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The Impact of CCUS Infrastructure on the Levelized Cost of Electricity (LCOE) at Cascade

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Summary

Based on Canada's Paris Agreement obligation and net-zero ambition by 2050, Carbon Capture, Utilization and Storage (CCUS) can be an important technology to achieve greenhouse gas (GHG) emission reduction goals. CCUS extracts CO_2 from an emission source for utilization and permanent storage, reducing the amount of anthropogenic CO_2 entering the atmosphere. Alberta's current baseload generation is amongst some of the most carbon-intensive in Canada. Intermittent sources of renewable energy like wind and solar may not entirely satisfy Alberta's baseload electricity demand in the near and distant future. Thus, as a province rich in fossil-based resources, natural gas will be used in electricity generation for the foreseeable future. Since combustion of natural gas results in CO_2 emissions, CCUS implementation can reduce the volume of CO_2 entering the atmosphere, helping Canada meet emission reduction goals.

This study evaluates the economic and technical feasibility of implementing carbon capture technology to Cascade, a 900 MW natural gas combined cycle (NGCC) power plant on Treaty 6 lands in Alberta scheduled to be in operation by 2023. Implementing CCUS to Cascade would impact its investment partners as well, one of which is Indigenous Communities Syndicate (ICS) comprising of six neighboring communities. The most significant barrier is the high cost associated with carbon capture technology. The levelized cost of electricity (LCOE) with and without carbon capture is calculated and presented. The model does not take into account potential revenue streams associated with CCUS such as selling to enhanced oil recovery (EOR) customers or other industrial processes. The LCOE modelling illustrates that at low carbon pricing ($40/tonne$_{CO2e}$ in 2021), CCUS implementation adds approximately $0.025/kwh and therefore hurts the competitiveness of Cascade in Alberta's deregulated electricity market. As carbon pricing increases to $105/tonne$_{CO2e}$ or more, the LCOE model demonstrates that it is beneficial to implement CCUS at Cascade.

Theory / Method / Workflow

This study evaluates the economic and regulatory feasibility of implementing carbon capture technology to Cascade, a 900 MW natural gas combined cycle (NGCC) power plant in Alberta scheduled to be in operation by 2023. The most significant barrier is the high cost associated with carbon capture technology.

The levelized cost of electricity (LCOE) with and without carbon capture is calculated and presented; this will illustrate how current and future carbon management policy, such as carbon pricing, may impact Cascade and investors which include neighboring Indigenous communities.

We assumed that CO_2 is captured and compressed near Cascade, then transported and stored in nearby geological formations. The costs reported in Table 1 are based on literature for CCUS components of NGCC power plants: post-combustion capture, transportation, and storage (Rubin *et al.*, 2015; Schmelz *et al.*, 2020; Rubin & Zhai, 2012; IEAGHG, 2012; USDOE, 2011; USDOE, 2013). The cost of transportation is for a pipeline with a capacity of 10 Mt/year and a length of 250 km. Table 1 illustrates that capture infrastructure is the most expensive component of CCUS and is regarded as one of the most important factors limiting CCUS growth (Irlam, 2017).

Table 1. Cost of CCUS components.

	Cost (US \$/ tCO_2)	Minimum cost (US \$/ tCO_2)	Maximum cost (US \$/ tCO_2)
Post-combustion capture	76	49	114
Transportation	3.05	2.3	3.8
Storage (saline aquafers)	6	3	15
Storage (oil and gas reservoirs)	5	1	13

Carbon pricing or a tax on greenhouse gas emissions is the easiest to implement for GHG emissions reduction strategy, which establishes markets for low-carbon technologies such as CCS. Figure 1 shows the effect of a Carbon tax on LCOE as a function of the added cost of a CO_2 emissions tax (or carbon price) for the NGCC plants with and without CCS. It is assumed that the emissions are reduced from 353 kg of CO_2/MWh to 42 pre- and post-CCS addition. The breakeven carbon price, at which the LCOE of both plants is the same, is about \$105/tCO_2e. For a CO_2 price or tax above this value, the natural gas plant with 90% CO_2 capture has a lower LCOE than the uncontrolled plant, thus making CCS economically attractive. At lower carbon prices the NGCC plant without CCS is more economical. Considering the effect of uncertainties in the natural gas price, financing rate, plant capacity factor and other factors the two cost lines shown in Figure 1 would shift upward or downward, and the resulting intersection or breakeven price would thus also vary. This means that a specific carbon price or tax that is intended to stimulate the use of CCS may or may not be currently adequate, but will be needed in the years ahead as emission reduction policy becomes more stringent and to remain competitive against lower cost electricity from renewable energy sources.

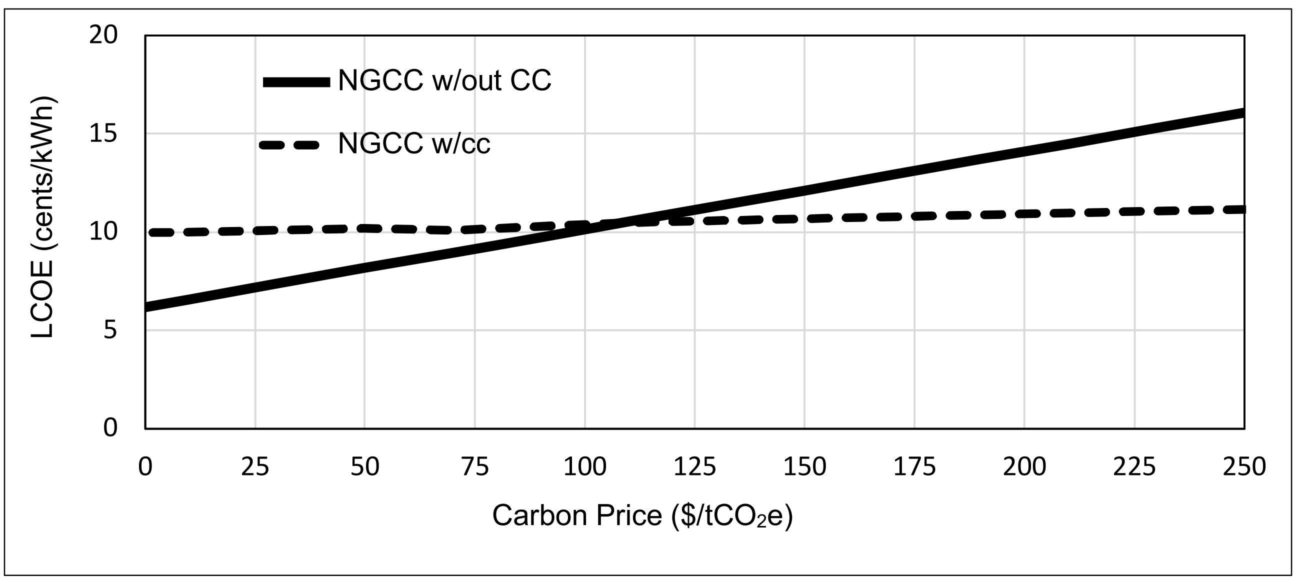

Figure 1. Natural Gas Combined Cycle LCOE with and without CCS, with no TIER credits

In terms of carbon emission reduction technologies and climate policies, variability in cost estimates can be due to the modeling assumptions or because of the inherent uncertainty about technology performance. These uncertainties can lead to inefficient policies and/or reluctance to adopt the technology. Rubin *et al*. (2012) concluded that to ensure an economic incentive for CCS in the face of estimated uncertainties, the CO_2 emission charge must be more than 70% above the nominal deterministic estimate. According to Akbilgic *et al*. (2015) the parameters that have large variability are LCOE penalty, capital cost of CCS, fuel price, and efficiency penalty.

We also evaluate prior studies on life cycle analysis (LCA) of a NGCC power plant with or without CCUS. The functional unit considered is 1 MWh (megawatt-hour) of produced electricity and the expected lifetime of the plant is 30 years. A gate-to-gate approach is applied for the LCA and the system boundaries include supply of natural gas, power plant operations, and carbon capture, compression, transportation, and storage. The impact category analyzed is primarily the global warming potential (GWP) expressed in GHG emissions in kg CO_2-equivalent. Acidification potential (AP) and eutrophication potential (EP) are also discussed. For CCUS, the majority of NGCC plants used post-combustion carbon capture technology via chemical absorption using MEA (Monoethanol Amine, Cuéllar-Franca & Azapagic, 2015).

Emissions during construction of the power plant or CCUS facility were not considered as they contribute negligible (0.4 % of the total system) amounts to GWP (Odeh & Cockerill, 2008; Spath & Mann, 2000). Specifically, for Cascade (900 MW) the estimated yearly operating emissions are 2,850 kt/y and during construction the contribution emissions are 114 kt/y over 3 years (Stantec EIA, 2019) (Table 2).

Table 2: Estimated GHG emissions of Cascade; modified from (Stantec EIA,2019)

Pollutant	Construction				Operation (kt/y)
	Year 1 (kt/y)	Year 2 (kt/y)	Year 3 (kt/y)	Total Over 3 Years (kt/y)	
CO_2	44.13	59.062	10.735	113.927	2832
CH4	0.0018	0.0024	0.0004	0.0046	0.055
N2O	0.00004	0.0005	0.0001	0.00064	0.049
CO_2e	44.282	59.266	10.772	114.32	2848

Emission intensities of NGCC plants with and without carbon capture from different studies are shown in Table 3.

Table 3: GHG emissions from NGCC plants with & without CCUS

Study	Emission without CCUS (kg CO_2 eq./MWh)	Emission with CCUS (kg CO_2 eq./MWh)	GWP Reduction (%)
Cuéllar-Franca & Azapagic (2015)	471	173	63
Singh et al. (2011)	425	125	64

Cuéllar-Franca & Azapagic (2015) determined that a NGCC plant without carbon capture emits 471 kg CO_2 eq./MWh and after implementing carbon capture it emits 173 kg CO_2 eq./MWh. In this case, 63% GWP reduction is achieved by adding carbon capture to the plant. Another study by

Singh *et al*. (2011) determined the emissions from a NGCC without carbon capture is 425 kg CO_2 eq./MWh. By adding carbon capture, the emissions decrease to 125 kg CO_2 eq./MWh. Here, GWP is lessened by 64%. On the other hand, acidification is increased by 43% and eutrophication by 35% through amine-based capture technologies (Singh et al., 2011).

LCA of CCS (ex. saline aquifer disposal) versus CCUS (ex. EOR) is also studied by Cuéllar-Franca & Azapagic (2015). Their results demonstrated that average GWP from CCS is 276 kg CO_2 eq./t which is much lower than any process of carbon capture with utilization. For example, production of chemicals is the worst option to utilize captured CO_2 as it results in 216 times higher GWP. Biodiesel production reflects 4 times higher GWP and carbon mineralization has 2.9 times higher GWP while EOR has 1.8 times higher GWP than carbon capture and storage in a saline aquifer.

From this LCA review, storage of CO_2 without any form of utilization is the most environmentally suitable. As previously discussed, captured emissions from Cascade could be utilized for enhanced oil recovery or disposed of in deep saline aquifers. Based on the LCA review, saline aquifer storage would have the lowest environmental impact in terms of global warming potential (GWP). Life cycle studies of CCUS were done based on the lifetime of power plants which is 30 years on average. As a result, there was no evidence found on the impacts spanning 7 generations. It is plausible that NGCC power plants will not be in operation for 7 generations (140 years) from now with technological advancements and increased renewable energy capacity contributing to Alberta's electricity grid.

Cascade Power Project near Edson, Alberta is situated on Treaty 6 lands. Cascade is partnered with the Indigenous Communities Syndicate LP (ICS) as a step forward to building meaningful relationships through investment participation. First Nations involved in the project received a loan from the Alberta Indigenous Opportunities Corporation (AIOC) for investment into Cascade. The transaction was coordinated by the team from Backwoods Energy Services which is an Alexis Nakota Sioux Nation owned company. The investment will generate revenue and bring prosperity to the communities. During construction nearly 600 jobs will be created, and 25 long-term skilled jobs will be provided to local community members when the plant starts to operate (Cascade Power Project, n.d.).

Results, Observations, Conclusions

This study analyzed the impact of Alberta emission reduction policies on the feasibility of CCUS at natural gas combined cycle (NGCC) power plants and specifically the impact of CCUS infrastructure on the LCOE for the Cascade NGCC power plant. LCOE modeling demonstrated the cost of electricity will increase when carbon pricing is low and may impact its competitiveness in Alberta's deregulated electricity market. However, if emission reduction regulation such as TIER (Technology Innovation and Emissions Reduction Regulation) and GGPPA (Greenhouse Gas Pollution Pricing Act) become more stringent, then CCUS technology will result in a lower LCOE. Therefore, the implementation of carbon capture technology on Cascade may be a necessity in the coming years. Specifically, as renewable energy capacity increases, Cascade will need to remain competitive in the electricity market and without CCUS this may not be possible. The modelling demonstrated that as carbon price approaches $105/tonne$_{CO2e}$, a NGCC facility without CCUS will see increased LCOE versus a NGCC facility with carbon capture. This means that at a low carbon price there will be a lack of incentive for Cascade to utilize CCUS, but the reverse is true at higher carbon prices. Specifically, the model illustrates that at the current carbon price of $40/tonne$_{CO2e}$, Cascade with CCUS would have higher electricity costs by approximately 2.5 cents/kWh. However, if carbon pricing increases, unabated emissions will negatively affect Cascade's LCOE and would therefore reduce its revenue. In either scenario, the addition or absence of carbon capture infrastructure has the ability to increase the LCOE based on the carbon price at the time. This could lead to decreased electricity dispatch in Alberta's deregulated market and negatively impact the project investors, including the Indigenous Communities Syndicate (ICS).

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