Outline

• Boundary Dam 3 - Review of the project business case.
• Boundary Dam 3 – Operational update
• Shand 2nd Generation CCS Study
The project consisted of two major parts:
1) refurbishment of the power unit and
2) capture facility construction

Refurbishment included a complete replacement of the steam turbine and generator, which were at their end of life, to provide adequate steam extraction to the capture facility while maximizing the output of the power plant.

Capture involves taking out other components before the amine removes the CO2. Nominal capture 1 Million Tonnes Year
Overview of the BD3 Project

• Projected approved in 2011, as the lowest cost option for electricity supply at the time
• BD3 went on line October 2014
• Projected 90% capture rate and 30 yr plant life extension
• Initial investment = approximately CDN$1.5 billion
• CO2 is sold for EOR or sequestered at Aquistore
Carbon Capture and Storage Initiatives

EXECUTIVE STRATEGIC PLANNING SESSION

THE WORLD’S 1ST INTEGRATED LARGE SCALE POST-COMBUSTION CCS FACILITY

BOUNDARY DAM
1. Operated at design capacity (3200 t/day) for 3 days

2. Capture of 800Kt of CO2 between Nov ‘15 - Oct ‘16

3. Total capture of 2Mt by Mar ‘18

4. Operation of the capture facility 98.3% of the time Jan - Apr ‘18.

*Trend of higher capture rate and reduced outages over time*
BD3 Performance Continued

![Graph showing CO2 Captured (tpd) and Unit Output (MW) from September 2017 to January 2019. The graph displays fluctuating CO2 capture and unit output over time.]
BD3 Performance: Exceeding Federal Coal Emissions Regulations

- **1100 t/GWh** = Lignite Coal Plant
- **550-500** = Current Natural Gas Plant
- **420** = Canadian Regulations on Coal Plant
- **375-400** = New Natural Gas Plant
- **300-325** = Wind (with peakers)
- **120-140** = CCS on Boundary Dam 3*

*Name plate capacity*
Introduction: The Shand CCS Feasibility Study

• The Shand CCS Feasibility Study was undertaken to evaluate the economics of a CCS retrofit and life extension on what was believed to be the most favorable host coal fired power plant in SaskPower’s fleet.
• Demonstrates the value of lessons learned.
• Collaboration between Mitsubishi Heavy Industries (MHI), Mitsubishi Hitachi Power Systems (MHPS), SaskPower and The International CCS Knowledge Centre (Knowledge Centre).
The Cost of CCS

Capital Costs reductions of the next CCS facility are expected at 67%

- The Shand CCS project would produce the second, full-scale capture facility in Saskatchewan with a design capacity of 2 million tons of CO₂ capture per year – twice the initial design capacity of BD3.
- Reductions in capital costs have been evaluated and are projected at 67% less expensive than they were for BD3 on a cost per tonne of CO₂ basis. This extensive reduction may be attributed to:
  a) lessons learned from building and operating BD3,
  b) construction at a larger scale using extensive modularization, and
  c) integration advantages afforded by the bigger 300MW units steam cycle.

Figure 2. Cost reduction of the Shand 2nd generation CCS facility as compared to the BD3 project.
The Cost of CCS

**The Calculated Cost of Capture from the Shand CCS Facility would be $45US/tonne of CO₂**

- **Economies of scale** contribute to cost savings realized by moving to the larger 300 MW unit
- **Factors considered when calculating the Levelized Cost Of Capture (LCOC) included:**
  - 30-year sustained run-time of the power plant
  - capture island capital costs
  - capture island OM&A and consumables costs
  - power island modifications costs
  - cost of the power production penalty assuming purchasing of power lost due to CO₂ capture-related generation losses at costs consistent with new Natural Gas Combined Cycle (NGCC) power supply

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**Figure 3.** Cost reduction of the Shand 2nd generation CCS facility as compared to the BD3 project
Key Findings of the Study

**Thermal Integration and Host Selection**
- Steam extraction to reboiler sourced from IP-LP crossover; addition of butterfly valve enables **continued capture operations at reduced loads**
- Use of rejected flue gas heat for LP condensate preheating using a FGC and novel condensate preheating loop configuration (3 CPHs aligned in series with LP FWHs 1 and 2) helps to reduce the energy penalty
- Overall parasitic load was determined at 22.9%
Key Findings of the Study

**Heat Rejection Design Considerations**

- CCS retrofit of Shand increases the heat rejection requirement by 50%.
- Shand operates as a Zero Liquids Discharge (ZLD) facility; additional water draw is not possible.
- New hybrid wet surface air cooler heat rejection system consists of air cooled heat exchangers (ACHE) and wet surface air coolers (WSAC) connected in series:
  - Water requirements satisfied solely by flue gas condensate.
  - Designed at the 85 percentile of a 26 years survey of Estevan weather data.
  - Dry cooling favored during summer months while wet cooling is dominant at cooler temperatures.
  - Average colder climate in Saskatchewan shifts the annual average of heat rejection load in favour of wet cooling.
- Overall power consumption for the design case is 4.96 MWe; the annual average of 2.58 MWe which is 52% of the design case.

![Figure 10. Proposed new hybrid heat rejection system](image)

![Figure 11. Variation in annual heat reject load](image)
Key Findings of the Study

**Power Plant Reliability / Capture Plant Partial Capacity**
- “Dual mode” is a risk mitigation strategy that allows continued power plant operations when experiencing issues with the capture facility
- Diverter dampers allows partial flue gas diversion

**Grid Support and Ancillary Services**
- Load adjustments of large thermal power stations are dictated by the supply-demand balance in the electricity grid
- Viable CCS would have to maintain the flexible operating range

**Plant Maintainability**
- Current coal fired power plant designs are the product of multiple generations of revision
- This level of refinement has not yet been achieved with amine based CCS facilities
- Experience at BD3 highlighted key process isolations and redundancy at selected locations in the process; these have been considered in the Shand CCS design
Key Findings of the Study

**CO₂ Market**
- CO₂ EOR opportunities exist within 100 km of Estevan, Saskatchewan
- Economical development of these opportunities is key to a successful CCS retrofit
- Opportunity exists to join the Shand CO₂ pipeline to the BD3 pipeline; this would increased reliability of CO₂ supply and reduce penalties associated with delivery challenges
- CO₂ from BD3 that is currently not sold to off-taker(s) could be used to develop the CO₂-use market prior to the completion of the Shand CCS facility
- Excess CO₂ capture volumes could be sequestered within the capacity of the existing Aquistore dedicated geological storage project.

![Figure 15. Location of potential CO₂ EOR in south east Saskatchewan](image-url)
Key Findings of the Study

**Over-Capture at Reduced Load**
- At lower loads the capture rate exceeds 90%
- Sensitivity analysis indicated capture rates reaching in excess of 96% at 75% load
- CCS equipped coal-fired power plant could be made responsive to variable renewable generation

**Increasing Capture Capacity From 90% to 95%**
- 95% capture is possible
- Overall increase in capital costs required to facilitate the increase in capture produces a lower overall cost per tonne

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**Table 2. Average performance for Shand CCS with 90% and 95% design capture at full load**

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>90% Capture</th>
<th>95% Capture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Electricity Production (MWh)</td>
<td>1,539,815</td>
<td>1,526,057</td>
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<tr>
<td>CO₂ Emissions (Tonnes)</td>
<td>163,521</td>
<td>108,991</td>
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<tr>
<td>CO₂ Emission Intensity (kg/MWh)</td>
<td>106.2</td>
<td>71.4</td>
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</tr>
</tbody>
</table>

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*Figure 17. Summary of % capture rate and energy consumption with variation in flue gas flow rate*
Emissions Profile of a Shand CCS Retrofit

Figure 18. Emission intensity of an NGCC plant integrated with wind

Figure 19. Emission intensity of a CCS coal plant integrated with wind
Studies

The International CCS Knowledge Centre experts spearheaded a feasibility study to retrofit SaskPower’s Shand Power Station, (Shand) a 330-MW coal-fired power plant that has double the capacity of Boundary Dam 3 CCS Facility (BD3) with a large-scale CCS facility.

- Read Full Public Report (110 pages) - Shand CCS Feasibility Study, click here
- Read Compendium Document - Summary for Decision Makers, click here
- Read Summary for Decision Makers in Charlie, click here

Read the announcement on the public release of the Shand Study.
Read What Others Are Saying about the Shand Study.

Key Highlights of the Shand CCS Feasibility Study (Shand Study):
- The study shows that compared to the Boundary Dam 3 CCS project (BD3), a CCS system at Shand could see capture capital cost reductions.
- The study (92%) of carbon dioxide (CO₂) captured as well as potential savings to power plant integration capital cost.
- Based on the model, the levelized cost of captured CO₂ is calculated at $45/tonne.
- Second generation CCS can capture more emissions at lower costs (i.e. power generation) such that more than a 90% capture rate could be achieved.
- The study shows that CCS has the potential to integrate well with renewables which provide a varying load, CO₂ capture rate could be up to 97% and save up to 10% in capital cost.
BECCS AT SHAND POWER STATION

- Shand is a 305 MW, single unit, coal-fired power plant located in Saskatchewan, Canada.

- The current historically low natural gas price in North America enables fierce competition between NGCC and CCS coal fired facilities when considering the most economical means to reduce CO₂ emissions.

- If maximizing CO₂ emissions reductions is the desired outcome, a case favoring the CCS retrofit of coal and subsequent conversion to BECCS can be made.
Among NET technologies, BECCS is most promising as it provides a potential solution on dealing with existing coal plant infrastructure while reducing CO₂ emissions from fossil-fuel combustion.
Conclusions

• Boundary Dam 3 CCS business case was compelling at the time

• Low natural gas prices needs to be countered with other improvements to the business case in order to remain competitive

• A second generation CCS facility on coal is possible
  • Capital costs have been reduced by 67%
  • Calculated cost of capture would be $45US/tonne of CO₂

• BECCS may represent a significant opportunity, existing infrastructure can lower the cost if not retired
Thank You

For more information please visit our website at:
ccsknowledge.com

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