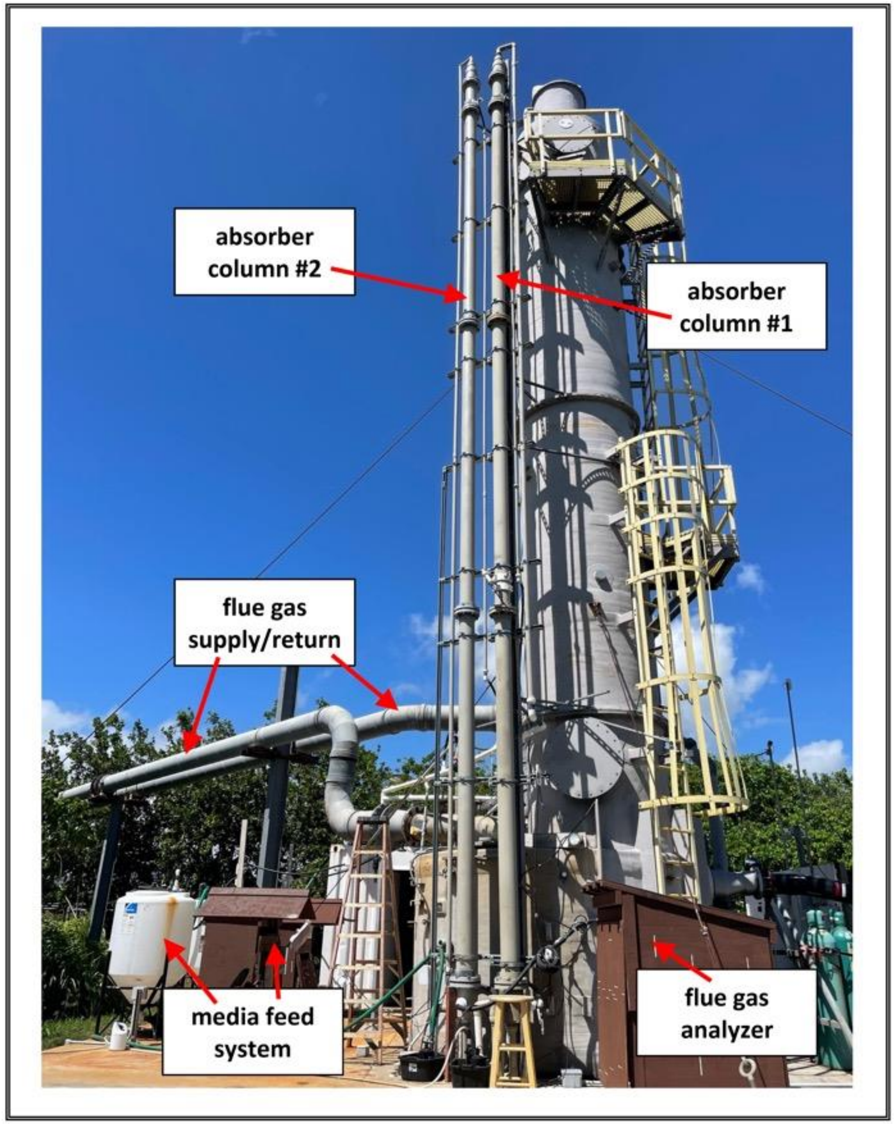
# $CO_2$ supply system advantages

- 24 hour per day $CO_2$ capture
- Storage of $CO_2$ to account for variable demand
- Very low energy: 2.5" water pressure drop on flue gas
- No ground level flue gas emissions, i.e., can be permitted
- Eliminates need for gas distribution or controls at the raceways
- Low cost, $25-50/ton captured, stored, and delivered to the raceways
- High capture efficiency, 70-90%
- High utilization efficiency, 90-100%

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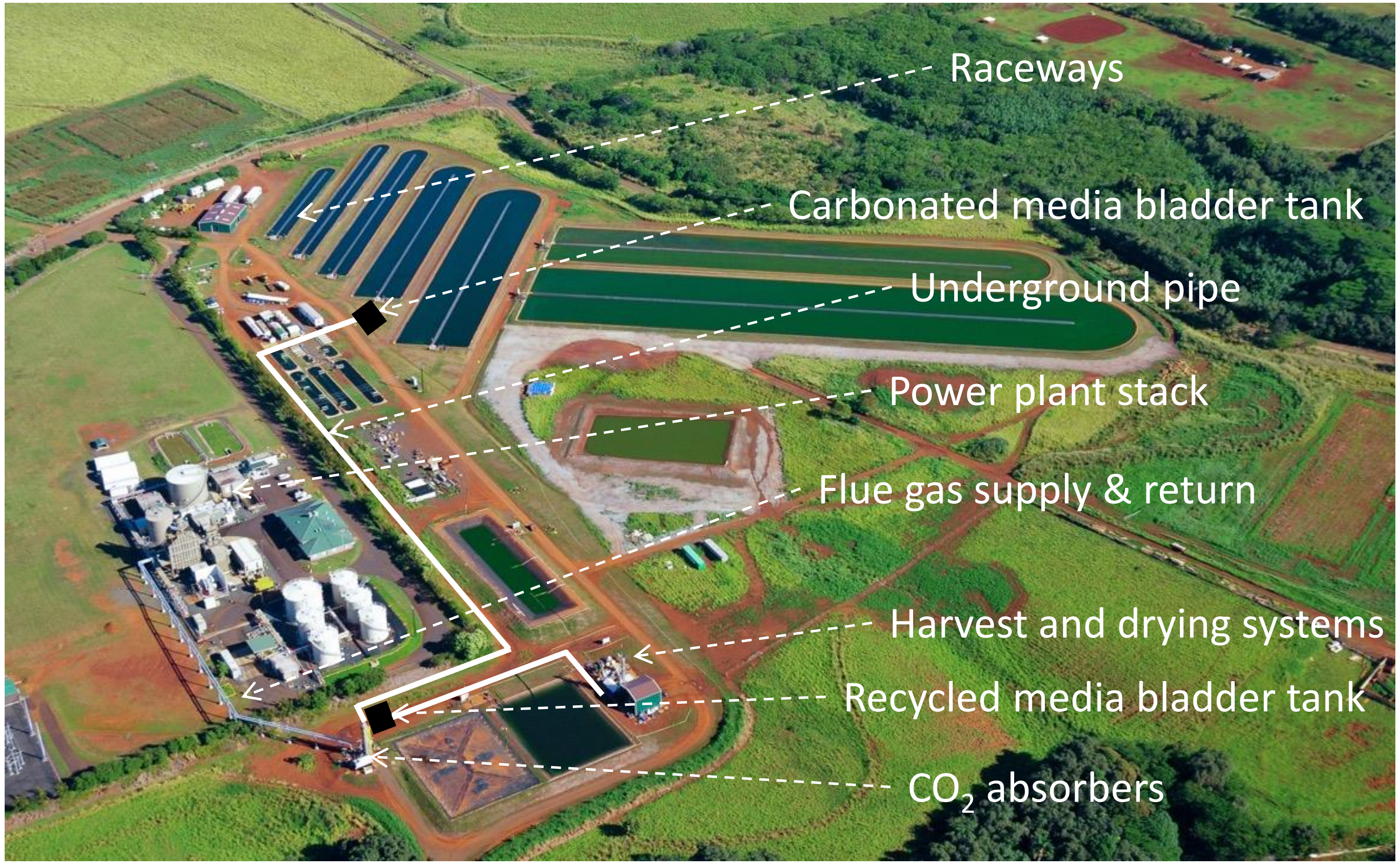
# Absorber and tanks integrated into the Kauai Algae Farm

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# Project Overview

| Category | Budget |
|---|---|
| Federal share | 2,000,000 |
| Cost share | 500,000 |

| Budget period | Start | End |
|---|---|---|
| 1. Cultivation & processing | 7/1/2023 | 12/31/2024 |
| 2. Scale-up and aquaculture trials | 1/1/2025 | 6/30/2026 |

| Subrecipient | Role |
|---|---|
| Algae4All | Technical expertise in Spirulina cultivation, processing, and product quality |
| University of California, Santa Cruz | Perform aquaculture feed trials and technical expertise in aquaculture feed ingredient quality |

# Budget Period 1 Objectives

1. Cultivation, harvesting, and drying (achieved July 2024)
   - 7-day field trial in a 1.8 $m^2$ outdoor open raceway
   - Average productivity of at least 16 g/m2/day
   - 70% capture efficiency
   - 80% carbon utilization efficiency
   - High quality spirulina, >60% total protein and < 1% phosphorous

2. Cultivation, harvesting, and drying (In-progress August-September 2024)
   - 30-day field trial in a 600 $m^2$ outdoor open raceway
   - High quality spirulina, >60% total protein and < 1% phosphorous

# Overall Project Objectives

1. Cultivation, harvesting, and drying (BP2):
   - 30-day field trial in a 600 $m^2$ outdoor open raceway
   - Average productivity of at least 20 $g/m^2/day$
   - 70% capture efficiency
   - 90% carbon utilization efficiency
   - High quality spirulina, >60% total protein and < 1% phosphorous

2. Feed trials with rainbow trout (Spirulina biomass shipping Oct 2024, Testing BP2)
   - Demonstrate potential of Spirulina as a fishmeal replacement in aquaculture feed

3. Verify economic and life-cycle benefits via TEA and LCA (Initial TEA and LCA complete; final in BP2):
   - Projected production costs show Spirulina is economical as fishmeal replacement (initial TEA
   - At least 50% GHG reduction relative to fishmeal (initial LCA 76% GHG reduction)

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# Project WBS

1. Project management

**Budget Period 1**

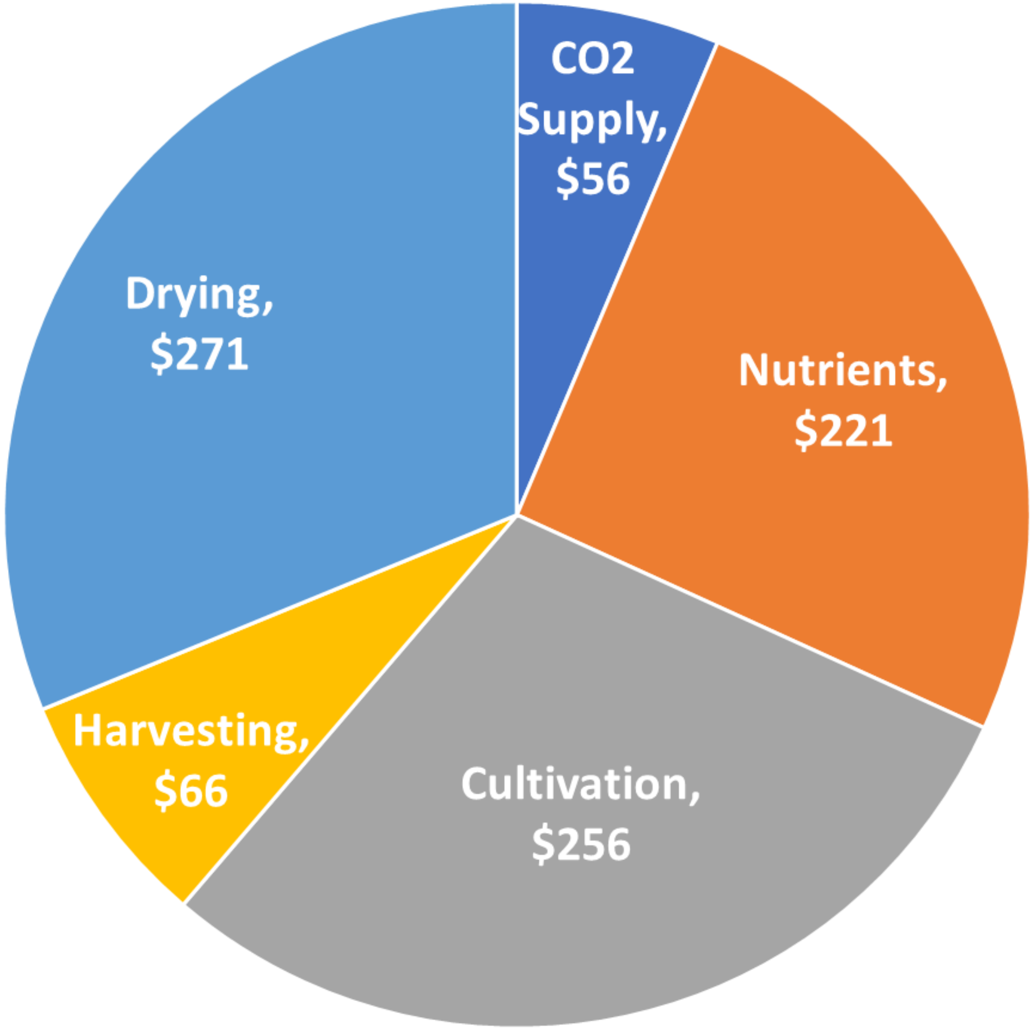
2. Initial TEA and LCA
3. Nutrient optimization
4. On-line nitrate and Ash-free dry weight sensor
5. Rapid assessment of algae health
6. Refining cultivation methods
7. Adapting harvesting and drying to Spirulina
8. Initial control methods development

(Items 3–6: Productivity improvement tools)

**Budget Period 2**

9. Large-scale integrated tests
10. Feed Formulation and testing
11. Final TEA and LCA

# Initial TEA for Spirulina cost is much lower than fishmeal




**2024 fishmeal price: ~$1800/mt**

**Projected cost $870/mt (2024$, 8% unlevered IRR)**
**4% $CO_2$ flue gas, 80% capture efficiency**

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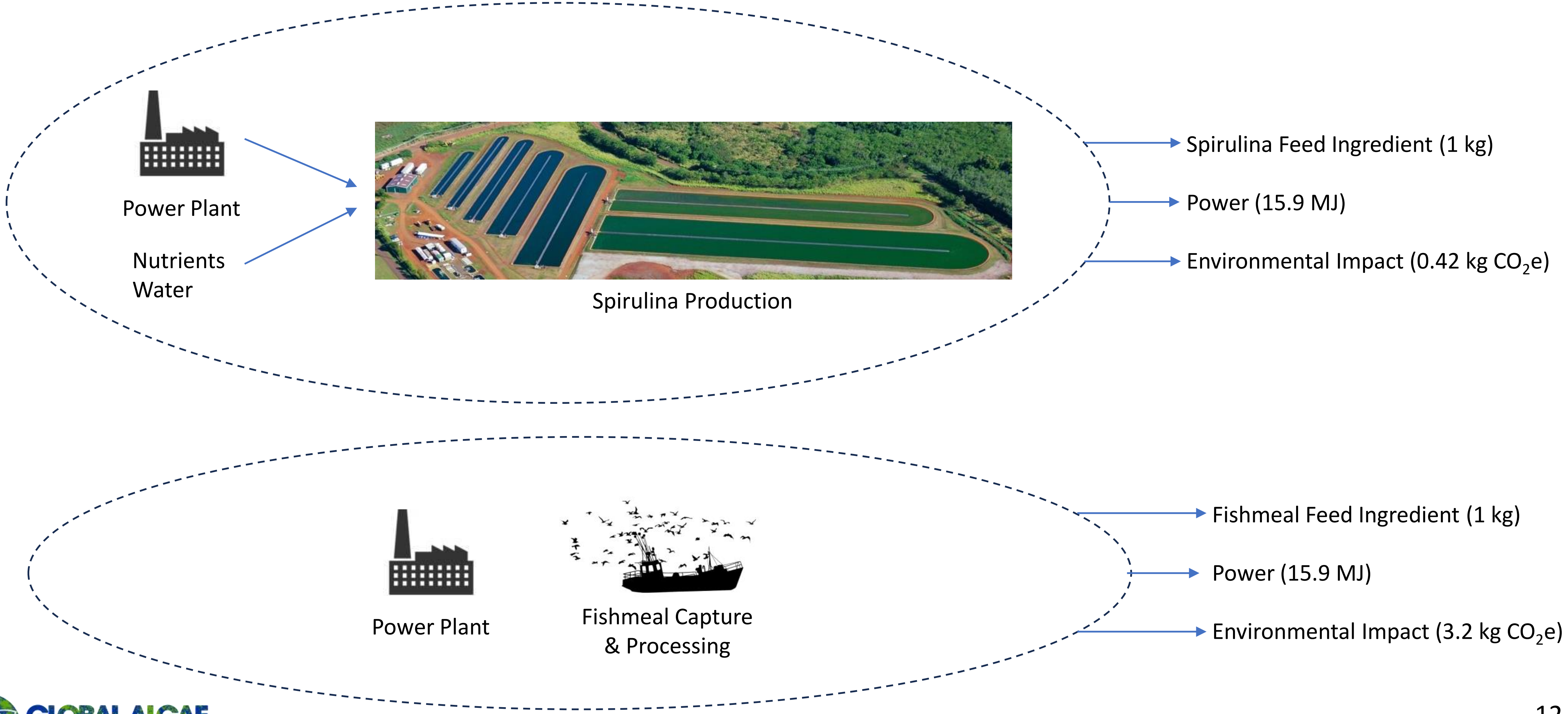
# Initial Life Cycle Analysis: 87% GHG reduction
# functional unit = 1 kg feed ingredient

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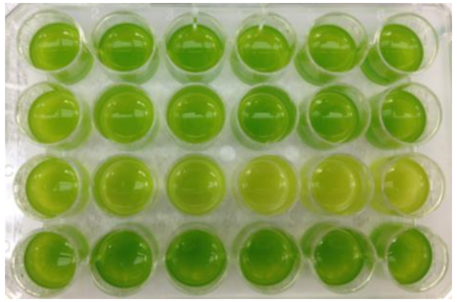
# Task 3 - Nutrient optimization for productivity and composition

- Media optimization for highest growth and biomass composition was conducted at the lab using microplates, flasks and photobioreactors.
- Optimal nutrient levels were determined at elevated pH.



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# Task 4. On-line Nitrate, pigments, and AFDW sensor

- Two IQ SensorNet NitraVis® TS Sensors from waste water treatment industry
  - 1 mm path length ($NO_3$)
  - 5 mm path length (biomass, pigments)

- Initial trial units test data looks promising for good correlations

- Supply chain delays on final sensor delivery

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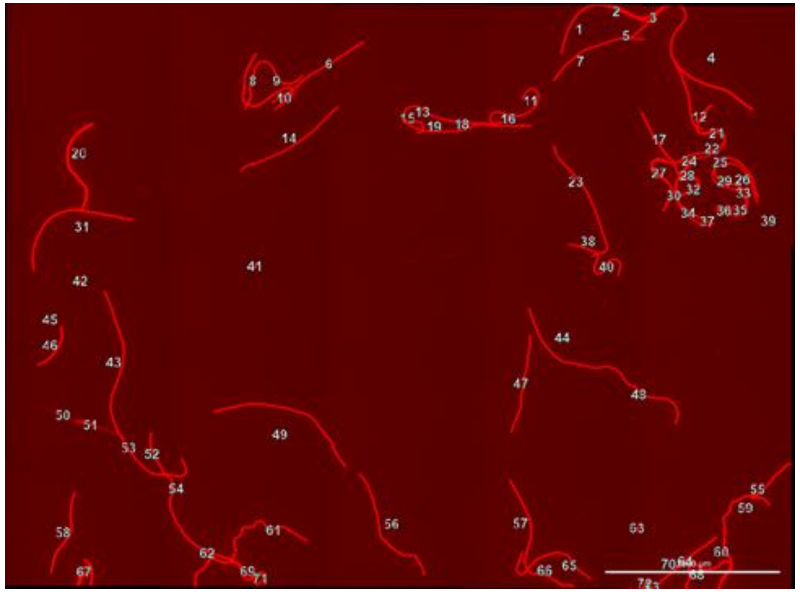
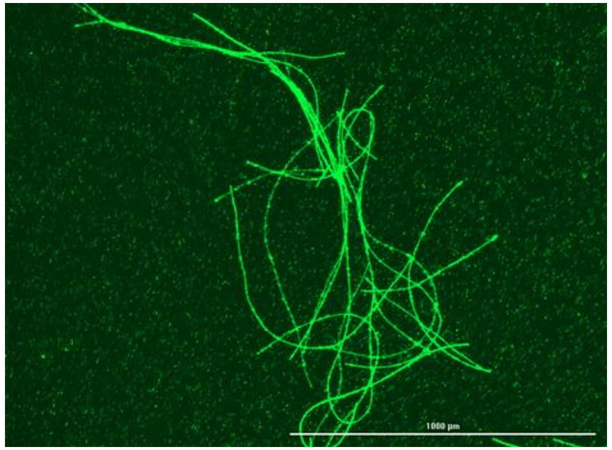
# Task 5 – Assessment of spirulina physiology

- New methods to assess spirulina physiology are being developed and tested using **automated microscopy**.
- Standard methods to photosynthetic performance with a Mini PAM.
- Methods include filament count and length; DNA, RNA, protein, and lipid content; reactive oxygen species, cell membrane permeability, alkaline phosphate activity, and peroxidase activity.
- Best performing methods will be applied to improve outdoor cultivation.





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# Task 6 – Refining Cultivation Methods

- Baseline integrated test in 600 $m^2$ raceway
- Broad test matrix in 1.8 $m^2$ raceways to develop productivity and composition correlations with abiotic and biotic variables
- Data used to achieve key production metrics, task 8

# Task 7 – Adapt harvest and drying technology to Spirulina

- Data from 600$m^2$ integrated tests were used to develop baseline harvesting and drying method.
- Baseline approach achieves targets:
  - Zobi harvester with rinses
  - Thermal drying with solar steam
  - Achieved go/no-go objectives

| Objective | Target | Measured |
|---|---|---|
| Protein content | > 60% | 61.2% |
| Phosphorous content | < 1% | 0.4% |
| Ash content | <10% | 9% |

- Still evaluating lower energy drying option

Zobi effluent paste

Dried Spirulina

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# Task 8 – Control methods optimization

Achieved Go/no-go objectives

| Objective | Target | Measured |
| --- | --- | --- |
| Capture efficiency (from 4% flue gas) | 70% | 90% |
| Utilization efficiency | 80% | 119%* |
| Productivity, 7-day average ($12 m^2$ raceway) | 16.0 $g/m^2d$ | 18.4 $g/m^2d$ |

* Net absorption of $CO_2$ from atmosphere

Remaining task is 30-day field trial to 600 $m^2$

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# Task 9 – Large-scale integrated tests (BP2)
# Mr. Rodney Corpuz

- Optimize control methods started in task 8
- Achieve project objectives for cultivation, harvest, and drying
- Generate Spirulina biomass for feed trials

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# Task 10 - Nutrient, heavy metals and digestibility of *Spirulina (BP2)*
## *Dr. Pallab Sarker*

**Three steps at UCSC**

**Step 1**: Biochemical nutrient and heavy metal analysis

**Step 2**: Compare Feed digestibility

**Step 3**: Compare Pollution potential

Ecological Aquaculture facility at UC Santa Cruz



- Indigestible marker ($SiO_2$) in diet
- Quantify % nutrients in diet relative to the marker
- Quantify % undigested nutrients in feces relative to the marker
- Formula computes ingredient digestibility

# Summary

- **Project on track exceeding all BP1objectives**
  - Productivity achieved: 18.4 g/m2d
  - Capture efficiency achieved: 90%
  - Utilization efficiency achieved: 119%
  - High protein biomass (62%) with low phosphorous (0.4%) and ash content (9%)
- **Initial TEA and LCA projection confirm economic and life-cycle benefits**
  - 87% GHG reduction
  - $870/mt for Spirulina vs fishmeal at $1800/mt
- **BP2 starts next year:**
  - larger-scale testing, more challenging productivity targets, and feed trials