Industrial Production of Ammonia Fertilizer Using Cyanobacteria

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Project Design Criteria

- Design an Ammonia production plant with a capacity of 50 metric tons per day while:
  - Employing modular manufacturing methods
  - Maintaining a small carbon footprint

Background

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- Ammonia is a popular nitrogen fertilizer
  - Crops use nitrogen in photosynthesis
- Ammonia production globally
  - 1-3% of total energy usage
  - 5% natural gas usage
  - 3% of greenhouse gas emissions
  - Half of world's population sustained using ammonia fertilizer

https://wcroc.cfans.umn.edu/news/greener-tractors

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Background

- Ammonia produced using Haber-Bosch Process
  - High Temperatures
  - High Pressures
  - Uses lots of natural gas

https://businessfacilities.com/2020/01/1b-ammonia-plant-coming-to-greater-houston/

The Idea

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- Use cyanobacteria in photobioreactors to produce ammonia
  - Reduce need for extreme operating conditions
  - Eliminate natural gas requirements
  - Make ammonia with minimal environmental impact

https://www.researchgate.net/figure/40-L-vertical-tubular-outdoor-photobioreactor-for-Chlorella-zofingiensis-G1-cultivation_fig1_325763128

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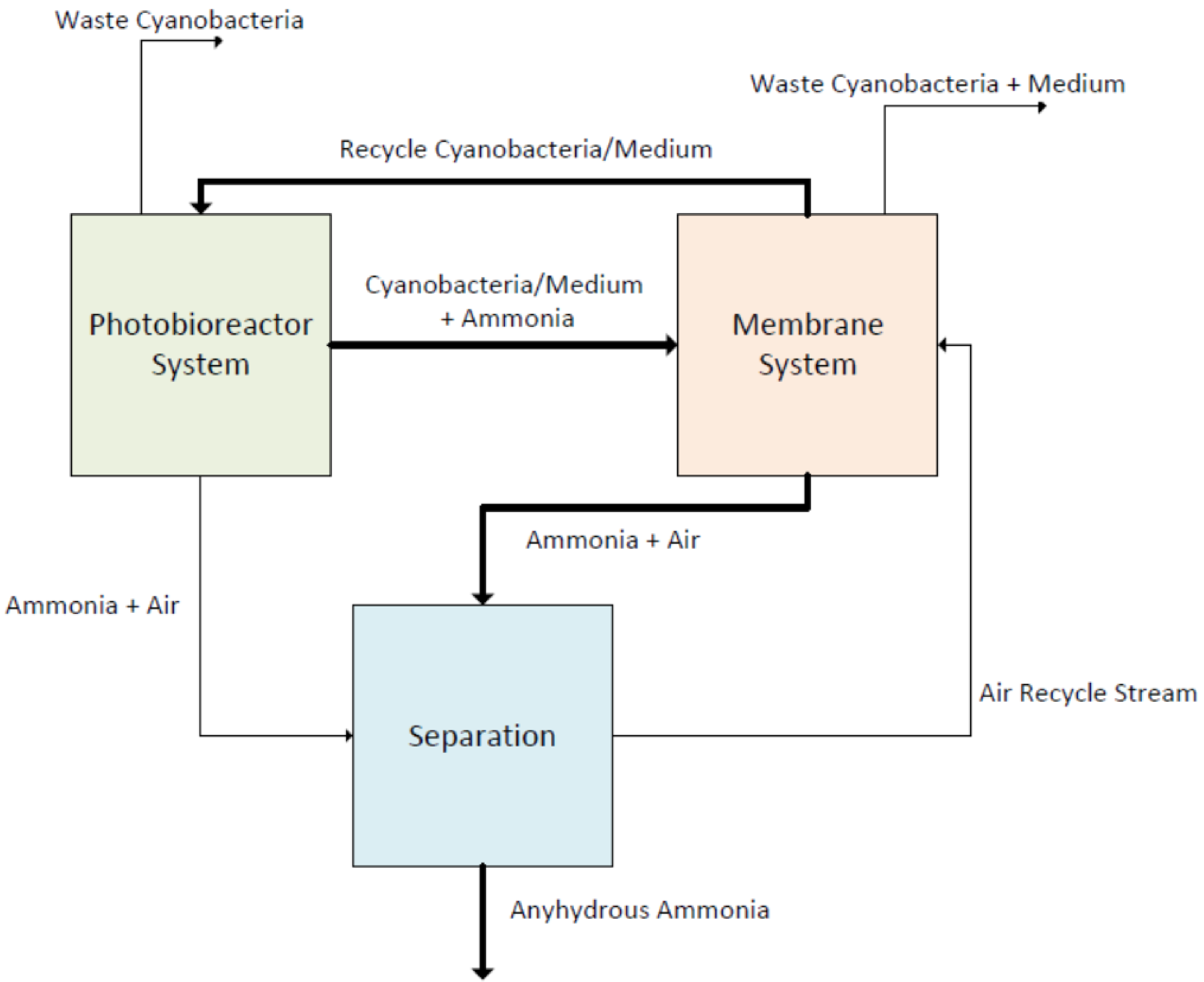
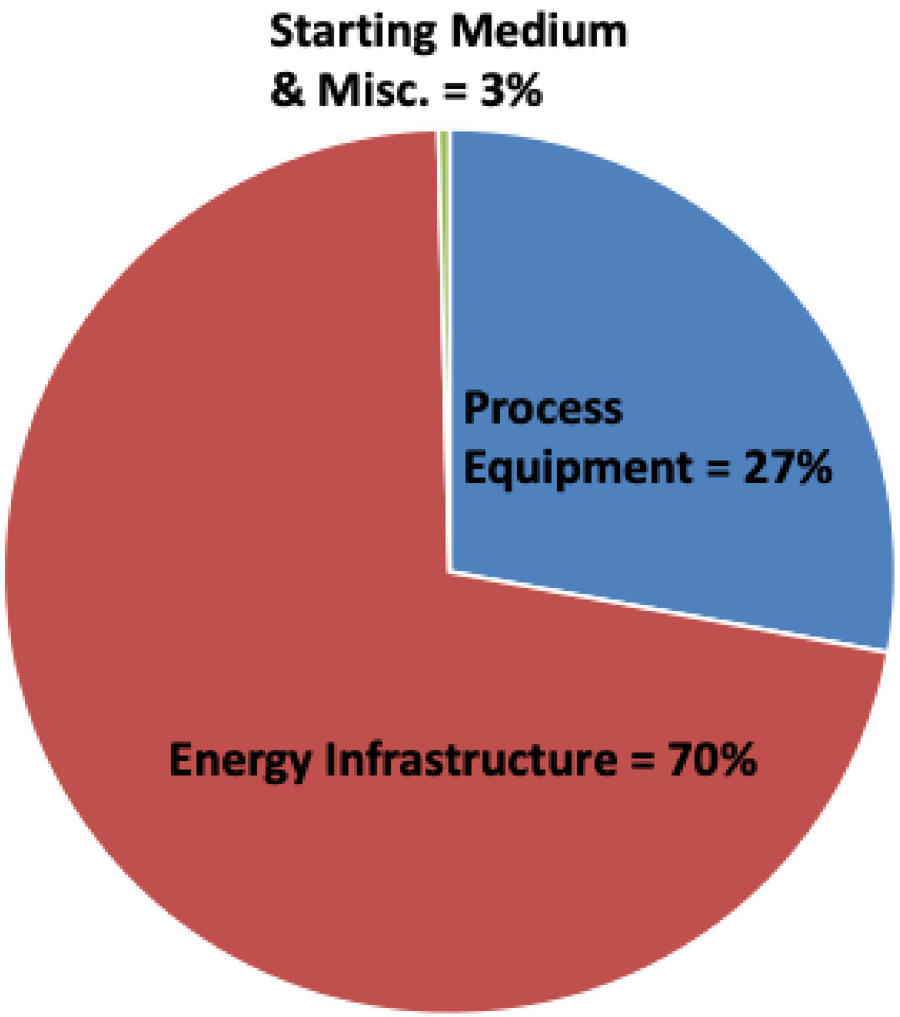
Process Description (per module)



Costs & Feasibility

- Market Price: $512/ton
- Design Unit Price: $9.0M/ton



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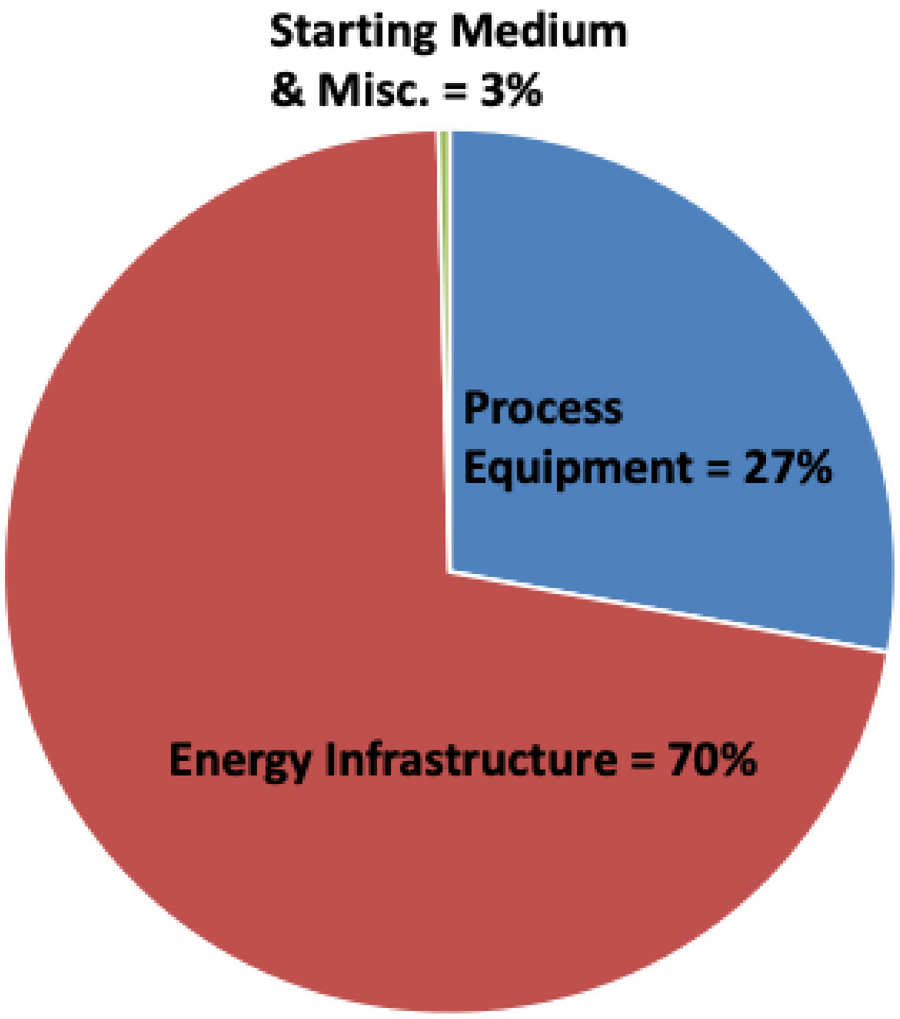
Costs & Feasibility

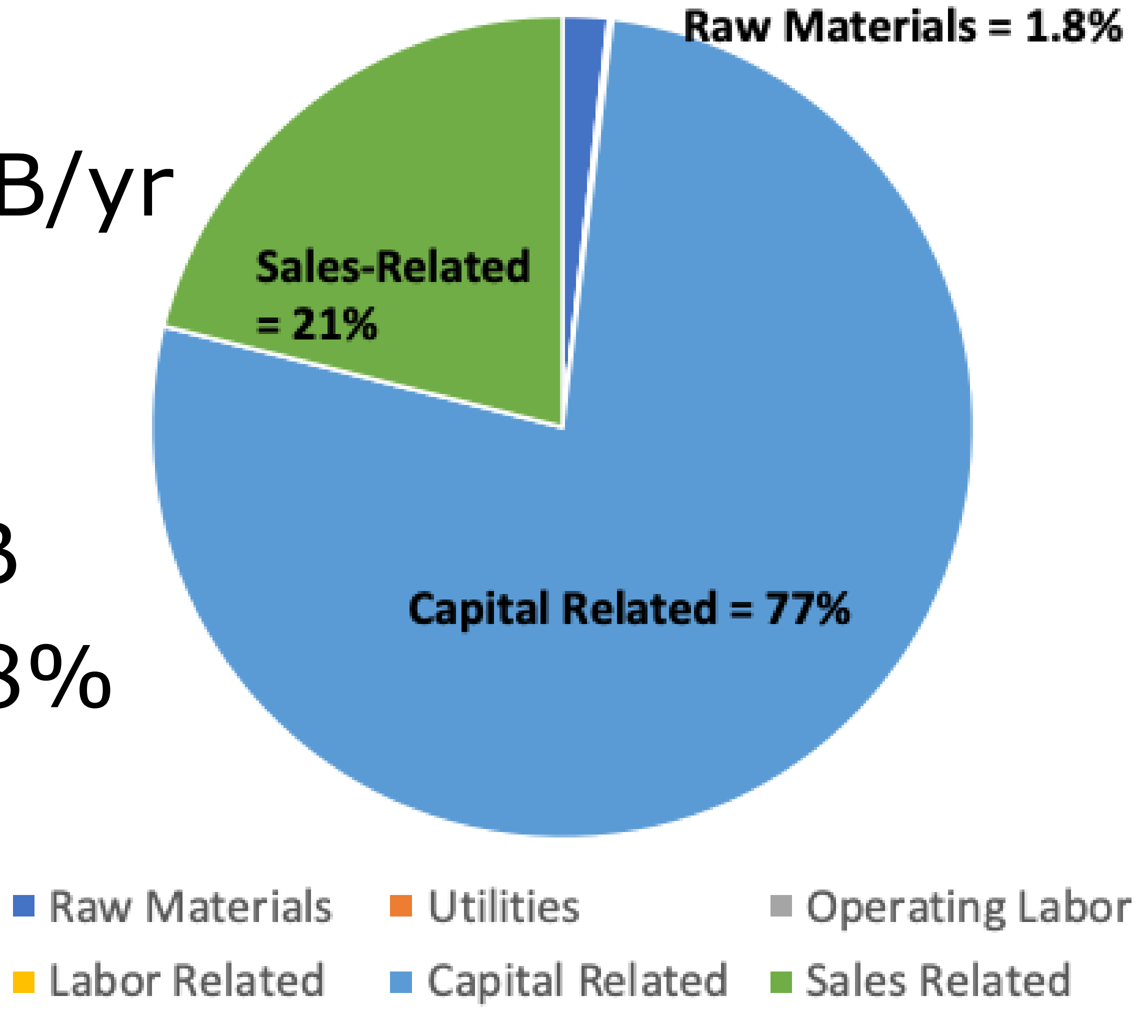
- Market Price: $512/ton
- Design Unit Price: $9.0M/ton

Total Capital Cost: $461B!



Costs & Feasibility

- Manufacturing Cost: $156B/yr
- Profit Margin: 25%
- Gross Profit: $8.2B/yr
- Net Present Value: -$350B
- Internal Rate of Return: -8%



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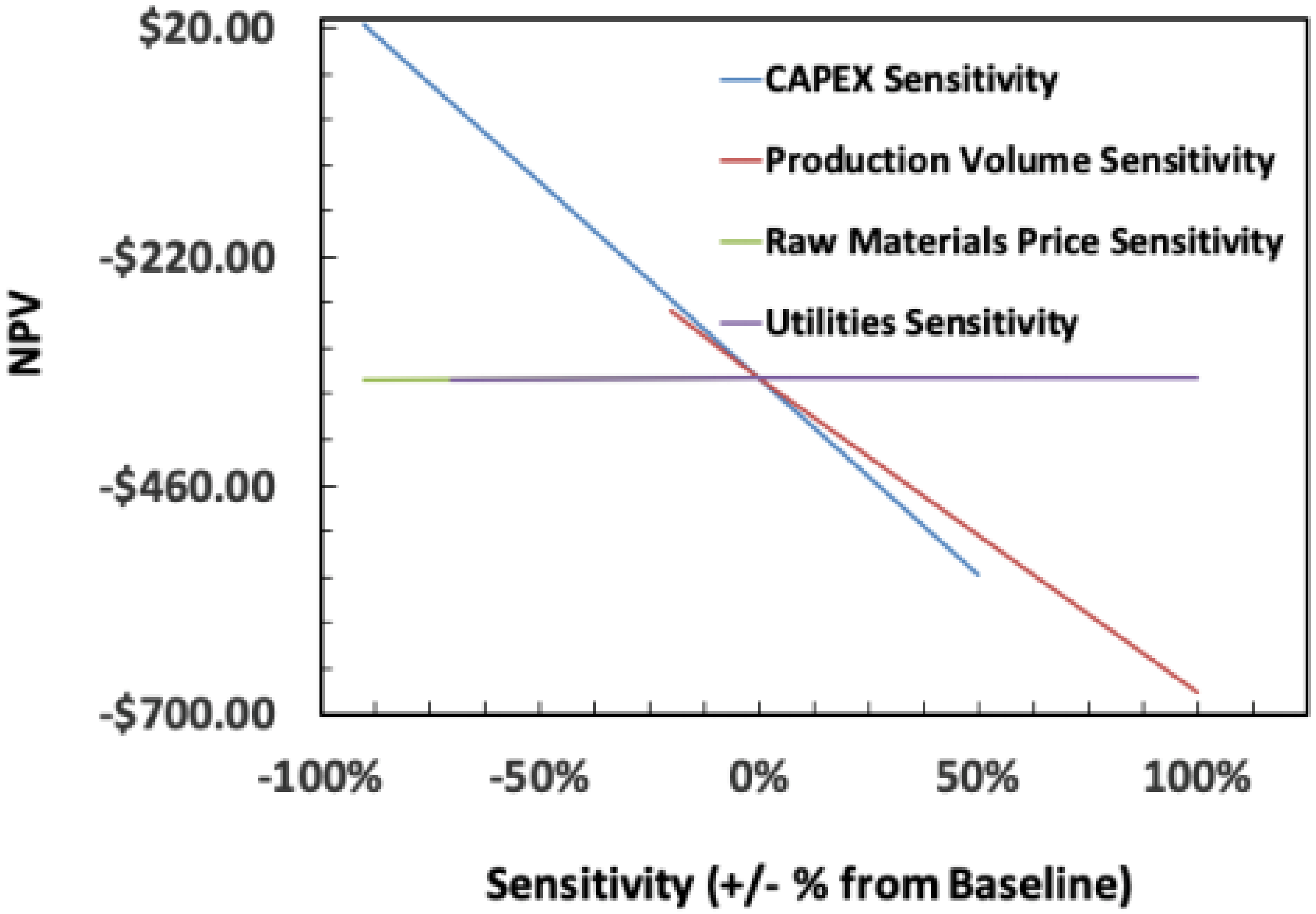
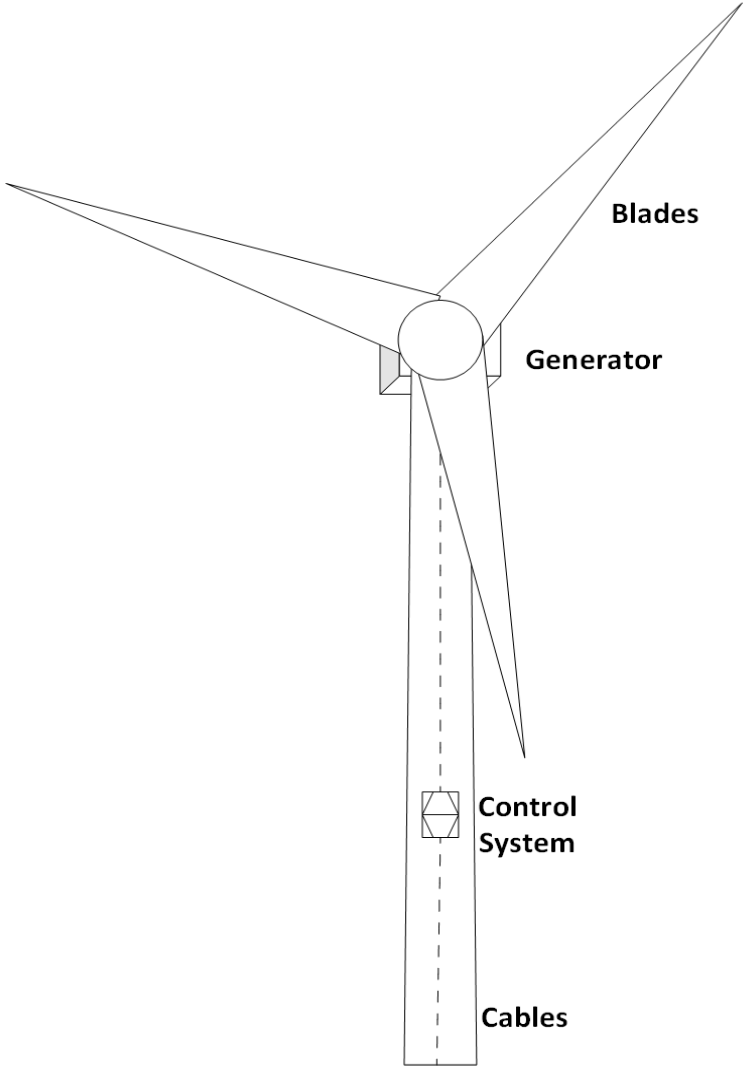
Costs & Feasibility

- NPV in billions of USD
- Cost Drivers:
  - CAPEX & Production Volume
  - Profitable at 90% decrease in CAPEX



Costs & Feasibility

- Land Requirements
  - 50,000 acres (5.5 times the size Corvallis!)
- Energy Requirements
  - 5,000 GW (31,000 3 MW wind turbines)
  - Primarily from pumping



3 MW Wind Turbine

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Reducing Costs

- Increasing module size
- Increasing concentration of cyanobacteria

Reducing Costs

- Increasing module size (from 60)
  - 120 modules decreased cost by 32%
  - 1000 modules decreased cost by 63%
- Increasing concentration of cyanobacteria

Reducing Costs

- Increasing module size (from 60)
- Increasing concentration of cyanobacteria (from 6 µg/mL)

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Reducing Costs

- Increasing module size (from 60)

- Increasing concentration of cyanobacteria (from 6 µg/mL)
  - Increased concentration 10-1000x
  - 1000x decreased cost 99.97% to $26M
  - Energy cost significantly decreased

Final Recommendations

- Do not build plant, too high cost
- Further cyanobacteria research could lower costs by lowering plant volume
  - Increased cyanobacteria density
  - Increased ammonia production rate
- Accounting for greenhouse gas absorption (carbon credits) could also make plant more profitable

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Sources

- *AIChE 2019-2020 Student Design Competition Problem Statement & Rules*
- Himstedt, H. H., Huberty, M. S., McCormick, A. V., Schmidt, L. D. and Cussler, E. L. (2015), Ammonia synthesis enhanced by magnesium chloride absorption. AIChE J., 61: 1364-1371. https://aiche.onlinelibrary.wiley.com/doi/abs/10.1002/aic.14733.
- Towler, Gavin Sinnott, Ray K. (2013). Chemical Engineering Design - Principles, Practice and Economics of Plant and Process Design (2nd Edition). Elsevier.
- Thomas, S. P.; Zaritsky, A.; Boussiba, S. Ammonium Excretion by an L-Methionine-Dl-Sulfoximine-Resistant Mutant of the Rice Field Cyanobacterium Anabaena Siamensis. Applied and Environmental Microbiology1990, 56(11), 3499–3504. https://doi.org/10.1128/AEM.56.11.3499-3504.1990.