THE QUEST FOR LESS CO_2: LEARNING FROM CCS IMPLEMENTATION IN CANADA

A Case Study on Shell's Quest CCS Project

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WHAT'S IN A NAME?

The name 'Quest' from the words 'quest' and 'sequester':

QUEST – "search or pursuit in order to find something" Pursuing a game-changing approach to managing CO_2

SEQUESTER – "to remove, separate and discard or exile". Describes what Quest is doing with the CO_2 captured, by permanently storing it deep underground

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Quest is the world's first commercial-scale carbon capture and storage (CCS) project in an industrial processing facility, designed to capture and permanently store more than one million tonnes of CO_2 annually - equivalent to the emissions from approximately 250,000 cars. Quest is an important project for Shell, demonstrating integrated CCS operations as a model for advancing and deploying CCS technology and supporting the company's commitment to action on climate change.

Through comprehensive funding agreements with the Canadian and Alberta governments, Shell has agreed to share its extensive experience and lessons learned through implementing CCS, such that globally Quest can serve as a model for advancing and deploying CCS in oil sands and other industrial operations ▪

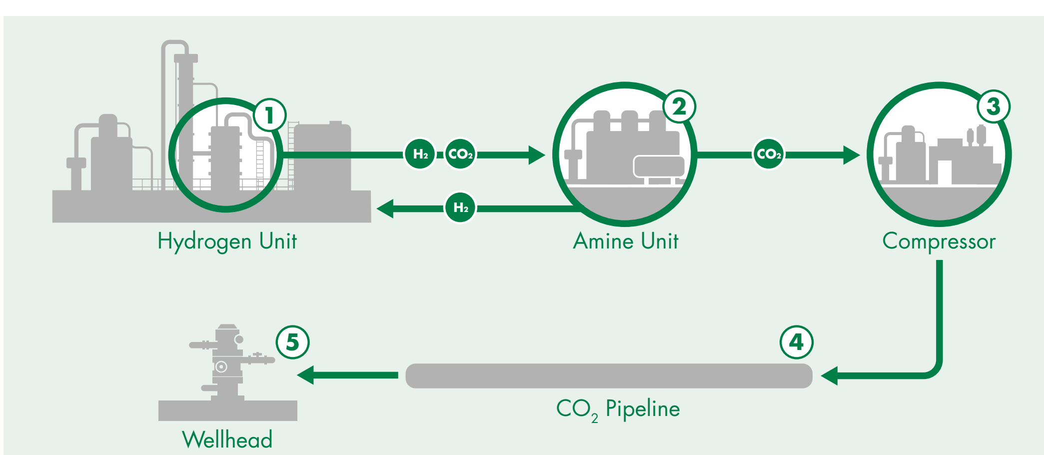


Figure 1: Quest Project Overview and the Scotford Upgrader Site

QUEST PROJECT BACKGROUND

Quest has been built on behalf of the Athabasca Oil Sands Project (AOSP) joint venture owners - Shell Canada Energy (Operator and 60% owner), Chevron Canada Limited (20%), and Marathon Oil Canada Corporation (20%), with support from the Governments of Canada and Alberta. The AOSP includes the Muskeg River and Jackpine mines (located northeast of Fort McMurray, Alberta), the Scotford Upgrader and the Quest facility (both located near Fort Saskatchewan, Alberta).

The Upgrader processes bitumen produced from the mining operations, upgrading it into synthetic crude feedstock suitable for refining into products such as gasoline, diesel and jet fuel. Successful integration of the new capture plant into the hydrogen manufacturing unit (HMU) allows CO_2 formed as a by-product of hydrogen production to be captured using Shell's ADIP-X amine technology. The CO_2 is captured directly from a high pressure syngas stream in the hydrogen manufacturing process with a solvent. Subsequently the solvent is regenerated releasing the CO_2, which is subsequently compressed, dehydrated, transported and injected into a saline reservoir for permanent storage, making Quest a fully integrated CCS project.

Shell has taken a forward-thinking approach to greenhouse gas (GHG) management throughout oil sands project development. Shell was keen to develop the oil sands resource in Alberta, but at the same time conscious of growing concern about climate change. In response, Shell Canada took a dual approach, which included a technical plan to address CO_2 emissions from the AOSP over time, and a strategy to engage stakeholders on core concerns relative to climate change.

Shell's approach considered a portfolio of CO_2 abatement options. The company also identified early on the importance of progressive regulation, market mechanisms and access to international markets. At that time CCS was just a concept and although there were few projects, Shell was considering feasibility of the technology.

In 2000, Shell Canada established a Climate Change Advisory Panel which brought together a number of local, national and international groups external to Shell. The panel particularly liked that a CCS project would be a tangible CO_2 reduction in Canada.

In 2008, the Alberta government announced its climate change strategy and identified CCS as a key technology needed in order to meet the Province's target reductions for 2030 and 2050. The government struck a special task force on CCS, which included a representative from Shell on one of the working groups. The task force articulated that CCS demonstration projects were needed ahead of regulation to demonstrate viability and to spur development to help bring down costs. Around this time, the Alberta government established a C$2B fund aimed at encouraging CCS demonstration projects. Shell submitted an application for Quest and was successful in acquiring C$745M in funding from the Government of Alberta. Around the same time, the Government of Canada was looking to demonstrate action on CCS, which led to investments in both the Quest project (C$120M), as well as in SaskPower's Boundary Dam project. Boundary Dam is a post-combustion carbon capture facility at a coal-fired power plant and uses Shell Cansolv technology.

> Shell progressed engineering studies and early feasibility work for a potential project during the early 2000s. Then towards the middle of that decade, CCS took on new importance for Shell when the company began focusing on developing a portfolio of CCS projects globally. Having done substantial foundational work, the Quest project was already positioned to lead amongst Shell's various opportunities.

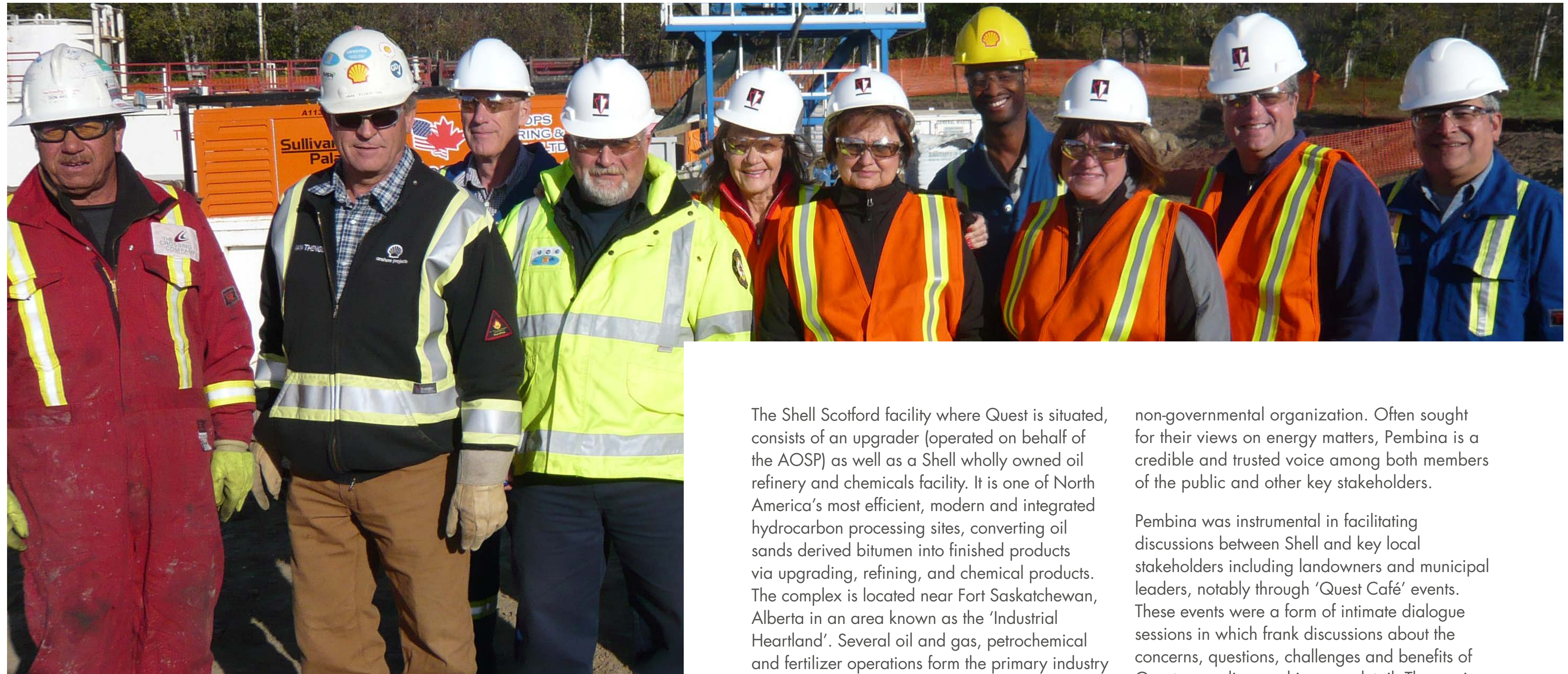
Upon conclusion of the detailed capture, transport and storage engineering studies and the regulatory processes in Q2 of 2012, the AOSP joint venture owners took a final investment decision on Quest in September 2012. Early works started in Q4 2012, with construction completed early in 2015. As of November 2015, Quest is on stream and injecting CO_2 ▪

PRECEDENT-SETTING COLLABORATION TO ADVANCE CCS POLICY FRAMEWORKS

As worldwide commercial-scale deployment of CCS is still in early days, government and public support for project development are essential to incent early demonstration projects, which are needed to achieve lower costs and greater efficiencies through economy of scale. In addition to the C$865 million of government funding (Provincial & Federal), significant government support was also required in Canada to enable the development of ground-breaking policy frameworks, including regulations tailored to CO_2 storage as well as a measurement, monitoring and verification (MMV) system and post-closure certification protocol to enable the storage responsibility to be transferred over to the government after the project lifetime.

> Before Quest, there was no method to acquire the subsurface rights to sequester CO_2 in Alberta.

Acts were in place for extraction, deep-well disposal of fluids, and the storage of gas, however not for the subsurface sequestration of CO_2. The government had to amend existing legal and regulatory frameworks. To support, Shell had to understand the processes the regulator had to follow to establish new legislation; and the government learned about the technicalities associated with sequestration leases. The Quest subsurface team clarified the science and specifics of CO_2 storage and the goals of the project in great detail. Workshops were held to discuss ideas surrounding the legislation under development. In addition, Quest underwent an environmental assessment to meet provincial government requirements. From late 2009, the legislative and regulatory strategy was pulled together and the project moved forward. In December 2010 the government introduced the act and the regulations were in place by April of 2011. Once the regulations were introduced, Shell applied for sequestration leases.



EARNING STAKEHOLDER TRUST AND CONFIDENCE

Securing local stakeholder support and regulatory approval are critical steps, which for many projects can become hurdles that significantly delay, or even prevent, approvals. As the concept of capturing and storing CO_2 underground was seen as still new in Alberta, the project team recognized the importance of gaining local support, and also broader public acceptance in order to proceed. Describing Quest as one of several approaches to managing the CO_2 from the oil sands helped provide an effective context for discussions with government and the public.

> Honest and open face-to-face discussions led by local staff were fundamental to the success of the project.

The Shell Scotford facility where Quest is situated, consists of an upgrader (operated on behalf of the AOSP) as well as a Shell wholly owned oil refinery and chemicals facility. It is one of North America's most efficient, modern and integrated hydrocarbon processing sites, converting oil sands derived bitumen into finished products via upgrading, refining, and chemical products. The complex is located near Fort Saskatchewan, Alberta in an area known as the 'Industrial Heartland'. Several oil and gas, petrochemical and fertilizer operations form the primary industry base in the region. The Shell Scotford facility, originally established with the refinery in 1984, has a long history in the area and Shell has built a strong reputation as a good employer and valued member of the community.

The stakeholder engagement plan for Quest needed to consider, and in many cases build upon this history, meanwhile recognizing the need to be integrated with Shell's outreach activities already underway in the area.

Channels of communication were established early on and remain open even today, enabling both formal and informal engagement to seek information and have questions answered or concerns discussed. Prior to submitting a regulatory application, and subsequently throughout the regulatory process, open houses were held to answer questions and inform the public on the project. The open houses also drew in suggestions and feedback from local residents, one of which was a groundwater quality-monitoring program, which is now part of the MMV program.

Another key success factor in the stakeholder engagement process was Shell's collaboration with the Pembina Institute, a Canadian non-governmental organization. Often sought for their views on energy matters, Pembina is a credible and trusted voice among both members of the public and other key stakeholders.

Pembina was instrumental in facilitating discussions between Shell and key local stakeholders including landowners and municipal leaders, notably through 'Quest Café' events. These events were a form of intimate dialogue sessions in which frank discussions about the concerns, questions, challenges and benefits of Quest were discussed in more detail. The sessions ensured stakeholders could express and receive credible responses and solutions (as an example, the pipeline route was modified over 30 times to incorporate local feedback and minimize disturbances). Discussions also ensured people had a full and accurate understanding of the project, and that Shell had a deep understanding of stakeholder perspectives and took these into account as the project was developed.

One of the most successful stakeholder engagement mechanisms to come out of the Quest Cafés, which is still in place today, is a Community Advisory Panel which is made up of local residents, members of the academic community, political and regulatory representatives. The primary purpose of the Panel is to share regular updates about the project, specifically the MMV program and results, and for Shell to take recommendations from the Panel on the best approach to communicate these results to the broader community.

Through comprehensive stakeholder outreach, engagement and education, the Quest team was able to successfully achieve approvals through the regulatory process.

CAPTURE TECHNOLOGY

Integration into Hydrogen Manufacturing Units

Quest combines tried and tested technology in an integrated surface and subsurface development. The CO_2 formed as a by-product in hydrogen production is captured using Shell's ADIP-X amine technology. ADIP-X is a widely applied CO_2 removal process and has been applied for decades within gas processing and liquefied natural gas plants. The successful integration of the capture plant into the hydrogen manufacturing unit's (HMU) operation is a critical technical component to Quest's success. That said, only the application for CO_2 capture is truly novel.

Quest captures CO_2 from the three HMUs at Scotford. Of the CO_2 produced in the reformer, roughly 80% is removed from the raw hydrogen - syngas - in an amine absorber (Figure 2). Capturing CO_2 from this source has advantages over post-combustion CCS. The higher pressure (~30 bar or 435 psi) allows for smaller equipment and more efficient CO_2 absorption in the amine. In addition the hydrogen is clean and no further gas clean-up is required.

In the earlier project phases various alternative capture technologies were considered. Reasons for selecting ADIP-X technology included the possibility to physically fit the system in existing units and the site specific utility systems. An amine based system only requires one column (absorber) and vessel (water-wash) to be on the HMU plot, which significantly reduces the footprint in the HMU area. The single amine stripper (common to the absorbers in the three HMUs), compression and dehydration is set on its own plot (Figure 4). In addition Shell has experience with applying amine technology in HMUs. In the 'conventional' HMU line-up, CO_2 is removed using an amine. There are numerous plants in operation with Shell's technology. The main utility needed for an ADIP-X unit is low pressure steam used to regenerate the amine solvent. At Scotford there was sufficient steam available from amongst other sources, the HMUs, which further strengthened the case for applying amine technology.

The successful integration of the capture plant into the hydrogen manufacturing unit's (HMU) operation is a critical technical component to Quest's success.

The ADIP-X absorber is fully integrated into the HMU process (Figure 2), which implies additional measures are taken to minimize the impacts on the hydrogen production. The raw hydrogen coming from absorber is sent to a water-wash column, which reduces the amine levels in the gas to very low levels to protect the downstream adsorbents. The hydrogen is further purified in the existing pressure swing adsorption units (PSA) removing CO, CO_2, and CH_4 and returning those to the reformer. To compensate for the increase in this PSA tail gas stream heating value (which contains less CO_2), flue gas from the HMU stack is recycled to the furnace via the combustion air. This is one of the crucial measures for NOx control. The recycled flue gas substitutes the CO_2 as an inert gas, which reduces the reformer temperature. At lower temperature there is less NOx formation.

In collaboration with the technology licensors for the PSA units, several modifications have been made to optimize and tune the PSA for Quest operation. A change to the operation mode is that the lower CO_2 load to the PSA allows the loading cycle times to be increased significantly. Several process control measures have also been developed to successfully dampen loss of CO_2 capture and prevent escalation of trips on the ADIP-X absorber.

The CO_2 absorbed by the amine is released in a common amine regenerator (stripper). The captured CO_2 from the amine regenerator is then compressed and dehydrated. Quest has an eight stage integrally geared compressor with inter-stage cooling and knock-out. The glycol dehydration unit is located between the 6th and 7th stage as at this location the pressure is optimal for water removal and equipment size.

The dry dense phase CO_2 is transported by pipeline ~64 km north of the Scotford facility to where it is injected into the Basal Cambrian Sands (BCS) more than two kilometres below the earth's surface. Three injection wells have been established to ensure sufficient redundancy/availability to store CO_2 ▪

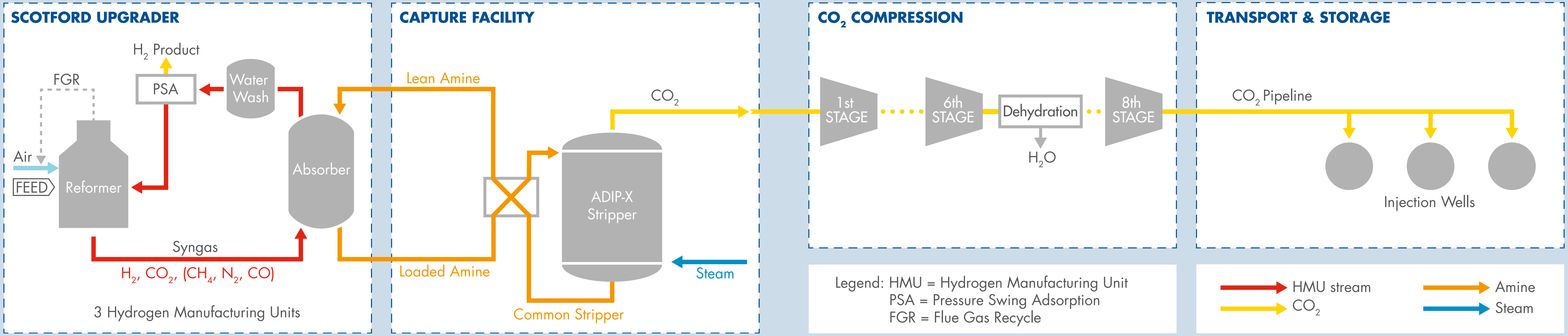


Figure 2: Basic overview of Quest's line-up

Storing the CO_2 subsurface

The BCS is a deep saline aquifer, located about 2 km below ground, far below groundwater levels and oil and gas reservoirs. The storage formation is at the base of the central portion of the Western Canada sedimentary basin. Here CO_2 will be injected over a period of 25 years and will remain permanently trapped in the formation.

In the site selection for CO_2 sequestration, it was key to find a subsurface formation that could store CO_2 and would contain the CO_2 such that it could not leak to any shallow reservoirs, neither hydrocarbon bearing nor aquifers. Above the BCS, a number of thick seals (cap layer) are present including the Middle Cambrian Shale, and the Upper and Lower Lotsberg Salts (Figure 3). In addition to having sufficient cap layers, the site had to be in an area with minimal penetrations of the storage complex by legacy wells.

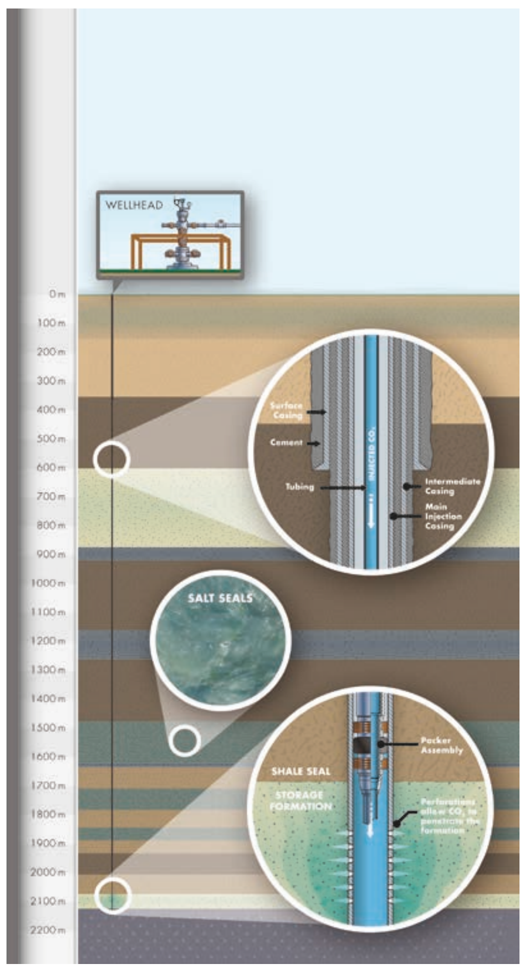


Figure 3: Schematic stratigraphic column of the BCS storage complex and an injection well

The site selection has placed the Quest project in a reservoir with excellent seals and minimal potential leak paths.

In addition, the formation has high injectivity. Consequently, lower injection pressures are required which lowers the driving force for leaks, but also deceases the operational cost of the facilities as less compression horse power is required. Modeling shows that even in the event of a leak path it is highly unlikely that groundwater would be contaminated given the multiple layers of thick, low-permeability, and extensive sealing formations that separate the BCS from groundwater sources ▪

Measurement, monitoring and verification

The Quest Project has a responsibility to carefully monitor activity within the storage area and to verify that the CO_2 remains permanently trapped in the subsurface. To this end, a comprehensive MMV program is in place, which is considered to be one of the most innovative aspects and demonstration elements of Quest. The Quest project received the world's first Certificate of Fitness for safe CO_2 storage from world-renowned risk management firm Det Norske Veritas (DNV). DNV assembled a panel of seven CCS experts from academia and research institutions to perform the review over a two-week period.

The monitoring results will be transparent and publically available to demonstrate that the Quest storage site is inherently safe.

The MMV program underpins the ability to demonstrate safe, long-term integrity of the storage, supports public acceptance, and can be used to define balanced MMV requirements for future CCS projects. The current program covers a wide range of technologies and analysis throughout the atmosphere, biosphere, hydrosphere and geosphere [3].

This MMV system is designed according to a systematic risk assessment, known as the bow-tie method. This focuses on the elements of the MMV to address specific issues and is a well-established barrier (safeguard) approach Shell uses for process safety throughout its global operations to achieve two distinct objectives:

ENSURE CONTAINMENT – to demonstrate the security of CO_2 storage and to protect human health, groundwater resources, hydrocarbon resources, and the environment.

ENSURE CONFORMANCE – to indicate the long-term effectiveness of CO_2 storage by demonstrating actual storage performance is consistent with expectations about injectivity, capacity, and CO_2 behaviour inside the storage complex;

MMV will achieve this in two ways. First, the expected effectiveness of existing safeguards created by site selection, site characterization, and engineering designs were verified. Second, the system creates additional safeguards using the same monitoring systems to provide an early warning to trigger timely control measures designed to reduce the likelihood or the consequence of any leakage from the storage site. Transfer of long-term liability to the government is supported by MMV activities designed to verify that the observed storage performance conforms to model-based forecasts and that these forecasts are consistent with permanent secure storage at an acceptable risk.

The Quest MMV program has been set up to test multiple approaches to define optimal MMV requirements for future projects with a reduced set of technologies. As such, the program is by no means a precedent for follow on projects.

In early 2015, the US Department of Energy and Shell announced plans to collaborate in field tests to validate advanced monitoring, verification, and accounting (MVA) technologies for underground storage of carbon dioxide ▪

COST EFFECTIVENESS THROUGH SMART CONSTRUCTION

Although Shell does not provide project specific costs, when the funding letters of intent were signed in October 2009 the gov't provided an estimate of $1.35 billion (CAD). The government's figure reflects costs over a 15-year period (which includes the development and construction phases and 10 years of operations.) The Quest Project team successfully managed to deliver the project cost effectively despite a heated labor market at the time of fabrication and construction. The stage was set through the project planning process, in which clear expectations, early alignment, construction-led planning and design and careful management of scope and changes were key. Quest took modularization to the next level, basing the onshore facility on offshore standards covered by Fluor's Third Generation ModularSM design practices. This delivered an integrated tight design on a comparably small plot, by stepping away from the traditional - "stick build"- backbone with a central pipe rack and units to the side. The modular construction considerably limited the amount of onsite construction hours. The maximum module size was 7.3m (wide) x 7.6m (high) x 36m (long). Modules were assembled in the Alberta area and transported by road to the Shell Scotford site over the Alberta Heavy Haul corridor. The modules include the complete processing facility. All mechanical, piping, electrical and control system equipment were already in place.

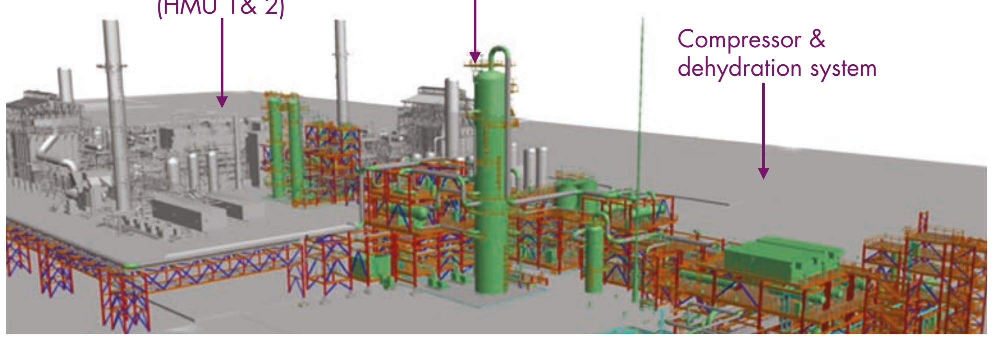


Figure 4: 3D model of capture plant facilities

Through construction of Quest, it became clear that cost can be further reduced with scale; if more CO_2 sources can be tied into the Quest facility, the cost per tonne of CO_2 sequestered could be further reduced. The 12 inch pipeline for Quest has been sized for 3.0 mtpa for CO_2 – with up to 1.2 mtpa of CO_2 currently available. A follow on project which met the regulatory requirements could potentially tap into the pipeline which would substantially reduce sequestration costs.

In the earlier phases of the project it would have been beneficial to have a firmer understanding of the storage formation; however this data requires significant upfront expenses. The consequence was that the subsurface and capture aspects of the project were not fully aligned until the lead-up to the final investment decision. The capture plant is therefore designed for a variety of subsurface options; notably the compressor and pipeline. Investing earlier in more appraisable would have reduced the capture plant costs.

The Quest project also bore cost to develop technology, legislative and regulatory frameworks which can now be used as templates for replication to reduce front-end-project costs for follow on projects. With the experience of operating the Quest carbon-capture facilities, areas are being identified in which contingencies in the design could be reduced. The MMV system is state-of-the-art and also a testing ground for various technologies. With prolonged injection experience at Quest, the program will be able to narrow down which technologies would be best suited for future CCS applications ▪

CONCLUSION

In addition to the novel application of CCS in an oil sands facility, Quest has yielded numerous lessons learned and best practices relevant to both technical and non-technical risks, which can help reduce the time, effort and cost required to advance other CCS projects worldwide. With prolonged operation and injection experience at Quest more information will be made available. Globally Quest can serve as a model for advancing and deploying CCS in oil sands and other industrial operations ▪

Resources

1. Athabasca Oil Sands Project (AOSP) - http://www.shell.com/global/aboutshell/major-projects-2/athabasca/overview.html
2. Alberta Oil Sands Statistics - http://www.energy.gov.ab.ca/OilSands/791.asp
3. S Bourne, S Crouch, M Smith, 2015, A risk-based framework for measurement, monitoring and verification of the Quest CCS project, Alberta, Canada, International Journal of Greenhouse Gas Control, 26: 109-126
4. Quest Knowledge Sharing: http://www.energy.alberta.ca/CCS/3848.asp