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Summary for Decision Makers on Second Generation CCS

BASED ON THE SHAND CCS FEASIBILITY STUDY

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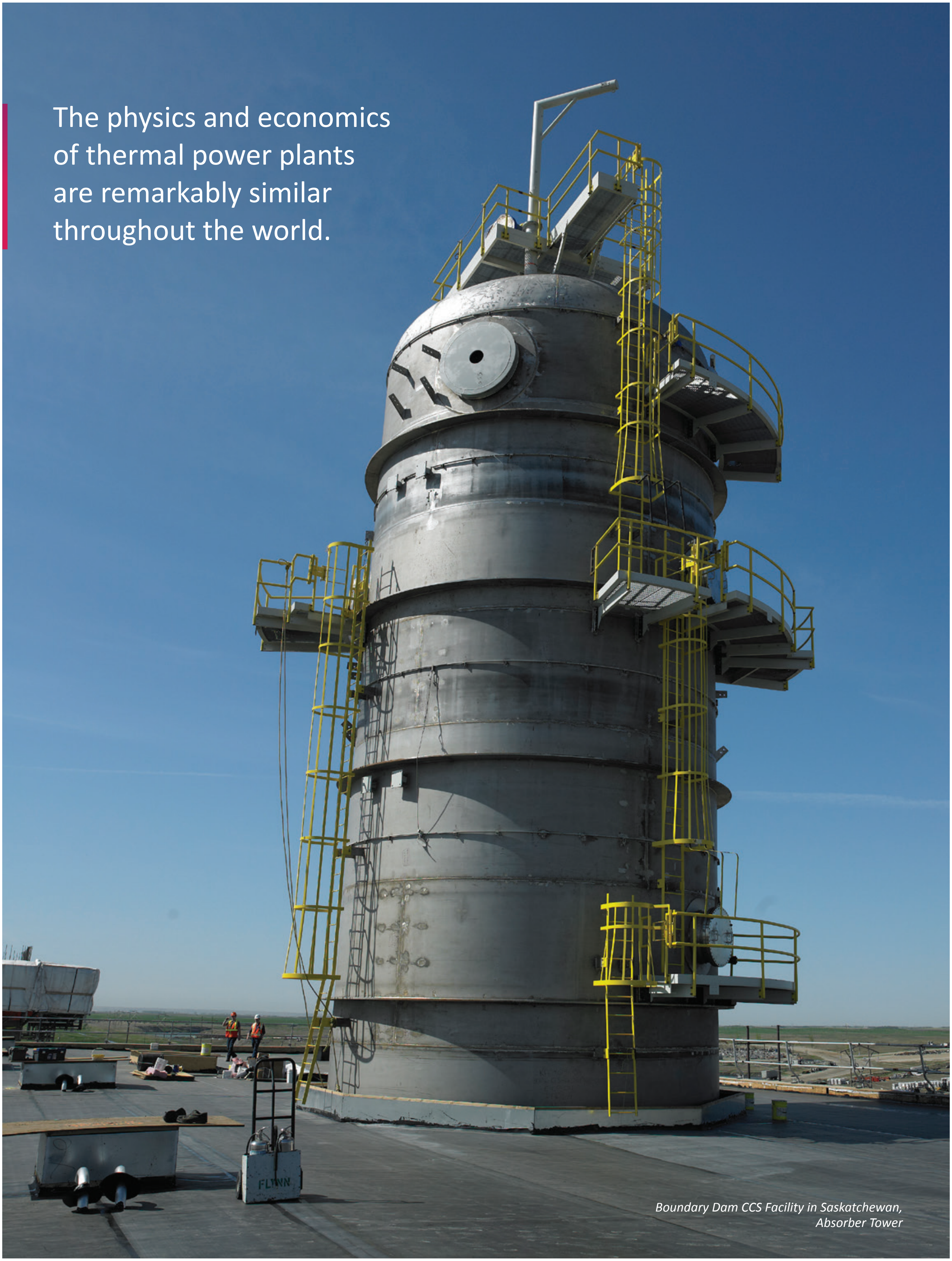

Boundary Dam CCS Facility in Saskatchewan, Absorber Tower

Introduction

The Canadian province of Saskatchewan is a world-leader in carbon capture and storage (CCS). Saskatchewan and its provincial utility, SaskPower, pioneered the way for full-scale carbon capture facilities around the world with their fully-integrated CCS project on Unit 3 of the Boundary Dam coal-fired power plant (BD3). Operations at BD3 have steadily improved since initial startup. The facility has addressed safety issues and has recently started to demonstrate a level of reliability that is consistent with a thermal-generating facility, although still at below design CO_2 production levels. Once stable operation of the facility is achieved, it will allow the plant operations and support staff to focus on improving the efficiency and cost effectiveness of the operation.

The world has considered SaskPower's fully-integrated post-combustion CCS facility a trailblazer. Design, construction, and operation of the large-scale facility all contribute to tangible understandings of how commercial CCS works. This study is based on learnings from actual deployment and as a result, the economics of CCS have credibility. While ongoing improvements are anticipated, this report will highlight that second-generation CCS will undoubtedly realize many improvements over the first generation. The expected reduction of both capital and operating costs can increase acceptance and drive deployment.

This *Summary for Decision Makers on Second Generation CCS* clearly establishes that insights from first-generation CCS can be leveraged to accelerate further CCS deployment. The physics and economics that govern the design and operation of thermal power plants are remarkably similar throughout the world; as such, the methods and concepts explored in this report can be applied broadly. In fact, many of the same fundamental findings can be further applied to other post combustion capture on industrial processes such as cement and iron and steel.

Saskatchewan and SaskPower are now approaching another important decision related to electricity supply and considerations for CCS in the future. The utility has a need to provide reliable and affordable base-load power, regionally only available from coal or natural gas, while meeting Canadian federal regulations limiting emissions from traditional coal-fired power plants. The International CCS Knowledge Centre (Knowledge Centre) has prepared this feasibility study to the American Association of Costing Engineers (AACE) guidelines for a class 4 estimate to study if a business case can be made for a post-combustion carbon capture retrofit of a second coal-fired unit in the province—specifically, the Shand Power Station.

Saskatchewan and its provincial utility, SaskPower, pioneered the way for full-scale carbon capture facilities around the world.

A detailed public document—*the Shand CCS Feasibility Study*—specifically and substantively focuses on the technical aspects of retrofitting the Shand Power Station. Should SaskPower decide to proceed, the Shand CCS project would produce the second, full-scale capture facility in Saskatchewan with a nominal capacity of 2 million tonnes (Mt) of carbon dioxide (CO_2) per year—twice the initial design capacity of BD3. Information contained therein represents the interpretation of the non-confidential portion of this study to highlight both the overall impact on the cost of CO_2 capture, as well as contrasting the impact of the major design modifications with the BD3 system.

General application of this information to other facilities globally are further articulated in this compendium document to the *Shand CCS Feasibility Study*. BD3 paved the way for next generation learnings for a climate technology that is necessary internationally. While this study focuses on the potential application to coal-fired emissions at the neighboring Shand Power Station, there is also a real and relevant importance from this study to other sources of emissions.

Key findings of feasibility study evaluates the economics of CCS on a 300MW coal-fired power plant in Saskatchewan

- Designed to capture 2Mt/year
- 67% capital cost reduction (per tonne of CO_2 captured)
- Cost of capture at USD$45/t CO_2
- Capture rate can reach up to 97% with reduced load (i.e. integrates well with renewable electricity)
- Fly ash sales can further reduce CO_2 (potential 125,000t CO_2/year reduced). Some believe this means the facility can be *carbon neutral.*

How did costs come down?

- Lessons learned from building and operating BD3
- Construction at a larger scale using extensive modularization
- Effective integration (a case-by-case imperative)

Boundary Dam CCS Facility in Saskatchewan

About the International CCS Knowledge Centre

The International CCS Knowledge Centre is a non-profit organization created and sponsored by BHP and SaskPower.

Its mission is to accelerate the understanding and use of CCS as a means of managing greenhouse (GHG) emissions. The Knowledge Centre houses seconded employees from SaskPower who were instrumental in the development and operations of the Boundary Dam CCS facility. Our team actively engages financiers and decision makers to ensure high-level information on CCS is conveyed with political, economic and other broad considerations. We also add practical, hands-on development experience, technical advice for planning, design, construction, and operation of CCS.

The Knowledge Centre's staff are available to provide experience-based guidance for CCS projects, including case-by-case feasibility analyses like the *Shand CCS Feasibility Study*.

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Boundary Dam CCS Facility in Saskatchewan

Boundary Dam CCS Facility: Building on Knowledge

SaskPower studied several carbon capture technologies for the BD3 unit and post-combustion was subsequently implemented. The BD3 project was aided by a one-time CAD$240 million grant from the Government of Canada. This grant, coupled with an assumed sale of the CO_2 for enhanced oil recovery (EOR), and extensive re-use of an end of life coal plant combined to create a project which evaluated to a Levelized Cost of Electricity (LCOE) that was equivalent to building a new Natural Gas Combined Cycle (NGCC) plant at that time.

When completed, the integrated carbon capture plant was designed to capture 1 Mt per year, reflecting a 90% capture rate and extending the life of the plant by 30 years. Approval for the construction of the facility on BD3 occurred in early 2011 and construction began that spring. The total investment in the power unit's retrofit and carbon capture plant was approximately CAD$1.5 billion.

In October 2014, the BD3 capture plant became the world's first utility-scale, fully-integrated post-combustion carbon capture facility on a coal-fired power plant. Captured CO_2 is used for EOR in a nearby oil field and for test injection into a deep saline reservoir at a research project called Aquistore. Overall, the BD3 demonstration project transformed Unit 3 at Boundary Dam Power Station into a long-term producer of more than 110 megawatts (MW) of clean, base-load electricity, while demonstrating EOR potential in a fully-integrated process.

The startup of CCS on the BD3 capture plant was the culmination of a decade's worth of work by SaskPower focused on continued operation of coal-fired power-generating stations which provide fuel diversity for its fleet, while mitigating the climate change impact of associated air emissions. Operations have steadily improved since initial startup. The facility has addressed safety issues and has recently started to demonstrate a level of reliability that is consistent with a thermal-generating facility, although still at below-design CO_2 production levels. Once stable operation of the facility is achieved, it will allow the plant operations and support staff to focus on improving the efficiency and cost-effectiveness of the operation.

FIGURE 1: Greenhouse Gas Emissions Profiles and Performance Standards in Saskatchewan

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*

Abating Coal Emissions: Going Beyond What is Required

National policies play a role in any case-by-case circumstance surrounding CCS deployment. Such is the case for considering CCS in Saskatchewan at the Shand Power Station. *The Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations,* which came in to effect July 1, 2015, set a stringent performance standard for new coal-fired electricity generation units and units that have reached the end of their useful life (nominally 50 years). The level of the performance standard is fixed at 420 tonnes of carbon dioxide per gigawatt hour (t/GWh) and has now been updated to phase-out all unabated traditional coal-fired power by 2030. The aim of these regulations is to implement a permanent shift to lower or non-emitting types of generation, such as high-efficiency natural gas, renewable energy, or fossil fuel-fired power with CCS. CCS is the only method by which coal-fired power generation plants (old and new) can achieve these emission targets. Therefore, in Canada, a coal-fired power plant past its retirement date must be retrofitted with carbon capture technology or closed by 2030.

Conventional lignite coal-fired power generation (used in Saskatchewan, Canada) emits roughly 1,100 tonnes of CO_2/GWh (t/GWh). Traditional natural gas-fired power facilities emit in excess of 500 t/GWh. Newer, continuously operating, combined-cycle facilities operate as low as 375t/GWh and when used as a backup to intermittent non-emitting renewable energy can contribute to an effective emission intensity less than 300t/GWh. In contrast, BD3 was designed to capture up to 90% of the CO_2 in the flue gas and operate as low as 120-140 t/GWh. The greatest gains in CO_2 emissions reductions, in an electrical system without the ability to add hydro or nuclear facilities, are realized with CCS.

Provincially developed regulations for coal can solely apply if both the provincial and federal governments agree they are equivalent. An Equivalency Agreement can be considered to avoid duplicative regulatory burden if provincial regulations serve the same purpose and have the same effect as federal regulations. Such agreements are not common and take time to be negotiated. An agreement-in-principle for equivalency between Saskatchewan and Canada exists, but the final agreement is still outstanding. Equivalency may be satisfied by balancing out the total emissions of all coal plants within a jurisdiction to satisfy regulations. The impact of emissions stem beyond individual plants, and individual jurisdictions; the balancing of emissions to meet regulatory requirements across a system therefore has greater benefits than a regulation targeted to specific units.

Rendering of Shand Power Station and Carbon Capture Facility

Studying the Shand Power Station

Commissioned in 1992, Shand is SaskPower's newest coal-fired power plant and is considered to be the best candidate for another CCS Project.

In Saskatchewan, the largest coal units produce around 300 MW of electricity. The four units at SaskPower that are in the 300MW class are Boundary Dam Unit 6, Poplar River Units 1 & 2, and the Shand Power Station. With effectively double the total emissions of BD3, a 90% capture plant on a 300MW unit would have a capture capacity of 2Mt per year.

Shand Power Station is a single unit plant located 12 kilometers from the Boundary Dam Power Station. Shand was originally designed with provisions for a second unit that was never built, therefore it has the space and infrastructure to support a carbon capture facility. Commissioned in 1992, Shand is also SaskPower's newest coal-fired power plant and is considered to be the best candidate for another CCS project.

A successful implementation of a CCS retrofit at Shand will provide an example of how to implement CCS at other coal units. Therefore, the *Shand CCS Feasibility Study* has established the basis for a standard CCS retrofit design that could be deployed with minor variations on other coal units and more importantly has direct application to other global coal-fired power plants and industrial applications.

The *Shand CCS Feasibility Study* and its associated documents reflect the findings and opinions of the Knowledge Centre. SaskPower has many factors that will determine if or when CCS will be deployed on units beyond BD3.

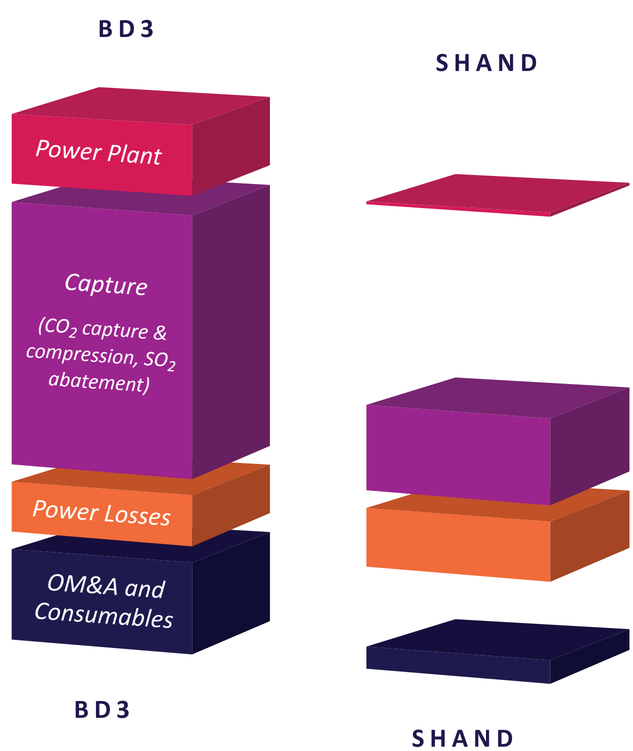
Second Generation CCS: Applying the *Shand CCS Feasibility Study* to a Global, Multi-Sector Context

Reliable and affordable energy with reduced emissions is imperative for energy security. The implementation of CCS can allow existing generating assets to operate cleanly and aid to decarbonize industrial emissions. Post combustion CCS takes flue gases (the emissions) and cleans them using a solvent (called an amine). Because the post combustion capture is downstream from an emissions source (i.e. "post" combustion), and because the emissions from a coal-fired power plant are in many ways similar to those from other industrial sources of emissions (although average CO_2 concentration and impurities may differ), post combustion capture on coal paves the way for other industrial applications.

This comparison chart represents the cost savings that can occur by progressing from BD3 to the second generation of CCS. The chart is evidence of the areas where significant improvement can occur. The *Shand CCS Feasibility Study* shows there is a 92% reduction to power plant capital costs (as highlighted below this stems from the case-by-case differences, in this case age of the power plant's boiler and other considerations); a 67% reduction to capture plant capital costs; and a 73% OM&A and consumables reduction. While these are significant cost reductions, further cost risks can still be reduced through optimization—particularly with amine health.

The *Shand CCS Feasibility Study* shows there is a 67% reduction to capture plant capital costs.

FIGURE 2: Cost Comparison of BD3 & Shand CCS Facility



Shand Power Station in Saskatchewan

SELECTING THE RIGHT FACILITY FOR CCS

Understanding commonalities with previously deployed CCS facilities can help direct development considerations. For example, the main factors for conducting a feasibility study at the Shand Power Station included location, space requirements, and age. The capital cost for the Shand CCS Facility is projected to be 67% less than the BD3 facility on a dollar per tonne of CO_2 basis. Factors such as scale, modularization, simplifications and other lessons learned as a result of building and operating the BD3 facility contributed directly to these reductions.

It is important to note, that while the Shand CCS Facility may be virtually reproducible for other coal units in Saskatchewan, simply duplicating a CCS facility is not an appropriate way to apply the technology. The first place to start when determining where to develop a CCS facility is to examine the options on a case-by-case basis.

Age:

Any large industrial facility will, over its lifetime, require maintenance and modifications. This is true for any facility on which a CCS project will be attached. When it comes to power generation—and often industrial processes—older facilities tend be less efficient and smaller, with less of a remaining lifetime and/or higher costs to refurbish. These are important economic considerations for CCS application because capital costs are incurred not only to build a CCS facility, but also to modify the unit on which it will be attached.

Size & Layout:

Economies of scale is a familiar concept throughout industry—in general, facilities that are larger are more economic. A proportionate saving in costs can be gained by an increased level of production. With a focus on reducing capital cost, building a CCS plant only as big as it needs to be to capture CO_2 permissible under regulatory caps, or for market demand, would seem reasonable. Studies were undertaken to determine the amount of capital cost reduction that could be realized at various capture rates. It was determined that building a small CCS facility or designing the plant to capture less than 90% of the CO_2 in the emission stream will ultimately increase the per tonne cost of CO_2 capture.

To that end, sometimes one large facility is a better option than two smaller ones. First-hand knowledge of studies has shown that combining two 150MW units to have a single carbon capture plant attached may appear to make sense, but the realities of interaction of the maintenance in combining Boundary Dam 4 & 5 for example (both 150MW units), resulted in a lower utilization factor compared to CCS on a single 300MW unit.

The availability of space for the CCS plant footprint is also a factor in determining a suitable location. The distance between the power facility and the capture facility on BD3 resulted in significant capital expenditures for interconnections. In addition, greater physical distance between the CCS facility and its host makes integration of the operations more complex and less effective. In contrast to the Boundary Dam site, the Shand site with its single unit is immediately next to the power plant and has the space to accommodate a CCS facility at a lower capital cost.

Proximity:

Creating a CCS facility around a hub of CO_2 distribution infrastructure can also save costs. The Alberta Carbon Trunk Line (ACTL) is a prime example of an initiative to maximize the opportunities for capture, utilization in the oil fields, and permanent sequestration. ACTL will consist of a 240km pipeline that can transport up to 14.6Mt of CO_2 per year at full capacity. The CO_2 is intended to be transported from capture plants at different industrial facilities and then injected into depleted oil reservoirs. Routing of the ACTL has access to oil reservoirs capable of producing over 1 billion barrels of oil.[1]

When considering the Shand Power Station, it was theorized that due to the proximity to BD3, along with the ability to connect the two CO_2 supplies by pipeline, it would create a more stable supply and reduce operational costs associated with delivery challenges. A review by the Ministry of Energy and Resources of the Government of Saskatchewan indicates the potential to store all CO_2 from this project, while unlocking an incremental oil recovery of 40,000 barrels of oil per day from depleted oil fields in the area. If additional capture projects and sources of CO_2 become available, then the total capacity for CO_2 storage combined with EOR is up to 230 Mt of CO_2, while unlocking 660 million barrels of oil.

Not every location has EOR opportunities—the concept of a new hub at the Port of Rotterdam is a prime example of how non-EOR CO_2 hubs can exist for storage, but only if the price of carbon increases or there is significant subsidizing of development. The port's plan is to create a CO_2 transport hub to serve the Netherlands' industrial facilities. A pipeline network would transport the CO_2 for injection in depleted oil and gas fields in the North Sea.[2] It has the potential to extend to serve industrial plants in other countries looking to dispose of their CO_2 such as Belgium, Germany or the UK.

> The *Shand CCS Feasibility Study* suggests CCS is a viable source of backup energy for renewable generation sources such as wind and solar.

INCENTIVES

Calibrating policy settings at an appropriate level to incentivise a project can drive deployment. The major incentive that is expected to increase adoption of CCS is the significant increase and extension to the Section 45Q tax credit in the United States. Prior to its recent revision, there was a cap of 75Mt that could be claimed by all projects. The incentive provided a USD$10 credit for CO_2 used for EOR, and a USD$20 credit for CO_2 permanently stored through sequestration (justification for the differing amounts was that the market will pay for CO_2 used for EOR). The new 45Q tax credit values are set at USD$35 and USD$50, respectively, and the cap has been removed. The increase in the tax credit coupled with cost reductions that can be realized by applying operational insight, is expected to increase CCS application in the United States in a practical way.

In the oil fields of Saskatchewan EOR incentives exist in the form of a Crown and Freehold royalty regime. This allows for only 1% of the royalties and taxes to be collected until capital costs are recovered, followed by a regular net-income-based fee structure. With costs being reduced for CCS, the sale of CO_2 to an EOR project may even provide adequate motivation for a CCS retrofit financed by the private sector. While this is a specific local benefit, incentives such as this are what may be needed to deploy CCS.

Wind Generation

RENEWABLES AND CCS GOING HAND IN HAND

Maximizing clean electricity is important, and therefore adding renewables to the electrical grid is integral to driving emissions reductions globally. Although energy storage (in various forms) will make a significant contribution over time, variable renewable power currently requires a reliable electricity supply as back-up. That reliable baseload power is currently filled by fossil fuel power generation—from coal and natural gas—nuclear or hydropower.

One of the most interesting findings in the *Shand CCS Feasibility Study* relates to the benefit of a post combustion carbon capture plant as an alternative to the use of natural gas as a source of backup energy for variable renewable generation sources such as wind and solar. A backup energy facility is generally able to provide all required power and reduces its power output in order to allow available renewable energy. In most instances the backup facility has a minimum output that it will maintain rather than shutting off.

If the backup energy is sourced from a natural gas plant, that plant's efficiency decreases at lower power output, and consequently the emission intensity of generation increases when a natural gas plant reduces load to allow variable renewable generation, somewhat muting the non-emitting impact of the variable renewable source. In contrast, a post combustion capture plant can further reduce its emissions when it has reduced its output in order to support variable renewable generation, in effect, amplifying the impact of the non-emitting renewable energy source. A CCS equipped thermal power plant, can be designed for over-capture at reduced loads with no appreciable capital cost increases, paving the way for these plants to integrate with renewables, resulting in a lower overall emission intensity. In the case of the Shand study, it was possible to increase the capture rate from 90% of the CO_2 at full load, to 97% capture at the minimum turndown that could support variable renewables.

[1] http://enhanceenergy.com/

[2] https://www.euractiv.com/section/energy/news/meet-europes-two-most-exciting-co2-storage-projects/

Optimization efforts are a balance between efficiency gains versus capital and operating costs. The *Shand CCS Feasibility Study* balanced optimization decisions through in-depth modelling and review of process configurations, while taking into consideration site specific dimensions. These decisions impacting equipment, operating parameters, equipment placement, and process all contribute to achieving the cost reductions.

Heat Integration:

Large cost reduction opportunities can be found through a process called heat integration and are broadly applicable to other industrial applications. One of the challenges of post combustion capture is the amount of thermal energy that is required when the solvent undergoes a process called "regeneration". The source of this thermal energy is steam and it is the basis for how efficient and flexible the plant will operate. Steam can come from within the power plant (integrated) or from an external dedicated steam supply. At the Petra Nova CCS facility in the United States, large, extra costs were incurred when an external, dedicated steam supply was added—a new natural gas turbine. This was due to a federal law called "new source review" which limits new coal plant additions—even if they reduce emissions.

Results show that extracting steam from an existing facility provides the most flexible and economic option. Recycling heat—like the rationale of recycling plastic—can minimize the amount of wasted heat, minimizing the amount of energy consumed and maximizing the amount of heat that is recovered during capture. Notably, this same concept can be applied to other facilities—such as cement—using waste heat.

Amine Risk:

The *Shand CCS Feasibility Study* finds that potential project risks for increased operating costs and barriers to project approval have been mitigated. Proactive measures to evaluate amine maintenance costs, which are of most concern for effective management of ongoing operating costs, would be realized by executing pilot testing at SaskPower's Carbon Capture Test Facility (CCTF). The CCTF's flue gas supply is directly sourced from Shand allowing rigorous evaluation of emissions and maintenance costs prior to a final investment decision. While this benefit is specific to this facility, the Knowledge Centre is working with the CCS community to reduce the size, cost and complexity of systems required to validate the maintenance and operation costs of specific amine and flue-gas combinations.

Water:

Water is a concern for many large-scale commercial facilities. Availability of water is often a key driver when identifying the site of a new facility and is often the limiting factor for expansion. Similarly, water supply at the Shand Power Station is limited and additional water draw for the capture facility would be an obstacle to deployment. As a result, the CCS system was designed without the requirement for additional water. The proposed heat-rejection design would eliminate this burden by only requiring the use of water that has been condensed from the flue gas. Limited water for cooling will be a common theme for CCS retrofits of thermal power plants globally, thus making this solution broadly applicable.

Concrete Finishing

> Including lifecycle emission reductions associated with the fly ash byproduct would result in a plant with net-negative CO_2 emissions.

MODULARIZATION OPTIONS

For the *Shand CCS Feasibility Study,* modular construction was determined to be an ideal option for achieving cost reduction. Modular construction is a process whereby components of the CCS facility can be constructed off-site, while meeting the same standards and requirements, but often at less cost and with less disturbances to the site. Major infrastructure projects in western Canada, specifically the Alberta oil sands, have embraced modularization as a means of controlling costs. Routes exist in Saskatchewan and Alberta that can support the road delivery of modules and vessels to a certain dimension. The opportunity for the assembly of structural steel, equipment, piping, electrical and instrumentation can offer dramatic increases in productivity, reduced travel costs, and shorter on-site construction time.

BYPRODUCTS DRIVING FURTHER REDUCTIONS

The Boundary Dam facility sells CO_2 for oil production, but also sees byproduct profits from the sale of fly ash. The *Shand CCS Feasibility Study* highlights that, subject to demand, up to 140 thousand tonnes per year of fly ash could be sold for the concrete market from the Shand project. Not only is this a valuable revenue consideration in the business case for the Shand CCS facility, but it also means that CO_2 emissions are further offset. When fly ash is used in the production of concrete, there are less process emissions than from traditional concrete manufacturing. Based on current calculations, this would allow for potential net emission reductions from fly ash sold from a CCS facility at Shand of 125,000 tonnes per year. At a 95% capture rate on Shand, including lifecycle emission reductions associated with the fly ash byproduct would result in a plant with net-negative CO_2 emissions.

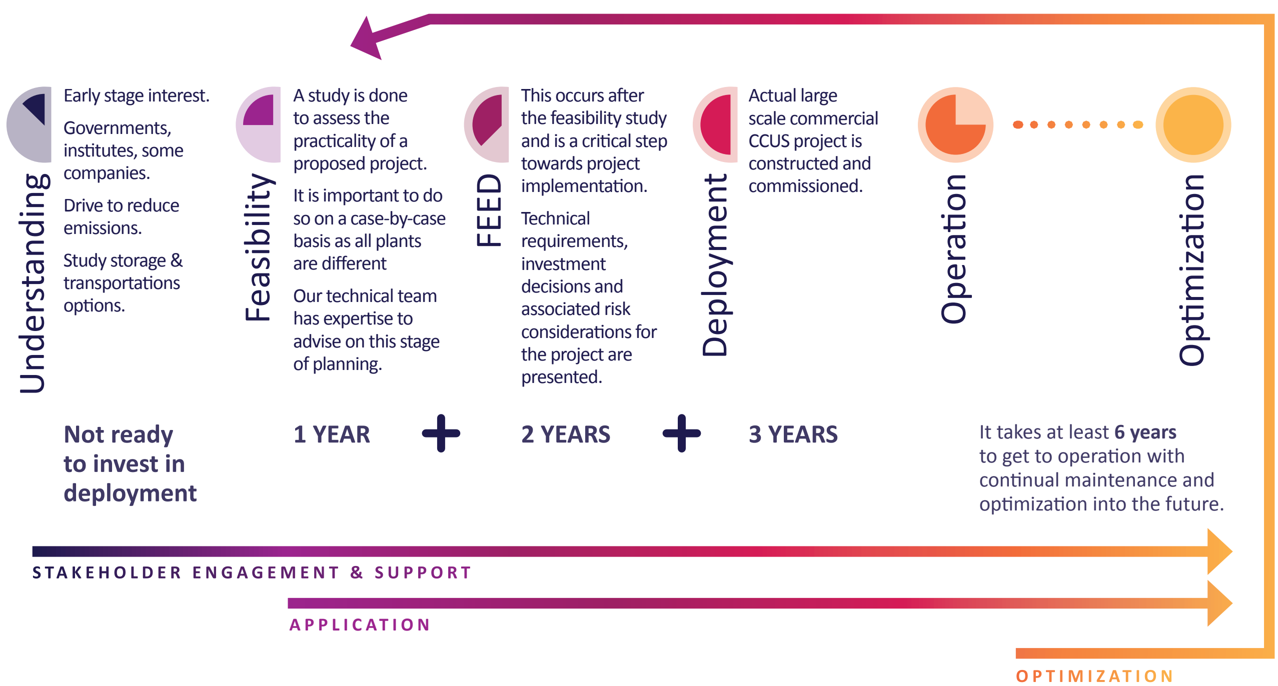
There may be an opportunity to convert some of the captured CO_2 into usable products. The conversion of CO_2 does not mitigate greenhouse gas emissions at the large-scale required to reach international climate change targets; however, finding use for CO_2 where EOR or storage is not available is an emerging option. The energy requirements to convert the CO_2 must also be factored into the overall emission reduction potential of conversion, as early research indicates that it is often energy intensive to utilize CO_2 in this way. Further, the amount of CO_2 captured from large industrial point sources is far greater than what is able to be converted into usable products, so storage/EOR options will still be required.

CCS Timelines

CCS facilities require several technical milestones in order to ensure appropriate deployment. Each of these steps are based on levels of risk and varying levels of acceptance and approval internal to individual organizations. Nevertheless, following these steps can help a project have a greater chance of success. To date, many CCS projects that have been studied end up not proceeding – most often due to a lack of economics. Below are highlighted the steps for deploying a CCS project and the general factors to consider.

Rather than moving straight from a Front End Engineering Design (FEED) study to commercial scale deployment, developers may elect to first build test or pilot facilities, both because of the lessons that can be learned prior to developing commercial scale facilities and the reduced capital costs. While pilot facilities serve an important purpose, there may be more economic and less time-consuming pathways available, including utilizing test facilities that already exist in other locations or using small mobile units (as mentioned previously in the section on amine risk).

FIGURE 3: Aggressive Timeline to Deploy a CCS Project



Driving Future Opportunities: Some Added Insight

Regulations in Canada encourage moving away from coal-fired power generation without CCS; and while there is a significant revenue opportunity to utilize and sequester CO_2 for EOR operations in Canada, low oil prices have softened the demand for the CO_2. The economics of retrofitting coal with CCS are further challenged by an abundant supply of natural gas which is available at all-time low prices that have persisted long enough that the commodity's value is perceived to have found a new norm in North America. Against these headwinds, below is a non-exhaustive list of the enabling factors to drive future CCS opportunities both in Canada and globally. It highlights that CCS deployment will not occur without cooperative approaches, reduced administrative burden, and appropriate incentives and financing mechanisms.

Cooperative approaches to developing CCS are critical at this early stage where competition is less important than accelerated uptake. The Knowledge Centre is tasked with sharing lessons learned from operational insight. This practical form of cooperation should be heightened in order to ensure that potential facilities save time and effort in developing workable CCS projects. Such experienced-based decision making can avoid costly delays or allow projects to proceed. Cooperation should begin at an early stage.

Mike Monea, President & CEO
International CCS Knowledge Centre

Any organization contemplating CCS requires a strong business case often driven by a positive return on investment.

DRIVING FUTURE OPPORTUNITIES: SOME ADDED INSIGHT *CONTINUED*

Multi-stakeholder initiatives may also aid in driving development. This comes not only in the form of CO_2 hub infrastructure, discussed in greater detail above, but can also come from a shared cost burden or greater concentrated knowledge of the various stages of the process—such as the energy system, the industrial facility, the nearby oil fields or other considerations. For instance, the Petra Nova project was successful in utilizing a multi-stakeholder approach in its collaboration between JX Nippon Oil & Energy Corporation and NRG Energy.

Regulatory considerations mainly consist of enforcement and liability. Enforcement regulations for CCS stem from the need to ensure safety and security, proper storage, and monitoring and verification (at injection and after). Regulations in Canada were designed to facilitate CCS development by removing barriers to the storage and long-term security of CO_2. Prior to 2010, there had been uncertainties over the long-term liability for carbon stored underground, and access to pore space (underground storage spaces) to store the carbon. Granting ownership made clear legal process for companies and government and reduced overall risk/cost.

Canadian regulations regarding long-term CO_2 storage liability are often built into existing regulations, including the *Crown Minerals Act* and the *Oil and Gas Conservation Act.* This same practice occurs in some states, such as Texas. In Saskatchewan, a company that has stored carbon is liable for the injection site so long as the owner exists and is financially stable; whereas in Alberta the liability transfers to the province after a set amount of time regardless of the state of the company. The province of Alberta also makes it mandatory for CCS operators to contribute to a Post-Closure Stewardship Fund, which is used for ongoing monitoring, maintenance, and remediation.

Operational insight drove greater:
cost reductions,
complexity reductions,
and
emissions reductions.

Many places that have existing oil and gas regulations can reduce administrative burden by amending those regulations to incorporate CCS as was done in Canada.

Just as building on existing regulations is important to reduce time and process, permitting barriers should also be minimized. Permitting is necessary and rigorous review of projects should be enforced, however, streamlining processes to accommodate CCS projects may be an effective way for governments to relieve developers of the administrative burden of multiple permitting processes. In addition, important care and attention should be given to the classification of CO_2 as a commodity or as a waste—hazardous or otherwise—to enable the ease of securing transportation permits.

Interior of Boundary Dam 3 CCS Facility

The lack of regulations specifically for CCS should not limit development. In fact, regulations do not always come before national policy commitments or project-level developments especially since regulations alone are unlikely to drive CCS. Creating a variety of CCS incentives such as 45Q or the royalty regimes mentioned above are the types of incentives that are required to drive market shifts favouring CCS. These driving factors can shape a cleaner energy system, but also are important for industrial non-energy sources of emissions that are hard to abate. Subsidies and incentives can take various forms. One key example that may allow project developers to get moving on their initial large-scale commercial CCS projects is a double credit system for first movers that was demonstrated in Alberta and used by the developers of the Shell Quest CCS facility.

Financing of projects has been supported greatly by money from both federal and provincial governments in Canada and are the basis of new opportunities for CCS deployment in Norway, amongst other regions. Government contributions are beneficial, but such funding can extend further when leveraged with private funding. Multilateral Development Bank involvement is critical, especially for Asia, as are requests for money to international climate funds.

The Knowledge Centre hopes that based on the understanding of post combustion systems, investments in future projects can be de-risked based on application of past understandings. There has been recent global momentum to drive CCS forward, but ultimately a stall in large-scale deployment. The cost of CCS is often viewed as a limitation to broader acceptance, but costs will continue to rapidly decline by applying technological refinement at all stages of development. Operational insight is crucial to driving greater cost reductions, reductions in complexity, and emissions reductions.

Experience-Based Decision Making

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Summary for Decision Makers on Second Generation CCS

BASED ON THE SHAND CCS FEASIBILITY STUDY

INTERNATIONAL CCS KNOWLEDGE CENTRE