CCUS Business Cases

INTERNATIONAL CCS KNOWLEDGE CENTRE

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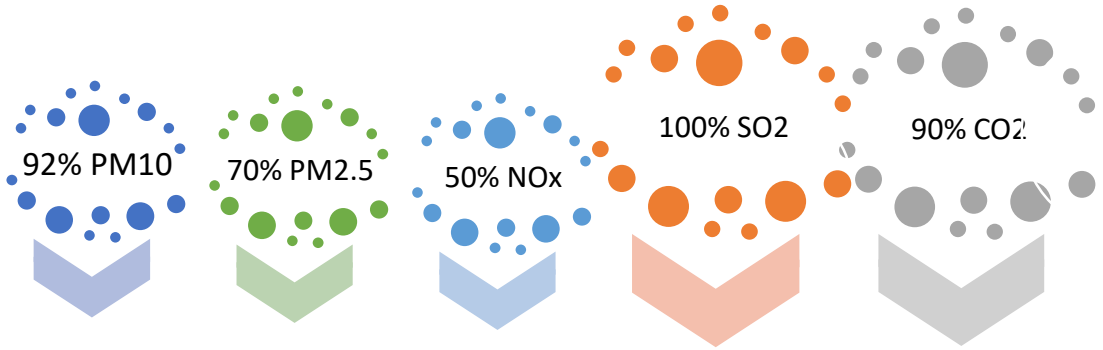
Outline

- Boundary Dam 3 - Review of the project business case.
- Boundary Dam 3 – Operational update
- Shand 2nd Generation CCS Study

Overview of the BD3 Project

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 CO_2. 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

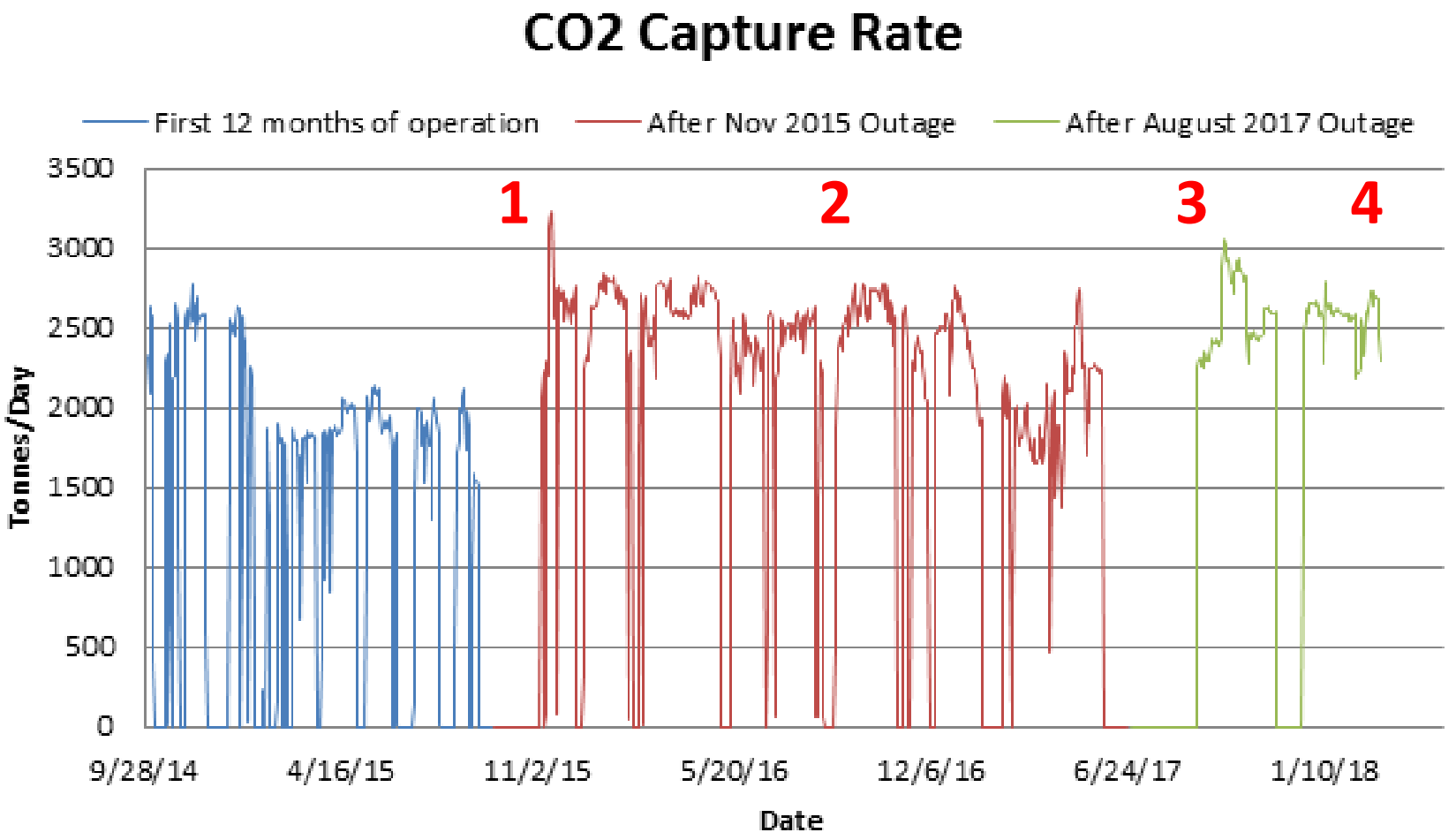
BOUNDARY DAM

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

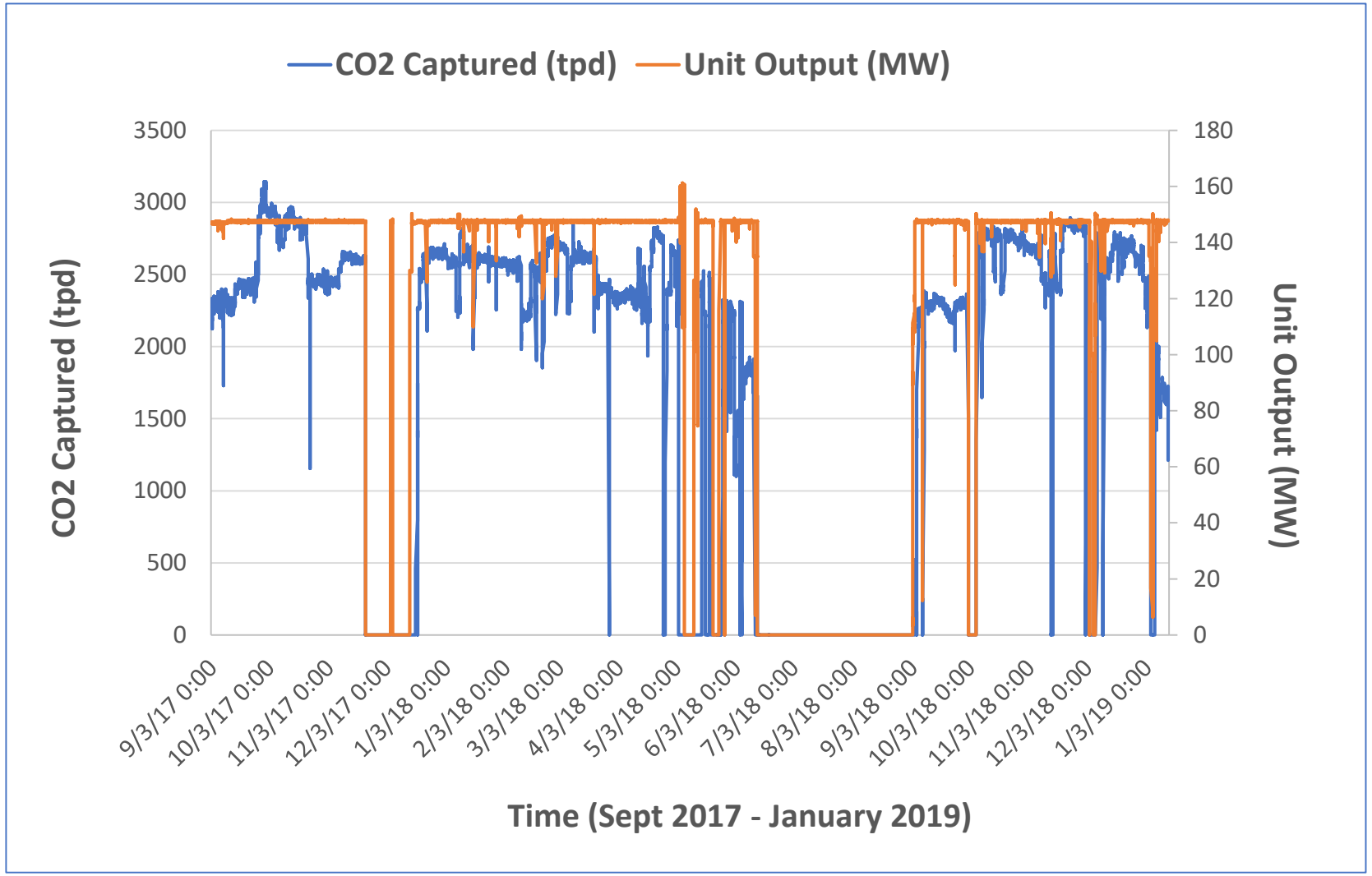
BD3 Operational Milestones

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



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

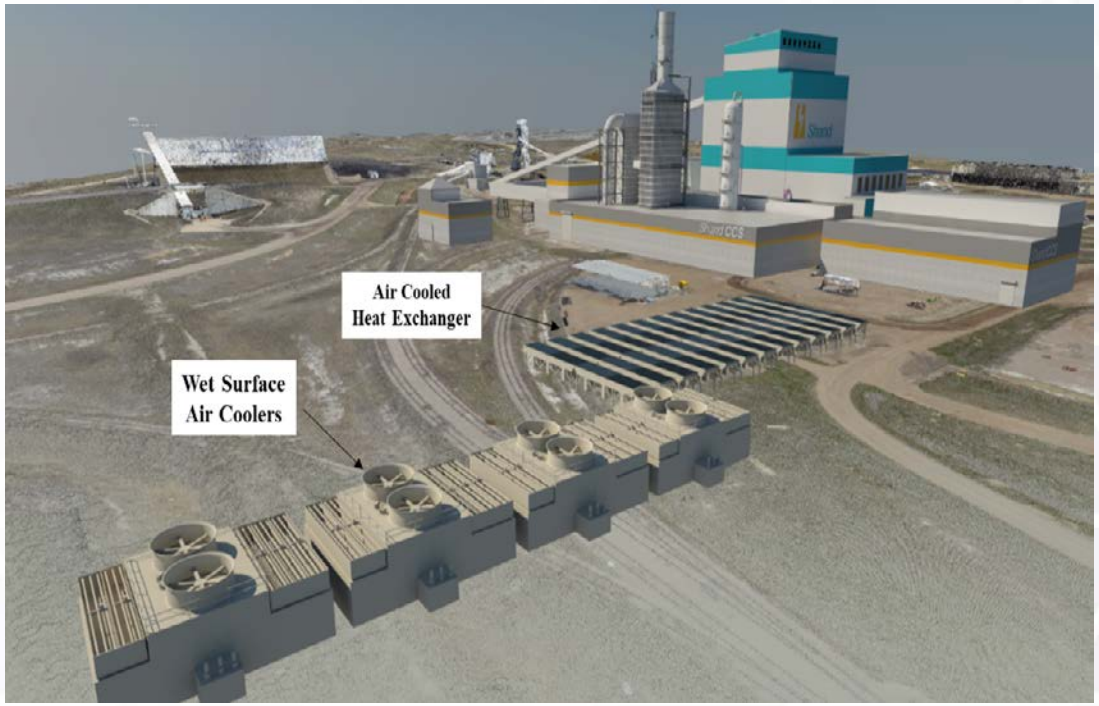
300-325 = Wind (with peakers)

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 CO_2 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 CO_2 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.

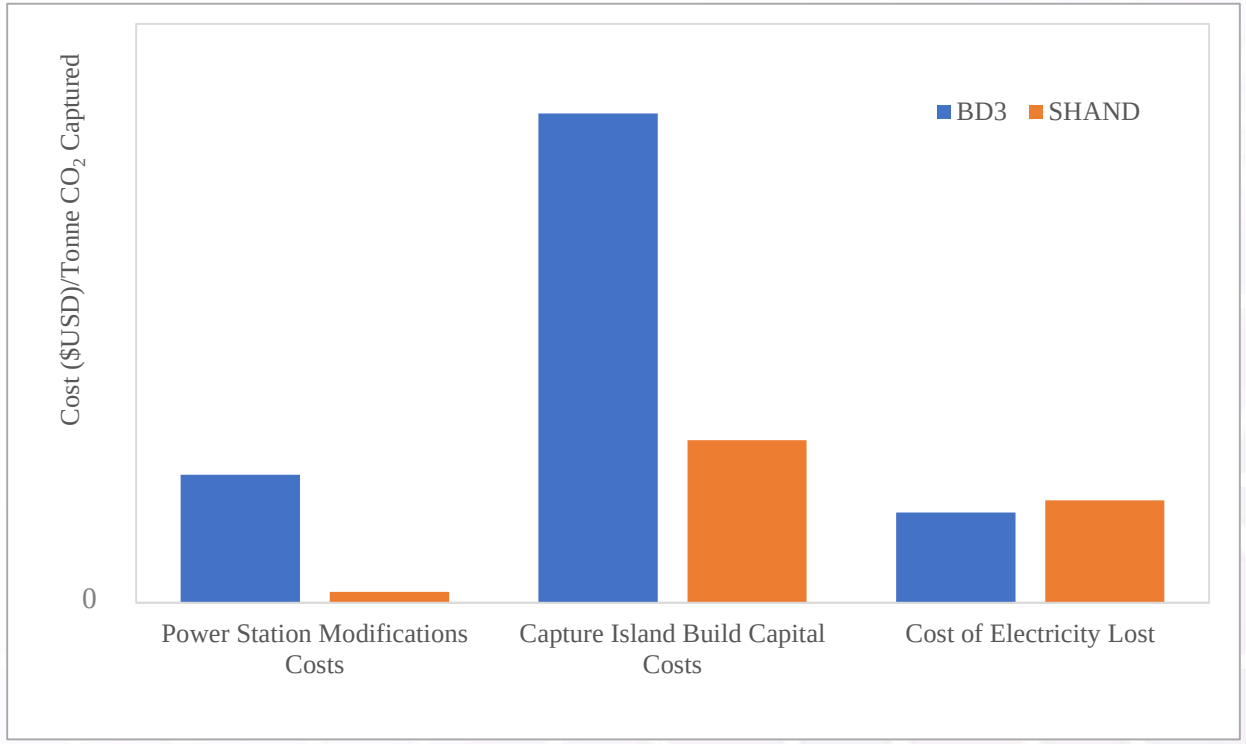


Figure 2. **Cost reduction of the Shand 2nd generation CCS facility as compared to the BD3 project**

The Cost of CCS

The Calculated Cost of Capture from the Shand CCS Facility would be *$45US/tonne of CO_2*

- 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 CO_2 capture-related generation losses at costs consistent with new Natural Gas Combined Cycle (NGCC) power supply

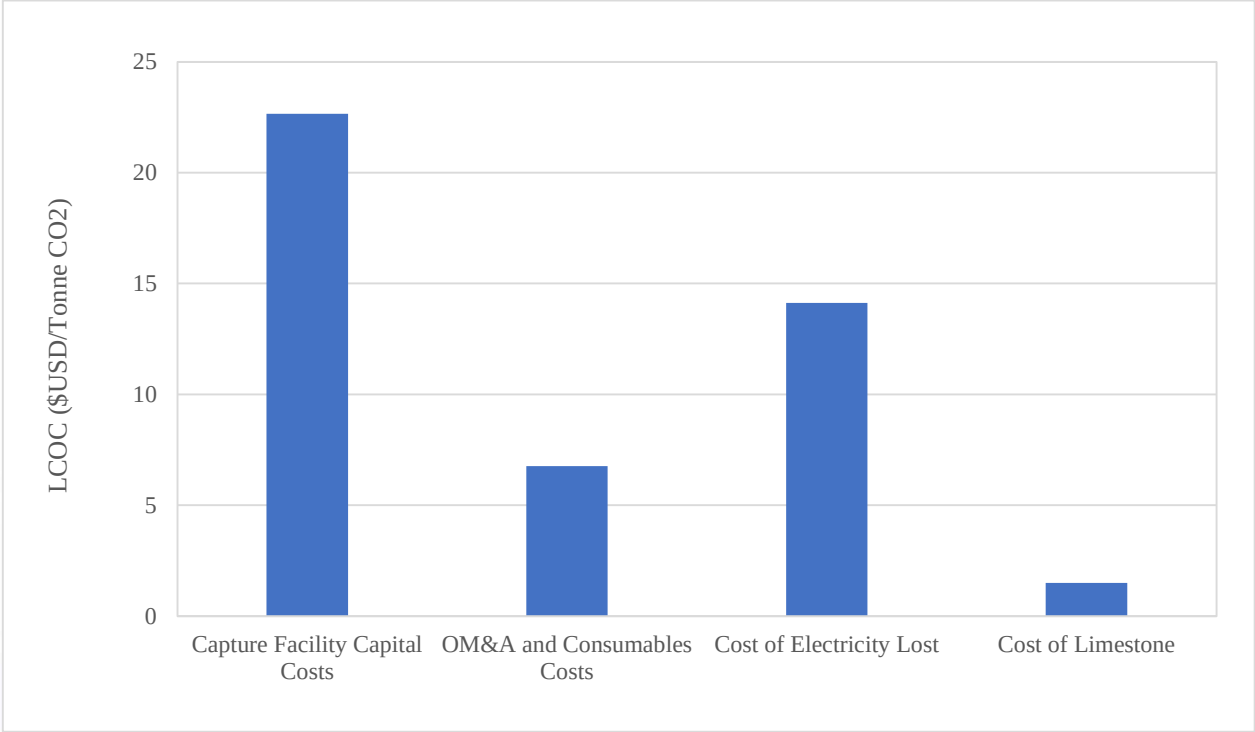


Figure 3. **Cost reduction of the Shand 2nd generation CCS facility as compared to the BD3 project**

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%

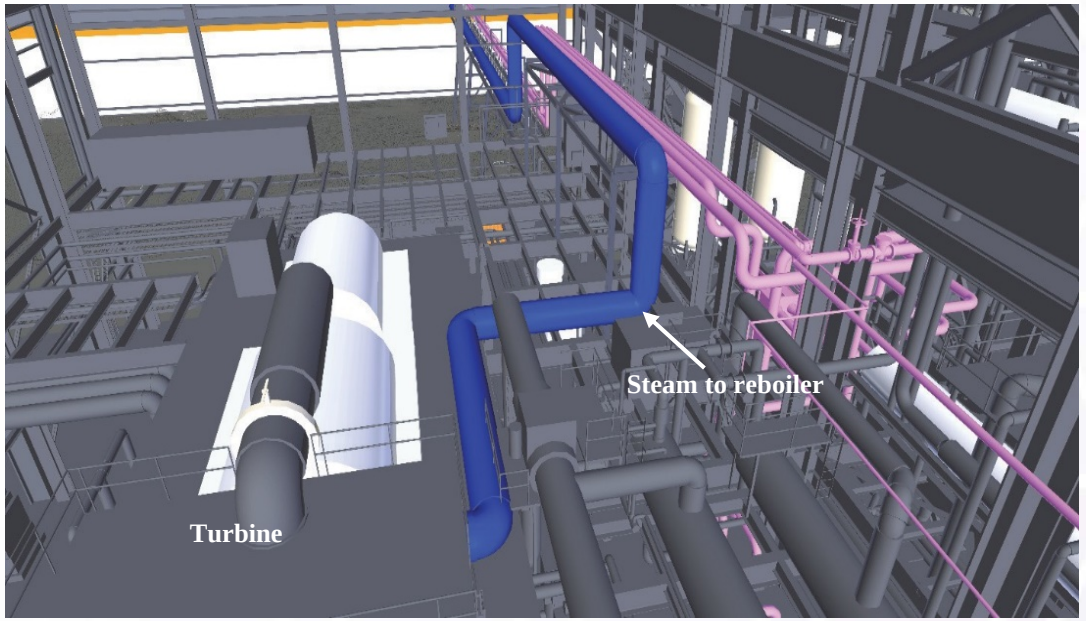


Figure 6. Proposed butterfly valve in IP-LP crossover

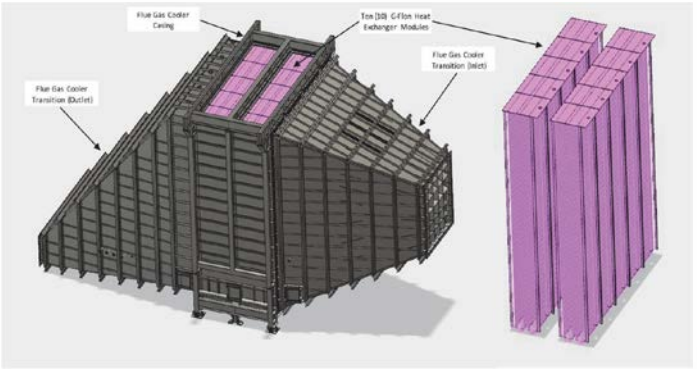


Figure 4. Proposed FGC and modules

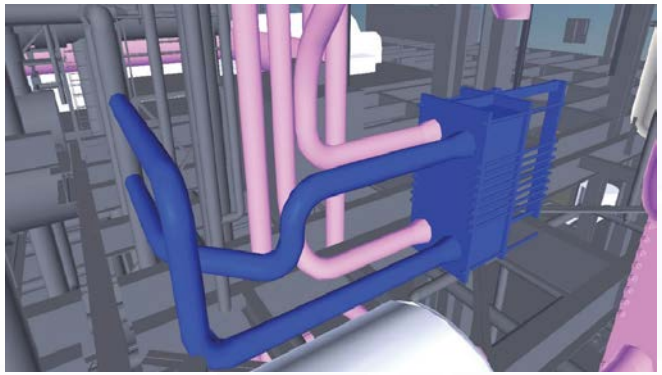


Figure 5. Proposed installation of CPH

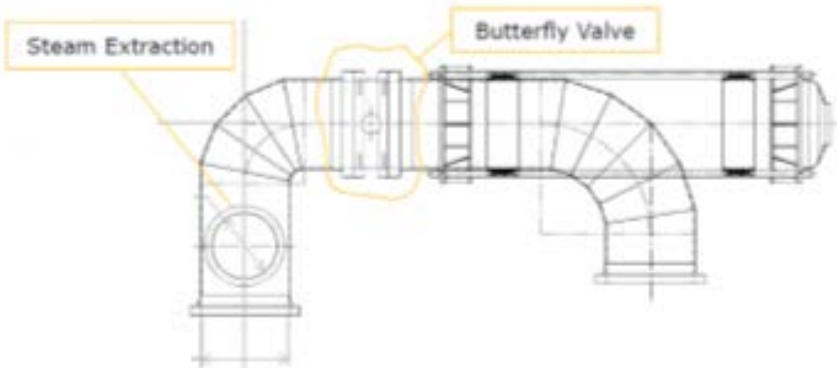


Figure 7. Proposed steam extraction line to the reboiler

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

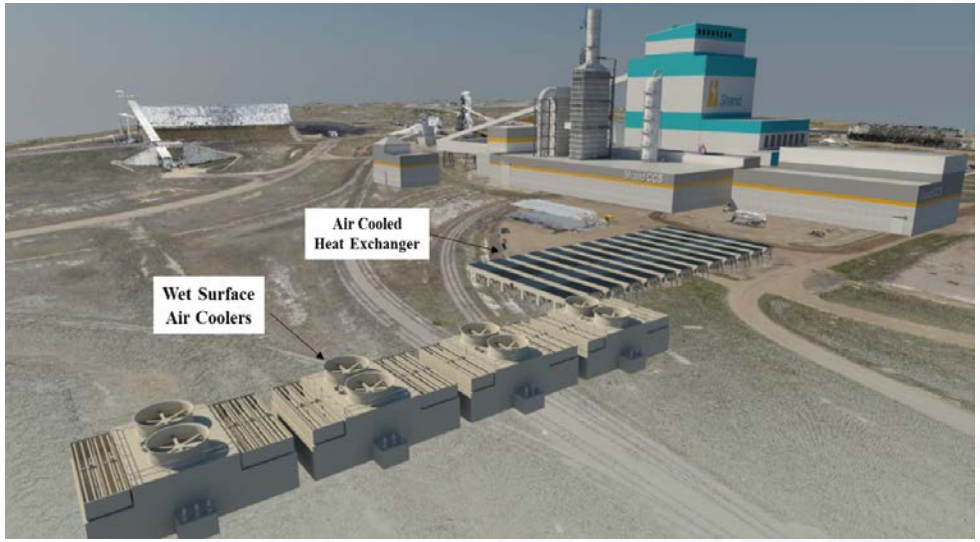


Figure 10. Proposed new hybrid heat rejection system

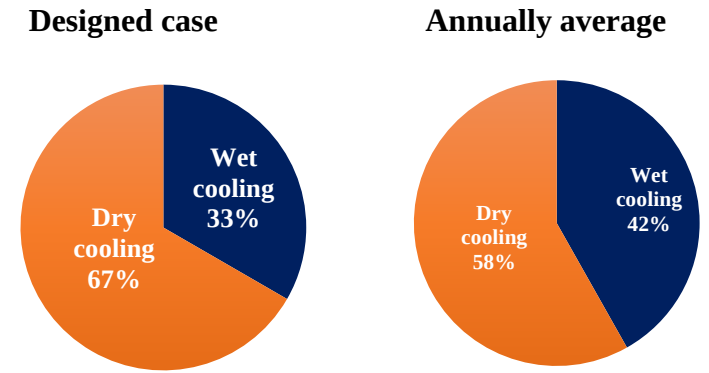


Figure 11. Variation in annual heat reject load

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

Figure 14. Proposed flue gas supply to the capture facility

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

CO_2 Market

- CO_2 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 CO_2 pipeline to the BD3 pipeline; this would increased reliability of CO_2 supply and reduce penalties associated with delivery challenges
- CO_2 from BD3 that is currently not sold to off-taker(s) could be used to develop the CO_2-use market prior to the completion of the Shand CCS facility
- Excess CO_2 capture volumes could be sequestered within the capacity of the existing Aquistore dedicated geological storage project.

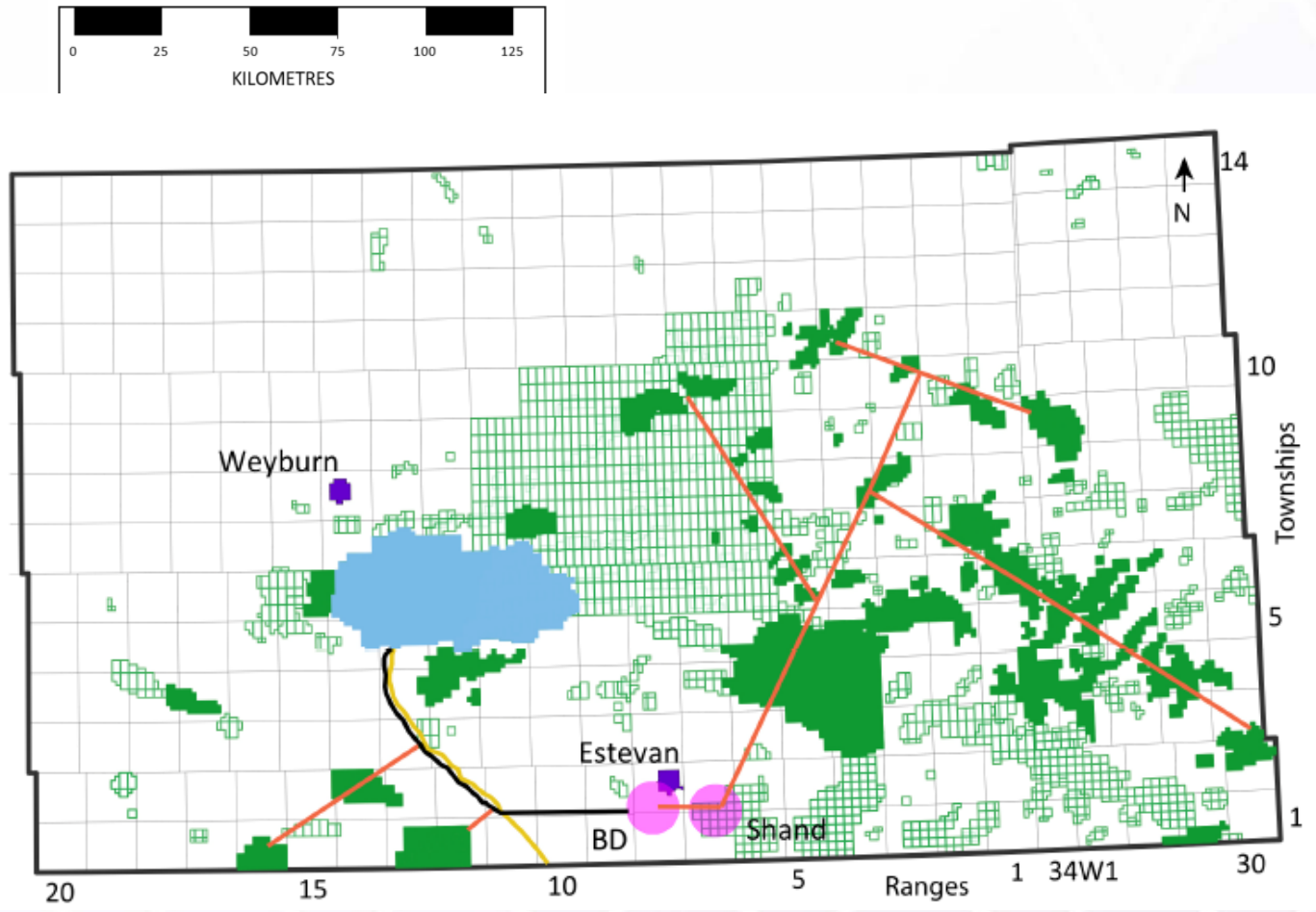


Figure 15. Location of potential CO_2 EOR in south east Saskatchewan

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

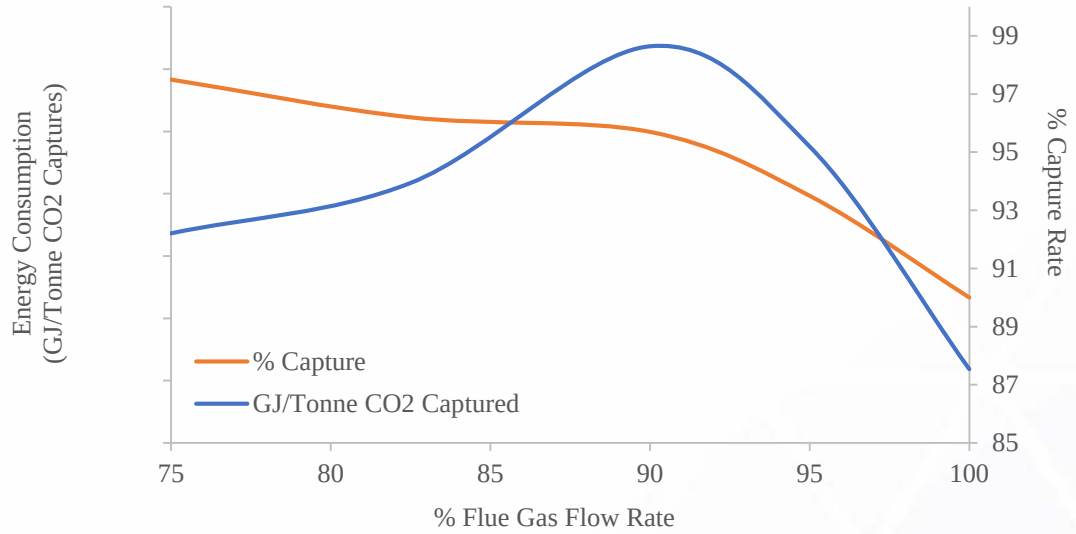


Figure 17. Summary of % capture rate and energy consumption with variation in flue gas flow rate

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

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

	Unit	90% Capture	95% Capture
Net Electricity Production	(MWh)	1,539,815	1,526,057
CO_2 Emissions	(Tonnes)	163,521	108,991
CO_2 Emission Intensity	(kg/MWh)	106.2	71.4

Emissions Profile of a Shand CCS Retrofit

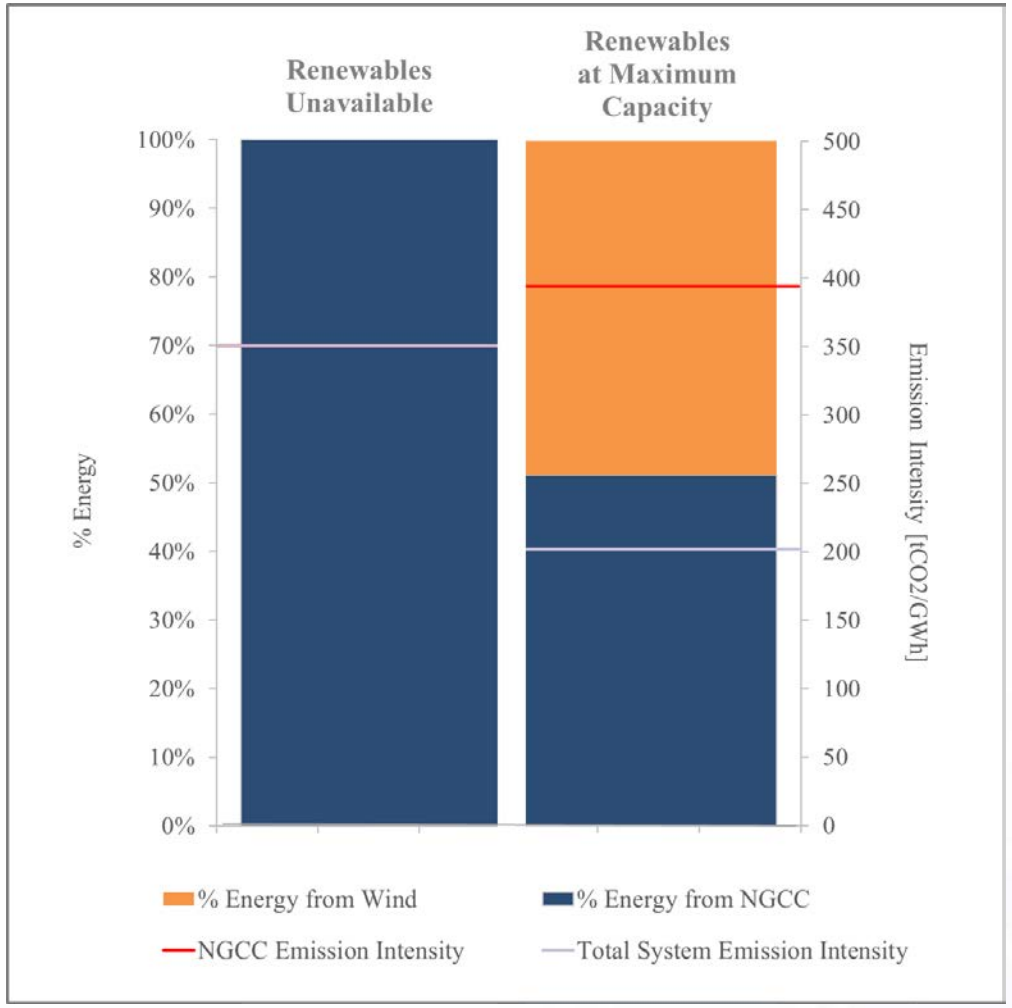


Figure 18. Emission intensity of an NGCC plant integrated with wind

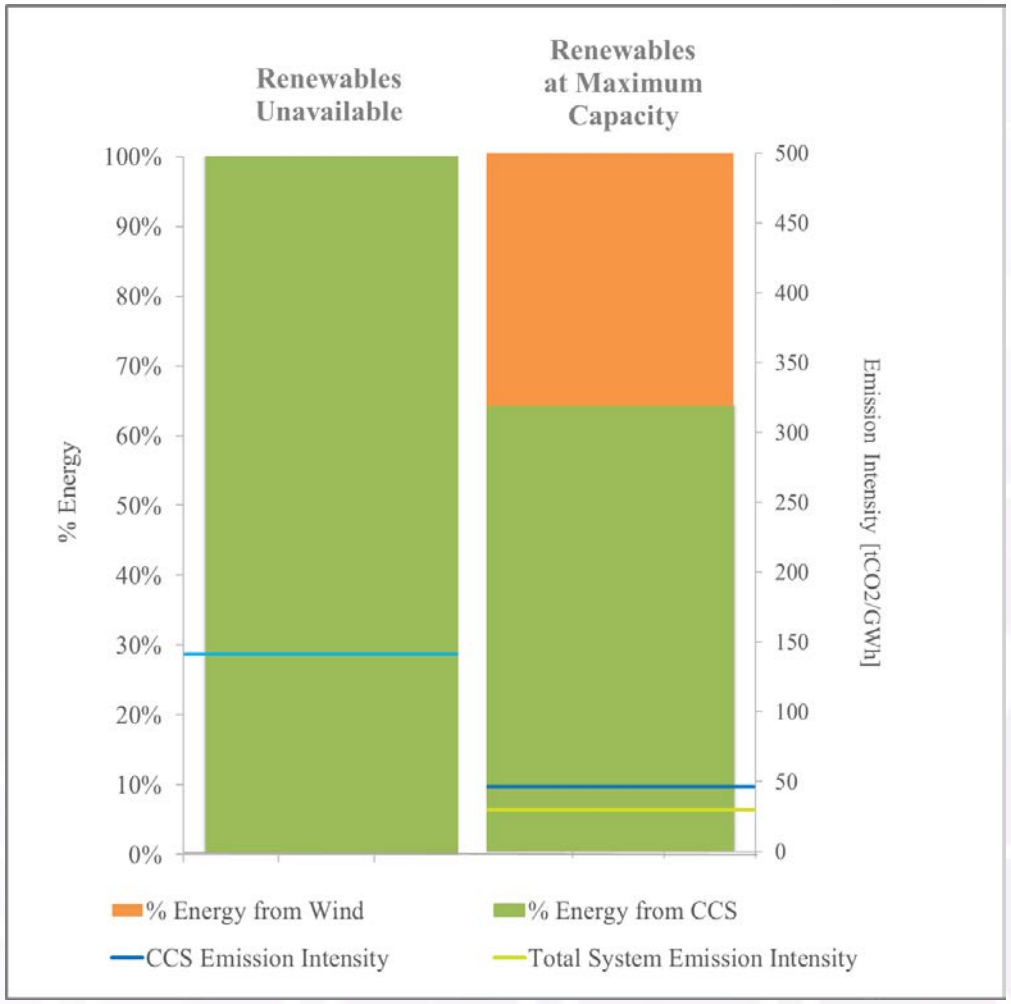


Figure 19. Emission intensity of a CCS coal plant integrated with wind

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2ND GENERATION CCS

Studies

The International CCS Knowledge Centre experts spearheaded a feasibility study to retrofit SaskPower's Shand Power Station, (Shand) a 300 – M 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 (120 pages) - *Shand CCS Feasibility Study*, click here
- Read Compendium Document - *Summary for Decision Makers*, click here
- *Read Summary for Decision Makers in Chinese, click here*

Read the announcement on the public release of the Shand Study.

Read What Others Are Saying about the Shand Study.

Key Hightlights 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 red of carbon dioxide (CO_2) captured as well as 92% in potential savings to power plant integration capital cost.
- Based on the model, the levelized cost of captured CO_2 is calculated at $45US/tonne.
- Second generation CCS can capture more emissions at lower loads (i.e. power generation) such that more than a 90% capture rate that CCS has the potential to integrate well with renewables which provide a varying load. CO_2 capture rate could be up to 97% at

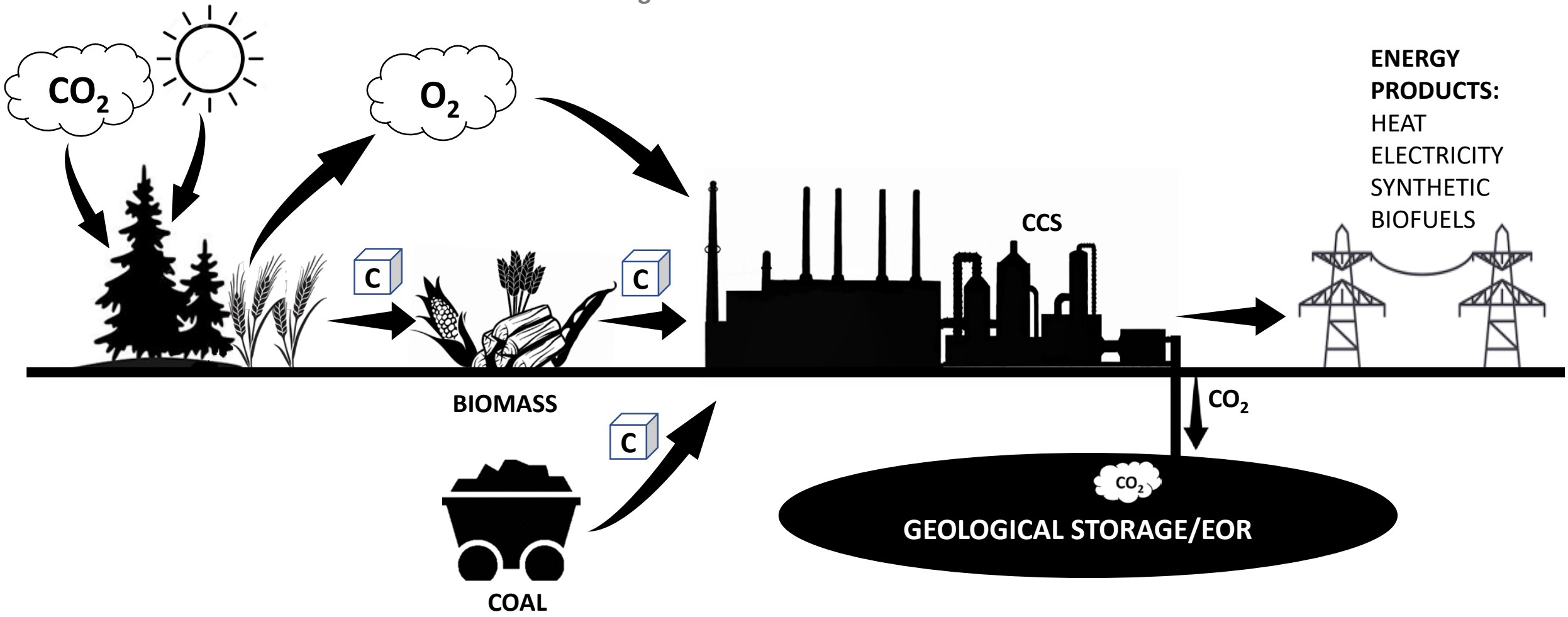
Link to Report - https://ccsknowledge.com/pub/documents/publications/.Shand%20CCS%20Feasibility%20Study%20Public%20Report_NOV2018.pdf

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 CO_2 emissions.
- If maximizing CO_2 emissions reductions is the desired outcome, a case favoring the CCS retrofit of coal and subsequent conversion to BECCS can be made

BIO-ENERGY WITH CARBON CAPTURE & STORAGE

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 CO_2
- BECCS may represent a significant opportunity, existing infrastructure can lower the cost if not retired

Thank You

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