DALHOUSIE UNIVERSITY

FACULTY OF ENGINEERING

Group 13

Cole Godfrey
Dan Russell
Kye Alleyne
Timothy Atamosa

Client:
Doug Colborne

Department of Process Engineering and Applied Science

Renewable Methanol Production Through Direct Carbon Dioxide Hydrogenation

Introduction

Project Objectives

- Develop a process design and equipment sizing for a renewable methanol production plant in Nova Scotia
- Economic analysis to study the feasibility of the design

Methanol Production

- One way to mitigate CO_2 emissions to the atmosphere is to capture and convert CO_2 to valuable products (i.e. methanol)
- Methanol can be produced via direct CO_2 hydrogenation

Design Basis

- A potential plant location was identified to provide a basis for design –> Point Tupper N.S. was selected
- The coal fired power plant provides a source of CO_2
- The 22 MW wind farm provides a source of renewable energy for H_2 and methanol production

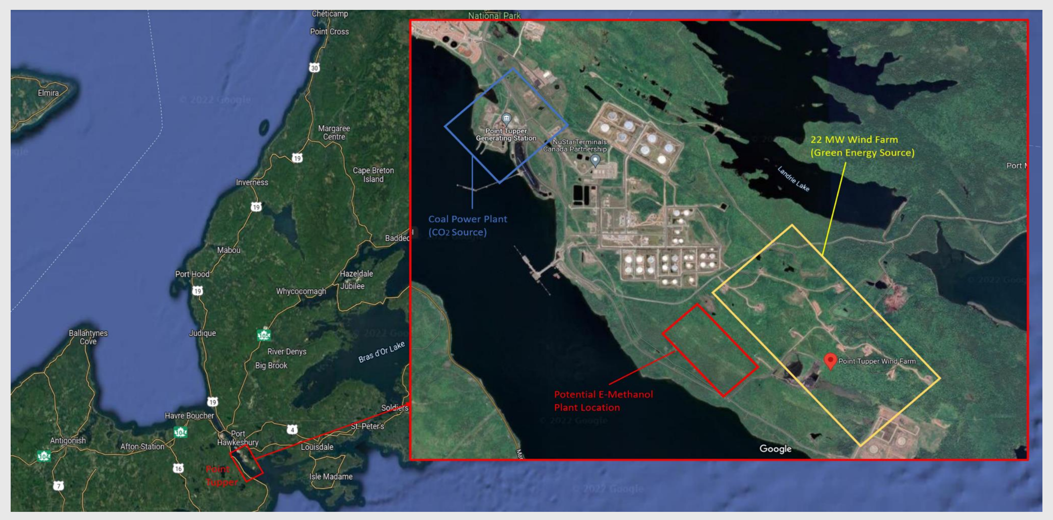


Figure 1: Potential Plant Location (Point Tupper, N.S.)

Design Requirements

- Use renewable energy to produce H_2 and methanol
- Produce commercial grade methanol at purity of 99.85% wt.

Design Process

Research Phase – Areas researched for plant conception

- Hydrogen production from PEM electrolysis and carbon dioxide collection from carbon capture
- Wind power generation using turbines for renewable energy
- Existing methanol plant design and required equipment

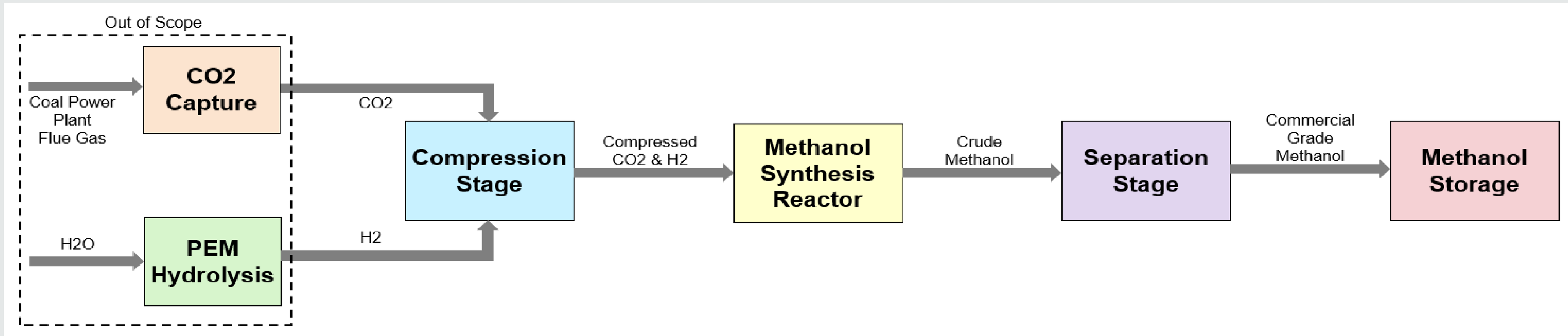
Design Phase

- First Ideas – Initial design aspects collected and BFD Produced
- Preliminary Design – Initial estimates of power and feedstock supply used to create preliminary Aspen HYSYS simulation
- Detailed Design – Produced detailed designs for the major equipment, economic estimates and initial P&IDs
- Tender Process – Materials and detailed design specifications optimized, and detailed economic analysis performed

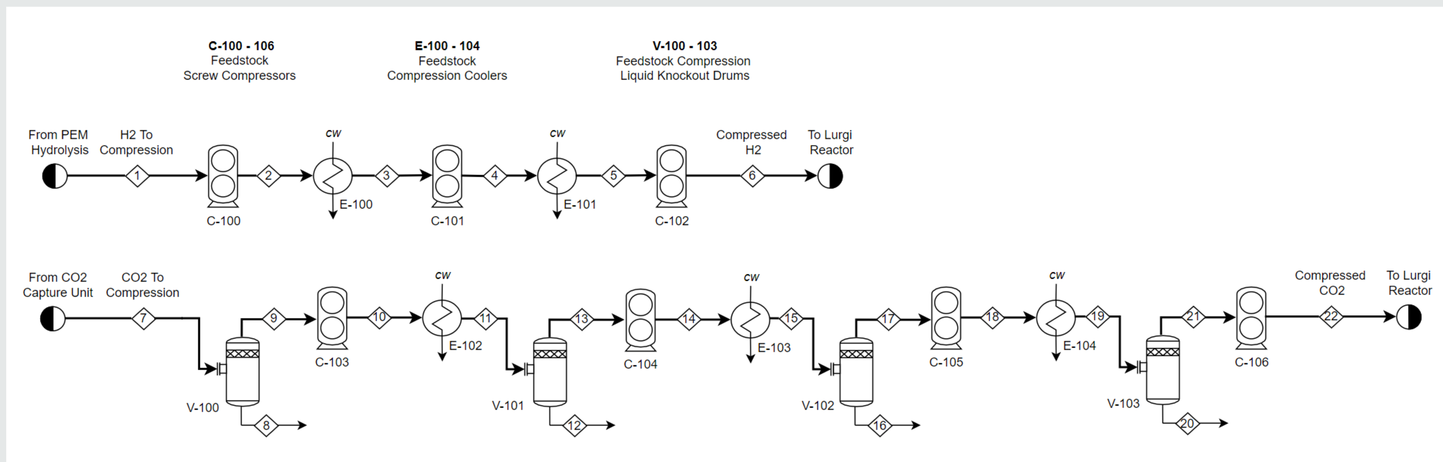
Construction Phase

- Out of project scope

Details of Design



Step 1: Compression Stage (Compresses CO_2 & H_2 to Reaction Pressure)



H_2 Compressors
- Carbon Steel
- Screw Compressors
- Compression Ratio = 1.9 per stage

H_2 Coolers
- Carbon steel
- Shell and tube (fixed sheet)
- Cooled to 40 °C after each stage

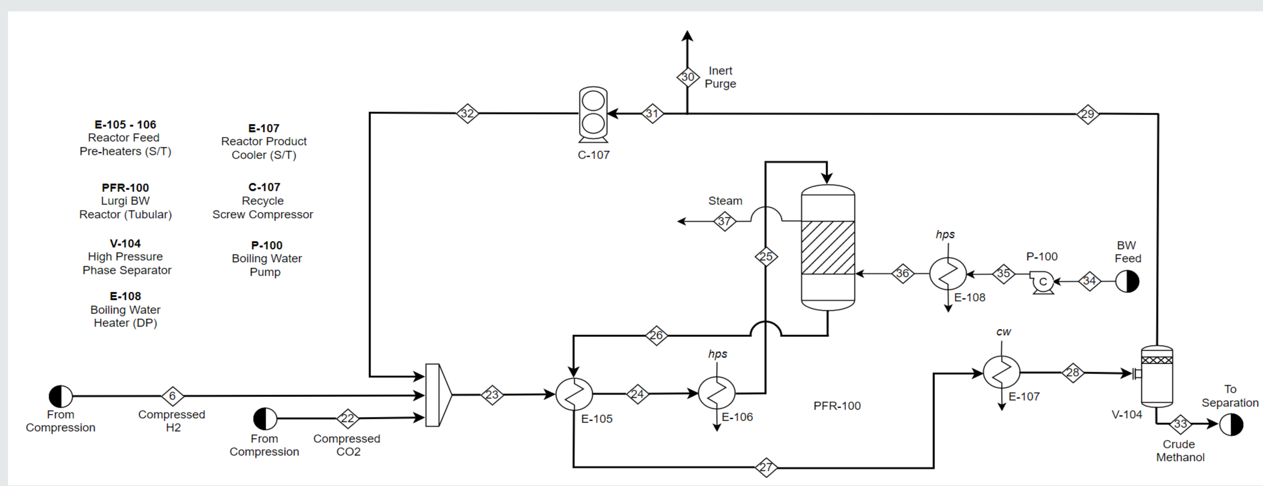
CO_2 Compressors
- Carbon Steel
- Screw Compressors
- Compression Ratio = 2.7 per stage

CO_2 Coolers
- Carbon Steel
- Shell and Tube (Fixed)
- Cooled to 50 °C after each stage

CO_2 Knockout Drums
- Carbon steel
- Vertical cylindrical drum
- D = 0.9 -1.5 m and H = 3.2 - 5.3 m

Step 2: Methanol Synthesis Reactor (Converts CO_2 & H_2 to Methanol)

Methanol Reactor
- Lurgi type tubular reactor
- $Cu/ZnO/Al_2O_3$ Catalyst
- Cooled by boiling water at 224 °C
- Reaction Conditions: 230 °C and 50 bar
- Carbon Steel
- V = 24.13 m^3 with a void bed fraction of 0.285
- Tube D = 0.08 m and # of tubes = 1200
- L = 4 m



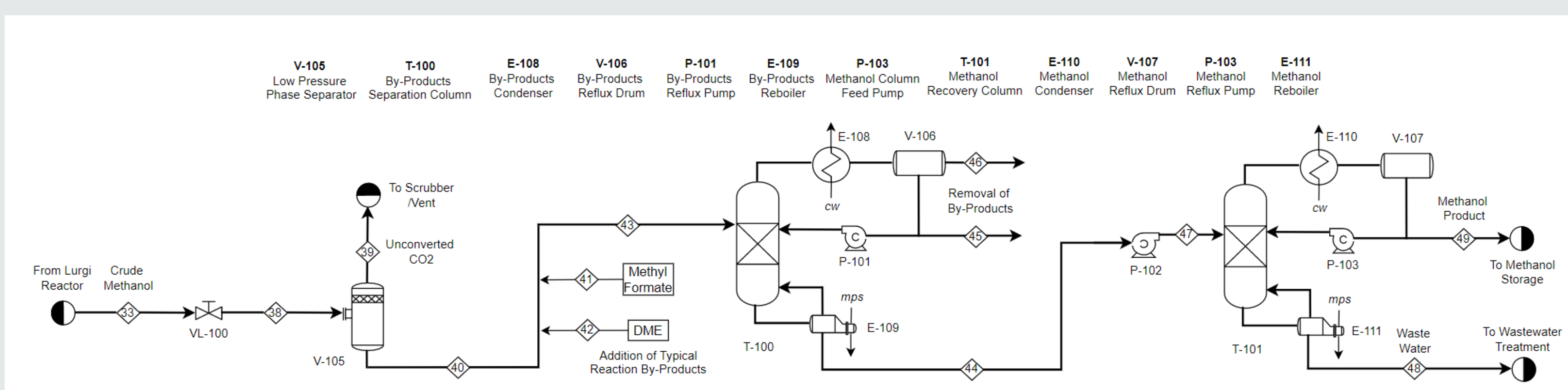
HP Phase Sep.
- Carbon steel
- Vertical cylindrical drum
- D = 0.91 m and H = 3.2 m

Recycle Compressor
- Carbon Steel
- Screw Compressor
- Compression Ratio = 1.02

Product Cooler
- Carbon Steel
- Shell and Tube (Fixed)
- HX Area = 593 m^2

Reactant Heaters
- Carbon Steel
- Shell and Tube (Fixed)
- HX Area = 377 (E-105) and 50 m^2 (E-106)

Step 3: Separation Stage (Purifies Crude Methanol)

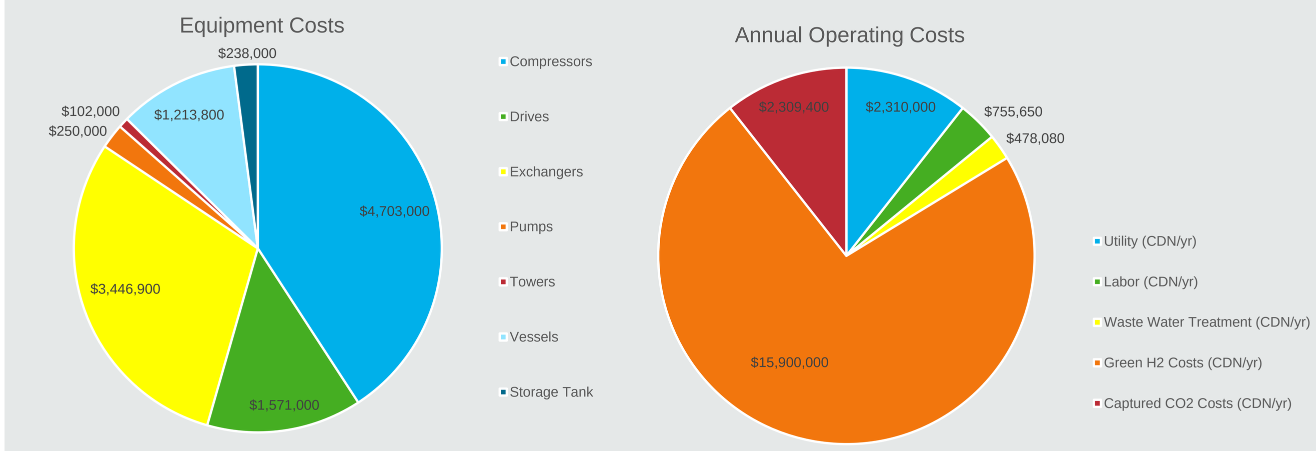


By-Products Column
- Carbon steel
- Pressure: 125.7 kPa
- D = 0.44 m and H = 8.7 m
- 9 Stages, packed with Super-Pak 150Y
- Partial condenser w/ HX area = 15.2 m^2
- Reboiler HX Area = 38.8 m^2
- Reflux Drum: D = 1.2 m and L = 3.7 m

LP Phase Sep.
- Carbon steel
- Vertical cylindrical drum
- D = 0.61 m and H = 3.4 m

Methanol Recovery Column
- Carbon steel
- Pressure: 200 kPa
- D = 0.61 m and H = 8.4 m
- 21 Stages, packed with Super-Pak 150Y
- Total condenser w/ HX area = 37 m^2
- Reboiler HX Area = 181.5 m^2
- Reflux Drum: D = 0.85 m and L = 2.6 m

Economic Analysis



- Total Capital Cost: **$11.5M**
- Operating Costs: **$21.75M**
- Methanol Price to Break Even Annually: **1042$/MT**
- Current Methanol Market Price **822$/MT**
- The largest operating cost, Green H2, is projected to drop in price over the next 20 years from over 6$/kg to no higher than 3.5$/kg
- Potential savings of ~30% on Green H2 costs

Conclusions and Recommendations

General Conclusion

- Methanol Production rate of 2600 kg/h (20800 tonnes/year)
- Design sales price is approximately 26% higher than the market price
- For this plant to be profitable, methanol will need to be sold for a higher price to pay off the capital and operational costs.

Hazards

- Leaks
  - Leak detection systems, containment units (liquid), and ventilation (gas)
  - Implement an emergency shutdown procedure
- H_2 embrittlement
  - Routine inspection and corrosion monitoring

Recommendations for Future Design

- Investigate applicability with less wind power availability
- Create a plant layout based on the site location

Project References

- Bowker, M. (2019). Methanol Synthesis from CO2 Hydrogenation. *ChemPubSoc Europe*, 4238-4246
- Chao, Cong, et al. "Post-Combustion Carbon Capture." *Renewable and Sustainable Energy Reviews*, vol. 138, 2021, p. 110490., https://doi.org/10.1016/j.rser.2020.110490.
- Gardner, D.(2009, January 01). *Hydrogen production from Renewables*. Renewable energy focus. http://www.renewableenergyfocus.com/view/3157/hydrogen-production-from-renewables/