Appendix K Quantifying the GHG Reduction Benefits from the Quest Carbon Capture And Storage (CCS) Project

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Prepared by:
Blue Source Canada ULC
Suite 700, 717-7th Avenue S.W
Calgary, AB T2P 3R5
T: 403-262-3026
F: 403-269-3024
www.bluesourceCAN.com

Quest Project GHG Emission Reduction Summary

Introduction

The purpose of this report is to summarize the expected greenhouse gas (GHG) emission reductions from the Quest carbon capture and storage project. Shell, on behalf of the Athabasca Oil Sands Project, a joint venture among Shell Canada (60%), Chevron Canada Limited (20%), and Marathon Oil Sands L.P. is planning to implement a carbon capture and storage (CCS) project ("The Quest Project") to reduce GHG emissions associated with hydrogen production from steam methane reformers (SMR) at the Scotford Upgrader and the Scotford Upgrader Expansion facilities, which upgrade bitumen to produce synthetic crude oil.

This report presents a summary of the results of several GHG lifecycle assessment (LCA) analyses completed for the Quest Project for inclusion under various regulatory applications and stakeholder consultation processes. While the utmost care has been taken to detail Shell's proposed Quest project, the information presented in this document is subject to change.

This report summarizes project based GHG emission reductions according to three different GHG accounting scenarios (as illustrated in Figure 2, to follow): 1) Full Lifecycle Assessment; 2) Streamlined Lifecycle Assessment; and 3) Direct Emissions Assessment. GHG emissions were quantified using guidance from Natural Resources Canada's SMART-Lite Protocol[1], the International Organization for Standardization's (ISO) standard 14064-2[2] and Alberta Environment Specified Gas Emitters Regulation (SGER).[3]

Since the primary purpose of the Quest project is to capture and store CO_2 permanently, it is important to calculate the GHG emission reduction potential of the project according to different GHG accounting scenarios and assessment boundaries. In general terms, GHG emission reductions from Quest will equal the total amount of CO_2 captured and stored permanently underground minus the incremental GHG emissions from operating the CO_2 capture, transportation, and storage infrastructure. This analysis provides a comprehensive review of the net GHG reductions from the Quest Project according to available GHG accounting frameworks, applicable to and of interest to stakeholders in Alberta, Canada and internationally.

Quest Project Overview

The purpose of the Quest Project is to deploy technology to capture CO_2 produced by the steam methane reformer units used at the Scotford Upgrader for hydrogen production, and to transport, compress and inject the CO_2 for permanent storage in a saline formation north of Fort Saskatchewan,

[1] SMARTLite is a streamlined version of the System of Measurement and Reporting for Technologies (SMART) Protocol developed by Natural Resources Canada, Environment Canada and Industry Canada
[2] ISO 14064 Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements.
[3] Alberta Environment. Alberta Regulation 139/2007. Climate Change and Emissions Management Act. Specified Gas Emitters Regulation (SGER).
http://www.qp.alberta.ca/574.cfm?page=2007_139.cfm&leg_type=Regs&isbncln=9780779738151&display=html

Alberta. Over one million tonnes of CO_2 per year will be captured from the Scotford Upgrader, representing greater than 80% capture of the CO_2 produced from hydrogen production at the Scotford Upgrader.

The CO_2 will be captured from three steam methane reformers used to generate hydrogen at the Scotford Upgrader using a commercially proven activated amine process in which the CO_2 is absorbed (captured) by the amine solution and later regenerated to at least 95% purity by heating the rich amine stream. The amine capture and regeneration units will be located upstream of the Pressure Swing Adsorption (PSA) unit at the Scotford Upgrader, which is used to further purify the hydrogen stream before it is used in the bitumen upgrading process by residual hydrocrackers (see Figure 1, below).

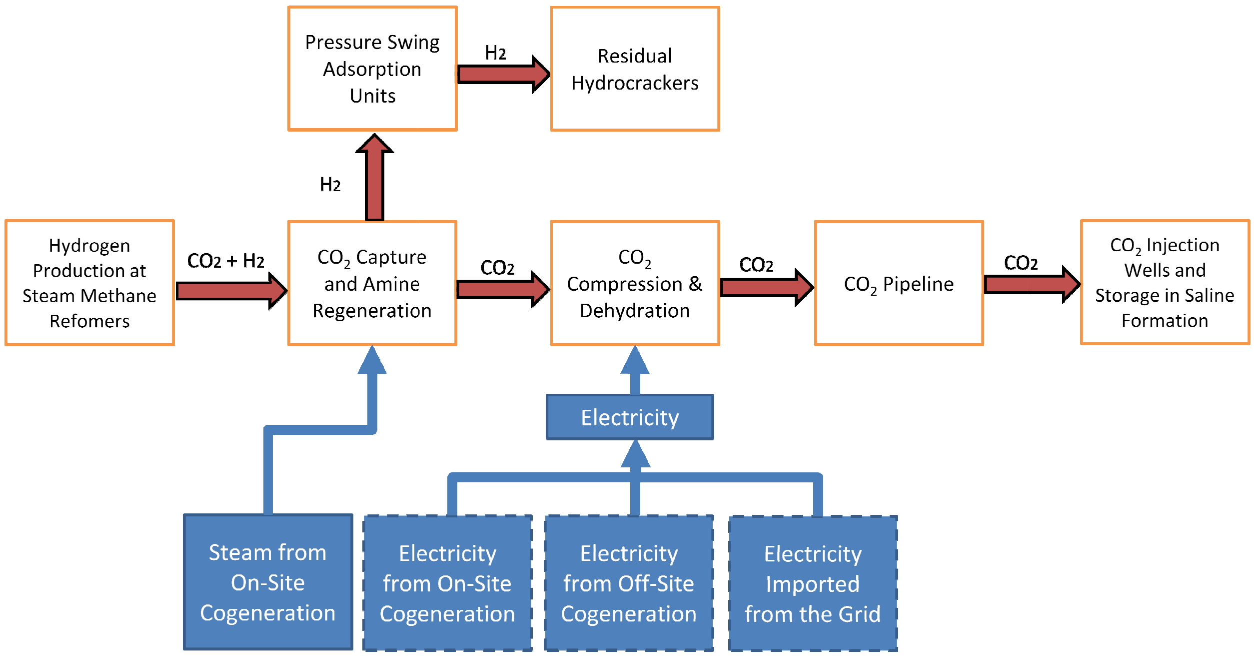
Following the regeneration of the amine used to capture the CO_2, the CO_2 will then be compressed to a pressure of approximately 2400 pounds per square inch (psi) by electric drive compressors. At this pressure the dense-phase CO_2 will be transported by a 12 inch diameter pipeline to a location approximately 84 kilometers (km) north of the Scotford Upgrader. No further compression or pumping is required to transport the CO_2 to the injection site.

At the injection site, CO_2 will be injected approximately 2000 meters underground into the Basal Cambrian Sands geological formation via 3 to 10 injection wells. The Basal Cambrian Sands formation is situated below layers of impermeable, continuous and thick cap rock, which will keep CO_2, isolated within the formation and will prevent any upward migration. The CO_2 will be trapped within the pore spaces of the rock formation in the same way that geological formations have naturally contained large reservoirs of oil and gas for millions of years.

A detailed measurement, monitoring and verification (MMV) plan will be implemented by Shell to monitor the storage of CO_2 and to protect public health and safety. The MMV plan will tie into the comprehensive GHG reporting system in place at the Scotford Upgrader.

Figure 1, below, provides a simplified process flow diagram of the Quest Project and the primary material and energy inputs required to operate the CO_2 capture, compression, transport and storage facilities.

Figure 1 - Simplified Process Flow Diagram of CO_2 Capture at the Scotford Upgrader[4]



Material Balance Design Assumptions

The Quest Project will capture approximately 80% of the CO_2 produced from the three SMRs at the Scotford Upgrader. The capture facilities are assumed to operate with 90% availability such that 1.08 million tonnes of CO_2 will be captured per year. The quantity of CO_2 sequestered will be equal to the quantity of CO_2 captured less any losses of CO_2 during compression/dehydration, transport and injection. The net GHG reductions will be equal to the quantity of CO_2 sequestered minus any greenhouse gas emissions (CO_2, CH_4, N_2O) during compression/dehydration, transport, and injection.

In this analysis it was assumed that small amounts of CO_2 will be vented or lost via fugitive emissions during compression/dehydration, pipeline operation and injection operations. Since the Quest Project is still in the design phase, the vented and fugitive emissions could only be estimated. Venting of CO_2 may occur in rare situations as the CO_2 pipeline will be equipped with emergency shutdown devices for safety reasons. These ESDs will be located at intervals of approximately every 15km along the pipeline. The vented emissions at each component of the CCS project (compression, transport and injection) were conservatively estimated to be 0.1% of the captured quantity of CO_2. Fugitive CO_2 emissions at each component of the CCS project (capture facilities, compression equipment, pipeline, and injection wells) were estimated to be 0.01% of the total captured quantity of CO_2.

Additionally, It was assumed that no leakage of CO_2 would occur from geological storage in the Basal Cambrian Sands formation. This is a reasonable assumption as the Quest project will involve injection and storage of CO_2 at a depth of over 2000 meters in a well characterized saline formation that is

[4] The elements related to electricity generation are shown with dashed lines as electricity sourcing arrangements have not been finalized for the Quest Project. Currently three different sources of electricity are being considered, including on-site or off-site gas-fired cogeneration and/or electricity imports from the grid

capped by an impermeable confining layer that has not previously been penetrated by other wells. The CO_2 will be injected into a saline formation for the sole purpose of geological storage and will not be injected into a producing reservoir for the purpose of enhanced oil recovery so no recycling of CO_2 can occur.

Energy Balance Design Assumptions

The two primary energy inputs into the Quest Project to enable to capture, transport and storage of CO_2 are steam and electricity. The current design for the Quest Project involves using 170 tonnes per hour (tph) of low-pressure steam at approximately 350 kiloPascals (kPa) and 165°C. Steam is assumed to be sourced entirely from an on-site steam turbine generator (STG) that is part of the ATCO Power-operated cogeneration unit at the Scotford Upgrader.

The total electricity consumption of the Quest Project is expected to average 22.1 MW with 90% availability. The source of electricity has yet to be confirmed, but current options include sourcing electricity from the existing on-site gas-fired cogeneration unit, from a nearby third party gas-fired cogeneration unit, from the provincial electricity grid (which is made up of predominantly coal and gas-fired generation units[5]), or a combination of these options. The overall GHG emission reductions from the Quest Project will depend on the choice of power source used to capture, transport, and store CO_2 from the Scotford Upgrader.

At present, Shell is considering three different scenarios for sourcing electricity for the Quest Project, as shown in Table 1, below.

Table 1 – Steam and Power Sources Considered for Quest

	Steam Source (170 tonnes per hour (tph))	Power Source (22.1 MW)
Case 1	100% On-Site Natural Gas-Fired Cogeneration	80% Off-Site Natural Gas-Fired Cogeneration and 20% Grid Electricity
Case 2	100% On-Site Natural Gas-Fired Cogeneration	80% On-Site Natural Gas-Fired Cogeneration and 20% Grid Electricity
Case 3	100% On-Site Natural Gas-Fired Cogeneration	0% Cogeneration and 100% Grid Electricity

[5] Alberta Energy. Electricity Statistics. http://www.energy.alberta.ca/Electricity/682.asp

Identification of Sources, Sinks and Reservoirs of GHG Emissions for the Quest Project

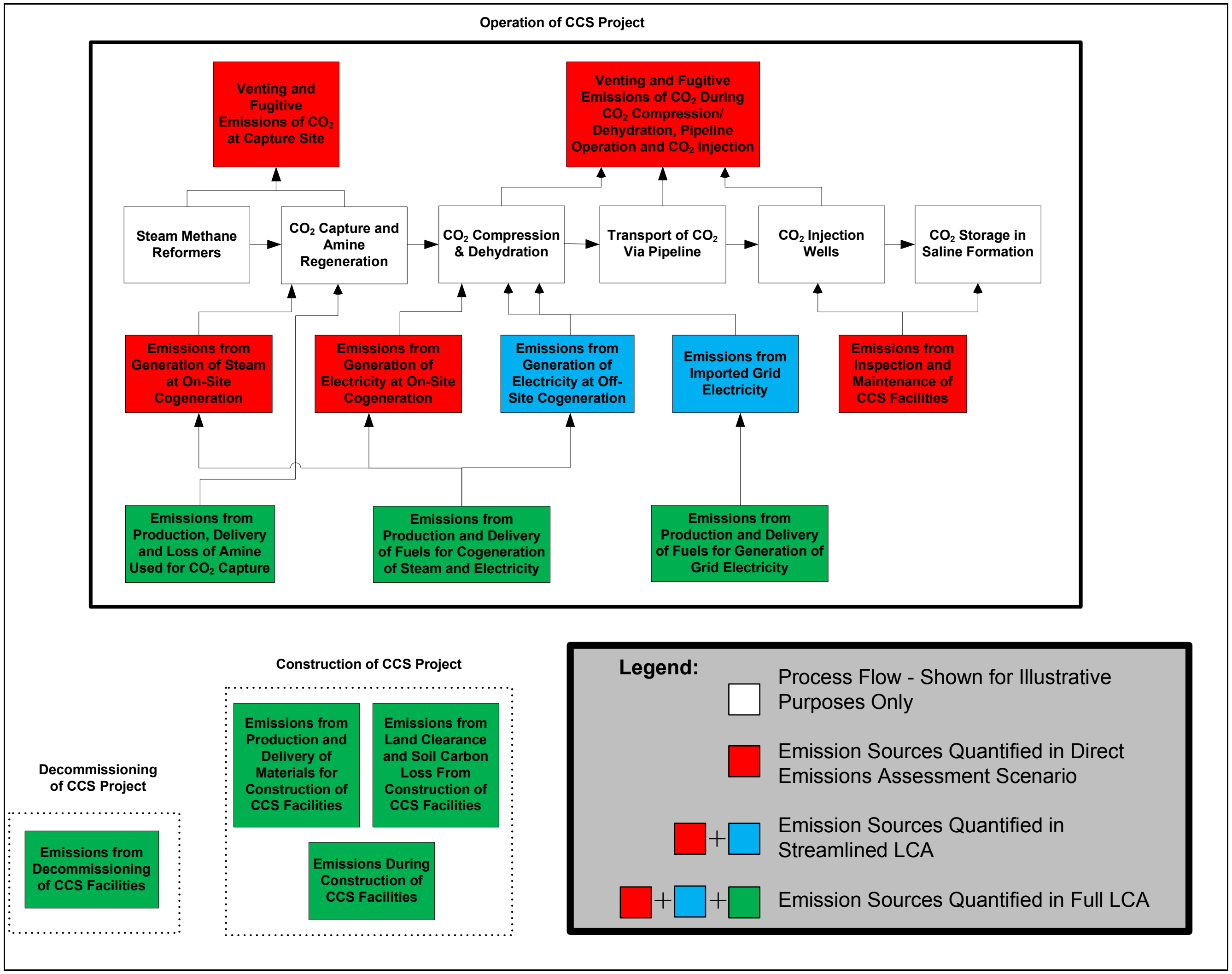
The quantified GHG emission reductions from the Quest Project will vary depending on how the lifecycle emissions assessment boundary is defined. The assessment boundary should include mention of not only direct and indirect sources of emissions, but also specify which emissions occur upstream or downstream of the project and whether emissions occur prior to, during or after the operation of the project.

Direct emissions are defined as those emissions that are under the direction and influence of the project operator.[6] Indirect emissions are generally defined as those emission sources, sinks or reservoirs that have material and energy flows into, out of, or within the Project.[7] In this analysis, a further distinction is made separate those indirect emissions related to purchased energy inputs during the project operation (herein referred to as 'indirect emissions'), from emission sources that occur upstream or downstream of the project (herein referred to as 'upstream/downstream emissions'). These upstream/downstream emission sources are identified separately as they generally relate to the production and delivery of materials and fuels used during the project operation or the commissioning or decommissioning of infrastructure for the project.

Under the ISO 14064-2 standard a project boundary is defined by identifying and assessing emission sources, sinks and reservoirs (SSRs). For the Quest Project, three different GHG assessment boundaries were compared to provide stakeholders with a complete picture of the GHG emission reductions from the project according to relevant GHG accounting practices. These boundaries are summarized below.

[6] ISO 14064-2 Definition of 'Controlled' greenhouse gas source, sink or reservoir.
[7] ISO 14064-2 Definition of 'Related' greenhouse gas source, sink or reservoir.

Figure 2 – The process flow diagram for Quest, below, identifies each relevant SSR and illustrates project boundaries for three different assessment scenarios: 1) Full Lifecycle Assessment (LCA) - direct, indirect and upstream/downstream emission sources are all included (red, blue and green boxes, respectively); 2) Streamlined LCA - direct and Indirect emission sources are included, but not upstream/downstream sources; and, 3) Direct Emissions Assessment - only direct emissions under the control of the Quest Project operator are included.



1. Full Lifecycle Assessment

The completion of a full lifecycle assessment (LCA) of GHG emissions for a project activity requires a detailed review of all of the material and energy inputs associated with each stage of the project in order to identify all relevant sources, sinks and reservoirs of GHG emissions. There are various approaches to completing project level LCAs, but this analysis was completed following guidance from ISO 14064-2 and SMARTLite. Following this approach, each process input is traced back to its source, to identify all of the sources of emissions related to that input, regardless of which entity is responsible for emitting them. All sources of emissions (i.e. direct, indirect, upstream, and downstream sources) are identified in this analysis.

Figure 2 shows the project boundary for the LCA scenario.

During the operational phase of the project, emission sources are identified based on the review of material and energy balances around the project facilities. Specifically, for the Quest CCS project this includes a material balance on the physical CO_2 stream to identify CO_2 emissions to the atmosphere via emergency venting and fugitive emissions. For the Quest Project the primary energy inputs include natural gas combusted in the on-site cogeneration unit for steam and electricity generation and electricity purchased from off-site (regional grid or third party cogeneration unit). The primary material input would be the amine used in the CO_2 capture process. Other minor operational emissions would occur during the inspection and maintenance of the CCS facilities and during on-going monitoring activities.

Upstream emission sources during the operational phase of the project include emissions related to the production and delivery of each material or energy input. For the Quest Project, these sources include the extraction, processing and delivery of natural gas; the production of electricity and associated transmission losses; and the production and delivery of amine to the capture site.[8]

Downstream emission sources during the operational phase of the project include the delivery and use of products and the disposal of by-products. Since the primary hydrogen product[9] from the Scotford SMRs is not altered by the Quest Project and since vented and fugitive sources of CO_2 emissions are already accounted for as direct emissions during the operation of the project, the only other downstream emissions associated with the Quest Project are from the loss of amine (e.g. ultimate release of CO_2, methane or nitrous oxide from the disposal or loss of the absorbent that was used in the CO_2 capture process).

Prior to the operational phase of the project a number of emission sources need to be identified, including emissions during the construction and commissioning of project facilities and during the manufacture and transport of materials and equipment to the project site. Emission sources during site decommissioning are also identified. For the Quest Project, these sources of emissions include emissions from land clearing and soil disturbance, emissions during construction of the CCS facilities, and emissions associated with the production and delivery of each material input (e.g. steel, concrete). For

[8] Note that emissions associated with water sourcing, distribution, treatment and discharge/disposal related to the steam consumption for the Quest CO_2 capture unit were considered to be negligible as relevant water/steam handling infrastructure is already in place at the Scotford Upgrader.

[9] Hydrogen yields and bitumen upgrading operations at the Scotford Upgrader are not expected to be impacted by the CO_2 capture equipment.

decommissioning the emission sources include the operation of equipment to dismantle the CCS facilities, to transport materials and to recycle/dispose of materials.

For all one-time emission sources from construction and decommissioning activities a 25 year project life was assumed to convert these emission sources into equivalent annual terms, consistent with the emission sources that occur during the operational period of the project.

2. Streamlined Lifecycle Assessment

The most common application of the ISO 14064-2 standard is a "streamlined" lifecycle approach in which emissions from SSRs related to the project by the primary material or energy flows (whether on-site or off-site) are included within the project boundary[10]. All sources of emissions that are under the direct control of the project operator (direct emissions) are quantified in this scenario. Major sources of indirect emissions, such as those from purchased energy streams, are also quantified. The streamlined approach does allow for the classification and exclusion of upstream or downstream sources of emissions that are outside the control of the project operator, if such emission sources are deemed to have a negligible impact on the net GHG reduction of the project. This approach is less inclusive than a full lifecycle analysis, but is much more practical for determining the net GHG reductions from a particular project activity.

For the Quest Project, the emission sources quantified under the streamlined LCA approach include all direct sources of physical CO_2 emissions under the control of the project operator (e.g. venting and fugitives at CO_2 capture, compression, transport, and injection facilities); all sequestered CO_2; all direct CO_2e emissions from on-site natural gas combustion for steam and electricity generation; all direct emissions from inspection and maintenance of CCS facilities (e.g. fuel combustion for mobile equipment); and, all indirect emissions from off-site electricity generation.

In this streamlined analysis, upstream, downstream and other indirect emission sources were excluded if they individually represented less than 1% (on a CO_2-equivalent basis) of the annual quantity of CO_2 captured at the Scotford Upgrader. This approach to inclusion and exclusion of emission sources is consistent with the concept of 'de minimis'[11] emission sources, commonly used by GHG reporting registries. As such, the indirect upstream emissions associated with the production and delivery of natural gas; the production and delivery of amine; and the transmission of grid electricity were excluded from this LCA scenario. In addition, indirect emissions from land clearance/soil disturbance; construction of CCS facilities; and decommissioning of CCS facilities were all excluded on the same basis of being immaterial relative to the primary sources of emissions and emission reductions.

Vented and fugitive emissions of CO_2 from the CCS facilities and emissions from inspection and maintenance activities were still quantified despite their respective magnitudes being below the 1% threshold, as these emission sources are under the direct control of the operator of the Quest Project.

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[10] ISO 14064 Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements.

11 The California Climate Action Registry defines 'De Minimis Emissions' as being from one or more sources, for one or more gases which, when summed, equal less than 5% of an organization's total emissions. http://www.arb.ca.gov/cc/protocols/localgov/pubs/lgo_protocol_v1_1_2010-05-03.pdf

This method of GHG accounting is generally consistent with ISO 14064-2-based GHG quantification protocols approved under the Alberta Offset System[12] and provides a practical assessment of on-going project emissions and emission reductions. The project boundary for the streamlined LCA of the Quest Project is outlined in Figure 2.

3. Direct Emissions Assessment

The final GHG assessment boundary includes only direct emission sources. In this analysis, direct GHG emissions are defined as those emissions that are directly under the control of the Quest Project operator. This definition is consistent with the World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD) GHG Protocol[13] definition of Scope 1 emissions.[14] For the Quest Project, direct emission sources include emissions from fossil fuel combustion for on-site steam and electricity generation and from the venting and fugitive emissions of CO_2 and do not include emissions associated with the purchase of energy (e.g. electricity or steam) from other third party off-site facilities.

This scenario is more limited in scope than the full or streamlined LCA scenarios as it does not consider indirect emissions. However, out of the three assessment boundaries considered in this report, the Direct Emissions Assessment scenario is the most consistent with the existing facility-based GHG reporting requirements under the Province of Alberta's Specified Gas Emitters Regulation (SGER)[15] and under Environment Canada's Facility GHG Reporting Program,[16] as described below.

The Direct Emissions Assessment boundary is similar to the current GHG reporting boundary defined for the Scotford Upgrader under the Alberta Specified Gas Emitters Regulation, as the SGER regulation only covers direct emissions within the GHG reporting fence line of the Scotford Upgrader as defined under the Alberta operating approval license for the facility. The assessment boundary for this scenario includes these same emissions sources, but also includes direct emissions related to the CO_2 pipeline and injection wellheads that are not currently within the SGER defined reporting boundaries for the Scotford Upgrader. As such, this assessment boundary is inclusive of all of the direct emissions associated with the Quest Project, but differs from the two scenarios defined above, as it does not include indirect emissions or upstream/downstream emissions.

The primary emission sources quantified under the Direct Emissions Assessment scenario include on-site fossil fuel combustion to generate steam for the regeneration of amine and the on-site generation of electricity for compression of CO_2. Venting and fugitive emissions associated with the capture, compression, transport and injection of CO_2 and fuel combustion emissions associated with the inspection and maintenance of CCS facilities are also accounted for within the assessment boundary, but are relatively minor contributors to the total emissions. The project boundary for the Direct Emissions Assessment scenario is shown in Figure 2.

[12] Alberta Offsets Guidance Document. http://environment.gov.ab.ca/info/library/7915.pdf
[13] WRI/WBCSD Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard. Revised Edition.
[14] The WRI/WBCSD GHG Protocol defines Scope 1 Emissions as "Direct GHG emissions that occur from sources that are owned or controlled by the company, for example, emissions from combustion in owned or controlled boilers, furnaces, vehicles, etc.; emissions from chemical production in owned or controlled process equipment.
[15] Alberta Environment. Alberta Regulation 139/2007. Climate Change and Emissions Management Act. Specified Gas Emitters Regulation (SGER).
http://www.qp.alberta.ca/574.cfm?page=2007_139.cfm&leg_type=Regs&isbncln=9780779738151&display=html
[16] http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=040E378D-1

The main difference between this assessment boundary and the previous scenarios is the exclusion of indirect emissions related to electricity generation at off-site cogeneration facilities and/or electricity imports from the regional grid. These emission sources, while significant to the overall GHG balance for the project, would not be reflected under provincial or federal GHG reporting systems.

Summary of GHG Emission Reductions from the Quest Project

GHG emission reductions have been calculated for the three project boundaries described above using each of the three different scenarios for meeting the energy demands of the Quest Project. Table 2, below, summarizes the net GHG emission reductions on an annual basis from the Quest Project according to the three assessment boundaries.

Table 2 – Summary of GHG Emission Reductions from the Quest Project

	Type of GHG Emissions	**Case 1 (tCO_{2e}/year)**	**Case 2 (tCO_{2e}/year)**	**Case 3 (tCO_{2e}/year)**
(A)	Gross Captured CO_2	1,080,000	1,080,000	1,080,000
(B)	Direct Emissions	54,581	107,549	54,581
(C)	Indirect Emissions	83,703	30,735	153,677
(D)	Upstream/Downstream Emissions	19,377	19,377	24,813
(E)	Construction and Decommissioning Emissions	4,893	4,893	4,893
	Net Annual GHG Reductions			
	Direct Emissions Assessment [(A)-(B)]	**1,025,419**	**972,451**	**1,025,419**
	Streamlined Lifecycle Assessment [(A)-(B)-(C)]	**941,716**	**941,716**	**871,742**
	Full Lifecycle Assessment [(A)-(B)-(C)-(D)-(E)]	**917,446**	**917,446**	**842,036**

As shown in Table 2, above, direct and indirect emissions make up the majority of emissions for the Quest Project, but both are substantially smaller in magnitude compared to the quantity of CO_2 that is captured and sequestered. Upstream, downstream and construction and decommissioning emissions are relatively insignificant when normalized over a 25 year project life and the inclusion of these emission sources results in less than a 3.5% change in quantified emission reductions for the Full LCA.

In conclusion, all three LCA scenarios demonstrate that the Quest Project will achieve large scale Alberta-based GHG reductions, regardless of the defined project boundaries or the selected LCA approach, after accounting for the GHG emissions associated with energy inputs required to capture, compress, transport, inject and store CO_2. In all cases, the Quest Project is expected to deliver net GHG reductions of greater than 840,000 tonnes of CO_2-equivalent emissions per year in Alberta after accounting for all significant indirect sources of emissions at all stages of the project. If electricity is supplied to the project by a gas-fired cogeneration facility, rather than by imports from the Alberta grid, the net GHG reductions will exceed 917,000 tonnes CO_2e per year under all three defined LCA scenarios. Further, the Quest Project will reduce direct emissions by greater than 970,000 to 1,025,000 tonnes CO_2e per year at the Scotford Upgrader, which will be reflected in facility-based GHG reporting available to the public at both the provincial and federal levels in Canada.