WHY CHOOSE **POST COMBUSTION CAPTURE?**

RETROFITTING AN AGING COAL-FIRED POWER PLANT

It is important to note that choosing to shut down a coal-fired power plant is a final, irreversible decision to make and one that SaskPower cannot take lightly. The ability to continue to generate power from a price-stable, long-term supply of coal, albeit clean generation going forward, and to continue to benefit from a past capital investment in the power unit seemed the logically strategic course of action. It assured a diversity of power sources with the continued ability to generate power from coal, ensured a variety of fuel source pricing at any given point in time, and was simply a prudent approach to ensure power price stability in the future. However, whatever the course of action, it had to be the one that resulted in the lowest lifecycle cost of electricity.

Retrofitting a coal-fired power plant with post-combustion capture (PCC) technology to convert to clean power generation involved the following analyses:

1 Would the entire retrofit (power plant rebuild and capture plant new build) compete on a lifecycle basis with alternative power generation options?

2 Would the chosen CO_2 capture technology compete against alternative capture technologies in terms of capital and operating cost, technical operating risk, lifecycle cost of electricity, etc.?

When choosing a technology, its maturity will greatly impact how a project looks from inception to operation.

When choosing a technology, its maturity will greatly impact how a project looks from inception to operation. A mature technology would be preferred by any investor and strongly preferred by a power company like SaskPower that must deliver continuous service and the ability to generate the necessary power 24 hours each day, 7 days every week, 52 weeks of every year to meet demand needs.

All electric systems must maintain an "operating margin" that will keep the system operating in the event of a generation plant failure. Keeping that margin as small as practical is critical to keeping service costs under control. All potential sources of failure in a generating plant need to be assessed from a probability of failure perspective. Any significant probability of failure creates a high requirement for operating margins. Since the lifecycle cost assessment will reflect needs for operating margins, a project has little chance of being economically selected if an immature technology is carried forward.

From SaskPower's stewardship perspective, undertaking the risk of an immature technology without appropriate contingencies, and without recognition of operating margins, is irresponsible. This type of analysis figured heavily into the design ultimately chosen for the integrated BD3 retrofit project.

The evaluation to determine the technologies of choice for a particular power station requires that designing engineers take into account all aspects of operation. They need to assess how failure of each and every system or subsystem will impact overall electrical system operations. Modern power generation economic modeling tools for trading off reliability, capital and operating costs are used to determine optimal scenarios for various technology choices. But in general, the more uncertainty there is in the performance of a particular technology, the more a power company needs to spend on contingencies, whether that is backup equipment or backup power generating capacity elsewhere in its power supply system. Once those contingencies are factored in, one needs to choose the lowest lifecycle cost for a particular power generation option that is risk adjusted.

Furthermore, diversity of fuel supply will assure future electricity price stability that is important for adapting to many changing conditions, such as:

- Fuel price swings
- Evolving environmental expectations
- Changing consumption patterns
- Other macro-economic variations

The choice of post-combustion capture as a means to convert BD3 into a clean coal power plant was part of SaskPower's evolution from old coal power generation to an environmentally sustainable coal power fleet of the future. PCC technology allowed SaskPower to maximize the amount of CO_2 product available for sale to bolster the business case for the BD3 retrofit and enable power plant operation with or without carbon capture.

Given SaskPower's mission to consistently and reliably provide the Province's population with electricity, PCC power generation was the only way to deliver on that mission and maintain a coal-fired power fleet. Fortunately, there were relatively mature PCC technology options to choose from to reduce the risks of engineering scale-up and operation of full-size commercial plants.

To add to the complexity facing the company, SaskPower did not have the benefit of any guidance from regulation at the time of its construction decision and therefore opted for a technology that could reliably capture 90% of the CO_2 in the flue gas just in case anticipated regulation was very strict. To choose otherwise would risk the entire investment and its proposed 30-year lifetime.

Selection of the appropriate PCC technology, and the associated design choices in the power plant for integration with the capture plant, enabled SaskPower to optimize the power plant's operational flexibility at any given point in time.

The criteria for selecting the PCC technology and associated power plant retrofits were the following:

- technical needs,
- commercial cost,
- lifecycle cost of electricity,
- capability to remove 90% of effluent CO_2,
- operational flexibility,
- acceptable technical and financial risk, and
- a levelized cost of electricity[44] comparable to alternative forms of generation, such as NGCC.

The winning capture technology developed and owned by Shell Cansolv was chosen for CO_2 capture at BD3. It was an amine solvent absorption capture process.

WHY CHOOSE SHELL CANSOLV'S COMBINED SO_2–CO_2 CAPTURE PROCESS?

Both of the leading CO_2 amine capture technologies contemplated at the FEED stage required ultra-low levels of SO_2 in the flue gas prior to CO_2 capture due to preferential absorption of SO_2 by the amine solvent used in the CO_2 capture unit. Using an SO_2 capture system ahead of the CO_2 capture system would also facilitate the removal of flue gas contaminants, such as particulates, ahead of the less-proven, more technically risky amine-based CO_2 capture unit.

SaskPower had gained considerable experience in technologies to capture and remove SO_2 when designing the Shand Power Station, as a requirement of its environmental permit. However, such low SO_2 flue gas emission levels were not something that SaskPower had worried about before.

One logical and proven process that was considered for achieving low SO_2 flue gas emissions was high-performance Limestone Forced Oxidation (LSFO) scrubbing, an industry standard. While LFSO is an expensive process, it is a mature technology and commercially well understood, resulting in near zero risk of deployment. The LFSO process requires large quantities of limestone, which when reacted with SO_2 produces calcium sulphate. In favourable markets, the calcium sulphate can be used to produce wallboard. However, Saskatchewan was not a region where wallboard produced from LFSO by-product would be commercially viable due to the distance of a limestone source (1000 km away in western Alberta) and the equally long transportation distance to "off-takers" (the end-user market). Consequently, LFSO was dismissed as an option for removing sulphur dioxide from the flue gas at BD3.

Ultimately, the regenerating amine in the CANSOLV SO_2 capture process was appealing from a cost-effectiveness perspective in comparison to LFSO. The proven performance of the CANSOLV SO_2 capture process deployed at other coal-fired power stations in China and elsewhere was an important consideration. The SO_2 captured in the solvent absorption process could be recovered and converted into saleable sulphuric acid that could be used by Saskatchewan-based chemical manufacturers to make sulphur-based fertilizer. This additional value-added by-product contributed to the positive business case for the combined CANSOLV SO_2-CO_2 capture system.

Further risk-reducing and/or positive features that supported the selection of the combined CANSOLV capture system were as follows:

- Competitive pricing on the combined process package;
- Technical and operational simplicity by integration of a single, combined SO_2 and CO_2 capture plant with the power plant rather than use of separate capture systems;
- The CANSOLV combined capture process would incorporate an energy recovery system that would enable heat used to regenerate the SO_2 solvent to be used in the CO_2 capture system, which would reduce the parasitic load of the combined capture system on the power plant and make it the most energy-efficient technology choice for BD3; and
- The EPC contractor, SNC-Lavalin, backed up the new capture plant with written performance guaranties.

ABBREVIATIONS

This is not a comprehensive list.

BD3 – Boundary Power Plant Station Unit 3

CCS – Carbon Capture, Transportation and Storage

CCPC – Canadian Clean Power Coalition

CCTF – SaskPower's Carbon Capture Test Facility (at Shand Power Station)

CEPA – The Canadian Environmental Protection Act

CIC – Crown Investments Corporation of the Government of Saskatchewan (owner of all Crown corporations such as SaskPower)

CO_2e – The climate forcing factor associated with a greenhouse gas expressed as "carbon dioxide equivalents". For example, the climate forcing factor of methane (CH4) is 21 times the factor for CO_2. Hence, one methane molecule is equivalent to 21 carbon dioxide molecules in terms of greenhouse impact on the climate.

C$ – Canadian Dollars

EC – European Commission

ECRF – SaskPower's Emissions Control Research Facility (at Poplar River Power Station)

EOR – Enhanced Oil Recovery

EU – European Union

GHG – Greenhouse Gas

GWh – Giga-Watt-Hour, the energy unit of total power generation

ICCS – Integrated Carbon Capture and Storage, which is the name of the combined BD3 power plant retrofit project and the geological storage of its captured CO_2.

IEAGHG – IEA Greenhouse Gas R&D Programme

MW – Mega-Watt, the energy unit used for power-generating capacity

PCC – Post-Combustion Capture

$PM_{2.5}$ – Fine Particulate Matter found in the air that is less than or equal to 2.5 mm (micrometres) in diameter and normally only observed by electron microscope. This material is often associated with energy combustion and the fine particulate matter is believed to cause serious health issues upon entering lungs of air-breathing animals.

PM_{10} – Coarse Particulate Matter found in the air that is less than or equal to 10 (mm) micrometres in diameter. It can be seen with the human eye in the air as soot, dust, dirt and liquid droplets. This material is often associated with energy combustion.

PTRC – Petroleum Technology Research Centre, a non-profit R&D corporation located in Regina, Saskatchewan

R&D – Research and Development

QA/QC – Quality Assurance and Quality Control

SE - Southeast

SaskPower – Saskatchewan Power Corporation

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[2] SaskPower's fiscal year runs from January 1 to December 31.

[3] From 2010–2014, SaskPower invested C$4.7 billion in capital assets (upgrades, new construction)

[4] Canada Gazette, Vol. 146, No. 19 — September 12, 2012 (Government of Canada)

[5] Provided by SaskPower

[6] **http://www.ir.gov.sk.ca/coal**

[7] The Encyclopedia of Saskatchewan. The Oil and Gas Industry. **http://esask.uregina.ca/entry/oil_and_gas_industry.html**

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[9] From Leasing Mineral Rights: "Unitization of a producing field: The purpose of unitization is to produce oil or gas more efficiently and effectively by bringing together an area involving a large number of sections. Unitization is used where the industry feels that a large portion of the oil and gas can be produced with fewer wells. Upon unitization, an owner within the boundaries of the unitized field is entitled to participate in production, even though no well is located on his land. The provisions of a lease may therefore permit "pooling," in which case you receive a portion of the royalty, based on the number of acres you put in the pool. The lease may permit "unitization," which converts your royalty into a "tract factor," based on a complex formula. Even though unitization in the vast majority of cases provides a better total income for the mineral owner, an owner should not grant the right to unitize automatically; nor should he leave it up to the company's discretion. Because participation in a unit is not based on the number of acres you have in the unit but is determined by the company, based on geological factors, you should very carefully assess your position. For example, while you may hold five per cent of the area in a unit, you may be allocated only two per cent of the production."

[10] **http://www.economy.gov.sk.ca/PR-IC11**

[11] Pan Canadian was a subsidiary company of Canadian Pacific Railway until it merged with Alberta Energy Company in 2002 to form EnCana Corporation, an independent oil and gas corporation. In December 2009, Cenovus Corporation split from EnCana to operate as an independent integrated oil company, including all of the oil assets from the original firm. EnCana continues to operate the natural gas assets of the original firm and is a leading independent Canadian natural gas producer.

[12] Numac Energy Inc. was incorporated in Alberta in 1971 and was an independent oil producing company until it was purchased by Anderson Exploration Inc. in early 2010. Anderson was subsequently purchased by Devon Energy (USA) to form Devon Canada Corporation in late 2010. Numac, in partnership with Nexen Inc., operated a CO_2–EOR pilot at its Elswick Midale oil leases in 2001 using trucked CO_2 from the Air Liquide plant in Medicine Hat, Alberta. It ultimately decided not to proceed with full-scale operation of CO_2–EOR due to various technical issues it encountered during the pilot as well as poor economics due, in part, to the lack of a pipelined source of CO_2. The Elswick oil field is one of many potential CO_2–EOR targets in SE Saskatchewan.

[13] **http://www.economy.gov.sk.ca/adx/aspx/adxGetMedia.aspx?DocID=10290,10289,3384,5460,2936,Documents&MediaID=26122&Filename=SPRI+CO_2+Pilot+Injection+Test.pdf**

[14] **http://www.ucsusa.org/global_warming/science_and_impacts/impacts/early-warning-signs-of-global-1.html#.Va6YMnnbKTM**

[15] **http://unfccc.int/kyoto_protocol/items/2830.php** ; The agreement came into force in 2005 upon ratification by 55 signatory parties belonging to the UNFCCC. Those signatories include Canada but notably exclude the USA as of mid-2015.

[16] Clift, R. and J. Seville (Editors), 1993. Proceedings of the Second International Symposium on Gas Cleaning at High Temperatures. University of Surrey, UK. Springer Science and Business Media. P. 129.

[17] **https://en.wikipedia.org/wiki/Integrated_gasification_combined_cycle**

[18] **http://www.nrcan.gc.ca/energy/coal/carbon-capture-storage/4307**

[19] **http://www.nrcan.gc.ca/energy/coal/carbon-capture-storage/4333**

[20] **http://cornerstonemag.net/exploring-the-status-of-oxy-fuel-technology-globally-and-in-china/**

[21] Tanner, C. S., Baxley, P. T., Crump, J. G., & Miller, W. C. (1992, January 1). Production Performance of the Wasson Denver Unit CO_2 Flood. Society of Petroleum Engineers. doi:10.2118/24156-MS

[22] Beliveau, D. A. (1987, November 1). Midale CO_2 Flood Pilot. Petroleum Society of Canada. doi:10.2118/87–06-05

[23] The Midale and Weyburn oil fields are operated in the same geological formation, along with several surrounding oil leases/operations. Each of the two oil fields is owned by approximately 30 owners but each field was "unitized" in the 1960s to support water flooding infrastructure investment. Each unitized oil field is operated by one major oil company on behalf of the owners. Pan Canadian was an owner of part of the Midale oil field and consequently had access to the CO_2–EOR pilot program undertaken by Shell Canada.

[24] **http://www.dakotagas.com/CO_2_Capture_and_Storage/Pipeline_Information/index.html**

[25] Apache Canada began a commercial CO_2–EOR flood at Midale in 2006 using approx. 1800 tonnes per day of CO_2 supplied by DGC. At that time Apache Canada contributed data and sponsorship to the renamed IEAGHG Weyburn-Midale CO_2 Monitoring and Storage Project.

[26] Hitchon, Brian (Editor), 2012. Best Practices for Validating CO_2 Geological Storage: Observations and Guidance from the IEAGHG Weyburn Midale CO_2 Monitoring and Storage Project. Chapter 1. Updated data from Cenovus and PTRC as of 2014.

[27] Approximately one-third of the CO_2 injected in a given oil production cycle is "lost" to the reservoir. The uncertainty prior to the IEAGHG Weyburn CO_2 Monitoring Project beginning its work was, "Where does the CO_2 go?"

[28] **http://ptrc.ca/projects/weyburn-midale**

[29] **http://www.canadiancleanpowercoalition.com/**

[30] **http://www.SaskPower.com/our-power-future/our-electricity/our-electrical-system/cory-cogeneration-station/**

[31] **http://www.canadiancleanpowercoalition.com/index.php/ccpc-materials/ccpc-reports-phase/phase-i/**

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