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Carbon Capture Processing and Loading onto Ships in Atlantic Canada

Introduction

Greenhouse gas emissions from previous generations have caused the rampant increase of effects of climate change in our planet today. Many countries across the world have plans developed to combat climate change; in North America, Natural Resources Canada is developing a national Carbon Capture, Utilization, and Storage (CCUS) framework which aims to promote CCUS technologies and projects across all industries within the country and push for a net-zero emission targets. The process involves capturing carbon dioxide (CO_2) from industrial flue gas, transporting, and storing it for long term in geological formations.

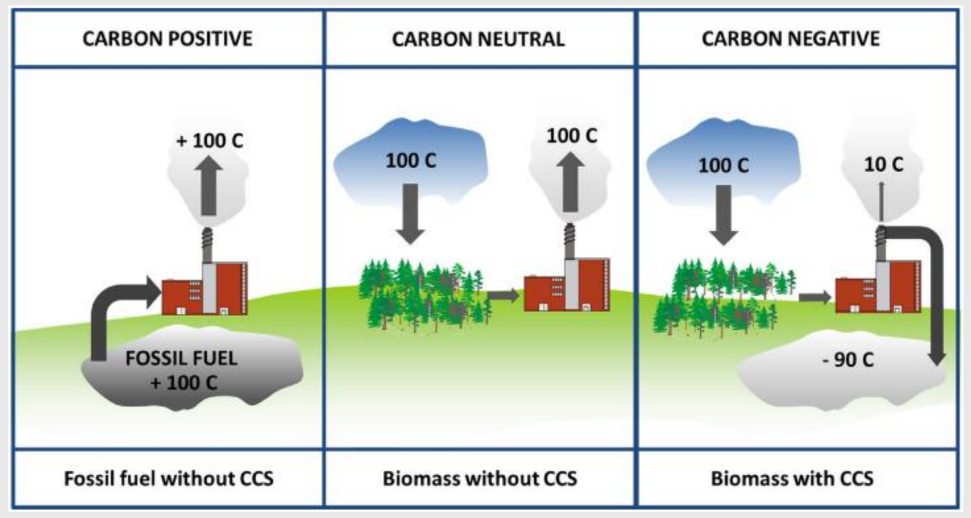


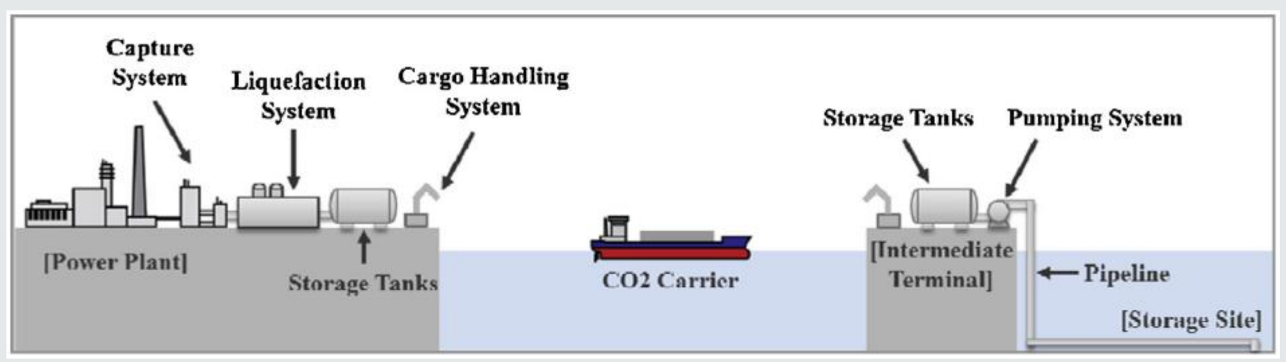
Illustration of Carbon Capture Concept (Onarheim et al., 2017)

Design Process

1. Selected the Irving Pulp & Paper facility in Saint John, NB to study
2. Defined project scope and identified units to be designed
3. Base-case simulation for carbon capture process using Aspen HYSYS
4. Detailed design of all equipment for carbon capture and liquefaction
5. Evaluated safety and sustainability aspects of the project
6. Performed detailed economic analysis

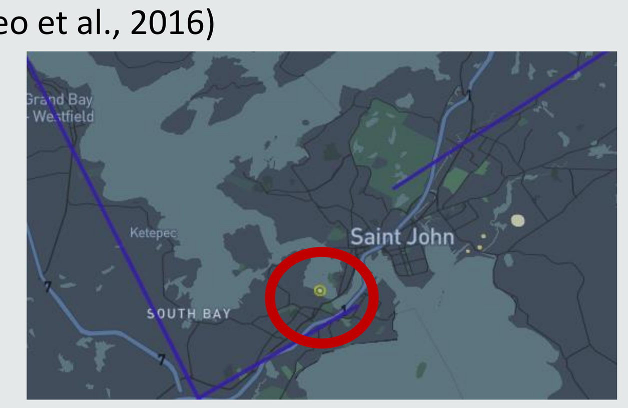
Facility Selection

- The Irving Pulp & Paper facility was selected due to its proximity to the Bay of Fundy for shipping purposes.
- Additionally, pulp and paper is considered carbon neutral. If a pulp mill were to adopt carbon capture it could become carbon negative.



Overall Process Diagram (Seo et al., 2016)

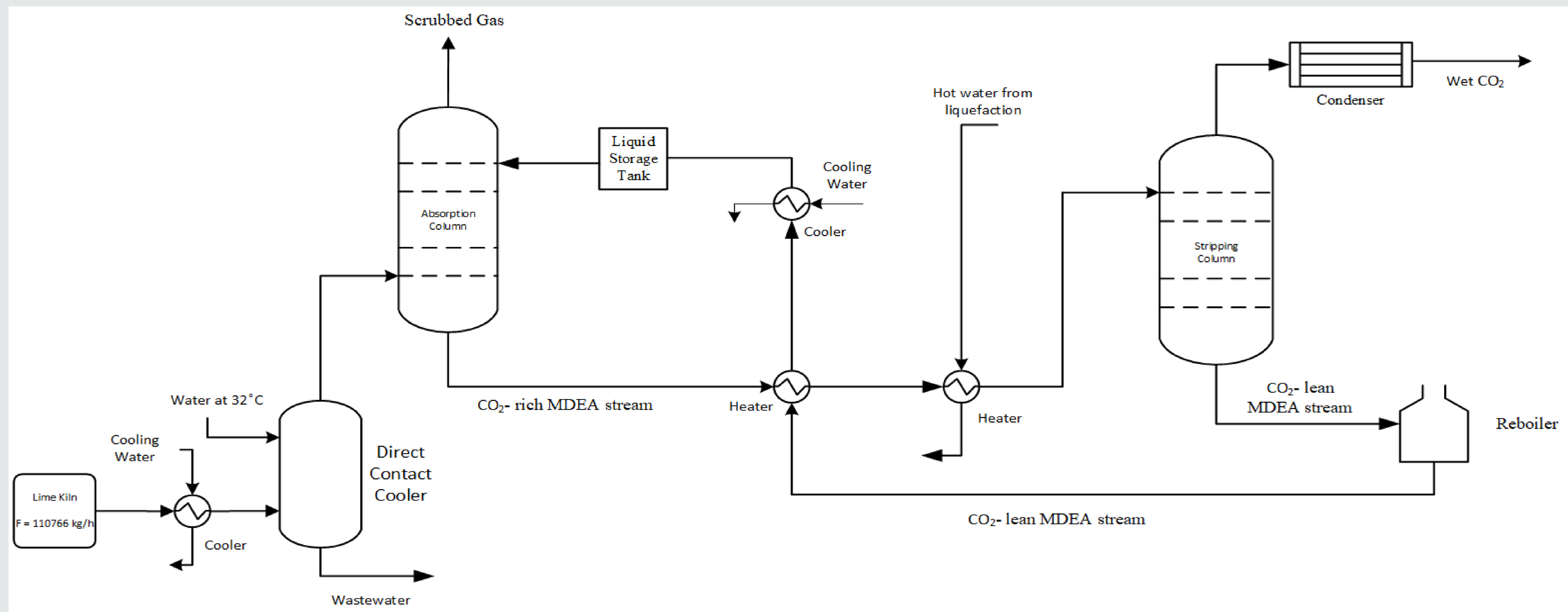
(JD Irving Ltd., 2016)



Location of Facility (Hughes, 2021)

Details of Design

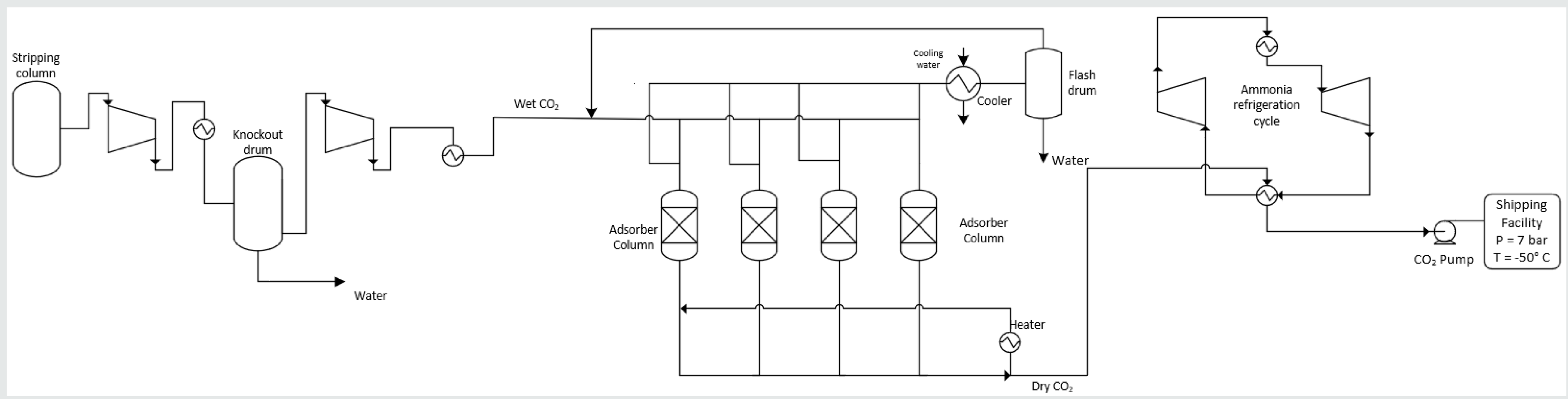
Step 1 – Capture



CO2 Capture System

- Flue gas from lime kiln enters a direct contact cooler for desulfurization, then enters the absorption column where CO_2 is absorbed by MDEA.
- Rich MDEA with CO_2 enters stripping column where CO_2 exits at the top and MDEA is recovered from the bottom.

Step 2 – Liquefaction

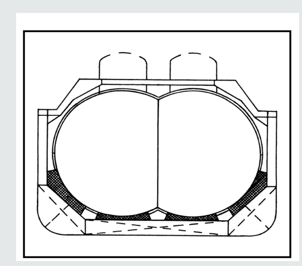


CO2 Liquefaction System

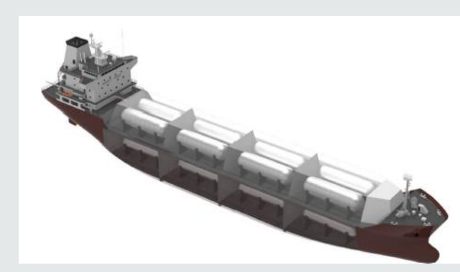
- A knockout drum is used after the first compression stage to remove excess water from the stream.
- An ammonia refrigeration system was designed to cool the CO_2 to -50°C for shipping.
- The molecular sieve is a 4-bed temperature swing adsorption dehydration unit.
- All liquefaction components prior to the molecular sieve are constructed of stainless steel due to the wet CO_2 stream being corrosive.
- The equipment following the molecular sieve are constructed of carbon steel, which is less expensive than stainless steel.

Step 3 – Shipping

- 60 –ton trucks used for initial transportation from facility to port.
- 25,000-ton ships used for transportation to offshore storage location.
- Ships are designed as a semi-refrigerated tanker with type 'C' independent tank
- Conditions for both transportation is maintained at -50℃ and 7 bar.



Type 'C' tank (McGuire et al., 2000)



Design of tanker (McGuire et al., 2000)

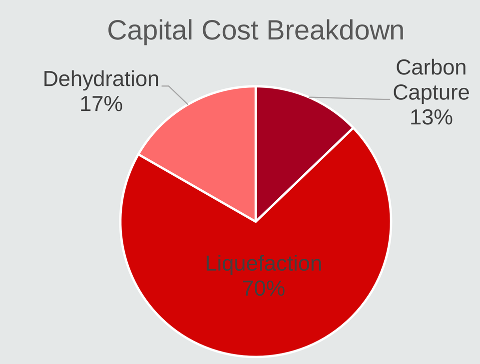
Step 4 – Storage

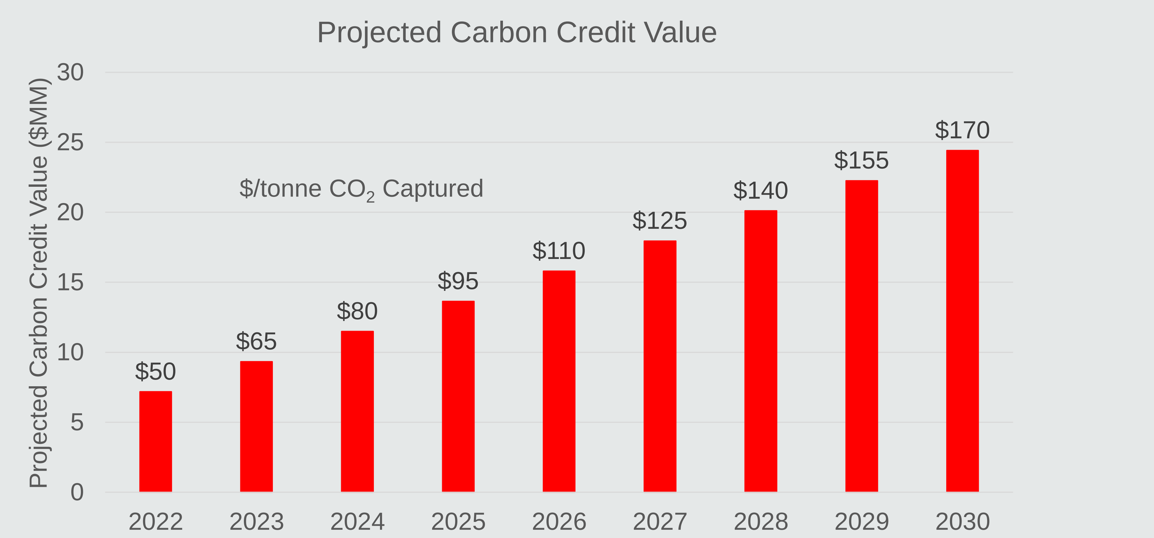
- Several points of interest:
  - West Mountain basalt formation in Bay of Fundy (44.9°N 66.2°W) – desired storage location.
  - Monterey Jack Oil Exploration Well (42.2°N 63.6°W).
  - Cheshire Oil Exploration Well (42.4°N 62.2°W).

The location of the Fundy basalt formation along with the Monterey Jack and Cheshire wells (from left to right)

Economics

- **32.6 tonnes** of CO_2 captured per hour
- Total module cost: $15 million
- Total equipment cost: $4.86 million
- Annual utility cost: $654,000
- Capture cost: **$2.51 per tonne of CO_2**





Sustainability

- Top CO_2 emission source from Pulp & Paper mill was from the lime kiln: 260,800 tonnes CO_2 released annually
- Total CO_2 captured annually: 128,000 tonnes CO_2
- Total CO_2 emission from module annually from natural gas-based electricity and steam usage: 22,100 tonnes CO_2
- Wastewater Stream from Direct Contact Cooler:
  - 289 tonnes NO_2 released annually
  - 6556 tonnes CO_2 released annually
- Scrubbed Gas from Absorption Column:
  - 497 tonnes CO_2 released annually

Conclusion and Recommendations

- Purity of CO_2 captured: 99.9%
- Required shipping conditions are met and the overall process is carbon negative.
- It is recommended to further explore other industrial facilities in Saint John, NB for carbon capture and develop a CCUS Hub in Atlantic Canada

References

- Hughes, R. (2021). Major CO2 Emitters Map. Ottawa, ON, Canada: Natural Resources Canada. Personal Communication.
- McGuire, & White. (2000). *Liquefied Gas Handling Principles on Ships and in Terminals* (Vol. 3). Witherby & Company Limited. Retrieved from https://www.pfri.uniri.hr/knjiznica/download/Lghp(siggto).pdf
- Onarheim, K., Santos, S., Kangas, P., & Hankalin, V. (2017). Performance and costs of CCS in the pulp and paper industry part 1: Performance of amine-based post-combustion CO2 capture. ScienceDirect, 59, 58-73.
- Seo, Y., Huh, S., & Chang, D. (2016). Comparison of CO2 liquefaction pressures for ship-based carbon capture and storage (CCS) chain. *Int J Greenh Gas Control, 52*, 1-12.