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Utilization of Waste Biogenic Carbon Dioxide for Production of Single Cell Protein

Goal

The goal of this project is to evaluate the economic prospects of developing *Curpiavidus necator* (*C. necator*) as a single cell protein source for use in animal feed. *C. necator* is a hydrogen oxidizing bacteria that can be grown in gas fermenters on mixtures of carbon dioxide, hydrogen, and oxygen[1-3].

Background and Motivation

Land Use and Emissions by the Agriculture Industry

The agriculture sector of the economy contributes one quarter of all greenhouse gas (GHG) emissions and utilizes one third of the global ice-free land[1]. Within the agriculture industry, meat production is the leading contributor to both land use and GHG emissions. To support the ever-growing population while reducing emissions in accordance with the 2015 Paris Agreement, new techniques and technologies are necessary[2].

Challenges

Mass Transfer Limitations

Hydrogen and oxygen both have a very low solubility in water[1,3]. In order to maximize biomass production, the mass transfer from the gas to liquid phase must improve.

Safety Concerns

Mixing hydrogen and oxygen in the gas fermenter presents an explosion hazard. Operating at a very low oxygen partial pressure, outside of the flammability limits of hydrogen, may reduce the growth rate of *C. necator*[3].

FDA Approval

C. necator does not currently have GRAS status and is not currently FDA approved for animal feed. However, many similar bacterial-based animal feeds and human foods have been FDA approved or are currently undergoing the approval process[4]. The production of *C. necator* uses similar equipment and processes, so FDA approval should be attainable.

Case Study

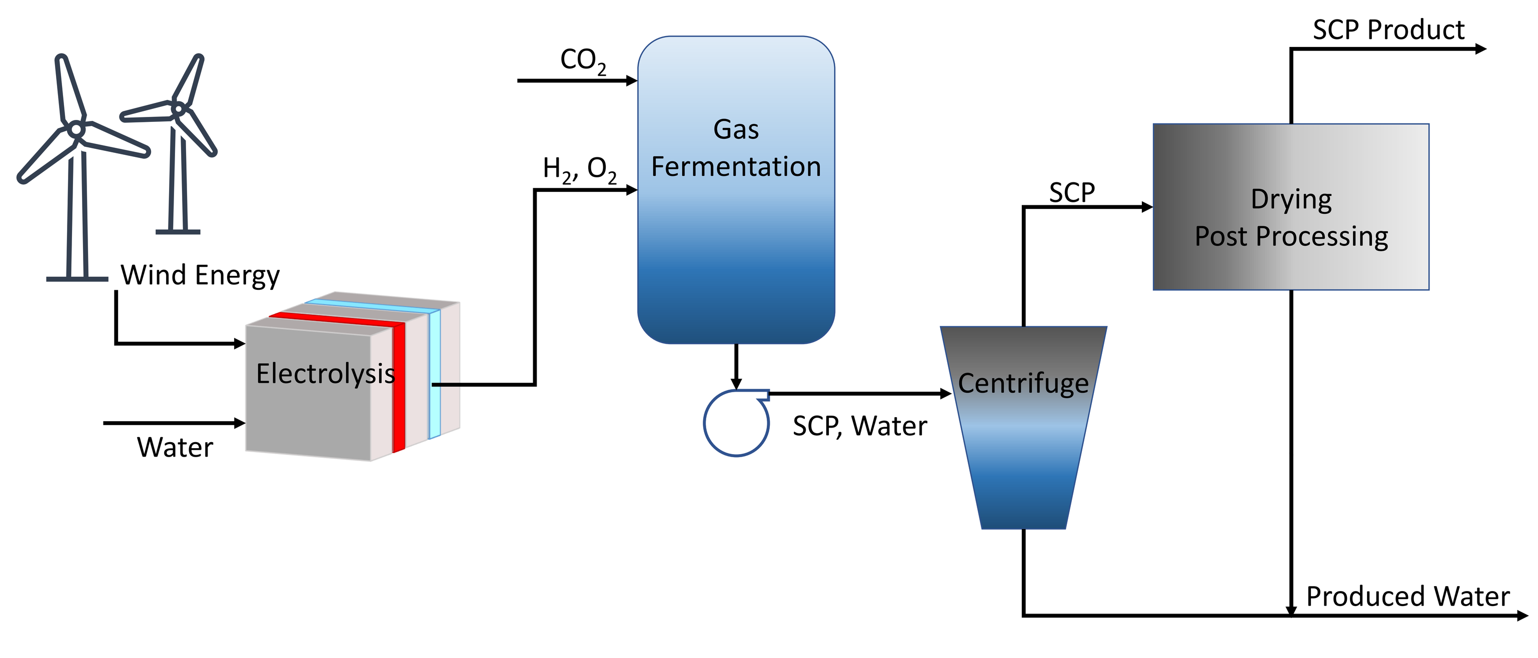

Figure 1. Proposed Process Diagram

$$4.09\,CO_2 + 0.76NH_3 + 21.36H_2 + 6.21O_2 \rightarrow C_{4.09}H_{7.13}O_{1.89}N_{0.76} + 18.70H_2O$$

Process Specifications

- 83,000 metric tons of CO_2 sequestered annually at Lincolnway Energy, LLC[5]
- Water is provided to the system at a price of $2.00/kgal[6]
- Wind energy provides electricity to all equipment at a price of $0.02/kWh[7]
- SCP sold for $2400/metric ton to mirror the historic maximum selling price of fishmeal[8]
- Alkaline electrolysis and PEM electrolysis both compared

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Results

Results Summary

	TPI	Operating Costs	Annual Depreciation	Annual Sales	NPV after 20 Years	Payback Period	Internal Rate of Return	Minimum Selling Price of SCP
Alkaline Electrolysis	$305 million	$49 million	$13 million	$108 million	$50 million	5.5 years	34%/year	$2020/metric ton
PEM Electrolysis	$334 million	$59 million	$15 million	$108 million	$11 million	10 years	27%/year	$2300/metric ton

Carbon Tax Incentives

- 45Q offers carbon tax incentives for CCU beginning construction before 2024 and capturing at least 25,000 tons of CO_2 per year[9]
- Linear increase from $10/metric ton CO_2 in 2018to $35/metric ton CO_2 in 2026

	NPV after 20 years	Payback Period	IRR	MSP
Base Case	$50 million	5.5 years	34%/year	$2020/ metric ton
Carbon Tax Incentive until 2026	$57 million	5 years	35%/year	$1970/ metric ton
Constant Carbon Tax Incentive after 2026	$59 million	5 years	36%/year	$1950/ metric ton

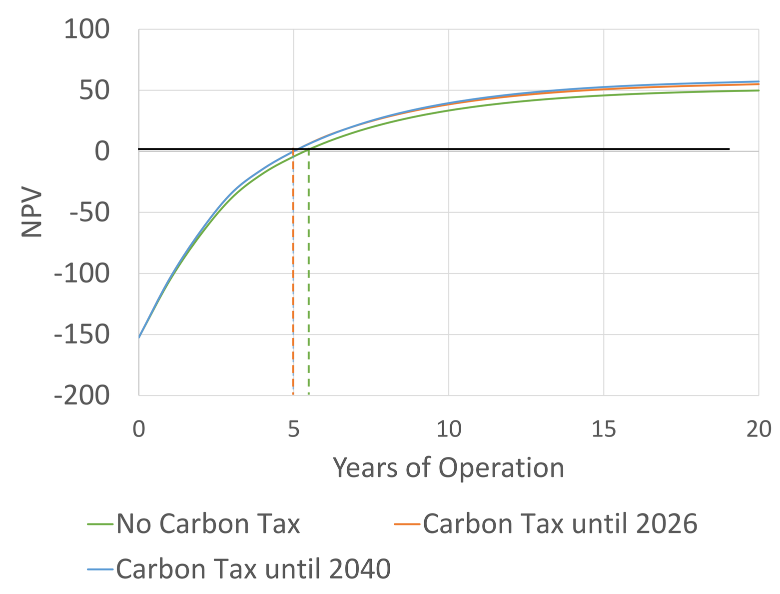

Figure 2. Impact of Carbon Tax Incentives on NPV

Electrolysis Projections

- Projected annual 2% decrease in CAPEX for electrolyzers[10]

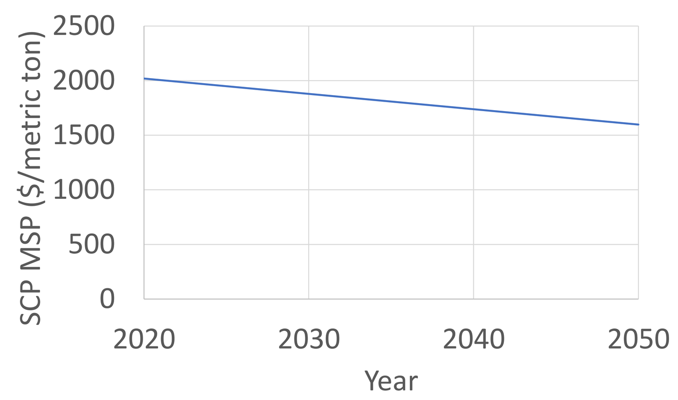

Figure 3. MSP Improvement by Electrolysis Price Decrease

Selling Price Analysis for Rate of Return

- 25% rate of return assumed because of novelty
- 10% rate of return is typical for most projects

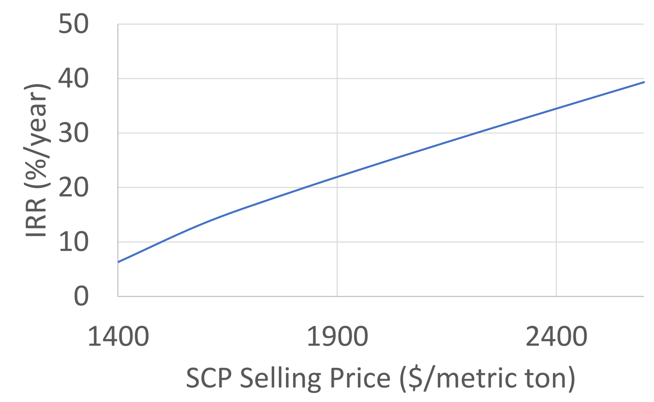

Figure 4. IRR vs. Selling Price of SCP

Sensitivity Analysis for Minimum Selling Price

- Fermentation and downstream processing CAPEX, electrolyzer CAPEX, and wind electricity are most important factors
- Electrolyzer CAPEX to projected to decrease by 2% per year[10]
- Wind electricity costs projected to decrease with growing wind energy infrastructure[11]

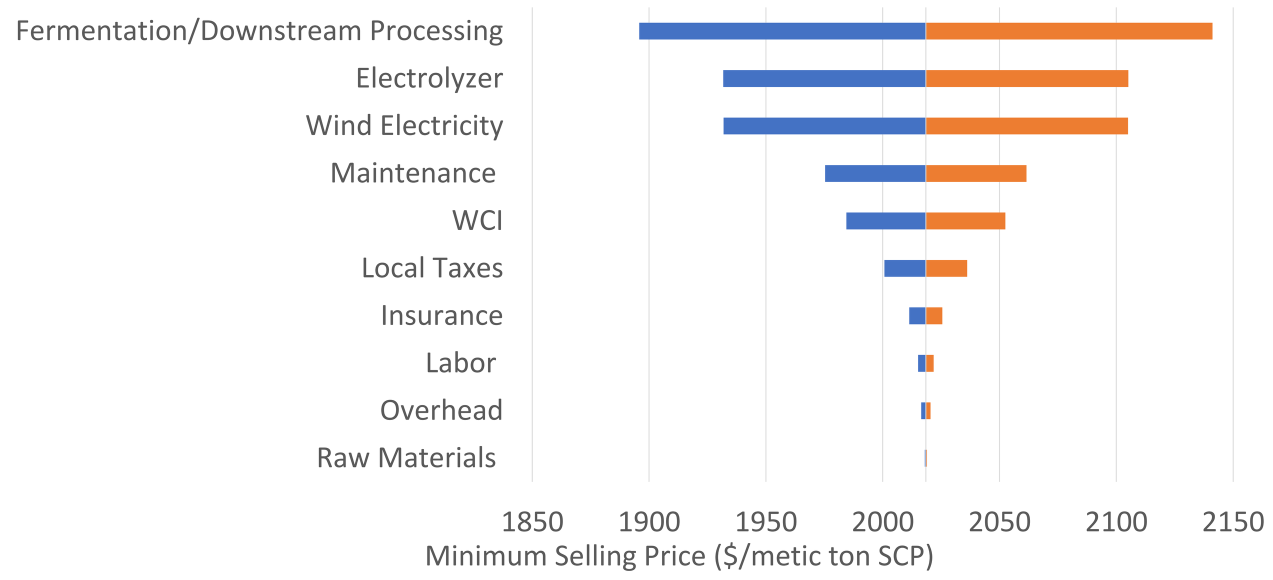

Figure 5. Sensitivity analysis on minimum selling price

Conclusions and Future Work

SCP production via gas fermentation has the potential to be economically competitive with fishmeal as a protein supplement in animal feed. Though the selling price of SCP is at the upper threshold of fishmeal selling prices, the continued reduction in wind energy and electrolysis costs will continue to reduce the selling price. To improve the viability of commercial production of SCP, the following future work is necessary:

- Develop methods to reduce mass transfer limitations
- Scale up gas fermentation for pilot demonstration
- Use experimental data to improve economic model of gas fermentation

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