SENIOR CAPSTONE/
SENIOR DESIGN EXPERIENCE
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Production of Oils from Microalgae

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Objective

To design and develop a process to sustainably culture *Nannochloropsis* microalgae and extract its oils. These algal oils can be further refined into biofuels to offset the usage of non-renewable fuels.

Market, Ethics, Trends

Microalgae oil is a precursor to 3rd generation biofuels. 3.1 billion gallons of biofuels are produced annually in the US

Microalgae has benefits over other biofuel sources: it isn't using plants that could otherwise be used for food, it has a smaller land footprint than corn or soy, and it requires less pre-treatment than lignocellulose feedstocks

In 2024, Reuters News projects that **US petroleum consumption will reach 238 billion gallons per year.** Biofuels are key to reducing the consumption of and reliance on fossil fuels and in fulfilling our ethical obligation to protect the environment for ourselves and for generations to come.

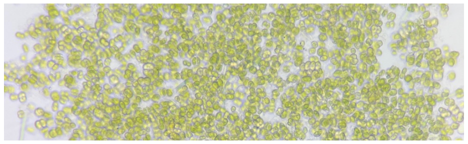


Fig. 1: Light microscope image of Nannochloropsis microalgae cultured in wastewater

Sustainability

- Culturing microalgae can be paired with industrial processes to reduce waste:
  - Wastewater treatment to remove excess nitrogen & phosphorus
  - Removal of CO_2 from flue gasses
- Solar power:
  - Most cost-efficient culture systems use energy from the sun
- Overall process seeks to replace fuels from non-renewable sources

Experimentation

Fig. 2: Laboratory-scale cultures of microalgae and cyanobacteria in the Simsek Lab

Algae Culture

- Lab scale cultures grown in carboys (Fig. 2) and fed with wastewater. Mixed via bubbled air and lit with LED bulbs. Used for downstream dewatering, drying, and oil extraction.
- Pure experimental cultures grown in BG-11 media. Mixed via shaking and lit with LED bulbs at a 12h:12h light to dark ratio. OD680 measured daily to construct growth curve (Fig. 3)

Algae Dewatering/Harvesting

- Initially, algae culture was dewatered by pouring water off the top of a volume of algae culture that was allowed to settle for several days
- Vacuum filtration was used as a second method to correspond more directly to industrial-scale methods

Biomass Drying

- Concentrated algae slurry dried using an oven at 110°C
- Algae dried in 20 mL volumes in aluminum weighing dishes

Oil Extraction

- Oil was extracted using a "green" Bligh and Dyer reaction with a mix of ethanol and ethyl acetate as the solvent (Fig. 4)
- Oil was separated from the organic extraction later using a rotary evaporator (Fig. 5)

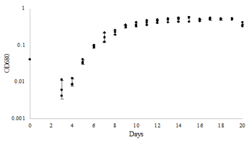


Fig. 3: Growth curve of Nannochloropsis

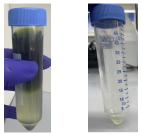


Fig. 4 (left): Separation of organic and aqueous phases during oil extraction
Fig. 5 (right): Recovered algal oil

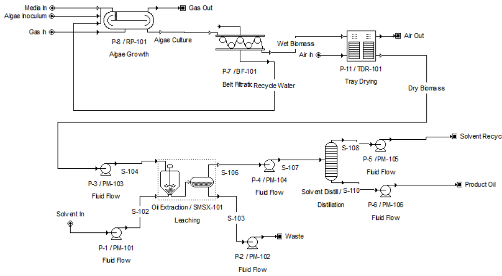


Fig. 6: Process flow diagram of industrial method to produce oil from Nannochloropsis microalgae. Made using SuperPro software.

Process Development

The industrial process was designed to produce 31,000,000 gallons of algal oil per year, running for 300 days. The major unit operations (culturing, harvesting, drying, and extracting) were analyzed to create a viable product and minimize costs. *Nannochloropsis* is cultured in raceway ponds, which provide a low-cost method using sunlight to produce large quantities of biomass. Harvesting and drying steps are most costly due to energy requirements. Filtration and conveyor belt drying both minimize these energy costs. To minimize waste, after filtration, water is recycled back to the raceway pond. Finally, lipids are extracted in a counter-current solvent extractor using ethyl acetate and ethanol. These solvents lessen environmental impacts compared to other Bligh & Dyer methods for oil extraction.

Plant systems analysis focused on waste treatment and water conservation as these are integral to the design and purpose of our process.

Optimization involved considerations of sizing and power usage for components of the various unit operations.

Algae Culture Alternatives

- Open-air ponds
  - **Raceway pond**
- Closed photobioreactors
  - Flat-plate
  - Tubular
  - Vertical column

Algae Harvesting Alternatives

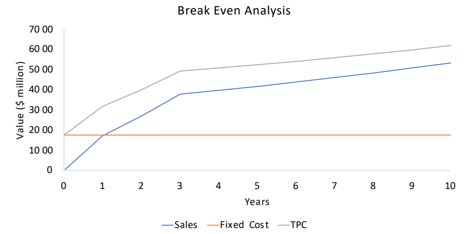
- Centrifugation
- **Filtration**
- Flocculation

Biomass Drying Alternatives

- Spray dryer
- **Conveyor belt dryer**
- Solar drying

Oil Extraction Alternatives

- Bligh and Dyer
- **Green Bligh and Dyer**
- Extrusion



Investments		Costs	
Total Capital ($)	6,817,000,000	Manufacturing Cost ($)	2,690,000,000
Fixed Capital ($)	5,800,000,000	Total Production Cost ($)	2,988,000,000
Working Capital ($)	1,016,000,000		
Equipment Cost ($)	1,355,000,000		

Economic Analysis

Operation Scale

- 1% of US market production (31,000,000 gallons).

Viability

- Currently non-viable due to gap in production cost and possible revenue.

Conclusion

- To make algae oil a valid precursor for 3rd generation biofuels, large subsidies would be required or a significant development in biomass oil extraction processes.

Future Recommendations

Research

- Scale-up of photobioreactors to reduce footprint and increase biomass yields
- Strain engineering for higher lipid yields

Design

- Minimization of plant footprint and storage space

Efficiency

- Further optimization of solvent to algae ratio in oil extraction

Profitability

- Consider the sale of dried waste algal biomass as a secondary product

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