

Scoping Study for Recommendation Not to Proceed With Neon Recovery Unit

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Title: Scoping Study for Recommendation Not to Proceed with Neon Recovery Unit

Dear Dr. Seames and Dr. Foerster

Enclosed is a scoping study report for a major retrofit project, designed to recover commercial-grade neon (Ne) and/or helium (He) as by-products from the nitrogen (N₂) product stream of an air separation plant in North Dakota. The proposed process utilizes the fundamentals of cryogenic distillation based on the Linde process and aligns with the high-purity specifications for neon (99.5%). This design outlines a Neon Recovery Unit (NRU) to process 13,000 metric tons/day of nitrogen (N₂) containing trace amounts of Ne and He impurities.

At present, the demand for Ne remains strong in imaging technologies, as well as in the rapidly growing semiconductor industry. This report details an approach to remove N₂ while producing ~3.28 million SCF/year. The NRU operates through three primary steps: (1) producing Ne-rich gas through partial liquification of the N₂ feed; (2) generating crude Ne gas via a high-reflux stripping column; and (3) producing high-purity Ne through partial liquification of the crude Ne stream.

This report contains input/output (I/O) diagrams, block flow diagrams (BFD), and process flow diagrams (PFD). A major equipment list, chemicals & catalyst, utility requirements, products list, economic assessment, economic hazards analysis, and safety impact are included.

This project requires a total capital investment of \$640 million with an NPV@16% of -\$170 million $\pm$ 40% over the ten-year lifespan of the project, with an operating factor of 95%. Given the negative NPV, the project does not have a DCFROR. The preliminary project duration is estimated to be 60 months.

Please review this scoping study report and contact our group with any questions or concerns regarding this major retrofit project or our upcoming budget meeting. The authors of this report declare no conflict of interest.

Best regards,

Avery Frith

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Group 8D

Title: Scoping Study for a Major Retrofit Project to Produce Commercial Grade Neon from an Air Separation Plant.

Funding Request: \$640,000,000 (Basis Date: April 2024)

Project Duration: 60 months

Proposal: The proposed installation of an NRU will operate downstream of an air separation unit ARU. The NRU will utilize a modified Linde cycle to process 13,000 MTD of a high-purity nitrogen product from the ARU, to produce 3.8 million SCF/yr of Neon at a purity of 99.5 %. The high-purity neon product will be sent to storage tanks.

Present Situation: An existing air separation plant is producing 13,000 MTD of a high-purity nitrogen product. The air separation plant is interested in further processing trace neon and helium already present in the exiting nitrogen stream. When purified, these commercial grade products have the capability to increase the profitability of a relatively low-value product stream substantially.

Qualitative Justification: The main purpose of this retrofit was to increase revenue. The proposed process will not allow the air separation plant to diversify and take advantage of a stable commercial market for neon. There are rising incentives to producing commercial grade neon due to the current war in Ukraine which limits the world supply of neon drastically. Additionally, growing demand in the medical and semiconductor sectors provides a promising future for economic growth. Unfortunately, with the current nitrogen stream and process design, this is not a viable investment for the air separation plant.

Quantitative Justification: The NPV@16% is -\$170 million +/- 40% over the 15-year lifespan of the project. Since the NPV is negative, the implication is that the project is not financially viable given the current process design.

Alternatives: The alternative of additionally capturing Helium at a purity of 99.998% was investigated and factored into the economic analysis to determine if the recovery of a second valuable commercial grade product from the same air separation stream yielded a positive NPV. This alternative was not pursued due to unfavorable economics.

Hazards: This project is highly sensitive to changes in the price of Neon, as well as the price of the stripping column estimated by the vendor. An increase in the price of the column, or a decrease in the price of neon at the outer ranges will make this project unprofitable.

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Scoping Study for Minimum Flow Recycle Retrofit for an Aromatics Recovery Unit

1. Introduction

This scoping study evaluates the profitability of recovering Ne from the high-purity N₂ product stream of an ASU. The proposed Neon Recovery Unit (NRU) processes 13,000 metric tons per day of high purity nitrogen gas containing trace Ne impurities to produce 230 kg/day of high purity Ne. The NRU also produces a crude Helium by-product that may be further processed. The NRU returns 6.5 MTD of high purity N₂ to the ASU product stream and retains the remaining 6.5 MTD for an internal refrigeration cycle.

The proposed design adapts literature on cryogenic air separation processes to a Ne Recovery Unit (NRU). Contrary to the literature on existing NRUs, the proposed design does not feature process integration with the ASU.¹

Conventional enthalpy diagrams and AspenPlus simulations were used as a starting point. Product purity specifications were attained while staying within the bounds of thermodynamics. Initial designs were improved to further specify equipment and utility usage, however, opportunities for optimization and greater profitability remain.

1.1 Economic/Market Background

The global supply of neon has been dominated by Ukraine. In 2022, Ukraine accounted for 50% of the world supply of neon. Neon is primarily produced using cryogenic separation technology. According to the US Trade Commission, the United States imported nearly 1 million cubic meters of neon from Ukraine alone in 2021.² With Ukraine's production currently stunted by the war with Russia, the price of neon has increased by 5000%.³

¹ c.f. of Saedi, M., Mehrpooya, M., Shabani, A., Zaitsev, A., & Nikitin, A. (2021). Proposal and investigation of a novel process configuration for production of neon from cryogenic air separation unit. *Sustainable Energy Technologies and Assessments*, 47, 101875.
<https://doi.org/10.1016/j.seta.2021.101875>

² Decarlo, S., & Goodman, S. (2022). International Trade Commission Executive Briefings on Trade.
https://www.usitc.gov/publications/332/executive_briefings/ebot_decarlo_goodman_ukraine_neon_and_semiconductors.pdf

³ Guo, J. (2022, August 12). The war in Ukraine is disrupting the world's supply of neon. NPR.org.
<https://www.npr.org/2022/08/12/1117263854/the-war-in-ukraine-is-disrupting-the-worlds-supply-of-neon>

Demand for neon remains high, due to its use in the expanding semiconductor and medical imaging device markets. Demand for neon remains high due to its use in the expanding semiconductor and medical imaging device markets. The market for neon is expected to reach \$759 billion by 2030 with a compound annual growth rate (CAGR) of 1.2%. China has begun investing in neon production and the US is expected to follow suit.⁴

2. Present Situation

An air separation unit is currently producing 13,000 MTD of high purity N₂ with trace quantities of Ne and other trace impurities. High-purity N₂ is valued at \$.0085/scuft. Assuming an operating factor of 95%, the ASU has a potential annual sales revenue of \$3.1 million.

There are 9.6 kg/h of Ne available for recovery in the high-purity N₂ stream were perfect separation is possible. High purity neon is valued at \$65/scuft. Assuming a 95% operating factor, the NRU has a potential maximum annual sales revenue of \$207 million.

3. Scope of Work

This scoping study proposes an NRU design at the unit operations level. I/O, BFD and PFD drawings were completed. A major equipment list was compiled from the PFD and costed using AspenPlus and vendor input. Estimating factors were applied to the individual equipment and aggregate levels to arrive at the Total Capital Investment.

Vendor communications provided a rough procurement time estimate. Rules of thumbs were then applied to estimate the total project execution lifecycle.

Operational costs were found by compiling all utilities, maintenance, material, laboratory, and operator labor costs, with the use of estimating factors as needed. Operational costs and capital expenditures were compiled in a cashflow sheet Table 5 over a project lifespan of 10 years. NPV@HR, DCFROR, economic sensitivity analyses for capital costs, product pricing, and electricity were performed.

4. Overview Description

4.1. General Description

The proposed NRU removes a total of 13,000,000 kg/day high purity nitrogen from the ASU product stream and generates 9.213 kg of Ne per day. The NRU proceeds through 3 major steps: (1) the production of an Ne rich gas through partial liquification of the N₂ feed, (2) the production of crude Ne gas in a stripping column, and (3) the production of high purity Ne product through the partial liquification of the crude Ne stream. These 3 steps are outlined in the BFD.

All liquification steps follow a Linde Cycle of sequential compression, cooling, and adiabatic expansion through a Joule-Thompson (JT) valve into a flash separator. Unlike standard

⁴ Neon Production by Country 2023. (n.d.). Worldpopulationreview.com. <https://worldpopulationreview.com/country-rankings/neon-production-by-country>

applications of the Linde Cycle, however, the liquified stream itself (liquid N₂ in Step 1, and liquid Ne in Step 3) is used in interstage cooling rather than the vapor product of the flash separation. Because the goal of each of these steps is not to produce a liquid product, the latent heat of vaporization of these streams can be used in the high cooling duty cross exchangers that precede the JT valves of each step.

In step 2, the rich N₂ gas is fed into the bottom of a high-reflux stripping column. A crude Ne (96% Ne, 4%He) stream leaves the partial condenser of this column. High reflux operation means extremely high condenser cooling duties. The liquid N₂ bottoms stream is used to partially condense the top vapor product to reduce cold utility usage. An additional trim condenser using a liquid N₂ utility completes the partial condensation. 10 kg/hr of crude Ne distillate is sent to Step 3.

The trim condenser serves 2 purposes. Complete coupling of the bottom and overhead systems of a column would make it uncontrollable. Bringing up and bring down the column are conditions that will rely heavily on the trim condenser. The liquid N₂ utility used in this trim condenser is discussed in greater detail below.

4.2. Detailed Description

4.2.1 Step 1: Production of Rich N₂

The detailed production of rich N₂ can be found in PFDs 04-A-013/1 and 04-A-013/2. The high purity N₂ feed, stream 11, enters at –19 C and 360 kPa. It is successively compressed and cooled in G-109, E-101, G-110 and E-102, where G denotes compressor and E heat exchanger. The compressor train is designed to bring the N₂ stream just above its critical pressure prior to final cooling in cross exchanger E-103. This allows cooling the stream in the critical region, above the liquid-vapor envelope, thereby avoiding the latent heat of condensation and decreasing required cooling duty. After exiting E-103, the N₂ stream passes through the JT valve at –196 C and 3500 kPa and drops isenthalpically to a pressure of 100kPa. At this temperature and pressure, the stream is centered within the liquid vapor envelope and 50wt% of the stream is liquified. The vapor fraction leaves the top of the flash separator D-126 as Ne-enriched gas and is sent to the stripping column of Step 2.

Step 1 begins at compressor G-109, which operates at 23 MW with a compression ratio of 4. G-110 operates at 18 MW with a compression ratio of 2.4. All compressors have a polytropic efficiency of 70%. Interstage coolers are shell-and-tube exchangers with duties set by assuming a cooling water utility will bring hot process streams to 30 C. E-101 operates a cooling duty of 23 MW and E-102 at 22 MW. Utility water consumption was approximated by fixing the approach temperature at 5 C and assuming no steam is generated. Process streams enter the tube side and cooling water the shell side. Cross exchanger E-103 achieves 34 MW of cooling by vaporizing and superheating the liquid N₂ bottoms of flash drum D-126. This superheated N₂ is sent back to the ASU to rejoin the N₂ product stream.

4.2.2 Step 2: Production of Crude Ne

The detailed production of crude Ne can be found on PFDs 04-A-013/3. Step 2 begins with stream 13, the Ne-enriched vapor product of flash drum D-126. Stream 13 is mixed with a side vapor product, stream 16, before entering the bottom of stripping column C-101. The combined stream, stream 14, enters the bottom of the stripping column at mass flow rate of 6.5 MTD and is the sole source of vapor and heat to the column. The column contains 20 sieve trays and is 34 m in height and 7.6 m in diameter.

The stripping column operates at distillate-to-feed ratio of 3.7×10^{-5} , corresponding to an extremely high reflux ratio. A crude Ne distillate (96% Ne, 4% He) is drawn from the top of the reflux accumulator D-127 at a rate of 230 kg/day.

The partial condenser system of the C-101 consists of cross condenser E-104 and trim condenser E-105. Cross condenser E-104 partially condenses the vapor overhead using the liquid N₂ bottoms, capturing its latent heat of vaporization and adding superheat. The cooling duty of the cross exchanger is limited by the relatively lower mass flow rate of the liquid N₂ bottoms and an assumed approach temperature of 3 C. Trim exchanger E-105 is added to complete the partial condensation of the overhead using a liquid N₂ utility. A critical function of E-105 is to enable operational control of the stripping column. If the overhead system were completely coupled to bottoms flowrate, the column could not respond to departures from steady state, such as may occur during shutdown and startup operations.

The liquid N₂ utility is one of two “black box” systems in the NRU design where full refrigeration cycles could not be specified. As noted on PFDs 04-A-013/3, this utility returns to the “N₂ Utility Liquification Cycle.” While unspecified, this refrigeration cycle would consist of a scaled-down version of the nitrogen liquification in PFDs 04-A-013/1 and 04-A-013/2.

The side stream vapor product, stream 16, is withdrawn from Tray 2 of C-101. The decision to include this tear stream in the AspenPlus simulation was based on analysis of the column flow profile. Prior to adding the tear stream, a large vapor buildup rich in Ne was present at Tray 2. As the vapor moved up to the top of column however, it encountered a large liquid reflux and was entrained and/or condensed in downward liquid flow. The addition of stream 16 drove distillate purity from 60% to 96%.

4.2.3 Step 3: Production of High Purity Ne

The detailed production of pure Ne can be found on PFDs 04-A-013/4 and 04-A-013/5. Crude Ne, Stream 19, enters a small cryogenic compressor train at -230 C and 100 kPa . The compressor train consists of G-111, E-106, G-112, E-107 and G-113.

The compressor train is designed to bring the crude Ne stream just above its critical pressure prior to final cooling in cross exchanger E-108. This allows the cooling of the stream in the critical region, thereby avoiding the latent heat effects and decreasing required cooling duty in E-109. After exiting E-109, the crude Ne stream enters the JT valve at -350 C and 3000 kPa . Pressure drops isenthalpically to 500 kPa , where 95.6% of the Crude Ne stream condenses to a 99.95% pure liquid neon stream in flash separator D-128.

Interstage cooling in the compressor train is specified to keep stream 19 at the critical pressure of pure Ne (-230 C). Compressor G-111 and G-112 operate at a compression ratio of 4, while G-113 operates a compression ratio of 1.9. All compressors have a polytropic efficiency of 70% and require roughly 0.7 kW .

Cross exchanger E-108 uses the latent cooling effects of partially vaporizing the pure liquid Ne product. Interstage coolers E-106 and E-107 rely on a Ne Utility stream. The Ne utility part of the second and final “black box” system in the NRU design where full refrigeration cycles could not be specified. As noted on PFDs 04-A-013/4, this utility returns to the “Ne Utility Liquification Cycle.” While unspecified, this refrigeration cycle would be a scaled-up version of the Ne liquification shown in PFDs 04-A-013/1 and 04-A-013/2.

The vapor product of D-128 is a crude He stream that may be sent to a downstream PSA system for purification. An evaluation of this process can be found in Appendix A.

6. Economic Assessment

6.1 Broad Cost Estimate

A project economic lifespan of ten years was assumed. Table 3 outlines the capital cost summary, including cost estimates for each piece of equipment based on vendor quotes, simulation, and literature values. Vendor quotes were obtained for the absorption vessel. These quotes are displayed in Appendix A. Appendix B shows the intermediary results for simulations for evaluating the price of compressors, drums, our largest heat exchanger. All remaining equipment items were scaled as part of our preliminary design. The total line item (TLI) costs were added for all of the equipment to find a total direct process cost (TDPC). Indirect costs were estimated at 30% of the total (TDC). The fixed capital investment (FCI) was estimated to be \$640 million $\pm 40\%$ by adding TDC and IDC. The total capital investment (TCI) required was the same as FCI.

6.2 Operating Cost Summary

Table 4 summarizes the operating costs for the proposed process over the lifetime of the project. The total operating cost was estimated to be \$39 million per year based on a 95% operating factor used for utility rates.

In the table, the total cost includes labor, maintenance, utilities, Lab charges, and some indirect costs. This process also had raw material from the stream of nitrogen that was produced upstream, but the amount was rounded down in the calculation.

The project requires five new outside operators and nine board operators per shift. The average salaries of the operators were composed from the bureau of labor⁵. Converting to loaded salaries was assumed to be 1.2 times the unloaded salary. The total operating labor costs are approximately \$2 million per year.

Maintenance costs were estimated to be 4% of the FCI for major retrofits, which gave us \$25 million per year.

The utilities used in the process were cooling tower water, and electricity. Cooler water pricing was \$.018/1000kg, and electricity was taken from the North Dakota industrial average of .0655⁶. This totaled \$1.5 million per year.

Finally, Lab charges were calculated at 15% of the labor costs, and Indirect costs account for 35% of the sum of the operating costs. Indirect costs amounted to \$10 million per year.

6.3 Revenues

Revenues for this retrofit come from only one product stream, which produces all the neon. The price for neon is \$65/scf, and we produce 373 scf/hour. This gives a total revenue of \$209 million dollars per year.

6.4 Taxes & Depreciation

The federal income tax rate of 21% and a North Dakota state corporate tax rate of 4.31% were used for this retrofit. A depreciation schedule for FCI was determined using a 7-year MACRS slide scale. Table 6 shows the cash flow sheet which factors in the annual taxes and depreciation.

6.5 Overall Profitability

The overall profitability of this project has a negative NPV@16 of \$-170 +/- 40% million dollars. This cash flow sheet can be found on Table 6. The preliminary schedule was calculated to be 5 years, and the \$600 million per year FCI was spread out over that time. Given the high FCI, this project is not likely to become profitable.

⁵ North Dakota - May 2020 OEWS State Occupational Employment and Wage Estimates. (n.d.). Wwww.bls.gov. https://www.bls.gov/oes/current/oes_nd.htm

⁶ Fargo, ND Electricity Rates. (2024). Electricity Local. <https://www.electricitylocal.com/states/north-dakota/fargo/>

7. Safety and Environmental Impact Statement

7.1. Safety Impact Statement

This process uses gases that do not pose an explosive atmospheric risk. Nitrogen, Neon, and Helium are all inert gases, and the cryogenic system does not create any potential hazards. Therefore, this project could safely be considered a Div. 3 classification.

7.2. Environmental Impact Statement

This project is mostly operated with inert gases that are naturally present in the atmosphere. Also, the product streams will go to storage for future sale, and there are no purge or waste gas streams. Wastewater that is used for cooling can be recirculated, warmed to ambient temperatures, and then used again, minimizing the need for waste disposal. Additionally, wastewater that does accumulate over time will go to a wastewater treatment plant. Additional work will be done to utilize the very cold liquid products, to avoid using unnecessary utility streams in the process.

8. Economic Hazards Analysis

This project is very capital intensive, with significant portions of the cost going towards the equipment. A sensitivity analysis on the Column costs shows that the region of most probable certainty lies within a range that indicates non-profitability at higher column costs. The also shows that if the price of the column were decreased, this project could approach profitability.

Another major component of this project is the price of Neon. Neon is the most valuable recovered product, so a majority of the profit comes from neon. As shown in figure 3, a variation on the price of neon +/- 40% shows that most of the area of most probably uncertainty lies in negative NPV@16. Only if the price of Neon shifted dramatically higher.

Finally, electricity is the primary utility used in this process. In North Dakota, the annual average increase over the last 20 years is 3.1%. Using this trendline we can adjust the electrical cost up to .09\$/kW-hr for a maximum value, and .060 as a minimum value. Performing an uncertainty analysis on this shows further drops in net present value, but not to a magnitude that would show electric price sensitivity.

9. Broad Comparison of Process Alternatives

The alternative option is to also continue on and recover helium to purity as well. This would be conducted using a PSA column to adsorb the helium from the neon. We are not pursuing this option because there is a -\$2.5 million NPV @ HR. We do not believe this option to be economically viable.

10. Conclusion

The objective of this report was to determine if adding the necessary equipment and utilities to this facility to recover neon or helium was a viable option. Our analysis leads us to recommend that

we do not proceed with building this facility for neon. The NPV@16% of this project gives us a projected loss of \$171 million. This project is sensitive to changes in the price of neon and equipment, and further evaluation may be warranted.

Table 1. Product Stream

Component	Weight %
Neon	99.5%

Table 2.Major Equipment List

Equipment Number	Equipment Name/Description	Equipment Specifications
E-101 A/B	High Purity N2 Cooler	Duty = 22876 kW
		Tube Inlet Temperature = 173 °C
		Tube Outlet Temperature = 30 °C
		Tube Pressure = 1440 kPa
		Tube MOC = Carbon Steel
		Tube Fluid = N2
		Shell Inlet Temperature = 20 °C
		Shell Outlet Temperature = 25 °C
		Shell Pressure = 207 kPa
		Shell MOC = Carbon Steel
		Shell Fluid = H ₂ O
		Area = 1386 m ²
		Heat Transfer Coefficient = 323 W/m ² - °C

Equipment Number	Equipment Name/Description	Equipment Specifications
E-102 A/B	High Purity N2 Cooler	Duty = 21470 kW
		Tube Inlet Temperature = 161 °C
		Tube Outlet Temperature = 30 °C
		Tube Pressure = 3500 kPa
		Tube MOC = Carbon Steel
		Tube Fluid = N2
		Shell Inlet Temperature = 20 °C
		Shell Outlet Temperature = 25 °C
		Shell Pressure = 207 kPa
		Shell MOC = Carbon Steel
		Shell Fluid = Cooling Water
		Area = 1465 m2
		Heat Transfer Coefficient = 303 W/m2- °C

Equipment Number	Equipment Name/Description	Equipment Specifications
E-103 A/B	High Purity N2 Cooler cooled with liq N2	Duty = 33327 kW
		Tube Inlet Temperature = 30 °C
		Tube Outlet Temperature = - 140 °C
		Tube Pressure = 3500 kPa
		Tube MOC = Aluminum
		Tube Fluid = N2
		Shell Inlet Temperature = - 195 °C
		Shell Outlet Temperature = - 143 °C
		Shell Pressure = 101 kPa
		Shell MOC = Aluminum
		Shell Fluid = Liquid Nitrogen
		Area = 1067 m2
		Heat Transfer Coefficient = 278 W/m2- °C

Equipment Number	Equipment Name/Description	Equipment Specifications
E-104 A/B	Hydrogen Trim Exchanger	Duty = 33327 kW
		Tube Inlet Temperature = 30 °C
		Tube Outlet Temperature = - 140 °C
		Tube Pressure = 3500 kPa
		Tube MOC = Aluminum
		Tube Fluid = N2
		Shell Inlet Temperature = - 270 °C
		Shell Outlet Temperature = - 143 °C
		Shell Pressure = 101 kPa
		Shell MOC = Aluminum
		Shell Fluid = Liquid Nitrogen
		Area = 1067 m2
		Heat Transfer Coefficient = 278 W/m2- °C

Equipment Number	Equipment Name/Description	Equipment Specifications
E-105 A/B	Hydrogen Trim Exchanger	Duty = 33327 kW
		Tube Inlet Temperature = 30 °C
		Tube Outlet Temperature = - 140 °C
		Tube Pressure = 3500 kPa
		Tube MOC = Aluminum
		Tube Fluid = N2
		Shell Inlet Temperature = - 270 °C
		Shell Outlet Temperature = - 143 °C
		Shell Pressure = 101 kPa
		Shell MOC = Aluminum
		Shell Fluid = Liquid Nitrogen
		Area = 1067 m2
		Heat Transfer Coefficient = 278 W/m2- °C

Equipment Number	Equipment Name/Description	Equipment Specifications
E-106 A/B	High Purity N2 Cooler	Duty = 1 kW
		Tube Inlet Temperature = -15 °C
		Tube Outlet Temperature = -226 °C
		Tube Pressure = 2000 kPa
		Tube MOC = Aluminum
		Tube Fluid = Neon
		Shell Inlet Temperature = -246 °C
		Shell Outlet Temperature = -220 °C
		Shell Pressure = 101 kPa
		Shell MOC = Aluminum
		Shell Fluid = Liquid Neon
		Area = 1067 m ²
		Heat Transfer Coefficient = 278W/m ² - °C

Equipment Number	Equipment Name/Description	Equipment Specifications
E-107 A/B	High Purity N2 Cooler	Duty = 1 kW
		Tube Inlet Temperature = -15 °C
		Tube Outlet Temperature = -226 °C
		Tube Pressure = 2000 kPa
		Tube MOC = Aluminum
		Tube Fluid = Neon
		Shell Inlet Temperature = -246 °C
		Shell Outlet Temperature = -220 °C
		Shell Pressure = 101 kPa
		Shell MOC = Aluminum
		Shell Fluid = Liquid Neon
		Area = 1067 m ²
		Heat Transfer Coefficient = 278W/m ² - °C

Equipment Number	Equipment Name/Description	Equipment Specifications
E-108 A/B	High Purity N2 Cooler	Duty = 1 kW
		Tube Inlet Temperature = -15 °C
		Tube Outlet Temperature = -226 °C
		Tube Pressure = 2000 kPa
		Tube MOC = Aluminum
		Tube Fluid = Neon
		Shell Inlet Temperature = -246 °C
		Shell Outlet Temperature = -220 °C
		Shell Pressure = 101 kPa
		Shell MOC = Aluminum
		Shell Fluid = Liquid Neon
		Area = 1067 m ²
		Heat Transfer Coefficient = 278W/m ² - °C

Equipment Number	Equipment Name/Description	Equipment Specifications
G-109	Gas Compressor	Stages = 1
		MOC = Carbon Steel
		Inlet Pressure = 360 kPa
		Outlet Pressure = 1440 kPa
		Inlet Temperature = -19 °C
		Outlet Temperature = 173 °C
		Fluid Components = N ₂
		Volumetric Flow Rate = 124378 scmh
		Power = 22989 kW
G-110	Gas Compressor	Stages = 1
		MOC = Carbon Steel
		Inlet Pressure = 1440 kPa
		Outlet Pressure = 3500 kPa
		Inlet Temperature = 30 °C
		Outlet Temperature = 162 °C
		Fluid Components = N ₂
		Volumetric Flow Rate = 37051 scmh
		Power = 17549 kW
		Stages = 1
		MOC = Carbon Steel
		Inlet Pressure = 1440 kPa
		Outlet Pressure = 3500 kPa
		Inlet Temperature = 30 °C

Equipment Number	Equipment Name/Description	Equipment Specifications
G-111	Gas Compressor	Stages = 1
		MOC = Carbon Steel
		Inlet Pressure = 100 kPa
		Outlet Pressure = 2000 kPa
		Inlet Temperature = -226 °C
		Outlet Temperature = -15 °C
		Fluid Components = N2
		Volumetric Flow Rate = 0.64 scmh
		Power = 0.7 kW
G-112	Gas Compressor	Stages = 1
		MOC = Carbon Steel
		Inlet Pressure = 100 kPa
		Outlet Pressure = 2000 kPa
		Inlet Temperature = -226 °C
		Outlet Temperature = -15 °C
		Fluid Components = N2
		Volumetric Flow Rate = 0.64 scmh
		Power = 0.7 kW
		Stages = 1
		MOC = Carbon Steel
		Inlet Pressure = 100 kPa
		Outlet Pressure = 2000 kPa
		Inlet Temperature = -226 °C

Equipment Number	Equipment Name/Description	Equipment Specifications
G-113	Gas Compressor	Stages = 1
		MOC = Carbon Steel
		Inlet Pressure = 100 kPa
		Outlet Pressure = 2000 kPa
		Inlet Temperature = -226 °C
		Outlet Temperature = -15 °C
		Fluid Components = N2
		Volumetric Flow Rate = 0.64 scmh
		Power = 0.7 kW

Equipment Number	Equipment Name/Description	Equipment Specifications
D-126	Flash Drum	Height = 5.5 m
		Diameter = 3.5 m
		Temperature = -196 C
		Pressure = 103 kPa
		MOC = Aluminum Clad Carbon Steel
		Height = 5.5 m
D-127	Flash Drum	Height = 3.5 m
		Diameter = 1 m
		Temperature = -256 C
		Pressure = 243 kPa
		MOC = Aluminum
D-128	Column 1 Drum	Height = 5.9 m
		Diameter = 2.1 m
		Temperature = -226 C
		Pressure = 103 kPa
		MOC = Aluminum Clad Carbon Steel
C-101	Stripping Column	Height = 34m
		Diameter = 7.6 m
		Trays = 20
		Tray Spacing = 0.61 m
		Temperature = -196
		Pressure = 103 kPa
		MOC = Aluminum Clad Carbon Steel

Equipment Number	Equipment Name/Description	Equipment Specifications
L-101 A/B	Reflux Pump	Power = 0.12 kW
		Volumetric Flow Rate = 0.07 m ³ /hr
		Inlet Pressure = 101 kPa
		Outlet Pressure = 160 kPa
		Temperature = -196 C
		MOC = Aluminum
		Fluid Components = N2
L-102 A/B	Reflux Pump	Power = 0.12 kW
		Volumetric Flow Rate = 0.07 m ³ /hr
		Inlet Pressure = 101 kPa
		Outlet Pressure = 160 kPa
		Temperature = -196 C
		MOC = Aluminum
		Fluid Components = N2

Preliminary Schedule	Time	Weighted Time Factor
Procurement	24	40%
Implementation	18	30%
Design	18	30%
	Total Project Time	60 Months

Figure 1. Preliminary Project Schedule

Utility Description	Utility Conditions	Utility Requirements
Cooling Water	25 C	1600000 kg/hr
	207 kPa	
Electricity	-	56500 kW

Figure 2. Utilities List

Table 3. Capital Cost Summary

Major Equipment Item w/ key specifications	Unadjusted Unit Equip Supplier Cost	Basis Date Adjustment Index (if required): eqn. 4.2	Matls of Const Adjustment Factor (if required): eqn 4.3	Pressure Adjustment Factor (if required): eqn 4.4	Adjusted Basis Date Unit Equip Cost	Number of units	Line Item Equip Cost	Estimating Factor, FT (Table 4.10)	Total Line Item (TLI) Cost (eqn. 4.5)
23000 kW Gas Compressor	27	1	1	1.1	30	1	30	2.5	74
17500 kW Gas Compressor	13	1	1	1.1	14	1	14	2.5	36
Cooling Water Heat Exchanger	0.40	1	1	1.2	0.48	2	0.96	3.2	3.1
Nitrogen Cross Exchanger	1.20	1	1.5	1.3	2.30	2	4.70	3.2	15
Neon Cross Exchanger	0.20	1	1.5	1.3	0.39	1	0.39	3.2	1.2
Stripping Column	25	1	1.5	1	38	1	38	6.6	250
N2 Flash Drum	0.14	1	1.5	1	0.21	1	0.21	4.4	0.92
Neon Flash Drum	0.03	1	1.5	1	0.05	1	0.04	4.4	0.18
Reflux Pumps	0.03	1	1.5	1.1	0.05	2	0.10	3.2	0.32
Basis Date April 2024							Total Direct Process Cost (TDPC= $\sum$ TLI)	380	
							Additional Direct Costs (ADC, Table 4.3)	110	
							Total Direct Costs (TDC=TDPC+ADC)	490	
							Indirect Costs (IDC= 0.3*TDC)	150	
							Fixed Capital Investment (FCI=TDC+IDC)	640	
							Initial Charge of Chemicals & Catalysts (CC)	0	
							Total Capital Investment (TCI=FCI+CC)	640	

Dollar Amounts are in Millions.

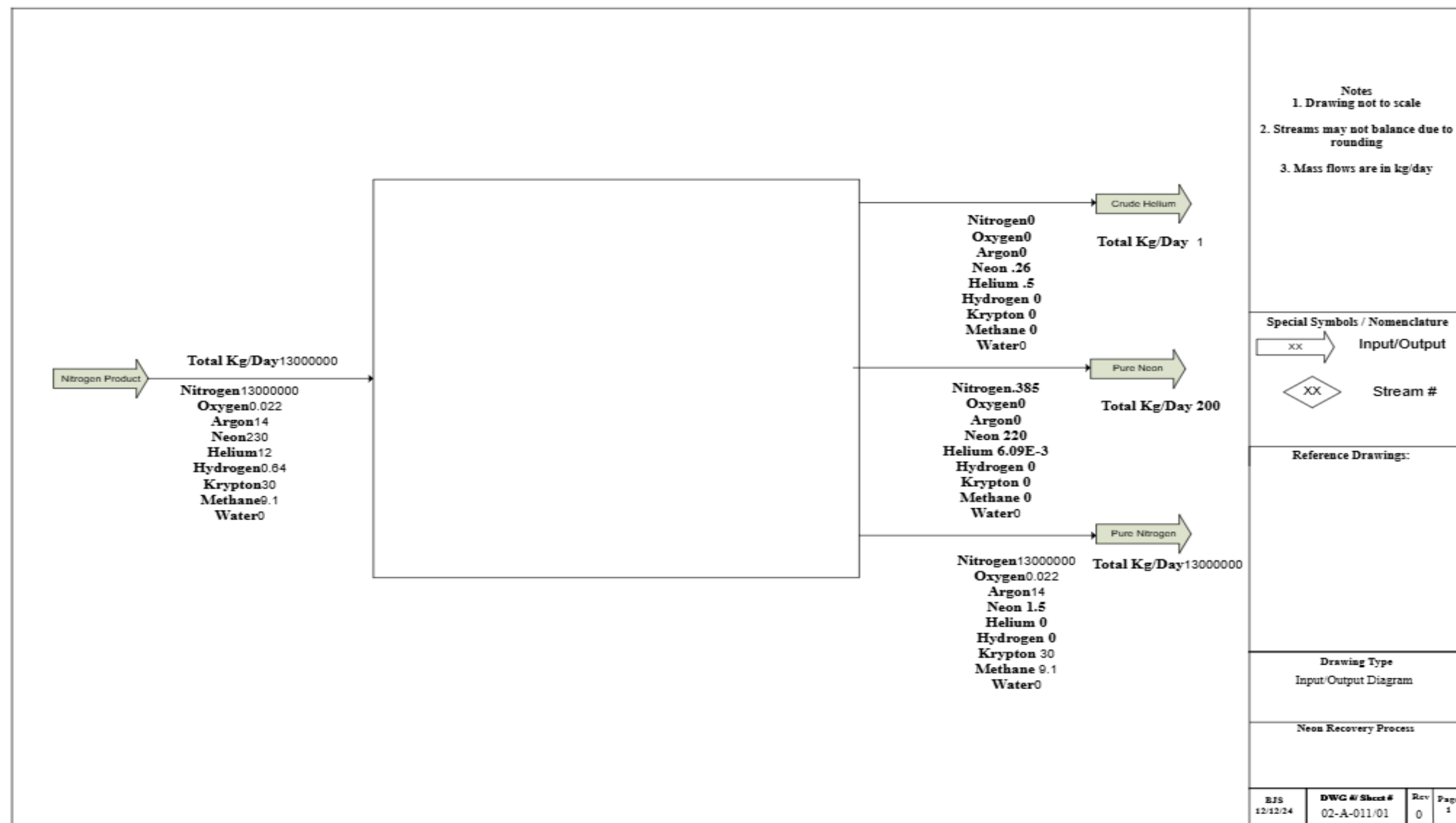
Table 4. Operating Costs Summary

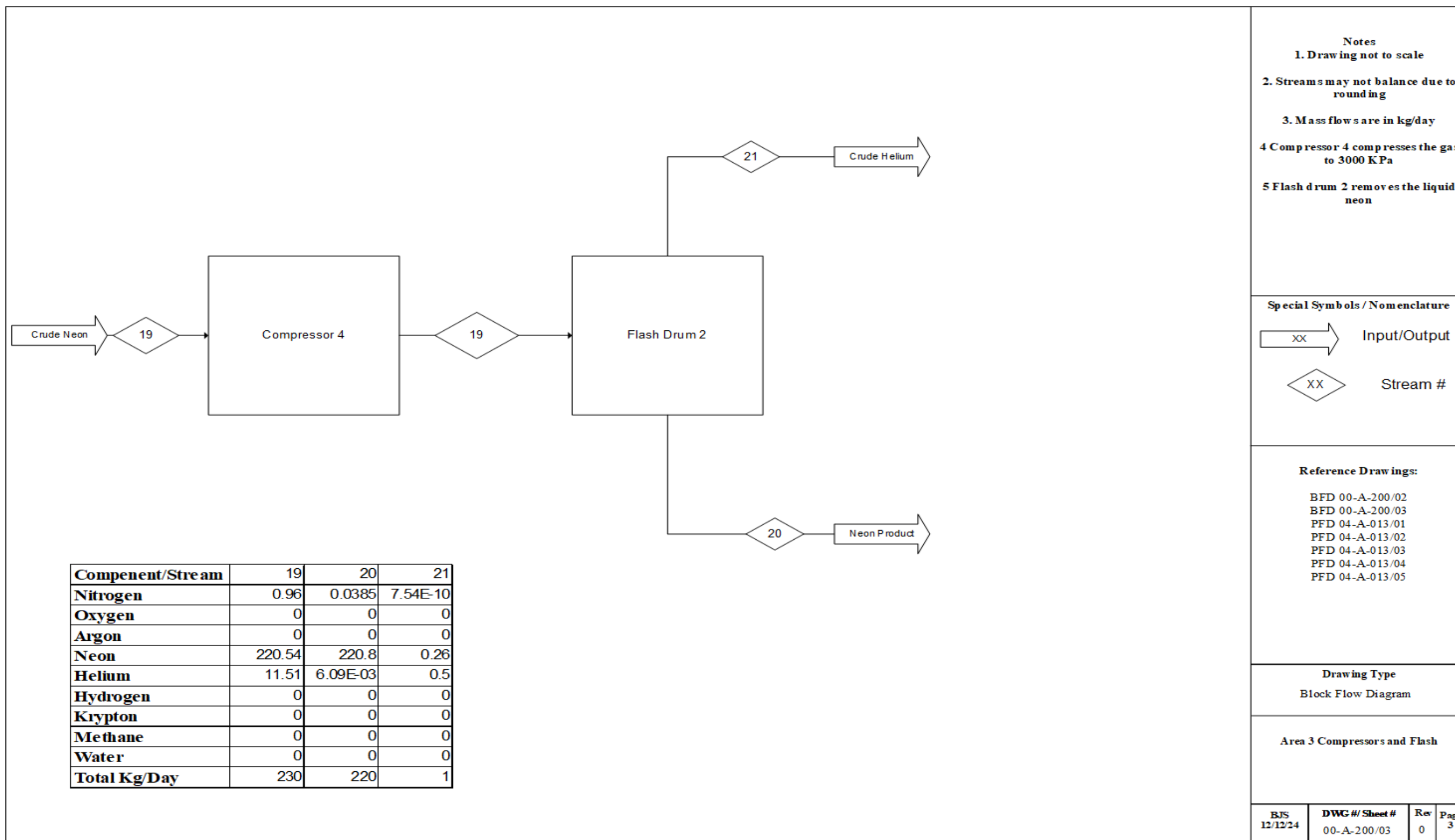
A. Time Since Project Commissioning (Months or Years)	B. Operating Labor	C. Maintenance	D. Utilities	E. Chemicals & Catalysts	F. Other Taxes	G. Operating Matls and Lab Charges	H. Other Direct Costs	I. Total Manufacturing Costs (sum of B - H)	J. Raw Materials	K. Total Direct Operating Costs (sum of I and J)	L. Indirect Costs	M. Total Operating Costs (sum of K and L)
1	\$2	\$26	\$2	\$0	\$0	\$0.10	\$0	\$29	\$0	\$29	\$10	\$39
2	\$2	\$26	\$2	\$0	\$0	\$0.10	\$0	\$29	\$0	\$29	\$10	\$39
3	\$2	\$26	\$2	\$0	\$0	\$0.10	\$0	\$29	\$0	\$29	\$10	\$39
4	\$2	\$26	\$2	\$0	\$0	\$0.10	\$0	\$29	\$0	\$29	\$10	\$39
5	\$2	\$26	\$2	\$0	\$0	\$0.10	\$0	\$29	\$0	\$29	\$10	\$39
6	\$2	\$26	\$2	\$0	\$0	\$0.10	\$0	\$29	\$0	\$29	\$10	\$39
7	\$2	\$26	\$2	\$0	\$0	\$0.10	\$0	\$29	\$0	\$29	\$10	\$39
8	\$2	\$26	\$2	\$0	\$0	\$0.10	\$0	\$29	\$0	\$29	\$10	\$39
9	\$2	\$26	\$2	\$0	\$0	\$0.10	\$0	\$29	\$0	\$29	\$10	\$39
10	\$2	\$26	\$2	\$0	\$0	\$0.10	\$0	\$29	\$0	\$29	\$10	\$39

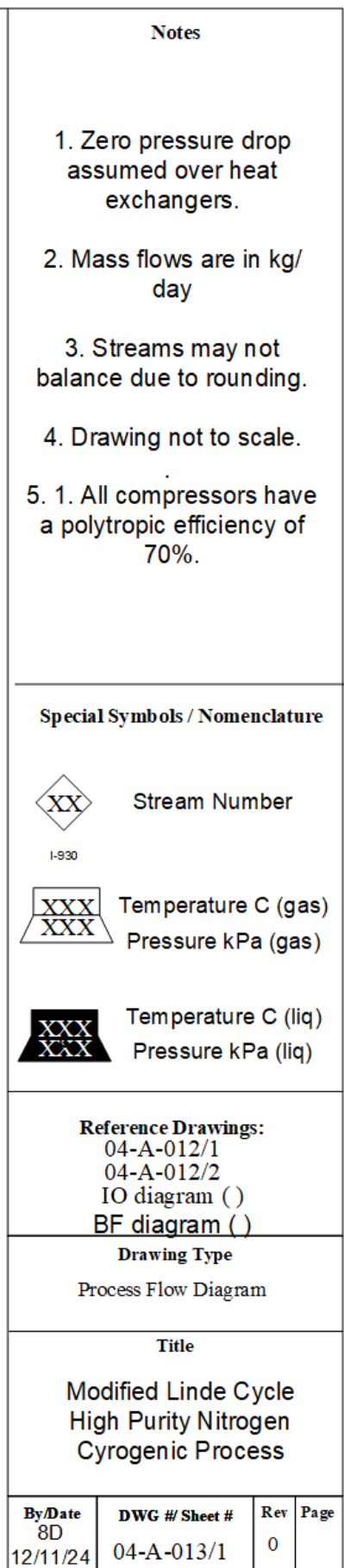
Basis Date

April 2024

Dollar Amounts are in Millions.

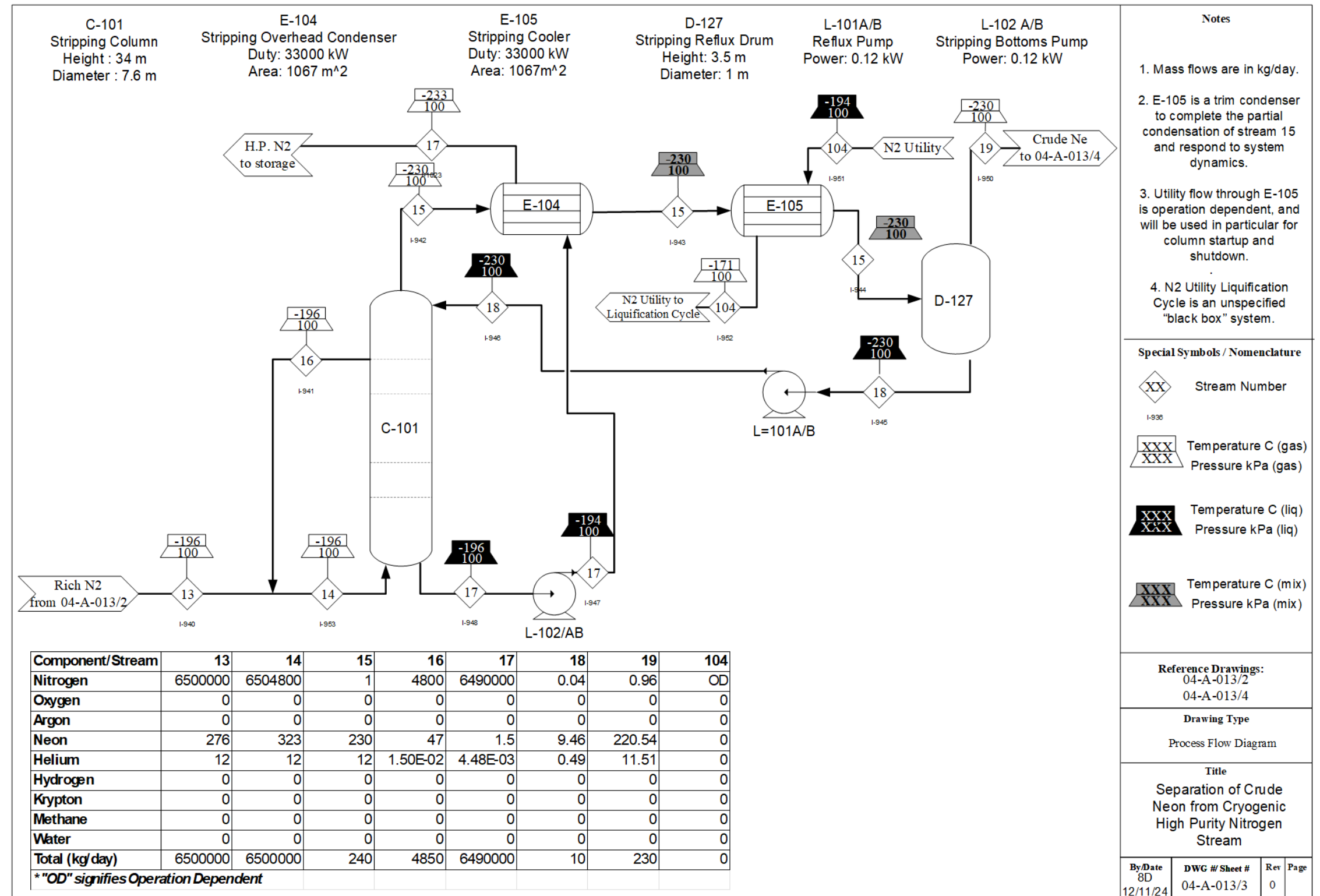






Component/ Stream	11	101	102
Nitrogen	13000000	0	0
Oxygen	0.022	0	0
Argon	14	0	0
Neon	230	0	0
Helium	12	0	0
Hydrogen	0.64	0	0
Krypton	30	0	0
Methane	9.1	0	0
Water	0	95000000	290000000
Total (kg/ day)	13000000	95000000	290000000

Move the HXs so 4 equip
each sheat



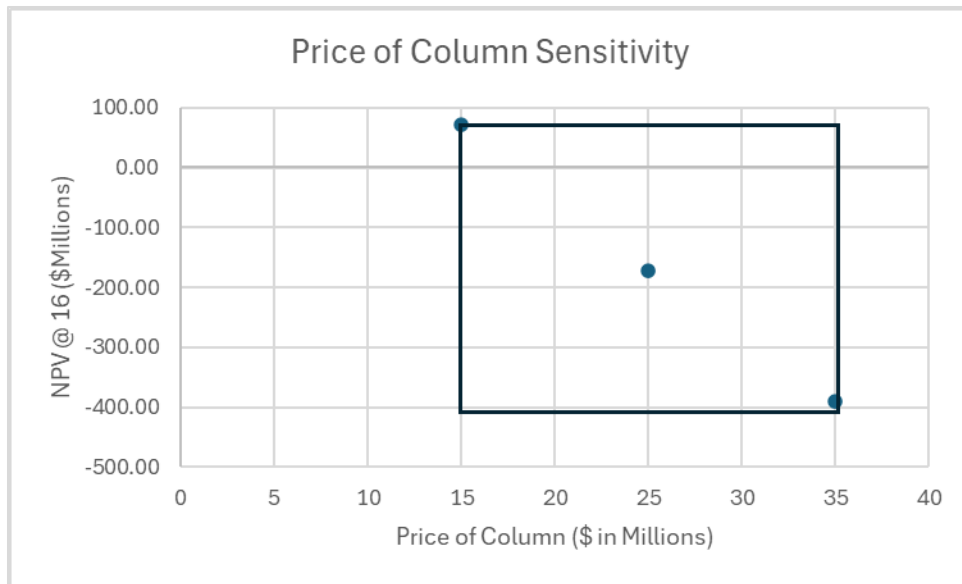


Figure 3. *Region of Most Uncertainty - Column*

Column Costs were obtained from a vendor who gave a broad estimate of the column. Sensitivity Analysis shows that if the column is at the outer limits of +/- 40%, positive NPV@16 is a potential outcome. This indicates high sensitivity to column costs.

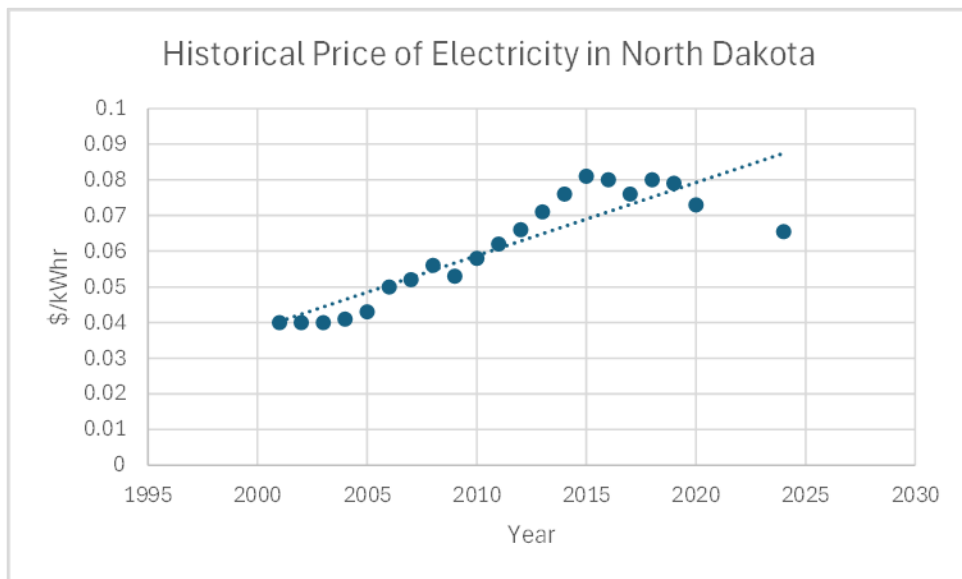


Figure 4. *North Dakota Industrial Trend Prices*

North Dakota Industrial User electrical trend prices were found by trend line pricing with the last 20 years trended.

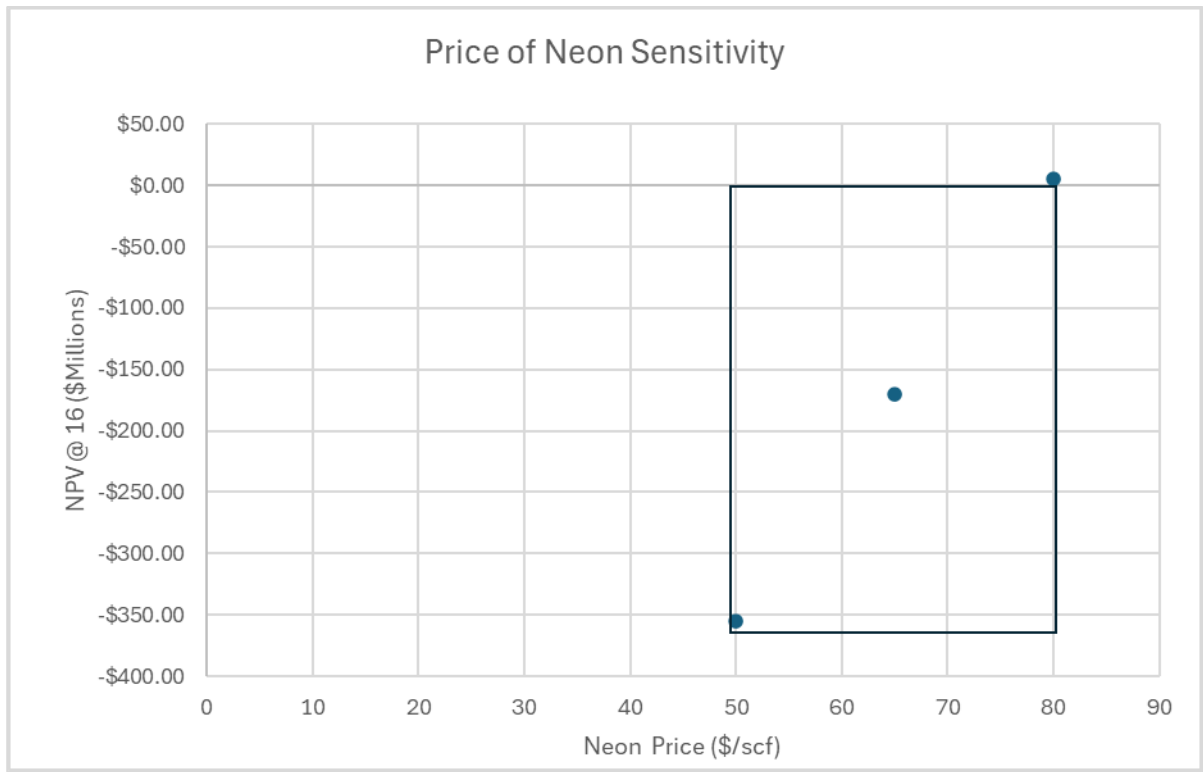


Figure 5. Sensitivity to Price of Neon

Neon is our only product in this recovery unit, so the price of neon will play a large factor in the NPV@16. This sensitivity shows that a decrease in the price of neon would result in a negative value for NPV@16. In fact, only a large shift to the outer limits of +/- 40% ends with a positive value. This means that the project is highly sensitive to the price of neon.



Figure 6. *Insensitivity to Annual Electricity Increases*

In this region of most probable uncertainty, the high electrical cost from trend pricing shows marginal decrease to NPV@16, and even smaller increases, as electrical costs tend to go up over time. This would indicate that this project is not sensitive to changes in electrical costs.

Appendix A: Proposal and Economics Sections for Fully Developed Alternative

Alternatives Analysis Report for the Scoping Study for a Major Retrofit Project to Produce Commercial Grade Neon from an Air Separation Plant.

Introduction

The purpose of this document is to present the results from analyzing an alternative process that would recover helium in addition to neon from a nitrogen rich stream originating from an air separation plant. This proposed alternative is designed around the modified Linde cycle process that produced crude a crude neon stream containing helium. This crude helium stream was designed to be the input stream to a pressure swing absorber system that uses an organic metal framework as an adsorbent to separate neon from helium. The scope of work is to recover helium to 99.998% purity. The potential was analyzed at the process sketch, process flow, proposal, and quantitative justification level. This report includes the present situation, background information on the method, a process sketch, Aspen Plus simulations, and an economic study.

Present Situation

Presently, the crude neon stream contains a potential of 1920 SCF/day of helium. We are not currently recovering the helium from that stream and would like to explore the potential profitability of recovering the helium.

Background

Helium is an inert gas that is used in many different applications, namely in the industrial, medical, and research sectors. There is currently a shortage of helium, therefore a scoping study into the viability of producing helium is being conducted. According to the US department of the interior, “while the United States has significant domestic helium-production capacity, recent geopolitical events may impact foreign production capacity.” meaning that the world supply of helium may be increasingly constrained and there may be a need for additional domestic suppliers to supply this valuable commodity. This instability could lead to increased sale prices and increased revenues for this facility in the future.

Proposal

We propose we collect helium after a cycle that cryogenically separates the lighter gases from the neon. This is done with a Linde cycle that liquifies the nitrogen and removes it through flash drums and a distillation tower. The remaining light gases are cooled to drop out the neon in a flash drum, and the helium is sent forward through a pressure swing adsorption unit. In this unit, Co₃(ndc)₃dabco metal organic framework, an experimental adsorbent for neon, will act as the adsorbent for neon. At the inlet conditions, this adsorbent has a neon adsorption equilibrium

isotherm (q) of 5 mol/kg). ⁷Crude neon will enter the adsorption vessel D-340 A at 5 bar and -246C and the tank will begin the adsorption process. The cycle time for the adsorbent to collect the neon into the Co₃(ndc)₃dabco metal organic framework is 10 minutes. This time ensures a high purity of helium at the outlet of 99.998%. Once adsorption has terminated, the pressure of the adsorption vessel D-340 A will drop from 5 bar to 1 bar, by opening the valve to the purge muffler, and the absorbed neon will desorb, and leave through the purge stream, effectively clearing the adsorbent of most of the neon, preparing it for subsequent use. Helium will then be separated at a high purity in the overhead of the adsorption vessel, by opening a valve at the overhead section of the adsorption vessel be transported to storage containment. During the desorption cycle of D-340 A, the flow of the inlet crude neon stream will be routed by opening the valve to D-340 B an identical adsorption vessel, and closing the valve to D-340 A. This allows for process efficiency by reducing downtime during the PSA operation. When D-340 A is undergoing adsorption, D-340 B will undergo desorption and vice versa. The helium outlet will then enter a E-344 shell and tube heat exchanger with 100 psi steam utility tube side. This will cause the helium to reach standard temperature, expanding the gas, and greatly increasing the volume of saleable products. The adsorbent has a life of 2 years under these conditions.

Qualitative Justification

A \$18,000,000 investment (Basis Date: April 2024) in this PSA system yields an NPV of approximately – 2.5 million over a 15-year project lifecycle, assuming a hurdle rate of 16%. Because the NPV is negative, this alternative is not a financially viable solution and presents significant risk as an investment. There are two main contributing factors to this negative NPV. The first is the inlet stream of crude neon, which represents approximately 1 kg/day, and the maximum potential of commercial grade helium is only 1920 SCF/day. The second crucial factor is the high temperature differential of –250C to 25C, leading to a high equipment cost for the heat exchanger E-344 A/B with an adjusted TLI of 11 million dollars.

To obtain volumetric flow rates, equipment sizing, and utility usage, the four streams were modeled in Aspen Plus V14. The Peng-Robinson method was selected as the thermodynamics package, as it is widely used for gas phase systems. Due to a lack of the adsorption software package, the pressure differential was modeled with a valve, with outlet pressure modeled at 1 bar, being atmospheric pressure that PSA units typically function at for the desorption stage. The crude neon stream was inputted as the overall inlet stream, and a shell and tube heat exchanger with steam at 100psi was modeled in order to raise the pressure. Below are the simulation results that were helpful in determining product volumetric flow rates of high purity helium. The process flow sketch for this process area is presented as drawing 04-A-013/6.

⁷ Author links open overlay panel Rui P.P.L. Ribeiro a 2, & Mounfield. (2020a, February 4). *Cryogenic Neon Adsorption on CO₃(NDC)₃(DABCO) metal-organic framework*. Microporous and Mesoporous Materials. <https://www.sciencedirect.com/science/article/pii/S1387181120300585>

Conclusion

The intention of this report on the alternative was to subsequently purify helium to 99.998% after the modified Linde cycle using the outlet crude helium stream. A process for purification of helium using a PSA system has been designed and the information documented. Because of the negative 2.5 million NPV over the project lifecycle, this process alternative is not capable of satisfying this economic opportunity.

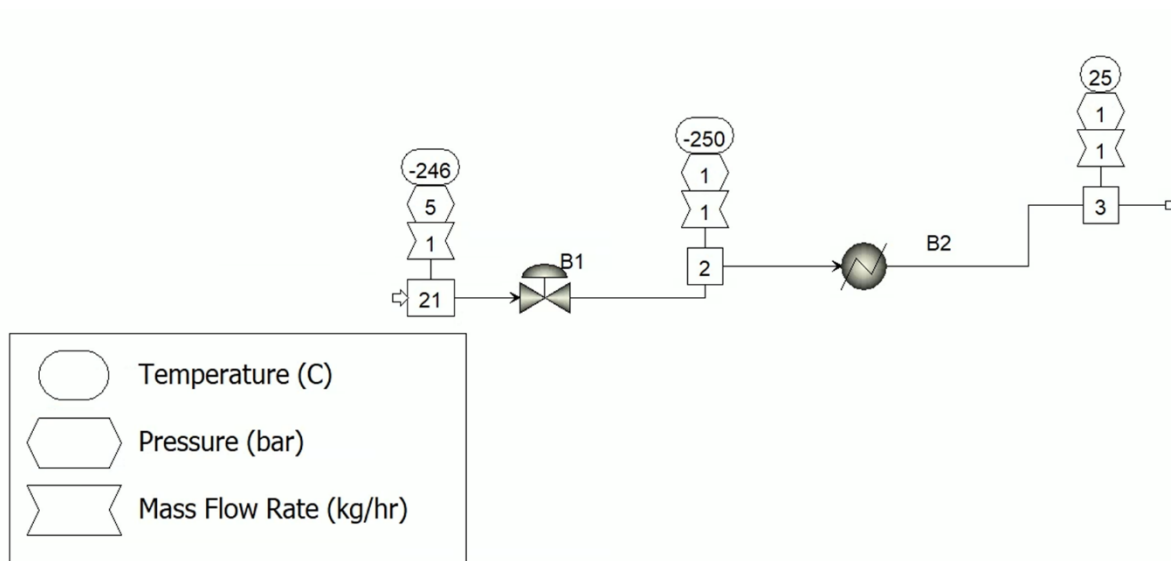


Figure 6. Aspen Plus V14 Main Flowsheet for basic Pressure Swing Absorption unit undergoing desorption process.

Total Capital Cost [USD]	1,120,640
Total Operating Cost [USD/Year]	954,339
Total Raw Materials Cost [USD/Year]	0
Total Product Sales [USD/Year]	0
Total Utilities Cost [USD/Year]	39,919.8

Figure 7. Aspen Plus V14 100 psi steam utility cost, and E-344 equipment cost.

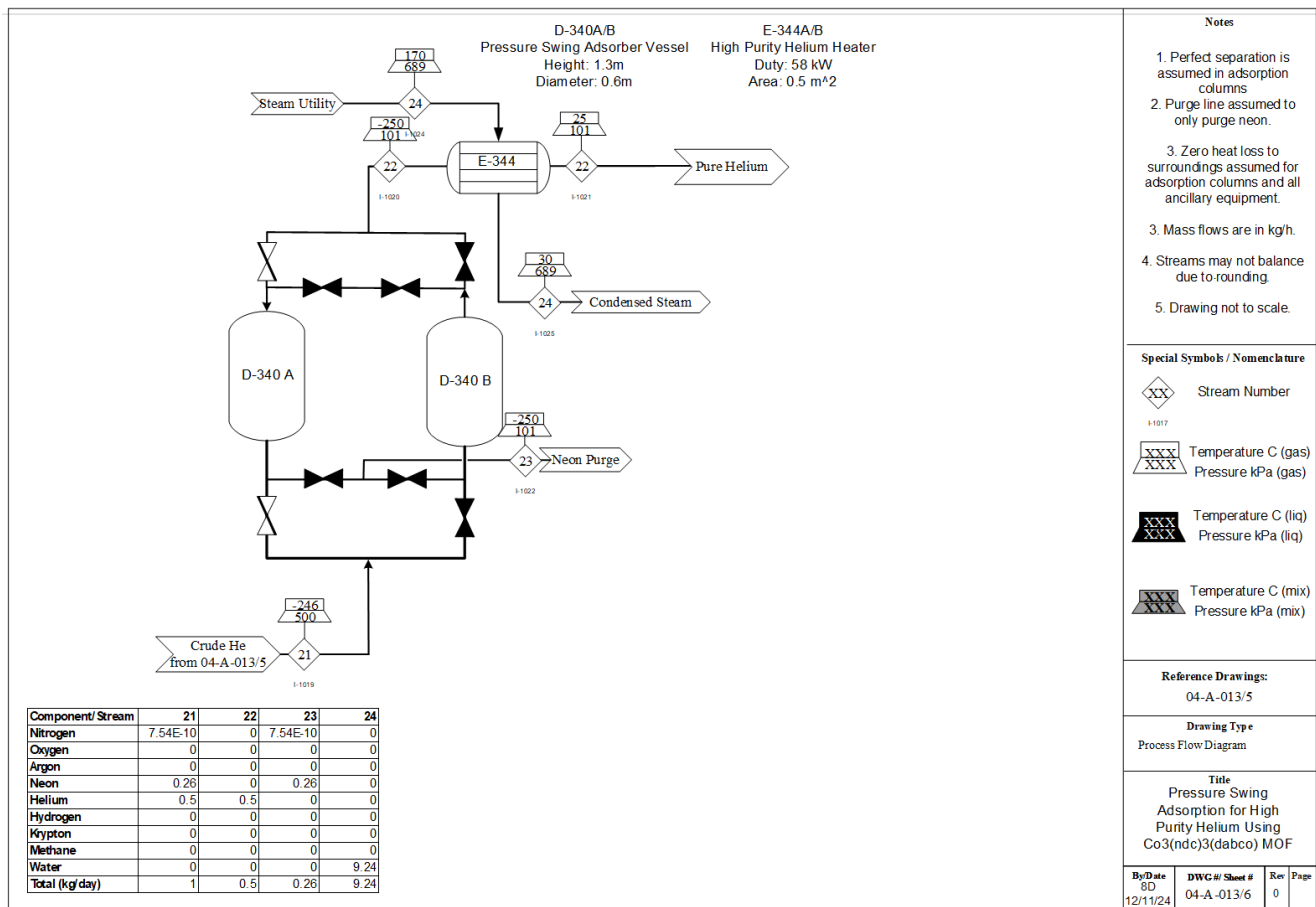


Figure 8. PFD of PSA system with Co₃(ndc)₃dabco MOF as adsorbent to purify Helium to 99.998 %.

Table 4.12 Capital Costs Estimate Worksheet: Major Retrofit Projects

	Unadjusted Unit Equip Supplier Cost	Basis Date Adjustment Index (if required): eqn. 4.2	Mats of Const Adjustment Factor (if required): eqn 4.3	Pressure Adjustment Factor (if required): eqn 4.4	Adjusted Basis Date Unit Equip Cost	Number of units	Line Item Equip Cost	Estimating Factor, Fr (Table 4.10)	Total Line Item (TLI) Cost (eqn. 4.5)	
Major Equipment Item w/ key specifications										
High Purity Helium Heat Exchanger	1	1	1.5	1	2	2	3	3.2	11	
Pressure Swing Adsorber Vessel	0.003	1	1.5	1	0.005	2	0.009	4.4	0.04	
Basis Date										
Apr-24						Total Direct Process Cost (TDPC= $\sum$ TLI)				\$11
						Additional Direct Costs (ADC, Table 4.3)				\$3
						Total Direct Costs (TDC=TDPC+ADC)				\$14
						Indirect Costs (IDC= 0.3*TDC)				\$4
						Fixed Capital Investment (FCI=TDC+IDC)				\$18
						Initial Charge of Chemicals & Catalysts (CC)				\$30
						Total Capital Investment (TCI=FCI+CC)				\$48

Figure 9: Capital Cost Estimate Worksheet for alternative.

Table 5.5 Operating Costs Estimate Worksheet

A. Time Since Project Commissioning (Months or Years)	B. Operating Labor	C. Maintenance	D. Utilities	E. Chemicals & Catalysts	F. Other Taxes	G. Operating Mats and Lab Charges	H. Other Direct Costs	I. Total Manufacturing Costs (sum of B - H)	J. Raw Materials	K. Total Direct Operating Costs (sum of I and J)	L. Indirect Costs	M. Total Operating Costs (sum of K and L)
1	\$129,402	\$547,335	39919.8	12.6	0	\$25,880	0	\$742,537	0	\$742,537	\$259,892	\$1,002,442
2	\$129,402	\$547,335	39919.8		0	\$25,880	0	\$742,537	0	\$742,537	\$259,888	\$1,002,425
3	\$129,402	\$547,335	39919.8	12.6	0	\$25,880	0	\$742,537	0	\$742,537	\$259,892	\$1,002,442
4	\$129,402	\$547,335	39919.8		0	\$25,880	0	\$742,537	0	\$742,537	\$259,888	\$1,002,425
5	\$129,402	\$547,335	39919.8	12.6	0	\$25,880	0	\$742,537	0	\$742,537	\$259,892	\$1,002,442
6	\$129,402	\$547,335	39919.8		0	\$25,880	0	\$742,537	0	\$742,537	\$259,888	\$1,002,425
7	\$129,402	\$547,335	39919.8	12.6	0	\$25,880	0	\$742,537	0	\$742,537	\$259,892	\$1,002,442
8	\$129,402	\$547,335	39919.8		0	\$25,880	0	\$742,537	0	\$742,537	\$259,888	\$1,002,425
9	\$129,402	\$547,335	39919.8	12.6	0	\$25,880	0	\$742,537	0	\$742,537	\$259,892	\$1,002,442
10	\$129,402	\$547,335	39919.8		0	\$25,880	0	\$742,537	0	\$742,537	\$259,888	\$1,002,425
11	\$129,402	\$547,335	39919.8	12.6	0	\$25,880	0	\$742,537	0	\$742,537	\$259,892	\$1,002,442
12	\$129,402	\$547,335	39919.8		0	\$25,880	0	\$742,537	0	\$742,537	\$259,888	\$1,002,425
Basis Date April 2024												

Figure 10: Operating Cost Estimate Worksheet for alternative.

ECONOMIC CASH FLOW SHEET

Project Title:

Estimate Performed By:

Group 8D

Year	Revenues	Operating Costs	Gross Profit	Depreciation	Overall Taxable Profit	Federal Income Tax	State Taxable Profit	State Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR	
-4	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0				
-3	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0				
-2	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0				
-1	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0				
0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	-\$18,244,496	-\$18,244,496	-\$18,244,496	
1	\$4,555,200	\$ (1,002,425.07)	\$3,552,775	\$(5,212,713.26)	-\$1,659,938	\$ -	-\$1,659,938	\$ -		\$3,552,775	\$3,062,737	
2	\$4,555,200	\$ (1,002,442.08)	\$3,552,758	\$(3,723,366.61)	-\$170,609	\$ -	-\$170,609	\$ -		\$3,552,758	\$2,640,278	
3	\$4,555,200	\$ (1,002,425.07)	\$3,552,775	\$(2,659,547.58)	\$893,227	\$ (187,577.74)	\$893,227	\$ -		\$3,365,197	\$2,155,939	
4	\$4,555,200	\$ (1,002,442.08)	\$3,552,758	\$(1,899,676.84)	\$1,653,081	\$ (347,147.03)	\$1,653,081	\$ -		\$3,205,611	\$1,770,430	
5	\$4,555,200	\$ (1,002,425.07)	\$3,552,775	\$(1,583,064.04)	\$1,969,711	\$ (413,639.29)	\$1,969,711	\$ -		\$3,139,136	\$1,494,583	
6	\$4,555,200	\$ (1,002,442.08)	\$3,552,758	\$(1,583,064.04)	\$1,969,694	\$ (413,635.71)	\$1,969,694	\$ -		\$3,139,122	\$1,288,428	
7	\$4,555,200	\$ (1,002,425.07)	\$3,552,775	\$(1,583,064.04)	\$1,969,711	\$ (413,639.29)	\$1,969,711	\$ -		\$3,139,136	\$1,110,719	
8	\$4,555,200	\$ (1,002,442.08)	\$3,552,758	\$ -	\$3,552,758	\$ (746,079.16)	\$3,552,758	\$ -		\$2,806,679	\$856,108	
9	\$4,555,200	\$ (1,002,425.07)	\$3,552,775	\$ -	\$3,552,775	\$ (746,082.73)	\$3,552,775	\$ -		\$2,806,692	\$738,028	
10	\$4,555,200	\$ (1,002,442.08)	\$3,552,758	\$ -	\$3,552,758	\$ (746,079.16)	\$3,552,758	\$ -		\$2,806,679	\$636,228	
Date Date for Estimate =						HR =		NPV@HR = \$				(2,491,017)
Apr-24						16%		DCFRR =				

Figure 11: Economic Cash Flow Sheet for alternative.

Appendix B: Intermediate Results

Aspen I/O

Stage	N2	NEON	HELIUM
1	0.99	0.010	8.17E-07
2	1.00	5.37E-05	1.17E-09
3	1.00	5.25E-07	6.91E-10
4	1.00	2.34E-07	6.90E-10
5	1.00	2.32E-07	6.90E-10
6	1.00	2.32E-07	6.90E-10
7	1.00	2.32E-07	6.90E-10
8	1.00	2.32E-07	6.90E-10
9	1.00	2.32E-07	6.90E-10
10	1.00	2.32E-07	6.90E-10
11	1.00	2.32E-07	6.90E-10
12	1.00	2.32E-07	6.90E-10
13	1.00	2.32E-07	6.90E-10
14	1.00	2.32E-07	6.90E-10
15	1.00	2.32E-07	6.90E-10
16	1.00	2.32E-07	6.90E-10
17	1.00	2.32E-07	6.90E-10
18	1.00	2.32E-07	6.90E-10
19	1.00	2.32E-07	6.90E-10
20	1.00	2.32E-07	6.90E-10

Figure 7. Stripping Column Composition Profile, Mass Fraction

Appendix C: Sample Calculations

Equipment Sizing Sample Calculations

Heat Exchanger Sizing

In order to calculate the size of the initial cross exchangers for the modified Linde Cycle, the area of the heat exchangers was calculated using the equations below. U was provided by Aspen Plus V14. These heat exchangers used cooling water as a utility, and the minimum approach temperature was assumed to be 5C.

$$Q = MCp\Delta T = AU\Delta T_{lm}$$

Where: ΔT_{lm} Log mean temperature difference

A Heat exchanger area (m^2)

U Heat exchanger coefficient ($J/m^2 \cdot s \cdot K$)

Q Heat duty of process fluid (W)

M Molar flow of a smaller duty stream $J/mol \cdot K$

Cp Heat capacity of smaller duty stream ($J/mol \cdot K$)

ΔT Temperature change to bp (K)

Below is an example of a sample calculation for E-101 High Purity Nitrogen Cooler:

$$\Delta T_{lm} = \frac{(T_{shell\ in} - T_{utility\ out}) - (T_{shell\ out} - T_{utility\ in})}{\ln \frac{(T_{shell\ in} - T_{utility\ out})}{(T_{shell\ out} - T_{utility\ in})}} \quad \Delta T_{lm} = \frac{(20C - 30C) - (25C - 173C)}{\ln \frac{(20C - 30C)}{(25C - 173C)}}$$

$$\Delta T_{lm} = 51.2$$

$$A = \frac{22876348W}{51.21 \cdot 322 \frac{J}{m^2 \cdot s \cdot K}} = 1386m^2$$

Sample Calculations of Economic Estimates

FCI

Fixed Capital Investment (FCI) was calculated as the Σ of TDPC and IDC:

$$\begin{aligned} TLI &= UMC * Shipping * Direct Cost Factor (DCF) \\ TDPC &= \Sigma TLI \\ IDC &= 0.5 * TDPC \\ FCI &= TDPC + IDC \end{aligned}$$

Where:

- UMC Unit Material Cost (December 2023)
- Shipping 3% of Supplier Cost (SC)⁸
- DCF Adjustment factors for Materials of Construction, Stainless/Carbon Steel⁹

The following example was utilized in the helium recovery alternative:

Total Direct Process Cost (TDPC= Σ TLI)	378,215,000
Additional Direct Costs (ADC, Table 4.3)	113,464,500
Total Direct Costs (TDC=TDPC+ADC)	491,679,500
Indirect Costs (IDC= 0.3*TDC)	147,503,850
Fixed Capital Investment (FCI=TDC+IDC)	639,183,350
Initial Charge of Chemicals & Catalysts (CC)	0
Total Capital Investment (TCI=FCI+CC)	639,183,350

⁸ Seames, W. (2023). *Designing Controls for the Process Industries* (Chapter 4.3.1). Routledge.

⁹ Seames, W. (2023). *Designing Controls for the Process Industries* (Table 4.6). Routledge.

Depreciation

The depreciation for this retrofit was determined using the Modified Accelerated Cost Recovery System (MACRS). The fixed capital investment (FCI) was depreciated over a seven-year period. The first half of the duration was depreciated using the double-declined balance (DDB) method, and the final duration was calculated using a straight-line (SL) method.

Double Declining Balance Method

The DDB method uses the following formula:

$$ddbi = (2/N) * \text{Book Value}_{i-1}$$

Where:

- $N = 7$, the total depreciation duration in years.
- Book Value_{i-1} is the remaining value of the asset at the beginning of year i .

The annual depreciation values for the DDB method were calculated iteratively until switching to the SL method in years 5-7.

Straight Line Method:

Once the remaining book value reached a point where the annual depreciation under the DDB method was smaller than the SL method, the remaining depreciation was calculated using the SL method:

$$SL_i = (\text{cost basis} - \text{salvage value})/n$$

Appendix D: Assumptions List

1. All pump/motor sets are assumed to have an overall efficiency of 70%.
2. Aspen simulation equipment pricing quotes were used where available.
3. Costs were estimated based on the course textbook for utilities where data was unavailable.
4. All compressor/motor sets should be assumed to have a polytropic efficiency of 75%.
5. Any equipment/piping operating below -40°F were sized with MOC of aluminum.
6. The trend prices at a basis date of December 2023 for the evaluated by-products for the process are \$6.50/SCF (SCF = standard cubic foot) helium and \$65/SCF neon. Any neon and/or helium removed from the nitrogen product stream should be valued at a raw material price of \$0.0085/SCF.
7. A hurdle rate of 16% and a basis date of April 2024 was used.
8. The price of electricity was assumed to be \$0.0655/kWh.¹⁰
9. The lifetime of the project is 10 years.
10. An operating factor of 95% was assumed for the duration of the project.
11. Federal corporate tax rate of 21% and a North Dakota State Tax of 4.31%.¹¹

¹⁰ YCharts. (n.d.). *North Dakota electric utility industrial retail price* (I:NDEUIRP). Retrieved October 18, 2023, from https://ycharts.com/indicators/north_dakota_electric_utility_industrial_retail_price

¹¹ Tax Foundation. (n.d.). *Taxes in North Dakota*. Retrieved October 25, 2024, from <https://taxfoundation.org/location/north-dakota/>

Appendix E: Vendor Quotations and Documentation

EMAIL CONVERSATION RECORD

ORIGINATOR: Avery Frith

RECEIVER: Ben

EMAIL: avery.frith@und.edu

EMAIL:sales@tankpv.com

COMPANY: University of North Dakota

COMPANY: Zhejiang Tank Pressure Vessel
Co., Ltd.

DATE OF CONTACT: 12/11/23

TIME OF CONTACT: 8:32 4:02 pm

REASON FOR THE CONTACT:

Adsorption Pressure Vessel Quote

>The following email was sent as a request for a quote for an adsorption pressure vessel, to be used in the PSA alternative process: Looking for a budgetary estimate on a pressure vessel with a volume of 14 m³, 500kpa, and -246 °C, with aluminium construction.

<Ben responded:

Aluminum is beyond our capability. We are good at stainless steel. Sorry.

>I followed up: Stainless steel is fine. Could I get a quick estimate on this equipment?

<Ben responded:

Price is \$3200 for one unit

>I followed up:

Could you let me know a quick estimate on the lead time?

<Ben responded:

The delivery time depends on the quantity you order, usually around 2 months.