Design of a New, Small-Scale Modular Ammonia Synthesis Process

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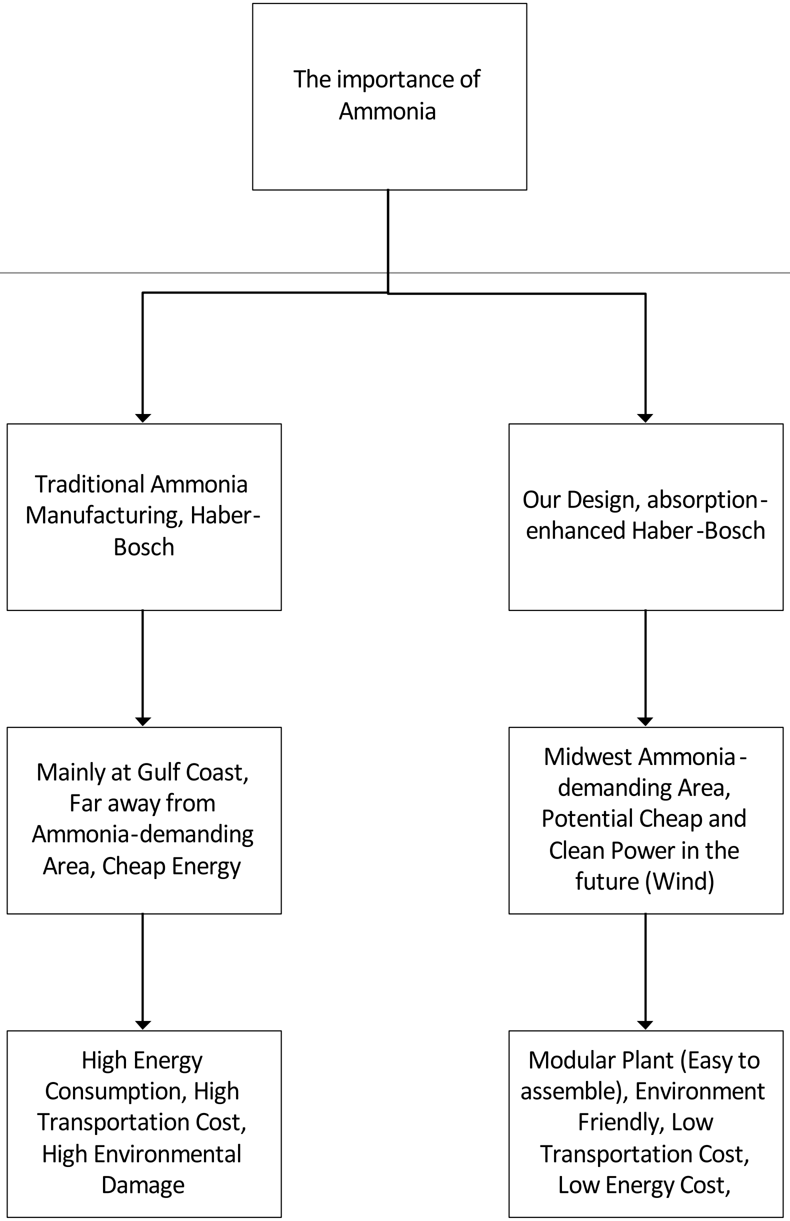
CHEME 486

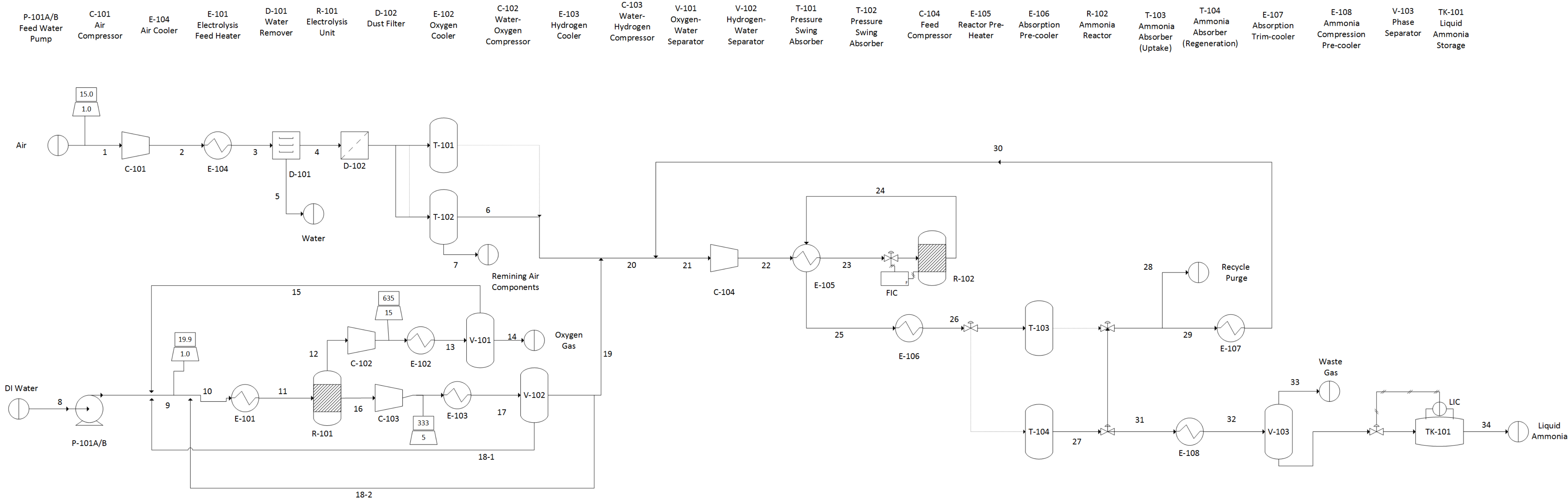
Outline

- Introduction/Objective: Design a modular ammonia synthesis system (50 mtpd) for ammonia-demanding area to reduce the overall cost of ammonia
- Upstream Process: Electrolysis, PSA
- Downstream Process: Reactive-absorption ammonia synthesis loop
- Economic Overview: Fixed capital investment, manufacturing cost, and profitability
- Conclusion: Not profitable. Design should not be further pursued
- Recommendation: Increase modular size, renegotiate energy cost, renegotiate equipment cost (discount on large scale order)

Introduction

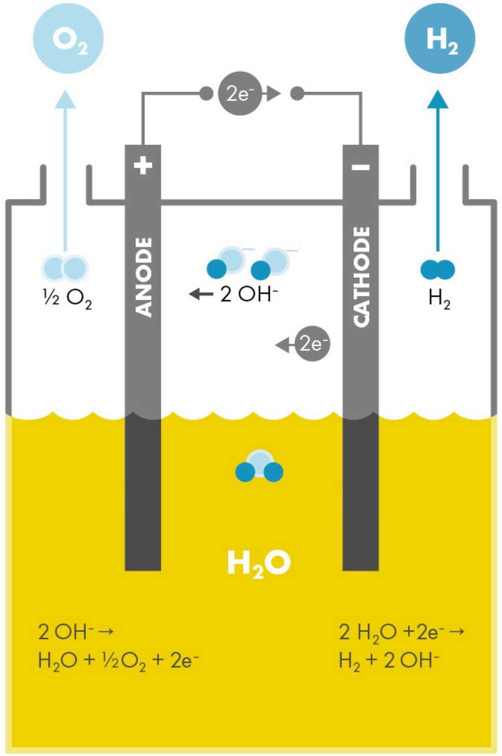


Process Flow Diagram (PFD)



Electrolysis

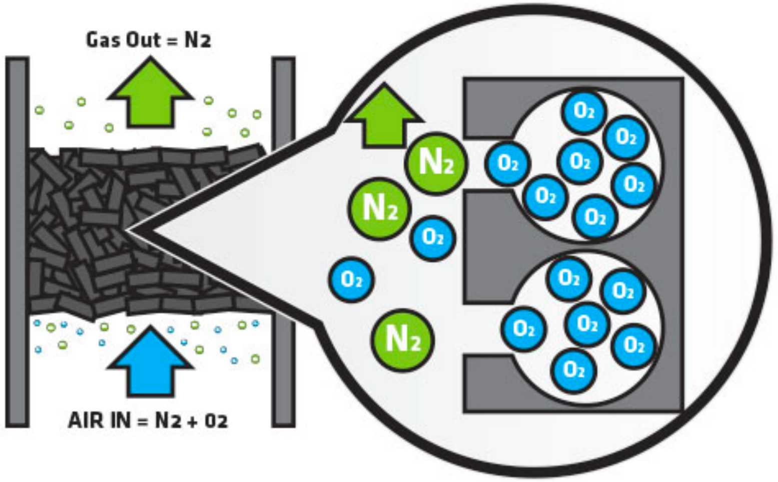
- Pros:
  - Environmentally friendly
  - Potential to achieve high purity hydrogen gas
  - Suitable for small scale processes
- Cons:
  - Energy-intensive, uses a lot of electricity (but we have renewable energy)
  - Does not scale (not an issue in our case)



Shell Hydrogen Study © Shell

Pressure Swing Adsorption (PSA)

- Pros:
  - No need for air liquefication (a requirement for many other processes such cryogenic distillation)
  - Potential to achieve high purity nitrogen
  - Input is air (essentially free)
  - Low operating cost
- Cons:
  - Does not scale (not an issue for our case)



Absorption

- Used to recover ammonia product after reactor
- Pros:
  - Help reduce operating pressure and temperature
  - Minimize equipment size
  - Good choice of absorbent could achieve high recovery rate
- Cons:
  - Does not scale (not an issue for our case)

Design Discussion

- Parallel Structure:
  - 6 modules, each produces 8.9 mtpd anhydrous ammonia to meet 50 mtpd specification
  - More consistent and flexible
  - Economic of scale
  - Suits small scale topic
- Alternatives
  - Non-thermal plasma (NTP) reactor for greener ammonia synthesis
    - Technology still at lab-bench scale and very expensive
  - Water-gas shift reaction for hydrogen production
    - Significantly increased carbon emission
- Carbon emission
- Equipment matches heuristics

Safety and Environment

Personnel Safety: high voltage electric, and high Temperature

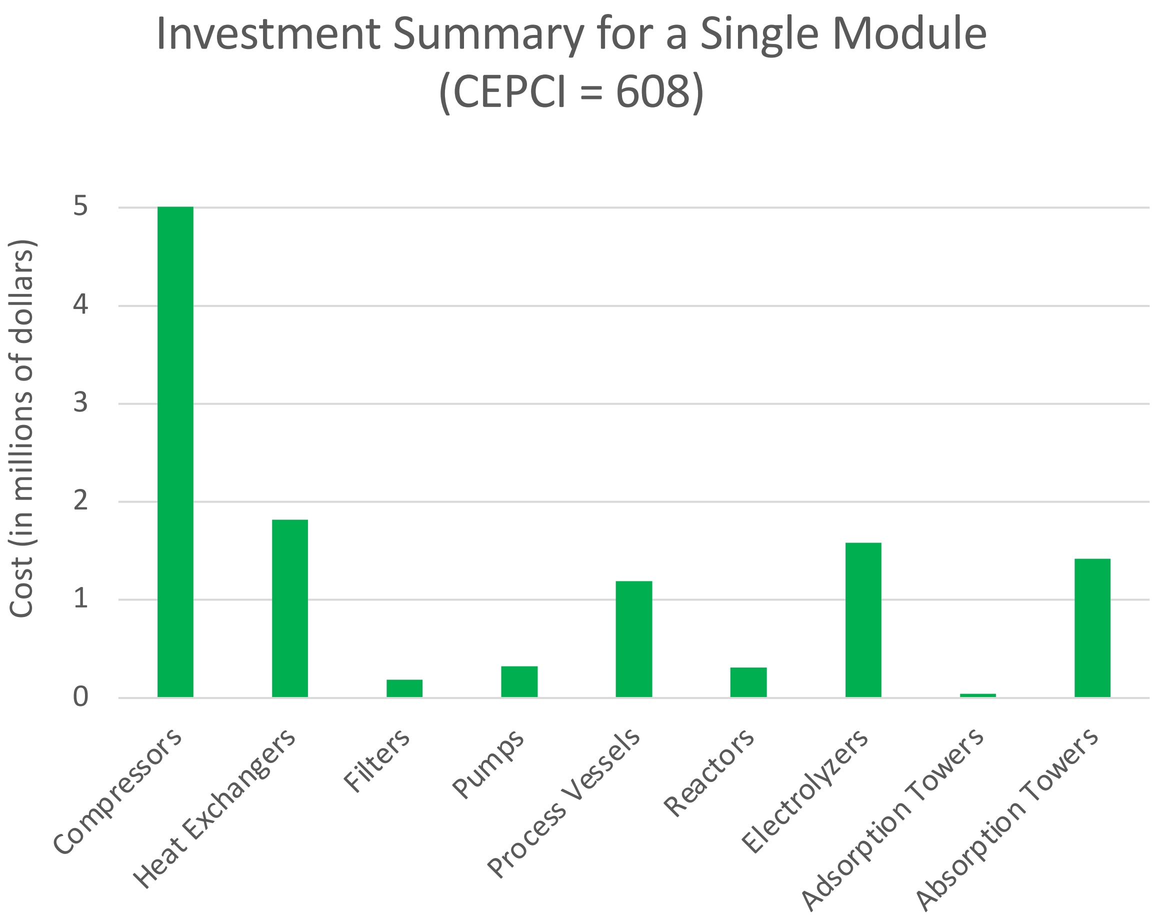
Material Safety: nitrogen (Suffocation), hydrogen (Suffocation & Explosion), ammonia (respiratory diseases and skin Irritation)

Environmental Safety: ammonia affects aquatic live growth, leads to heavy algae growth, blocks the surface of water, and leads to deficiency of oxygen in water

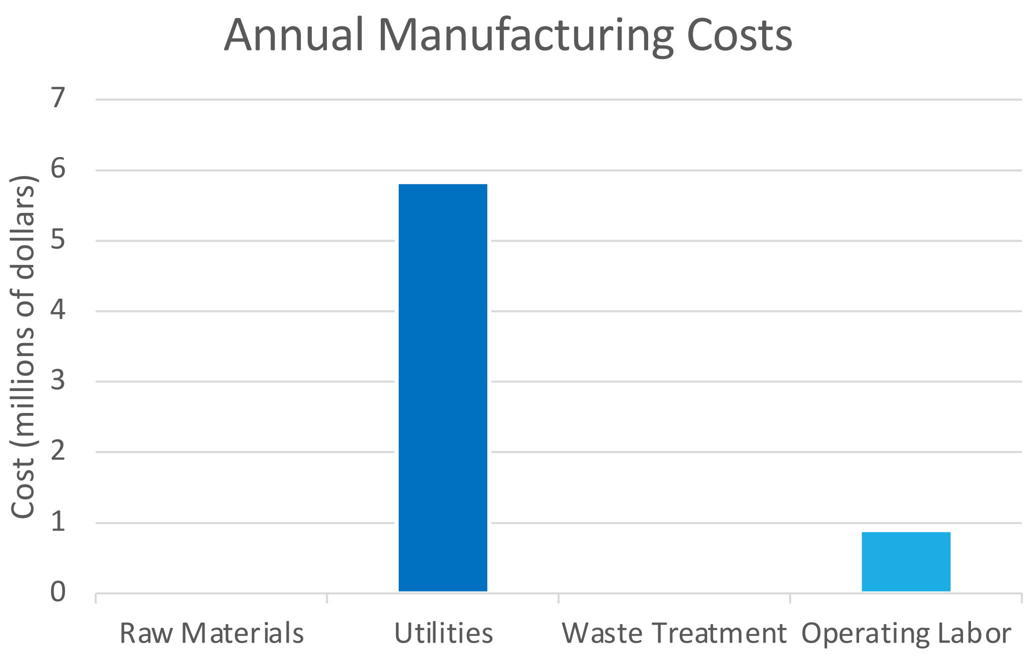
Fixed Capital Investment (Total Grassroots Cost)

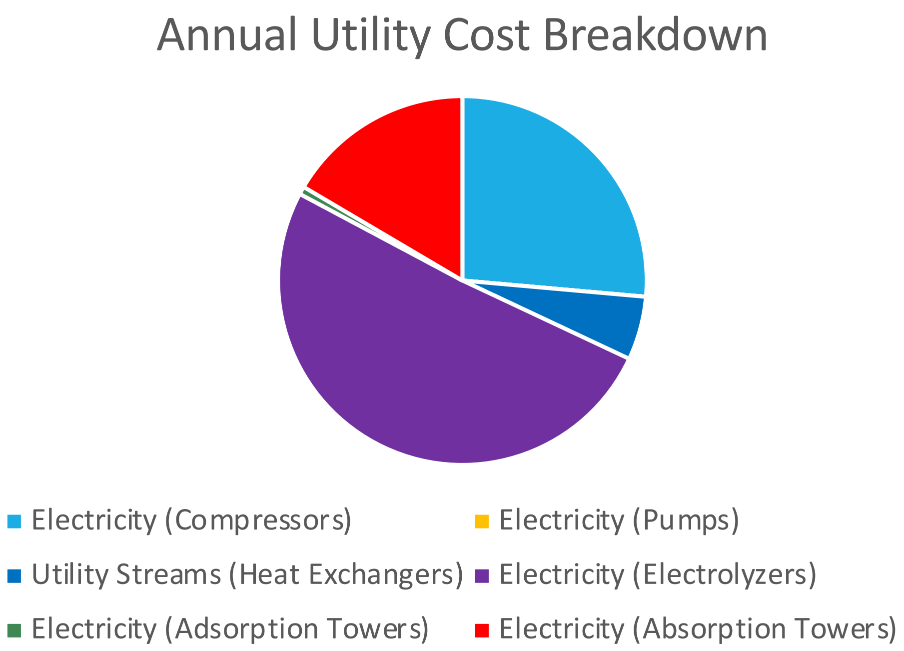
- First-of-a-kind (FOAK) module cost: **$12,144,000**
- $k_n = k_1 * n^{log_2(p)}$
  - p = 0.8 for modular manufacturing

Module Number	Module Cost ($)
1 (FOAK)	12,144,000
2	9,715,000
3	8,526,000
4	7,772,000
5	7,233,000
6	6,821,000
Total	**52,210,000**



Manufacturing Costs

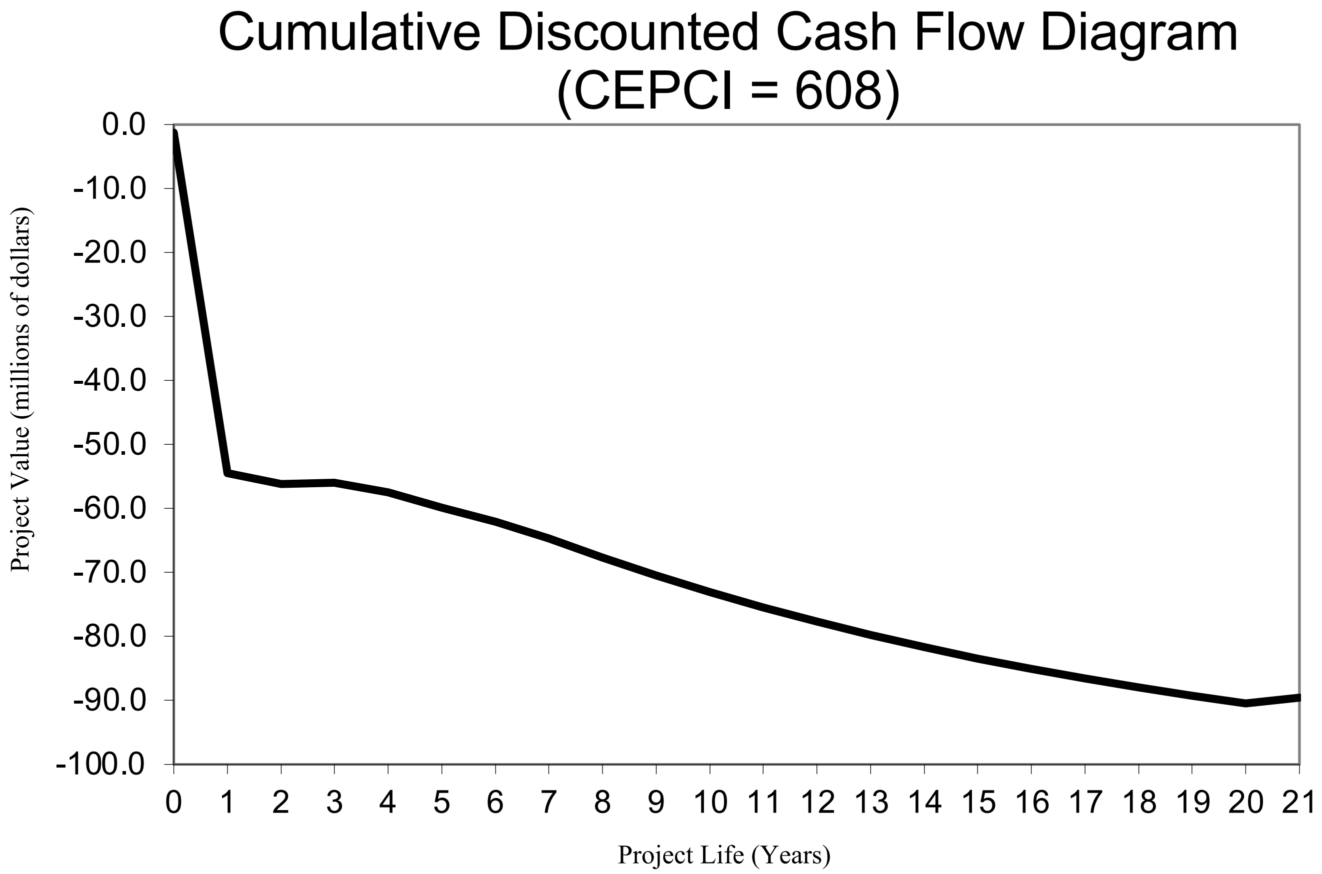




- Annual Cost of Manufacturing without depreciation (COM_d): $19,081,000
- Annual Anhydrous Ammonia Product Sales: $10,485,000

Economics Analysis

- Assume:
  - 20-year project lifetime
  - Construction period of one year
  - 35% taxation rate
  - 8% discount rate
  - MACRS 5-year depreciation schedule
- Net present value: **-89.6 million dollars**
- **Our current process is not profitable and should not be pursued further**



Why Is Our Process Not Profitable?

- Imbalance between small revenue range (small-scale process) and high capital/operating costs

- Compressors/electrolyzers/absorption towers are 77.8% of FCI
  - $40.6 million
  - Loss of economy of scale most important for compressors
- Electrolyzers account for 51% of utility costs
  - $2.97 million annually

- Max annual product sales of $10,485,000 (50 mtpd capacity)

Electrolysis isn’t currently an economically viable process for hydrogen production at this scale.
Even with reduced reaction/operating pressures, loss of economy of scale is still significant for compressors

Conclusion

- New small-scale modular design for achieving 50 mtpd of anhydrous ammonia
  - Meets ammonia demand in Midwest region
  - Take advantage of cheap renewable energy
- Parallel modular manufacturing
- Minimizes carbon footprint
- Currently not profitable and should not be further pursued at this time

Recommendations

- Increase module sizes and overall production rate for improved product revenue
  - Large demand for ammonia fertilizer in the region meets this increased supply
  - Mitigate loss of economy of scale
- Better PPA (power purchase agreement) to lower electrical cost
- Energy storage system for continuous supply of electricity
- Other methods to produce hydrogen to minimize capital/operating costs
  - Trade off between cost and environmental impact

Sources

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