CARBON CAPTURE, UTILIZATION & STORAGE

WHITE PAPER

CARBON CAPTURE EVALUATION:

POST-COMBUSTION COMPRESSOR EXHAUST

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SUMMARY

CANUSA EPC has prepared the following analysis related to the feasibility of carbon capture from the exhaust streams of natural gas driven compressors at a compressor station located in North America. This analysis is based on CANUSA EPC's experience with carbon capture technologies, applying those existing technologies to exhaust gas from post-combustion processes, and leveraging our project expertise with compressor stations.

The basis of the analysis considered 27 metric tons per day (MTPD) from a single engine unit, 189 MTPD from seven (7) units, and 300 MTPD with an exhaust stream of 5.59 mol % CO2. Available technologies allow for a recovery of 90 mol % CO2 and a purity of 98 mol % CO2. The findings of the white paper identify the normalized value of CO2 for the various flow rates to develop the economics of these projects.

HIGHLIGHTS

- Summary of the process
- Major equipment
- Project economics

PROCESSING OPTIONS

- Amine Solvent - Conventional
- Amine Solvent - Proprietary
- Temperature Swing Adsorption (TSA)

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Analysis Basis

Capturing G3608 exhaust with amine technology

CANUSA EPC evaluated the feasibility of capturing CO_2 from the operations at a compressor station and providing that CO_2 at pipeline or sequestration quality. The main source of the operation considered is the exhaust gas from the Caterpillar G3608 engines. Each exhaust stream contains 27 Metric Tons Per Day (MTPD) for a total of 189 MTPD of CO_2 if all seven (7) compressor engine exhausts are considered. This exhaust stream is a 5.59 mol % of CO_2 on a wet basis, which is in line with combustion exhausts utilized on our previous CO_2 capture projects. This gas analysis has been confirmed with the engine manufacturer.

CANUSA EPC has provided process summaries of the technologies required to pre-condition and pre-treat the exhaust gas so that CO_2 can be captured and provided at pipeline or sequestration quality. When considering CO_2 capture projects, CapEx, OpEx, and overall emissions reductions from the project should be considered to determine feasibility of the project and its ability to meet the goals of your organization.

There are three processing approaches that can be evaluated specific to a compressor station to provide this detail. The metrics presented in the economics are based on traditional solvent technologies.

Three Processing Approaches for Evaluation

Amine Solvent: Conventional

Amine plants using conventional solvents such as Monoethanolamine (MEA) are the traditional approach to capturing CO_2. This technology is deployed in existing applications to remove CO_2 as a waste stream from process gas. Standard process packages are readily available on the market and consist of an absorber and desorber along with auxiliary equipment.

Amine Solvent: Proprietary

Amine plants using proprietary solvents are specially formulated for capturing CO_2. They have the ability to reduce energy consumption of the CO_2 capture plant which in turn reduces CO_2 emissions and operational costs. They are also used when high CO_2 recovery is required. These solvents are utilized in standard and custom process packages but are higher in capital expenditure.

Temperature Swing Adsorption (TSA)

TSA is a new efficient technology for capturing CO_2. This proprietary process is a rapid cycle system that uses advanced structured adsorbents. It is completed in three (3) steps as adsorption, regeneration and conditioning.

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Economic Summary

From CANUSA EPC's experience on projects, we believe that a system capable of 27 MTPD removal will need to value CO2 at $307 USD of present value per metric ton for a 5-year payback. This aligns with roughly one (1) single compressor exhaust.

If the system were scaled to handle seven (7) engines, which equates to 189 MTPD of CO2 removal, the 5-year payback value of CO2 would be reduced significantly to $164 USD of present value per metric ton.

A comparison case was also evaluated for a system that can remove 300 MTPD of CO2 from compression or a similar application. The 5-year payback period results in the value of CO2 of $160 USD of present value per metric ton.

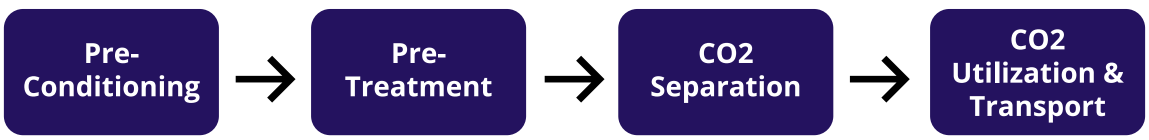
The economic model utilized was based on a Net Present Value (NPV) of 10% for cash over a five-year period. This model incorporated the CapEx and OpEx associated with the construction and operations of the CO2 facility on an existing compressor site. The accuracy of the estimate for the budgets of each basis is that of a Class V estimate. Costs for the sequestration well system or pipeline are not considered in this analysis.

> **When considering CO2 capture projects, the value of CO2 will determine the economic feasibility of the project. Current markets are taking two approaches to the value of CO2; one as a revenue generation stream if the CO2 is geologically sequestered and meets minimum requirements of CO2 reduction for the facility, a purity quality of the sequestered gas, and complies with verification of long term storage. Other markets are developing where regulations are placing a cap on the CO2 emissions permissible and penalizing the emission source for exceeding the limits. In both cases, the future value of CO2 is unknown, but expected to increase.**

Processing Requirements

Based on CANUSA EPC's experience with CO2 capture, the exhaust gas will require processing to facilitate the separation and then handling for pipeline or sequestration quality.

CARBON CAPTURE PROCESS



On the subsequent pages, we will address key considerations for each stage of the carbon capture process.

1 Pre-Conditioning

Cooling then transfer of the exhaust gas

Pre-Conditioning → Pre-Treatment → CO2 Separation → CO2 Utilization & Transport

CONSIDERATIONS

- **Low pressure & high flow application**
  Exhaust gas will be at atmospheric pressure.
- **Engine specifications for design basis**
  Rich or lean burn engines will have different gas profiles for exhaust. What type of engine are you running at your site?
- **Elevated temperatures & cooling requirements**
  Temperature is important to meet process package specifications.
- **Equipment area & location**
  Pipe and structural steel costs can be minimized based on the existing site layout. Does the layout of the facility allow for reduced cost of installation?

Stage Summary

The G3608 engine exhaust will need to flow through the CO_2 capture plant while ensuring the back pressure on the engine is kept to a minimum and that the temperatures are within the allowable for the downstream equipment. The exhaust stream operates at elevated temperatures and will be water saturated. Once cooled, liquid drop-out will occur and require storage.

Major Equipment

Standard process packages include a cooler, scrubber and blower. Blower sizing and cooling in the form of waste heat recovery have been considered for a single compressor and all seven (7) compressors. Both packages greatly affect the capital and operating cost of the carbon capture package.

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Pre-Treatment

Preparation to facilitate CO2 capture

Pre-Conditioning → **Pre-Treatment** → CO2 Separation → CO2 Utilization & Transport

CONSIDERATIONS

- **Tower designed with packing internals**
  Total contact surface area can exceed typical tower dimensions.
- **Caustic scrubbing to remove NOx & SOx**
  Does the exhaust profile require additional pre-treatment?
- **Liquid handling & storage**
  What is the disposal and recycle plan for the water?
- **Water wash sections design aligned with operations**
  Automation and turn down controls need to be reviewed.

Stage Summary

The stream temperature will need to be further cooled for optimal contact and CO2 separation. This is achieved using water with either a cooling tower or an aerial cooler depending on the site's existing infrastructure. Liquid storage will be required due to the excessive amount of water condensation. Caustic can also be added to the Direct Contact Cooler (DCC) to remove NOx and other impurities at this stage.

Major Equipment

The DCC is the main processing unit and can be either packaged along with the auxiliary equipment as a standard process or stand-alone for installation on site with additional interconnects.
Auxiliary equipment required include pumps, heat exchangers, storage tanks and coolers.

3 CO2 Separation

Extracting CO2 with liquid solvents or adsorbent beds

Pre-Conditioning → Pre-Treatment → **CO2 Separation** → CO2 Utilization & Transport

CONSIDERATIONS

- **Regenerative process**
  Amines and adsorbents can be reused.
- **Reduce re-boiler duty and CO2 emissions**
  Are you including the re-boiler emissions in your overall CO2 reduction basis?
- **Leverage existing operations experience with amines**
  Does your operations team have a preference for technology?
- **Customized process packages**
  Will a proprietary design allow for future changes?

Stage Summary

CO2 separation is completed at atmospheric pressure and packaged as a process module. The feed stream passes through a contactor where CO2 extraction takes place. The lean feed stream is vented to the atmosphere while the CO2 rich stream undergoes regeneration and uses heat to release the CO2. Cooling is then required to condense the water vapor and produce a high purity stream of CO2. Purification along with cooling is also required to condition the contactor in adsorber applications.

Major Equipment

Technologies include amine solvent (conventional or proprietary) and TSA. These are proven to work and can provide a recovery of 90 mol % CO2 and a purity of 98 mol % CO2. Technology selection will be impacted by the overall performance, consideration for existing site infrastructure, and the client's comfort with proprietary equipment.

4

CO2 Utilization & Transport

Pressurization of CO2 for transport or sequestration

Pre-Conditioning → Pre-Treatment → CO2 Separation → **CO2 Utilization & Transport**

CONSIDERATIONS

- **Pipeline or injection specifications**
  Depending on the delivery point of the CO2, some specifications could be more stringent. What does the custody transfer require?
- **Electric or engine driven compression**
  Greatly affects the overall emissions of the entire site. Are existing utilities sufficient for more compression?
- **Supercritical and high flow application**
  Do you require variable control of the delivery pressure?
- **Materials of construction**
  Stainless steel or carbon steel with corrosion resistance should both be considered to reduce CapEx.

Stage Summary

For this review, we included costs for compression, dehydration, and a metered sales point to transport the CO2 for pipeline or sequestration. Both scenarios will need to meet their delivery specifications which can include oxygen limitations, water content, and minimum pressures. It is expected that sequestration will occur onsite or offsite from the compressor station.

Major Equipment

The options to consider for compressor selection include reciprocating or Integrally Geared Centrifugal (IGCC). Standard process packages for dehydration and metering are available. The custody transfer requirements must be considered when selecting the materials of construction for the pipeline. Final stage compression and transportation can also be achieved with pumps.

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Utilities & Site Considerations

MAJOR NEEDS

- Heating
- Cooling
- Fuel Gas
- Power

MINOR NEEDS

- Vent
- Drain
- Instrument Air

The CO_2 capture plant will require an auxiliary heating and cooling system.

OPTIONS TO CONSIDER:

- Waste heat recovery
- Liquids such as water and glycol
- Use of immersion heaters to reduce the load on firetube burners and decrease additional CO_2 sources introduced from the CO_2 capture plant
- Steam boiler and generation

Analysis of Existing Site & Facility

The addition of a CO_2 capture plant will require you to utilize existing facility space and utility systems. These types of plants are situated in Class 1, Zone 2, or general purpose environments.

KEY CONSIDERATIONS:

- Do the existing site utilities drive a technology selection?
- Is the site designed for future carbon capture equipment?
- Can heat and utilities within the facility be used to reduce the operational footprint?

CONNECT

To gain clarity on your specific site requirements, connect with CANUSA EPC to discuss what options are best for you to leverage.

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Project Economics

Three key factors will affect the financial success of any carbon capture project:

Price of CO2

This is a critical factor as it directly affects the revenue potential or cost savings of the project. The higher the market price or value attributed to captured CO2, whether through carbon credits, taxes, or utilization opportunities, the more economically attractive the project becomes.

Amount of Net CO2 Captured

Higher capture rates translate to more CO2 being processed and potentially sold or stored, impacting the project's profitability. The net amount of CO2 captured, after accounting for the CO2 emissions generated by the capture process itself, is a crucial metric.

Existing Infrastructure

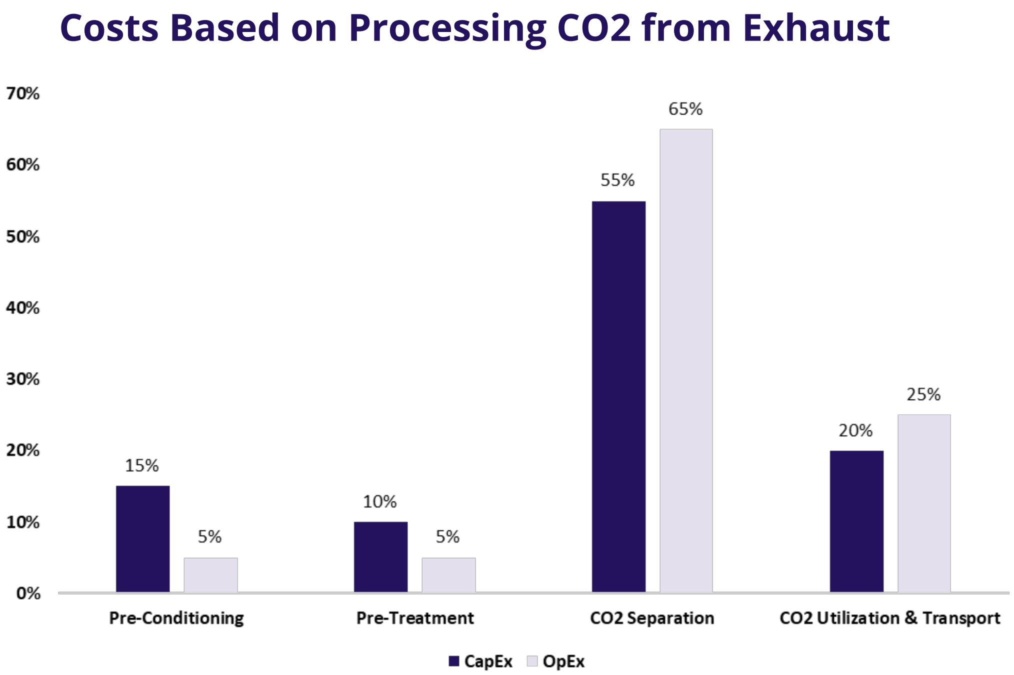
The availability and condition of existing infrastructure can significantly impact the initial investment and ongoing operational costs. Utilizing or adapting current facilities can reduce costs compared to building new infrastructure. Additionally, the proximity of the capture site to storage or utilization facilities influences transportation costs and logistical complexities.

Lower the cost impact by leveraging the compressor station infrastructure

- Locate compressor stations near permitted rights of way for CO2 transport or sequestration sites
- Additional volumes of carbon capture are readily available to provide economies of scale
- Excessive water condensation can be sent to disposal
- Power, instrument air, and fuel gas are available and in abundance
- Produced water can be used for cooling via DCC
- Waste heat recovery using glycol heat trace in the winter can decrease the emissions from the line heater

Lowering the Cost of CO2 Capture

Technology developments may drive project adoption



Lower Capital & Operating Costs Related to Capture Technology

Based on the pricing analysis above, 55% of the cost of the facility project is comprised of the separation process. Other than the pricing levels increasing above inflationary rates, technology developments for the capture of CO_2 could drive economic feasibility. So, what are the promising technologies that could provide a lower CapEx and OpEx for this application?

Membranes

Membranes for CO_2 separation could lead to a relatively pure product but will have a lower overall reduction capacity based on the efficiency that these can handle with partial pressure.

High-Efficiency Regeneration of Amines

Selective amine chemicals and energy-efficient designs are on the market and as these are proven, some winners will emerge into commercial scale units that are readily available.

Metal Organic Framework

TSA technology is developing in pilot plant applications where adsorbents on a packing could capture, and release carbon using less energy than amines and occur in a smaller footprint.

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Market Analysis

Project viability across North America

The cost to capture CO2 from the exhaust gas and compress it for transportation or sequestration is on the order of $164 USD per metric ton based on the economic model from this analysis. Backing out the percentage of the cost related to compression and dehydration, roughly 20% as indicated above, we have found that $131 USD per metric ton is reasonable to estimate for the capture of the carbon from exhaust gas. This number aligns with IEA findings for power generation capture [1].

In the Canadian market, carbon is regulated and from 2023 to 2030, the price will increase from $50 CAD per metric ton ($38 USD) to $155 CAD per metric ton ($116 USD) by 2030, as indicated by the Canadian Federal Government Regulation [2]. Pricing through regulation alone won't support these projects in Canada.

In the US, current federal compensation for CO2 sequestration is at $80 USD per metric ton, there is still limited support for these projects. There are discussions in Congress to consider carbon pricing mechanisms, but until those are law, many operators will wait until they are required to capture the carbon from compression [3].

So, is $164 USD per metric ton the magic number? Not quite. What is missing from the total cost is the end location of this carbon. Pipeline fees or sequestration facility development costs will need to be included and can be shared across many projects.

In the current market for North America, this is still not a feasible project on economics alone; pricing carbon at $80 USD per metric ton in the US or $65 CAD per metric ton in Canada's regulated market.

So, *when will* future pricing make these projects economical?

Charting the course

As industrial operators evaluate new opportunities in the CO2 space, the capture of exhaust from large concentrations of engine units is an area of focus. In the current market, there is not a commercially deployed technology that can support the economics of the current CO2 value chain. We don't see these projects as viable in the short to medium term until the pricing value for CO2 approaches $160 USD per metric ton or technology lowers the cost for separation. The first compressor engine exhaust capture projects will develop near planned CO2 infrastructure, and compressor sites with multiple units will provide scalability for the project. Separation technology accounts for 55% of the cost of the project and new technology developments will need to lower the cost per metric ton of carbon when separating CO2 from exhaust streams. Designing sites with future carbon capture projects in mind will be important to provide the largest net reduction, lower capital requirement, and economical integration into the facility.

WHITE PAPER REFERENCES:

1. https://www.iea.org/commentaries/is-carbon-capture-too-expensive
2. https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/carbon-pollution-pricing-federal-benchmark-information.html
3. https://www.congress.gov/bill/117th-congress/house-bill/2307#:~:text=Introduced%20in%20House%20(04%2F01%2F2021)&text=This%20bill%20imposes%20a%20fee,greenhouse%20gases%20into%20the%20atmosphere

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Connect with us to discuss your project and request a complimentary Class V estimate.

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