# THE ROAD TO DEPLOYING **CARBON CAPTURE + STORAGE**

## AT SASKPOWER

# WHY CONTINUE TO GENERATE POWER FROM COAL IN **SASKATCHEWAN?**

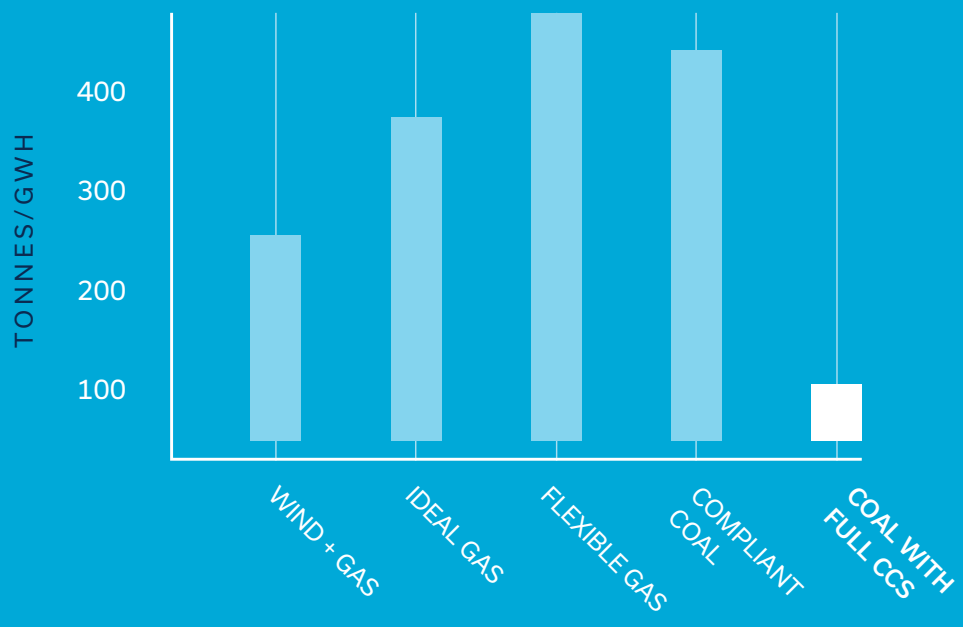
SaskPower generates electricity using a variety of energy sources: coal, natural gas, hydro and wind.

North America currently has a plentiful supply of inexpensive natural gas and a number of alternatives to coal-fired power generation, such as wind, solar, hydro and nuclear. Furthermore, when utilizing modern technology, all of these alternative power sources are considered cleaner, from a GHG perspective, than traditional coal-fired power generation. Natural gas, for instance, has no soot (particulates) to manage. Power plants run efficiently in the case of Natural Gas Combined Cycle (NGCC), and the fuel is consistent in quality. So you might well be asking yourself the question, "Why would SaskPower contemplate continuing to generate power from coal by making major investment(s) in clean coal?"

Natural gas has not always been as inexpensive in Saskatchewan, Canada and North America as it was in mid-2015. In some jurisdictions around the world, natural gas has been in short supply and therefore very expensive. That has made North America an easy target for production and transportation of natural gas in liquefied form (LNG) to other parts of the world where it has commanded a higher market price. This has put pressure on the supply of natural gas available in North America. Hence, natural gas pricing in the North American context will be unlikely to remain low in the future, implying that natural gas electrical power generation may not necessarily be the most cost-effective form of power going forward, assuming new and sufficient natural gas reserves could continue to be found and economically exploited to meet demand.

Wind power is an appealing alternative to coal power in Western Canada. There is, indeed, significant generating capacity in Saskatchewan and Alberta. But it is always subject to weather variations, with extreme wind being common on the Prairies, while too little wind is also frequent. Hence, wind power generation using existing turbine technology cannot be relied upon to provide stable base load power unless it is coupled with readily-dispatched power-generating backup systems, such as simple-cycle natural gas power generation, which is not as clean and efficient as NGCC. At some point, simple-cycle natural gas power generation may become the target of GHG emissions regulation, either federally or provincially, which must be taken into account when considering investment in future power generation options.

**FIGURE 9 | ILLUSTRATIVE GHG INTENSITY BY ENERGY SUPPLY OPTION[5]**




Although Saskatchewan is one of the largest global suppliers of high-grade uranium, no nuclear power station has ever been built in Western Canada. Consequently, the Saskatchewan regulatory permitting process for nuclear power, even for recently touted small scale nuclear reactors (SNRs), would likely be protracted. Doubtless, it would be worth the effort to begin that permitting process well before it would be required, but it would be time intensive the first time around.

Saskatchewan has a large, shallow, subsurface, lignite coal resource (the Ravenscrag formation) that is amenable to straightforward surface mining and is located in the southeast, relatively close to Regina, with its population of over 230,000. This coal reserve is expected to last for about 250–500 years[6] and is cost-effective for nearby thermal power generation. It is co-located with a good supply of surface water and is served by transmission facilities that integrate existing power stations into the grid for the supply of electricity to about one third to one half of the province's population. If executed properly, clean coal power generation has the potential to be cleaner than NGCC and cleaner than wind with simple-cycle natural gas power backup. The downside is that coal requires large infrastructure to be cost effective. This would entail major capital investment in clean coal-fired power generation if coal is to remain an acceptable and viable energy source in Saskatchewan.

SaskPower focuses its power generation choices on meeting service and regulatory obligations at the lowest expected cost when considered over the expected operating lifetime of a facility (i.e. the life-cycle cost of electricity). Preference may be given to installations that have superior environmental and/or socioeconomic outcomes. In order to ensure stable pricing and electricity supply to its customers, SaskPower must maintain a diverse portfolio of power generation capacity. Coal is plentiful and, if possible, should continue to form part of the power generation fleet, although it must be used more cleanly than has been the case historically.

# THE HISTORY OF CARBON CAPTURE AND STORAGE AT **SASKPOWER**

SaskPower's contemplation of $CO_2$ capture and storage (CCS) from its coal-fired power generation fleet was driven in large part by a number of external forces that came into play from the 1980s to the 2000s. However, SaskPower was clearly proactive in its approach to managing upcoming issues, seizing new technology opportunities, and anticipating regulatory changes.

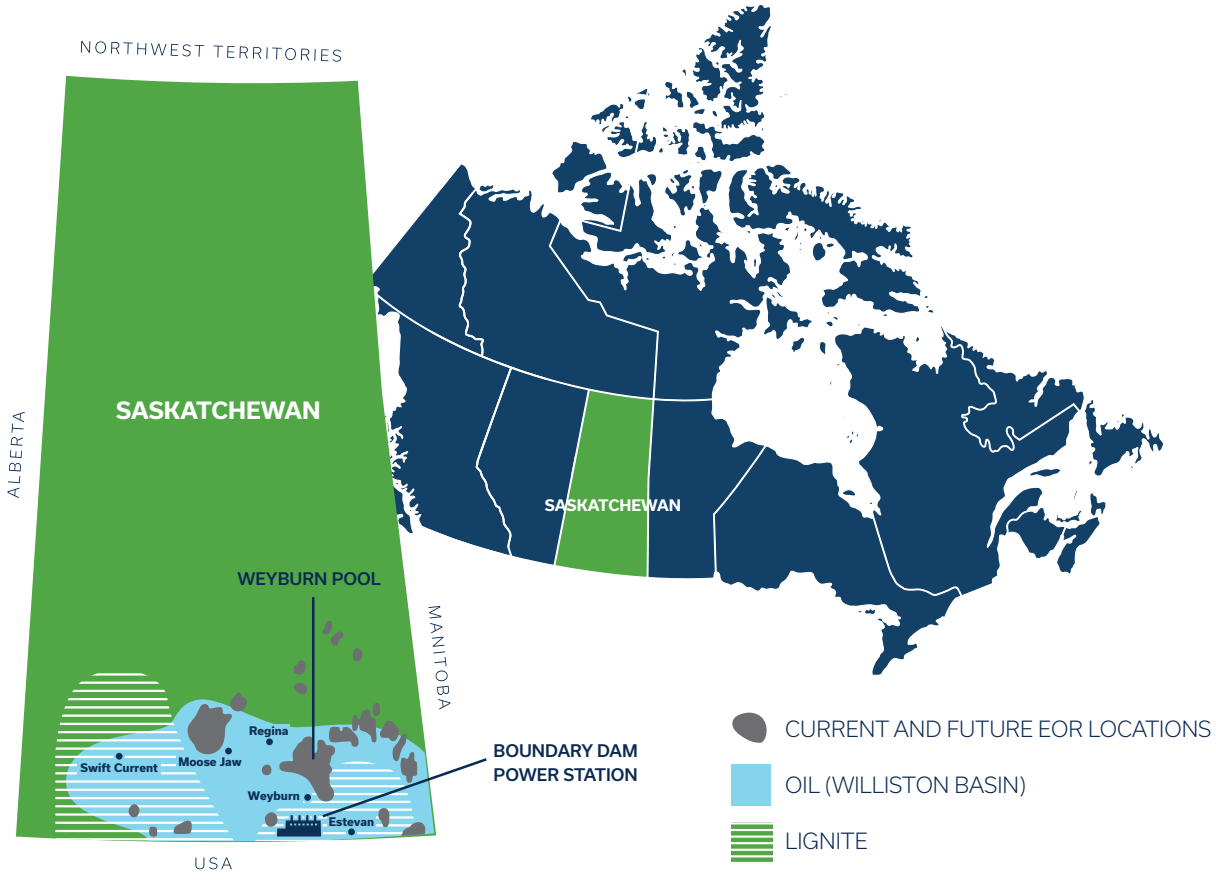
## THE 1980s

**DURING THE 1980s,** oil fields in southeastern Saskatchewan that had been in operation since the 1950s were maturing. Oil production associated with water-flooding practices was in decline[7] and water cuts were approaching 80%. The oil operators looked to the success of carbon dioxide enhanced oil recovery ("$CO_2$–EOR") in West Texas[8] as a model for the next generation of technology that could economically boost production. The Saskatchewan industry was fortunate that "unitization" of leased mineral rights had become common in order to support infrastructure investment in water flooding during the 1960s. That unitization was one of the keys to supporting $CO_2$–EOR development; lack of unitization[9] in some jurisdictions, such as Alberta, has hindered widespread implementation. Discussions began between interested oil operators and the Government of Saskatchewan on ways to provide incentives to the industry to support the business case of $CO_2$–EOR[10]. Supporting incentives emerged by the late 1990s.

What was immediately apparent to the Government of Saskatchewan was that generation of a sufficient supply of pure $CO_2$ was essential to support the oil industry and could result in significant socio-economic spin-off benefits in terms of sustained jobs in southeastern Saskatchewan associated with both the power and oil industries, as well as royalties on incremental oil production that would benefit the entire Province (see Figure 10 on the next page).

# **EOR** IN SASKATCHEWAN

**FIGURE 10 | SOUTHERN SASKATCHEWAN COAL-FIRED POWER STATIONS AND NEARBY OIL POOLS**




## CURRENT AND FUTURE EOR **LOCATIONS**

However, unlike the situation in Texas, there was a paucity of relatively short-distance, abundant and economic sources of natural or anthropogenic high-purity $CO_2$ gas to pipeline to southeast (SE) Saskatchewan to support EOR development. Pan Canadian[11], Shell Canada, and Numac Energy Inc.[12,13], began discussions with SaskPower about supplying high-purity $CO_2$ that might be captured from the flue gas at a coal-fired power station, contemplating $CO_2$ supply from the Boundary Dam Power Station near Estevan, Saskatchewan, a short distance from the oil operations.

**AROUND THE MIDDLE OF THE DECADE,** with support from SaskPower, interested oil industry parties installed an amine-based $CO_2$ recovery pilot plant at the Boundary Dam Power Station, Unit 6 (BD6). The pilot was operated for a year and left the oil companies with the unsatisfactory conclusion that the presence of fly ash and sulphur dioxide made the $CO_2$ recovery system ineffective. Adjustments were made to the pilot plant to manage these flue gas constituents, but the results were still unsatisfactory after a further year of operation. Amine absorption of $CO_2$ to recover the gas for other uses was deemed technically and economically unsuccessful.

**MEANWHILE, IN 1985,** Shand was selected as the site for a new coal-fired power station in Saskatchewan. It was located relatively close to the Boundary Dam Power Station in southeastern Saskatchewan, conveniently located near the Ravenscrag lignite coal formation. Procurement of major equipment began immediately, providing for two power units. In 1988, the second Shand power unit was cancelled and construction began on the 300 MW (nominal) Unit 1, with provision for future addition of other power units.

# THE 1990s

**EARLY IN THE 1990s,** public concerns were being raised about $CO_2$ emissions and their greenhouse gas impact that was evidently resulting in global warming. These concerns were sparked by growing evidence from atmospheric scientists who had modelled global temperatures based on a variety of historical weather data[14]. Over the course of the 1990s, there were several international meetings on the subject, supported by continued knowledge development regarding the impact of rising levels of greenhouse gases on the world's climate. It had become clear that human industrial activity and widespread combustion of fossil energy was having a dramatically negative impact on the world's climate. Ultimately, the Kyoto Protocol[15] was signed in 1997, which was a binding and enforceable agreement amongst signatories to reduce national and global emissions of greenhouse gases relative to recorded emission levels in 1990.

**IN 1992,** the Shand Power Station construction was completed and the power plant was commissioned. Its engineering team was disbanded by SaskPower and reassigned to new projects elsewhere within the company.

**IN 1994,** a 2250 MW power station in Demkolec, The Netherlands was commissioned using next generation coal-fired power technology, namely, Integrated Coal Gasification with Combined Cycle (IGCC) from Shell Global Solutions[16]. IGCC involved oxidizing coal to produce syngas and removing impurities such as sulphur dioxide, mercury, and particulates[17]. IGCC was seen as producing electricity with fewer emissions than conventional coal power plant technology, with the added benefit that a relatively pure stream of $CO_2$ could be readily captured for sale to nearby oil producers for EOR. Around 1994, SaskPower negotiated licensing terms for IGCC technology from Shell Global Solutions, and received an environmental permit from the Government of Saskatchewan to construct an IGCC power plant at the Shand Power Station.

**IN THE MID-1990s,** with support from SaskPower, CanmetENERGY established a consortium to develop Oxyfuel coal combustion technology[18] at its laboratories in Ottawa. The goal of the consortium was to develop an efficient and economic next-generation coal combustion technology that could also provide a source of high-purity $CO_2$ for EOR from coal-fired power generation. A bench-scale pilot was constructed and began demonstrating positive results by 1996[19,20].

**DURING 1995–1996,** SaskPower revisited Shand 2 as a potential site for commercializing Oxyfuel combustion for power generation from coal. It began conducting technology screening studies to


support a go no-go decision. Shortly thereafter, upon consideration of capital constraints, coupled with technology and business risks, SaskPower decided not to venture into the $CO_2$ supply business.

Shell Americas had been operating the world's largest $CO_2$–EOR flood at its Denver Unit in West Texas since 1983[21]. In the mid-1990s, Shell Canada successfully conducted a tertiary miscible $CO_2$–EOR pilot project at its Midale oil field in SE Saskatchewan using $CO_2$ trucked from an Air Liquide gas plant in Medicine Hat, Alberta[22]. As part owner of the Midale oil field, Pan Canadian had access to the pilot project data and used it to justify investing in the development of a technical and economic evaluation of full-scale $CO_2$–EOR at its Weyburn oil field immediately adjacent to the Midale oil field.

**TOWARD THE END OF THE 1990s,** Pan Canadian decided to proceed with commercial $CO_2$–EOR implementation, rolling out $CO_2$ injection across most of the Weyburn oil field over 25 years[23]. Pan Canadian negotiated a long-term commercial agreement with Dakota Gasification Company (DGC) for $CO_2$ to be captured at its Great Plains Synfuels Plant in Beulah, North Dakota and transported to Weyburn. A dedicated carbon steel pipeline was constructed to transport up to 8000 tonnes per day of supercritical, high-purity $CO_2$ to the Weyburn area in southeastern Saskatchewan[24]. Shell Canada elected not to proceed with commercial–scale $CO_2$–EOR at the smaller Midale oil field* and subsequently sold its interest in the oil field to Apache Canada[25].

* The Midale oil field produces approximately one-third of the oil production at the Weyburn oil field.

# THE 2000s

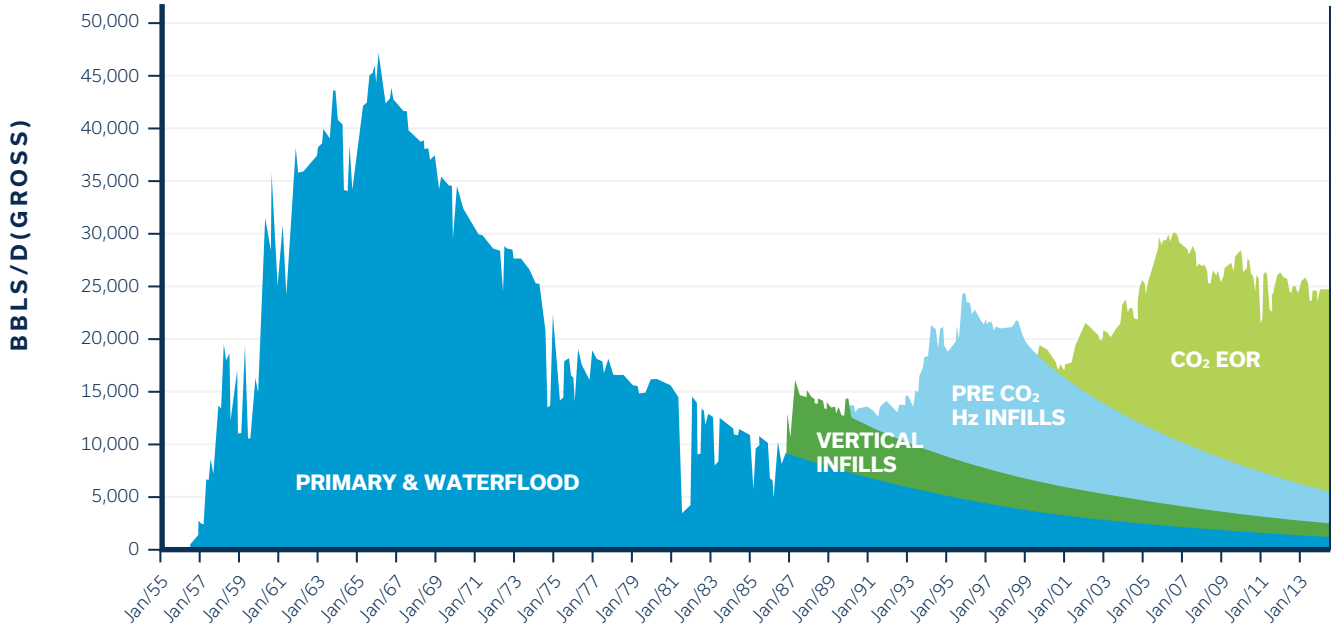
**IN SEPTEMBER 2000,** Pan Canadian began injection of $CO_2$ at its Weyburn oil field. $CO_2$–EOR production at Weyburn exceeded expectations[26] [Figure 11], capturing the attention of other oil producers nearby with similarly maturing water-flood production. There appeared to be an assured steady and stable $CO_2$ market for many decades to come.

In conjunction with the Pan Canadian commercial $CO_2$–EOR project, the IEAGHG Weyburn $CO_2$ Monitoring and Storage Project began its work to monitor the migration of $CO_2$ within and around the oil field. The goal of the project was to prove that $CO_2$–EOR was an effective strategy to permanently sequester $CO_2$ away from the atmosphere as well as shallow subsurface geological formations, such as drinking well aquifers[27].

SaskPower was a funding sponsor of the IEAGHG Weyburn $CO_2$ Monitoring and Storage Project[28] from 2000–2012, as part of its long-term strategy of investing in development of its understanding and knowledge of $CO_2$ emissions mitigation technologies. This was a prudent course of action given that SaskPower had realized by this time that the public no longer accepted coal-fired power generation without deploying technology to reduce GHGs, mercury, $SO_2$, $NO_X$ and particulates emissions. Ideally, these constituents could be removed from the stack and permanently sequestered as by-products or used for $CO_2$–EOR, representing an off-taker market for additional products beyond electricity.

**EARLY IN THE 2000s,** when it was collectively recognized that conventional coal-fired power plants could no longer be built, SaskPower, other power-generating utility companies, and coal-associated industries initiated the Canadian Clean Power Coalition (CCPC)[29]. In 2002, SaskPower commissioned its first Natural Gas Combined Cycle (NGCC) power generating station[30] as part of its overall strategy to diversify

**FIGURE 11 – CENOVUS' WEYBURN OIL FIELD PRODUCTION, INCLUDING CO2–EOR**




SEPTEMBER 30, 2014

its power supply mix and to reduce its overall air emissions. Shortly thereafter, natural gas prices increased to unprecedented levels and SaskPower began seeking viable alternatives to NGCC as part of its power fleet, although desirous of maintaining the low carbon emissions profile associated with NGCC.

**BY 2004,** the CCPC had demonstrated that clean coal might be cost competitive with NGCC[31]. Additionally, interim reports from the IEAGHG Weyburn $CO_2$ Monitoring and Storage Project demonstrated both the commercial value of $CO_2$ for EOR and the permanence of $CO_2$ geological storage in the oil reservoir[32,33]. SaskPower was gradually becoming convinced by EnCana, Apache and other oil operators to become a $CO_2$ supplier to the industry in southeastern Saskatchewan.

The public no longer accepted coal-fired power generation without deploying technology to reduce GHGs, mercury, $SO_2$, $NO_X$ and particulates emissions.

# **EXPLORING** OXYFUEL COMBUSTION

With strong evidence supporting a clean coal power generation approach, in 2005, SaskPower authorized engineering work to assemble commercial pricing for a clean coal power unit as a future power generation option. This work included preliminary engineering design and contracting with equipment suppliers for preparation of commercial proposals. After evaluating technology and equipment options, in 2006, SaskPower chose Oxyfuel combustion as the clean coal technology for a call for commercial proposals, naming the Shand Power Station as the location for the proposed power plant[34].

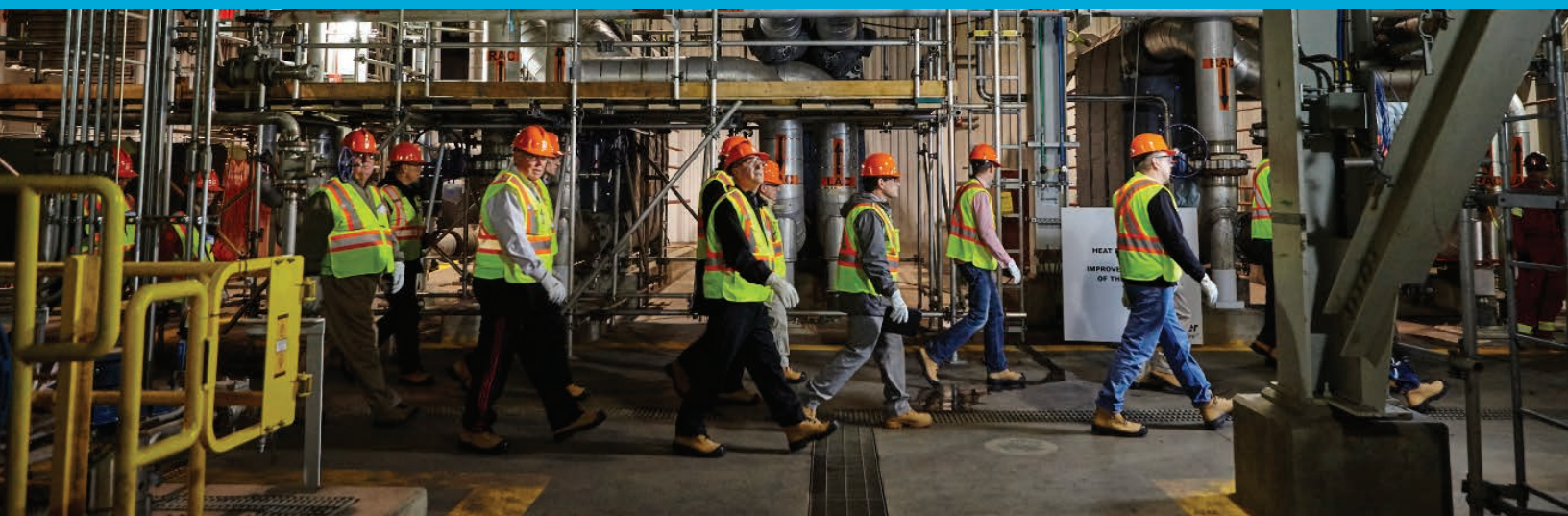
Following evaluation of the commercial proposals received from equipment suppliers, SaskPower determined that the cost to construct a coal-fired power plant incorporating carbon dioxide capture was at least two to three times more expensive than the vendors' original estimates. There were also incremental costs associated with a new coal mine, transmission and other infrastructure. The capital cost alone was going to run to several billion dollars! The SaskPower team concluded that the "new-build" Oxyfuel combustion concept was the wrong approach for pursuing clean coal power generation and stopped its work on the Shand 2 Oxyfuel power unit in mid-2007.

There were two important outcomes for SaskPower from its initial work on Oxyfuel-based clean coal power generation:

1 / Acquisition of the underpinning information necessary to develop a commercially realistic cost estimate for clean coal power generation; and

2 / Development of the internal capacity and business insight to better match technology choices with participation in the $CO_2$ supply chain.

This foundational work was critical to supporting SaskPower as it continued to pursue a clean coal power option using a different technology approach.



# **RETROFITTING** AN EXISTING COAL-FIRED POWER STATION

In mid-2007, post-combustion capture (PCC) technology was chosen by SaskPower for the evaluation of a Boundary Dam Power Station retrofitting project. The power station had the oldest power units in the SaskPower coal electricity-generating fleet and they were approaching the end of their useful lifespan. SaskPower had recognized that Oxyfuel combustion was not operationally flexible enough to handle the ups and downs of a $CO_2$ commodity market. Its Achilles heel was the continual production of $CO_2$ when generating power, which necessitated a buyer(s) who could always buy $CO_2$, regardless of a buyer's demand needs, operating challenges or economics.

At this point in time, there was no option to permanently geologically sequester $CO_2$ in deep saline aquifers; it was an unproven practice and was not publicly accepted at the scale necessary to support reduction of $CO_2$ emissions from a large power station[35]. Quite conceivably, SaskPower could be "held captive" by its customer(s) if it had deployed Oxyfuel combustion that would necessitate the sale of $CO_2$ at deeply discounted prices and would erode the economics of clean coal power generation. Yet, the sale of $CO_2$ to the nearby oil industry was the key to the economics for $CO_2$ capture, particularly in the absence of a carbon tax or any regulation regarding emissions from coal-fired power plants.

If it deployed PCC at a coal-fired power generating plant, SaskPower could choose to capture $CO_2$ and sell it to oil producers when the gas could command a good price. Or it could choose to operate the power plant with partial or no $CO_2$ capture when either the gas did not command a good price in the market or when the capture plant was in the process of being maintained. The latter factor enabled SaskPower to consider PCC technologies that had not been operationally proven, which was the case for all technologies at the scale of operation required at Boundary Dam. Operational flexibility was the key to managing market dynamics and the risk of commercializing a new technology.

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The engineering analysis that drove the decision by SaskPower to proceed with designing a retrofit of PCC at Boundary Dam included:

> The effort expended on evaluating Oxyfuel combustion at Shand clearly demonstrated that a newly-built clean coal-fired power plant was not competitive compared to alternatives.

> New generation by SaskPower was essential due to the expected retirements at Boundary Dam.

> When power plants were due to be retired in the near future, the infrastructure (the power plant, its transmission capacity, its fuel supply contracts, staffing, etc.) would become a salvageable asset that could be deployed on new power generation capacity.

Maintaining coal-fired power generation just made practical sense if it could be made affordable.

# GOVERNMENT SUPPORT OF SASKPOWER'S PURSUIT OF **CLEAN COAL POWER**

The Government of Saskatchewan was highly supportive of SaskPower's pursuit of clean coal power. In early 2008, as part of its annual budget, the Government of Canada announced funding to support the Government of Saskatchewan's efforts in its pursuit of commercialization of carbon capture and storage. The Government granted most of these funds to SaskPower for the commercial-scale development of clean coal-fired electricity generation at the Boundary Dam Power Station[36]. The Government of Saskatchewan had worked hard to secure this funding on behalf of its power utility since late 2007. SaskPower had done its homework, presenting a compelling business case for a retrofitted PCC clean coal power unit to both levels of Government. That federal funding was the catalyst for converting SaskPower's clean coal power concept into a fully engineered design.

Federal funding was intended to offset the cost of developing a project that was anticipated to incur first-time, technology risk-mitigating costs. And pursuing a clean coal project at Boundary Dam had solid socio-economic justifications for the Province:

1. Captured $CO_2$ could be sold to the oil industry in southeastern Saskatchewan, which had been experiencing declining oil production in the past couple of decades. EnCana (now Cenovus) had proven at Weyburn that it could boost oil reserves by deploying $CO_2$–EOR [Figure 11].
2. Royalties from increased oil production would benefit the entire Province's population.
3. The province already had incentives in place to assist oil companies in developing commercial-scale $CO_2$–EOR[37] operations as a result of working closely with Pan Canadian in the late 1990s.
4. A healthy oil industry would assure continued direct and indirect jobs in a region with few alternatives for the workforce.
5. Clean coal power generation would assure the ability to maintain a diversity of fuel mix by retaining the social license to operate.
6. Being able to continue to generate power from coal would help realize the value of the vast lignite coal reserve in southeastern Saskatchewan.
7. Continuing to generate power at an established facility would reduce the capital cost of investing in clean power, while extending the useful life of the power plant by 30 years (equivalent to a newly built coal power plant).

As a reminder, at the time the SaskPower was provided financial support by the government for pursuing clean coal power, there were no regulations in place, federally or provincially, that required capture and storage of $CO_2$, provided for offsets against $CO_2$ emissions or required payment of penalties for $CO_2$ emissions. Federal regulation was not enacted by the Government of Canada until September 2012, and did not come into force until mid–2015.

Designing a post-combustion capture (PCC) coal-fired power plant was a bold and progressive move by SaskPower. But appropriate technology risk management was afforded by the federal funding should SaskPower deem their clean coal power approach to be a poor investment.


Federal funding was the catalyst for converting SaskPower's clean coal power concept into a fully engineered design.

# EARLY ENGINEERING WORK ON PCC TECHNOLOGY FOR BD3

Throughout the engineering and design process that took place well into 2010, comparisons with alternative power generation options, such as NGCC, were continually updated and refined. The overarching philosophy was that whatever option was chosen for the next large power plant at SaskPower, it had to continue to provide stable and moderately-priced electrical power to its customers well into the future.

If designed appropriately, the retrofitted unit would generate power with or without the capture plant operating. This would satisfy SaskPower's core mission to deliver steady power to its customers, while capturing $CO_2$, which would mitigate the environmental impact of coal use, with associated generation of a revenue stream to offset the cost of capture.

The initial question was: "Which unit in the coal fleet should be retrofitted (first)?" Boundary Dam and its six power units totaled over 800 MW of generating capacity[38]. The units had been built contemplating a 30-year lifetime each and all of the units had undergone at least one life extension. The units were approaching 50 years of operation and were nearing retirement [Table 1]. The recent operating history of Units 1 and 2 had clearly demonstrated they were at the end of their useful life. The equipment in these units was likely becoming unsafe to operate and the technology was so old, the units could not be retrofitted to accommodate $CO_2$ capture. Furthermore, these units were each too small to be economic to retrofit.

It was therefore reasonable to plan to shut down Units 1 and 2 within a matter of a few years and to plan to retrofit Unit 3 (BD3), which had sufficiently modern technology that it could be upgraded to be more efficient, and it was of sufficient size to likely be economical for the addition of a $CO_2$ capture plant.

**TABLE 1 | BOUNDARY DAM POWER STATION**

| UNIT | GENERATING CAPACITY (MW) | DATE OF INSTALLATION | DATE OF RETIREMENT |
|---|---|---|---|
| 1 | 62 | 1959 | 2013 |
| 2 | 62 | 1959 | 2014 |
| 3 | 139 | 1970 | n/a |
| 4 | 139 | 1970 | TBD |
| 5 | 139 | 1973 | TBD |
| 6 | 273 | 1978 | TBD |

Furthermore, the output of BD3 could be more easily replaced during the retrofit than a larger power plant, such as Shand or Poplar River, as well as following startup of operations, should the unit become less reliable with the addition of carbon capture. From a risk perspective, it was the prime target for implementation of clean coal technology.

In the late 2000s, power requirements were continuing to grow in the Province, and new power would have to come from either a retrofitted unit or an alternative source of power, such as NGCC, that would entail the shutdown of BD3 if its retrofit was not the best investment to make. A clear business decision about the future fate of BD3 had to be made very shortly, particularly in anticipation of upcoming federal GHG emissions regulation.

SaskPower was very clear that whatever path was chosen, it had to be the most economical, reliable and sustainable power generation choice for the province. BD3 supplied half of the power to the grid required to meet the needs of the City of Regina (or approximately one quarter of the population of Saskatchewan). A reliable power station with assured longevity, that delivered a low lifecycle cost of electricity, would be essential.

In the late 2000s, power requirements were continuing to grow in the Province, and new power would have to come from either a retrofitted unit or an alternative source of power.

In the summer of 2008, following the federal cash infusion of C$240 million, SaskPower issued a request for commercial proposals (RFP) for post-combustion capture technologies to install at BD3. The SaskPower Board of Directors and Crown Investments Corporation approved development engineering for the project shortly thereafter, at which point SaskPower pulled together its Project Execution Team. Commercial development of clean coal-fired power generation in Saskatchewan had begun.

In order to support the deployment of PCC at BD3, it was a prerequisite to rebuild and upgrade the BD3 power plant both in order to assure an additional 30 years of operation, and to achieve effective integration with the carbon capture system. A thirty-year life of the retrofitted BD3 power unit would be a requirement to attain an acceptable lifecycle cost of electricity to support the business case. Modernization of the power unit was a separate design and approval process, and by necessity had to occur before the capture plant was approved. Engineered effective and efficient integration of the two plants was inherently essential.

The SaskPower technical team had narrowed down its choice of carbon capture technology vendors from the RFP by early 2009. They focused on liquid absorption/desorption capture technologies. Each of the top three vendors was contracted to develop detailed FEED proposals, involving engineering, procurement and construction (EPC) firms. It was anticipated that the FEED process would illuminate any technical scale-up or economic concerns and highlight key areas of risk for the first full-scale installation of $CO_2$ capture at a power plant in the world. During the FEED development, one of the vendors self-declared it could no longer proceed when it was clear its technology was not sufficiently advanced for commercialization.

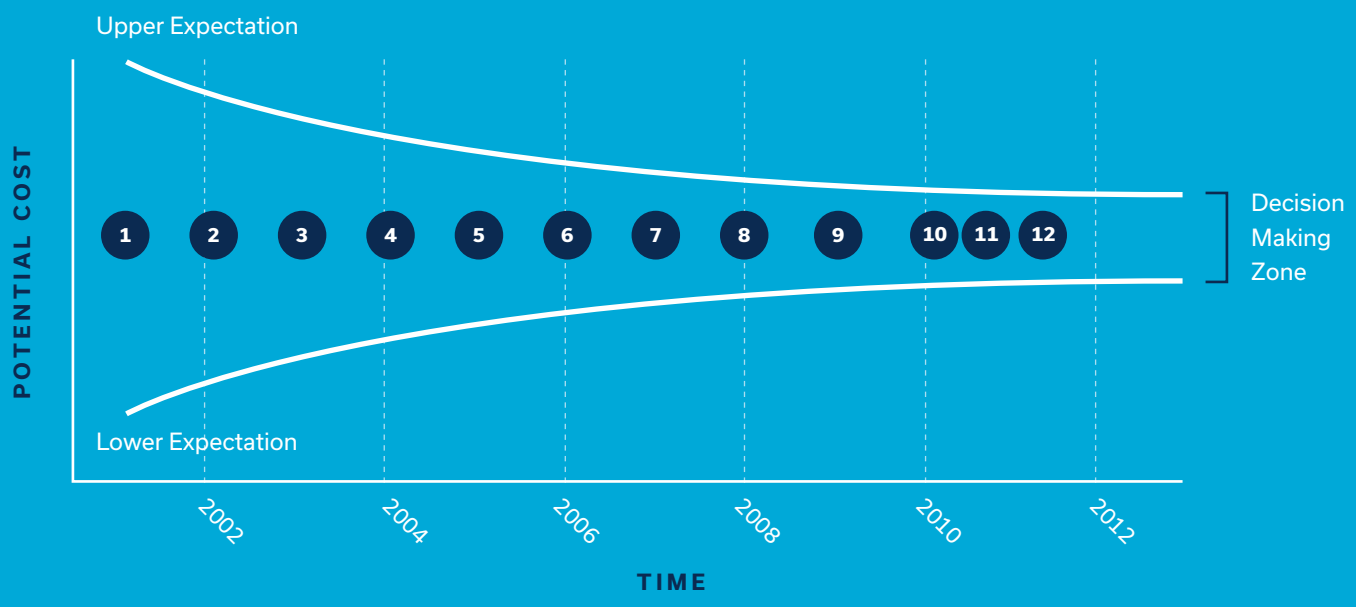
One of the main challenges in the technology evaluation was the lack of any commercial operating history for any of the competing $CO_2$ amine capture technologies. By the end of 2009, Shell Cansolv's $CO_2$ amine absorption capture process[39] was the leading technology option due, in part, to its proven record of deployment of very similar $SO_2$ capture technology in coal-fired power plants and other industrial facilities at various global locations. This assured SaskPower of a lower risk of scale-up by selection of the CANSOLV technology for $CO_2$ capture.

Furthermore, CANSOLV had developed an acceptable, reasonably-priced EPC arrangement with SNC-Lavalin, which could construct the combined $SO_2$ and $CO_2$ capture plant[40]. The Project Execution team selected SNC-Lavalin to proceed with construction, subject to approval by the SaskPower Board of Directors and Crown Investments Corporation. Figure 12 shows the go no-go decision time frame versus cost from the original SaskPower concept of $CO_2$ capture at a coal-fired power plant to the beginning of construction at BD3.

In order to support the approval process by senior leadership, the SaskPower team had, by the Fall 2009, converged on major equipment, finalized the design and construction plans, and had put out bids on the boiler, turbine and $CO_2$ compressors. Additionally, it had entered into EPC contracts for the construction of the capture facility with appropriate "exit", clauses should the project not get final approval. This assured solid pricing for the majority of the procurement and the construction work.

It would take a further year of work on the procurement and re-engineering cycle to narrow in on the final design for both the power plant and the capture plant. Overlapping this period, the SaskPower Board of Directors initiated a third-party technology and investment review in order to support stakeholders in the decision-making process.

**FIGURE 12 | GO-NO GO DECISION "FUNNEL" FOR BOUNDARY DAM UNIT 3**




**LEGEND**

**1.** Amine Oxyfuel Study, Phase 1
**2.** Coal-Fired Generation Option Study, (CCPC)
**3.** Oxyfuel Study, Phase 2
**4.** Pre-Commitment Engineering
**5.** Oxyfuel announcement
**6.** Amine PCC RFP
**7.** Amine PCC FEED begins
**8.** CANSOLV Amine PCC selected
**9.** Procurement and Engineering Continue
**10.** Third Party Review
**11.** CIC approves Power Plant
**12.** CIC approves Capture Plant and Construction Begins

# 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

# REFERENCES


[1] 2014 SaskPower Annual Report

[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**

[8] Melzer, Stephen, 2012. Report for the National Enhanced Oil Recovery Initiative, Center for Climate and Energy Solutions Carbon Dioxide Enhanced Oil Recovery ($CO_2$ EOR): Factors Involved in Adding Carbon Capture, Utilization and Storage (CCUS) to Enhanced Oil Recovery

[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/**

[32] Wilson, M. and M. Monea (Editors), 2004. IEAGHG Weyburn $CO_2$ Monitoring and Storage Project Summary Report 2000–2004. From the Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies, September 5–9, 2004, Vancouver, Canada. Petroleum Technology Research Centre, Regina.

[33] **http://hub.globalccsinstitute.com/sites/default/files/publications/151303/co2-stored-underground-ieaghg-weyburn-midale-co2-monitoring-storage-project.pdf**

[34] **http://www.environment.gov.sk.ca/adx/aspx/adxGetMedia.aspx?DocID=1273,1272,929,928,926,240,94,88,Documents&MediaID=619&Filename=2007-052_project_description.pdf**

[35] By this time, $CO_2$ sequestration in deep saline aquifers associated with "acid gas reinjection" at natural gas producing operations was an accepted practice, e.g. StatOil's Sleipner field. See Tore A. Torp and John Gale, Proceedings of the 6th Conference on Greenhouse Gas Control Technologies, 2003, Volume 1, p. 311–316.

[36] **http://www.pm.gc.ca/eng/news/2008/03/25/pm-and-saskatchewan-premier-announce-major-carbon-capture-and-storage-project**

[37] **http://www.publications.gov.sk.ca/details.cfm?p=56895**

[38] **http://www.SaskPower.com/our-power-future/our-electricity/our-electrical-system/boundary-dam-power-station/**

[39] **http://www.shell.com/global/products-services/solutions-for-businesses/globalsolutions/shell-cansolv/shell-cansolv-solutions/co2-capture.html**

[40] **http://www.shell.com/global/products-services/solutions-for-businesses/globalsolutions/shell-cansolv/shell-cansolv-solutions/so2-co2.html**

[41] Johnstone, Bruce, 2012. From Regina Leader-Post and Saskatoon StarPhoenix newspapers. "SaskPower, Cenovus sign $CO_2$ supply deal". December 20, 2012.

[42] There are many sources of ENGO criticism of the BD3 ICCS Project. One example from the Sierra Club of Canada is embedded in the newspaper article noted in reference 51.

[43] Zinchuk, B., 2015. Pipeline News. "Report critical of Boundary Dam suggests the answer is wind". April 1, 2015.

[44] **http://large.stanford.edu/courses/2010/ph240/vasudev1/**

[45] See for example: Lefebvre, R., Elena Simonova, and Liang Wang. July 2012. Issue in Focus. Certified General Accountants (Canada). "Labour Shortages in Skilled Trades – The Best Guestimate?" http://ppm.cga-canada.org/en-ca/Documents/ca_rep_2012-07_labour-shortage.pdf

[46] **https://en.wikipedia.org/wiki/R._W._Beck,_Inc. Due to various acquisitions since 2009, R.W. Beck is now part of Leidos Engineering LLC, www.leidos.com/engineering**

[47] **http://www.babcock.com/products/Pages/Subcritical-Radiant-Boilers.aspx**

[48] **http://www.snclavalin.com/en/**

[49] **http://www.mhps.com/en/products/generator/**

[50] **http://www.stantec.com/**

[51] **http://www.cenovus.com/operations/oil/docs/rafferty-landowner.pdf**

[52] Johnstone, B., 2014. Regina Leader-Post. "CCS best bet to stop climate change." October 4, 2014.

[53] Wu, Ying and John J. Carroll (editors), Acid Gas Injection and Related Technologies, Advances in Natural Gas Engineering, 2011. John Wiley & Sons. P. 170.

[54] **http://www.tcmda.com/en/**

[55] **http://www.oilsandsken.com/huge-challenge-facing-oil-and-gas-companies/**

[56] **http://www.ferc.gov/industries/gas/indus-act/lng.asp**

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

[58] **http://SaskPowerccs.com/2015-symposium/symposium/**

[59] **http://www.co2-research.ca/index.php/about-us/**

[60] **https://ukccsrc.ac.uk/**

[61] 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.

[62] Private communication with the PTRC.