Quest CCS

Future pathways to more CCS/CCUS deployment based on the success of Quest

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Business Opportunity Manager
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The energy challenge

There is more demand for energy globally as the world’s population and living standards increase.

Growing population
Global population is expected to increase from around 7.4 billion today to nearly 10 billion by 2050, with 67% living in cities.

Rising demand
Global energy demand will likely be almost 60% higher in 2060 than today, with 2 billion vehicles on the road (800 million today).

Ongoing supply
Renewable energy could triple by 2050, but we will still need large amounts of oil and gas to provide the full range of energy products that the world needs.

Mitigating climate change
Net-zero emissions is a potentially achievable societal ambition.
PROJECTED GLOBAL ENERGY DEMAND

Million barrels of oil equivalent a day

Source: Shell analysis, February 2014

Shell’s alternative energies:
- Biofuels
- Wind energy
- Hydrogen fuel
Towards a lower-carbon future

Shell is working to meet the energy challenge in many different ways.

- Continued investment in oil and gas to meet growing demand
- Bringing cleaner-burning natural gas to a wider market
- Managing the greenhouse gas emissions from our own operations
- Building a profitable New Energies business
- Industry leader in carbon capture and storage
- Advocating government-led carbon-pricing mechanisms
Shell Involvement in CCUS projects

Industry leader in carbon capture and storage

- Industrial scale projects in operation
- Industrial scale projects in construction
- Planned but cancelled industrial scale project
- Involvement through Shell Cansolv technology – no Shell equity

**Quest CCS**
- 1 mtpa
- Capture: amine
- Shell operated

**Lula CCUS**
- 0.7 mtpa
- Capture: membrane
- Petrobras operated, Shell is a JV partner

**TCM test centre**
- up to 100 ktpa
- Capture: various technologies
- Shell is a JV partner and tests at TCM

**Peterhead CCS (cancelled)**
- between 3-4 mtpa
- Capture: amine
- Chevron operated, Shell is a JV partner

**Gorgon CCS**
- up to 1 mtpa
- Capture: amine
- Sasol project, uses Shell licensed technology

**Boundary Dam CCUS**
- 10–15 million tonnes over the project’s lifetime
- Capture: amine
- Shell project developed with SSE through FEED but project cancelled
Quest CCS Overview

- One million tonnes CO$_2$ per year capacity
- Equivalent to emissions from ~250,000 cars
- 35% reduction of Scotford upgrader CO$_2$ emissions
- CO$_2$ capture at the upgrader from 3 hydrogen manufacturing units
- CO$_2$ transported by 12 inch pipeline to storage
- Permanent storage 2 km underground in the Basal Cambrian Sands
Quest Performance

Capture:
- Quest has captured, transported, and safely stored over **2 million tonnes of CO₂**
- Quest has the global CCS record for total injection volumes in a one-year period – **1.2 Mtpa CO₂**
- Operating costs lower than expected due to operating efficiencies

MMV:
- MMV systems working well – no triggers
- Multiple technologies indicate that the CO₂ is where it is expected to be

Wells:
- Only 2 wells active – contributing to significant wells and MMV savings

Reservoir:
- Excellent injectivity – comparable to high case scenarios
- After 25 years, we only expect to use 5-7% of the available pore space
CCS Policy Needs

CCS will require:
- An effective government imposed CO₂ pricing mechanism;
- A level playing field with alternative low carbon technologies; and
- Short term demonstration support to drive down costs

**FIRST OF A KIND**
- Development
  - CAPITAL GRANTS *(SUPPORT BUILD)*
- Demonstration
  - OPEX SUPPORT *(ENSURE PLANT OPERATES)*
- Deployment
  - EFFECTIVE CO₂ PRICING MECHANISM

**N² OF A KIND**
- NON-FINANCIAL MEASURES *(ENABLING REGULATIONS, LIABILITY AGREEMENTS, ETC)*
Opportunity for CCUS to bridge to full scale-deployment

- Replication/experience drives down cost

- CCUS allows for profitable carbon capture as a pathway to full-scale CCS deployment

- Alternative uses can drive CO2 demand and positively influence the supply/demand balance.
# Project Costs (Mln CAD)

<table>
<thead>
<tr>
<th></th>
<th>Mln CAD</th>
<th>Mln USD, Assuming rate of ~0.8</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FEED</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>139.4</td>
<td>~112</td>
</tr>
<tr>
<td><strong>CAPEX</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor and commissioning</td>
<td>147.9</td>
<td>~118</td>
</tr>
<tr>
<td>Tie-ins</td>
<td>37.1</td>
<td>~30</td>
</tr>
<tr>
<td>Capture</td>
<td>437.5</td>
<td>~350</td>
</tr>
<tr>
<td>Transport</td>
<td>127.4</td>
<td>~102</td>
</tr>
<tr>
<td>Storage</td>
<td>40.4</td>
<td>~32</td>
</tr>
<tr>
<td>Total CAPEX</td>
<td>790.3</td>
<td>~632</td>
</tr>
<tr>
<td><strong>Total for CAPEX + FEED</strong></td>
<td>929.7</td>
<td>~744</td>
</tr>
<tr>
<td><strong>Annual OPEX</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016 Actual</td>
<td>30.2</td>
<td>~24.2</td>
</tr>
<tr>
<td>2017 Estimate</td>
<td>35</td>
<td>~28</td>
</tr>
</tbody>
</table>

Project revenues (in Mln CAD)

### Funding and Grant

<table>
<thead>
<tr>
<th>Source</th>
<th>2009 - 2014</th>
<th>2015</th>
<th>2016+ Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alberta Innovates Grant</td>
<td>6.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NRCan Funding</td>
<td>108</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>GoA Funding</td>
<td>298</td>
<td>149</td>
<td>298</td>
</tr>
<tr>
<td>Total funding</td>
<td>412.6</td>
<td>161</td>
<td>298</td>
</tr>
<tr>
<td>Cumulative on Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spend (%)</td>
<td>30.2%</td>
<td>42.0%</td>
<td>63.9%</td>
</tr>
</tbody>
</table>

### CO₂ Reduction Credits

- 2016 – 3.3 MCAD

Cost per Tonne CO₂

Estimate of the Cost per Tonne of CO₂ for the Alberta’s CCS Funding Program

<table>
<thead>
<tr>
<th></th>
<th>2015**</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capture</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annualized CAPEX</td>
<td>$ million</td>
<td>41.20</td>
</tr>
<tr>
<td>Annual OPEX</td>
<td>$ million</td>
<td>8.12</td>
</tr>
<tr>
<td>Total</td>
<td>$ million</td>
<td>49.32</td>
</tr>
<tr>
<td><strong>Transport</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annualized CAPEX</td>
<td>$ million</td>
<td>8.97</td>
</tr>
<tr>
<td>Annual OPEX</td>
<td>$ million</td>
<td>0.01</td>
</tr>
<tr>
<td>Total</td>
<td>$ million</td>
<td>9.98</td>
</tr>
<tr>
<td><strong>Storage</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annualized CAPEX</td>
<td>$ million</td>
<td>7.42</td>
</tr>
<tr>
<td>Annual OPEX</td>
<td>$ million</td>
<td>1.78</td>
</tr>
<tr>
<td>Total</td>
<td>$ million</td>
<td>9.21</td>
</tr>
<tr>
<td><strong>Total CAPEX + OPEX</strong></td>
<td>$ million</td>
<td>67.51</td>
</tr>
<tr>
<td>Annual CO₂ Captured</td>
<td>million tonnes</td>
<td>1.03</td>
</tr>
<tr>
<td>Annual CO₂ Avoided</td>
<td>million tonnes</td>
<td>0.87</td>
</tr>
<tr>
<td>Reported Cost/Tonne Captured</td>
<td>$/tonne</td>
<td>65.31</td>
</tr>
<tr>
<td>Reported Cost/Tonne Avoided</td>
<td>$/tonne</td>
<td>77.35</td>
</tr>
</tbody>
</table>

Note: The costs in this table are in Canadian currency.

- Reported $/t cost is lower than forecasted $/t cost due to lower actual OPEX.
- The calculation is performed using methodology specific for the projects under the Funding Agreement (funding by Canadian government).
- The discount rate is weighted 75% towards the Alberta’s 10 year term bond rate and 25% towards the industry standard discount rate.
- Use of a different methodology including discounting of CO₂ (PV/RT, PV/PV, …) and value of discount rate may result in a different $/t outcome.

74 USD/t CO₂ avoided (at 0.8 USD/CAD)
Transport

- CO$_2$ compressed to >10 MPa to keep the CO$_2$ in dense phase through entire pipeline
- 65 km pipeline with 6 block valves (every 4-15 km)
- Pipeline construction Oct 2013 – Aug 2014, with over 30 re-routes to accommodate landowner requests
Where is the CO₂ stored?

- **PreCambrian Shield**: 40m
- **Upper Cambrian Shale**: 85m - **Primary Seal**
- **Lower Lotsberg Salt**: 10m - **Secondary Seal**
- **Upper Lotsberg Salt**: 85m - **Ultimate Seal**
- **Prairie Evaporite**: 85m - **Additional Seal**

**BCS Storage Complex**
How is the CO₂ stored and monitored?

- Sequestration Lease area of 3,670km²
- Three wells (only using 2)
- Current estimate of max plume lengths: 2.5 to 4.2 km
- First of a kind monitoring plan
  - Conservative approach
  - Comprehensive: from atmosphere to geosphere
  - Independently reviewed
Quest MMV Plan

- First of a kind – conservative approach
- Comprehensive: from atmosphere to geosphere
- Risk-based
- Site-specific
- Independently reviewed
- Combination of new and traditional technologies
- Baseline data collected before start-up
Regulatory Overview

Worked with the regulator to help create good regulatory environment for CCS:

- Create carbon credit system to provide incentives for sequestration
- Define pore space tenure – understand the subsurface impact
- Clarify long-term liability, closure planning
- Set requirements for monitoring, measurement and verification (MMV)
- Build quantification protocol (based on ISO standard)
Government Support

- Total Cost of Quest - $1.35 billion, FEED, Capital + 10 years OPEX

- The governments of Alberta and Canada contributed CAN $745M and CAN $120M respectively to Quest, for a total of $865M

- As a result of the funding, Quest is required to have:
  - extensive knowledge sharing
  - stringent reporting and MMV plan
  - net revenue neutral requirement
A BETTER LIFE WITH A HEALTHY PLANET. PATHWAYS TO NET-ZERO EMISSIONS

Shell’s latest thought piece builds on its 2013 New Zero Scenarios to illustrate choices, challenges and ideas for society to decarbonise the global economy in a way that might address both the challenge of climate change and the desire for broader economic growth.

The Shell Scenarios, Mountains and Oceans, provide a detailed analysis of current trends and their likely trajectory into the future. They delve into the implications for the pace of global economic development, the types of energy we use to power our lives and the growth in greenhouse gas emissions.

The two scenarios also highlight areas of public policy likely to have the greatest influence on the development of cleaner fuels, improvements in energy efficiency and on moderating greenhouse gas emissions.

To learn more, visit www.shell.com/scenarios

MOUNTAINS
This is the world with status quo power locked in and held tightly by the currently influential.

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Plausible balance in an Emerging Net-Zero Emissions World

Meeting the goal of the Paris Agreement by balancing emissions from sources and removals by sinks

The diagram shows how the balance is met. The upper section of the diagram shows the emissions from fossil fuels. Most CO2 is either captured by CCS or embedded in materials produced by the chemicals industry; the remaining 6.8Gt CO2 is emitted to the atmosphere. The lower part of the diagram shows the accounting from the biomass resource base with 6.8Gt CO2 of net-negative emissions. The configuration of the energy system, across fossil energy and biomass, nets out to zero CO2 emissions.

CO₂ Capture

- The Hydrogen Unit combines steam and natural gas to produce high pressure steam and H₂ for use in the upgrader
- The Amine Unit uses Shell technology to capture the CO₂ directly from the process
- The process produces a 99% pure CO₂ output
- Award winning integrated, modular construction (Fluor)
Transport

- CO₂ dehydrated and compressed to >10 MPa to keep the CO₂ in dense phase through entire pipeline
- 65 km pipeline with 6 block valves (every 4-15 km)
- Pipeline construction Oct 2013 – Aug 2014, with over 30 re-routes to accommodate landowner requests
- Cleaning and preserved with nitrogen by October 2014
- First CO₂ into pipeline August 2015
Storage Facility

• 3 well pads: each pad has 1 injection well, 1 deep monitoring well and multiple shallow ground water wells

• Conventional drilling methods

• Multiple steel casings for injection wells, 3 in freshwater zone, all cemented to surface

• Comprehensive Measurement, Monitoring and Verification program
Quest Capture Learnings

• Compressor reverse rotation – shutdown depressuring study based on installed arrangement

• Carbon steel in low pH water service – piping spec changes must be caught in design phase

• Filtration Management – foaming/flooding in amine absorbers tied to carbon entrainment and throughput management

• Existing HMU operating strategy required modifications to operate reliably in Quest mode – successfully implemented

• Below Budget Chemical Loss – both TEG and amine

• Reliability Performance Beating Plan – good design and operating strategies producing strong CO₂ capture performance
**Quest Storage Learnings**

**MMV:**
- MMV systems working well – no triggers
- Microseismic array has been very quiet
- VSPs can image CO₂ in the BCS, DAS working well

**Wells:**
- Only 2 wells active – significant wells and MMV savings
- Pulse neutron logging confirmed that CO₂ is where it is supposed to be
- Important to keep water out of the wells, even the small amounts routinely used during logging

**Reservoir:**
- Excellent injectivity – comparable to high case scenarios
- After 25 years, we expect to use 5-7% of the available pore space
- Current estimate is that the ΔP at the end of the project may only be 2 MPa.
Stakeholder Learnings

• The need to listen
  • Perceived risk can be as real and important as actual risk
• Hear concerns and accept them as legitimate
  • Be open to changing the plan to accommodate community feedback
• Meet stakeholders on their terms and where they are comfortable
  • Don’t expect them to come to you and then be surprised when they later raise objections
• Develop consistency and deep relationships
  • They may mistrust the organization, but they will trust people
• They want to get to know the leaders and the experts – not just community relations team