INTERNATIONAL CCS KNOWLEDGE CENTRE

IEAGHG

# A DECADE OF CCS

## PUSHING THE BOUNDARIES AT BOUNDARY DAM 3

MARCH 2026

## About The International CCS Knowledge Centre

The International CCS Knowledge Centre ("Knowledge Centre") is an independent organization focused on advancing a sustainable future by sharing insights and expertise on carbon capture and storage (CCS) and other climate solutions. With unparalleled experience developing CCS projects, the Knowledge Centre fosters collaboration and the exchange of knowledge to reduce greenhouse gas emissions and support global net-zero goals.

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INTERNATIONAL CCS KNOWLEDGE CENTRE

### CITING THE INTERNATIONAL CCS KNOWLEDGE CENTRE

# A Decade of CCS:
# Pushing the Boundaries at Boundary Dam 3


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Section 1

# A Decade of Innovation

On October 2, 2014, SaskPower made history when the Boundary Dam Unit 3 (BD3) carbon capture facility became operational. It was the world's first commercial-scale coal-fired power plant incorporating Carbon Capture and Storage (CCS). Using advanced amine technology, BD3 proved that large-scale carbon capture could be integrated into existing energy infrastructure. This project demonstrated a viable pathway for coal-fired power generation to reduce its carbon dioxide ($CO_2$) emissions, offering a starting point for other heavy-emitting industries to reduce their carbon footprint.

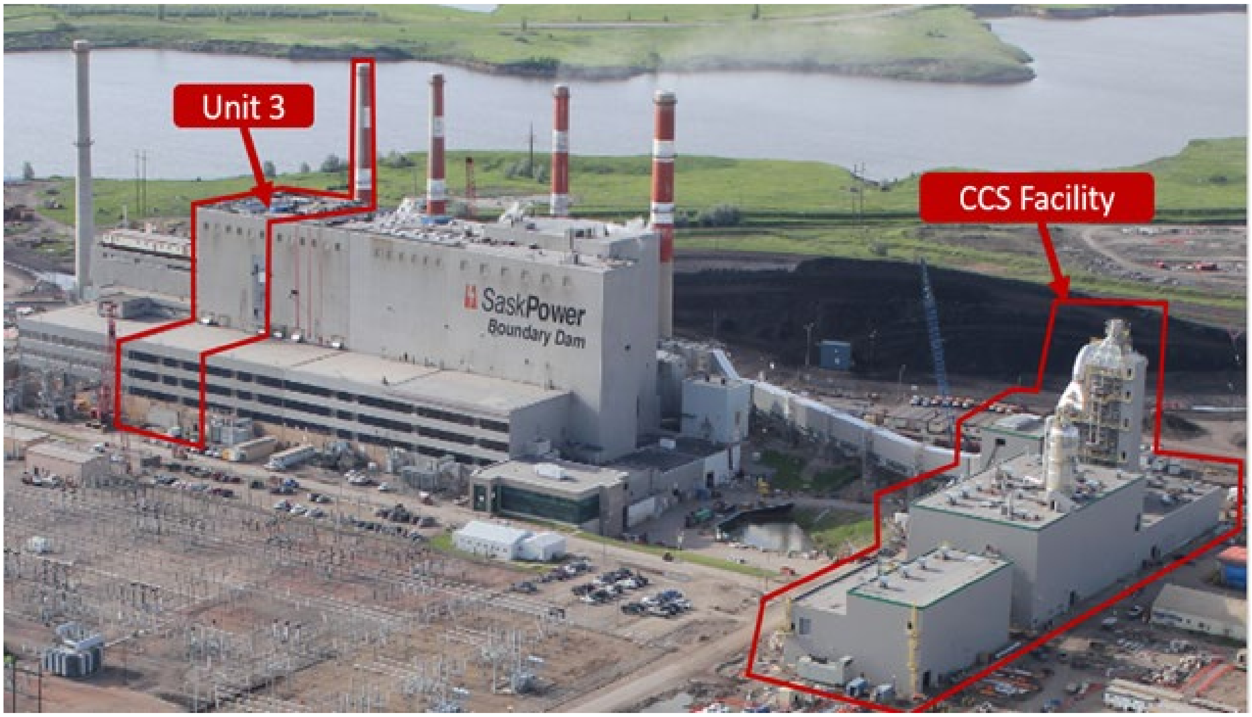



*Figure-1: SaskPower Boundary Dam Power Station and ICCS Facility*

The early stages of BD3's CCS operations were documented in the 2015 IEAGHG report (IEAGHG 2015-06), Integrated Carbon Capture and Storage Project at SaskPower's Boundary Dam Power Station, which highlighted the complexities of retrofitting an aging power plant while sharing the strategies used to overcome these challenges. This publication builds upon the 2015 report, examining the key decisions that have driven the project's development, its long-term performance, operational advancements, and the lessons learned in the first generation of CCS technology implementation.

BD3's operations have been a testament to the impact of commercial-scale CCS development, having captured and stored more than 7 million tonnes of $CO_2$ as of August 2025, the equivalent of removing approximately 1.5 million passenger vehicles from the road for a year.

The majority of the $CO_2$ captured at BD3 is utilized by a local off-taker at a nearby oil reservoir for Enhanced Oil Recovery (EOR), with the remainder permanently stored in a deep saline aquifer at the Aquistore site, where ongoing research by the Petroleum Technology Research Centre (PTRC Sustainable Energy) supports Monitoring, Measurement, and Verification (MMV) efforts while providing invaluable information on $CO_2$ storage for future project developers. These initiatives have reinforced Saskatchewan's leadership as a global knowledge hub, informing future CCS projects across multiple industries, including power generation, cement, steel, and hydrogen production.

The past decade has seen BD3 undergo continuous optimization, refining its processes and addressing technical hurdles, paving the way for more efficient CCS implementation. SaskPower's leadership in providing opportunities for sharing insights gained from BD3's operations has helped to shape best practices in carbon capture projects worldwide.

This report serves as both a historical record and a forward-looking analysis, capturing BD3's evolution from a technical concept to a guide for the application of large-scale carbon capture. As the world requires continued efforts to reduce carbon emissions, BD3's journey provides an invaluable record for the future of CCS technology.

**BD3 has captured and stored over 7 million tonnes of $CO_2$—celebrating a decade of innovation, refinement, and global leadership in commercial-scale carbon capture.**

Section 2

# Concept & Strategic Justification

The BD3 Integrated Carbon Capture and Storage (ICCS) project was conceived in 2005 as part of SaskPower's long-term strategy to balance Saskatchewan's need for reliable, affordable electricity with the growing imperative to reduce greenhouse gas emissions from coal-fired power generation. At the time, emerging federal regulations aimed at limiting coal plant emissions provided motivation to find a new, sustainable solution. Although SaskPower was expanding wind power capacity, Saskatchewan's electricity grid relied heavily on coal to provide a stable baseload power source alongside intermittent renewable generation. Natural gas was considered as an alternative, but volatile fuel prices and supply uncertainties posed financial and energy security risks. In this context, SaskPower identified CCS as a transformative solution, allowing the continued use of low-cost, locally mined lignite coal while significantly reducing emissions and ensuring grid stability.

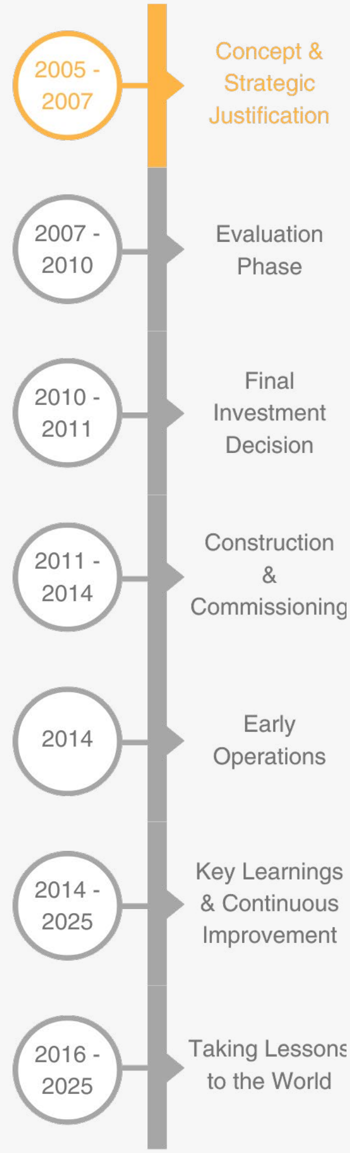
The Boundary Dam Power Station, located near Estevan, Saskatchewan, originally consisted of six coal-fired power generation units, with nameplate capacities of 66 MW for Units 1 and 2, 150 MW for Units 3, 4 and 5, and 300 MW for Unit 6. Units 1 and 2 were retired in 2013 and 2014 due to the high costs of retrofitting them to meet emissions regulations, while units 4, 5, and 6 continued to operate without CCS, providing reliable power to the grid. As Unit 3 neared the end of its operational life, retrofitting the plant and integrating it with CCS offered a way to extend its use and proactively reduce emissions.

As part of the evaluation process, SaskPower compared the capture solution against building a new natural gas combined cycle plant. The CCS pathway required SaskPower to refurbish the plant's boiler and turbine while integrating CCS technology, achieving performance comparable to a newly built natural gas power plant.

A key enabler in the development of the BD3 ICCS project was the Government of Canada, providing CAD$240 million in federal funding, covering approximately 16% of the total CAD$1.5 billion capital investment for the CCS process and the plant retrofit.

BD3's business case was improved with the potential for additional revenue streams from the sale of by-products from the updated facility. Captured $CO_2$ was expected to be sold to nearby oil fields for Enhanced Oil Recovery (EOR), and sulphuric acid was expected to be sold to regional industrial markets.

BD3 ICCS PROJECT TIMELINE



As SaskPower is a public utility, the incorporation of technical, financial, strategic, and socio-economic considerations was essential to building confidence among the many stakeholders in the project. SaskPower was proactive in creating an open dialogue and educating stakeholders about BD3's progress and impact throughout its lifecycle. This is an essential consideration for the next generation of projects, where a number of international projects have been cancelled due to public opposition, which can be caused by numerous factors, including inadequate stakeholder engagement.

## Section 3

# Evaluation Phase

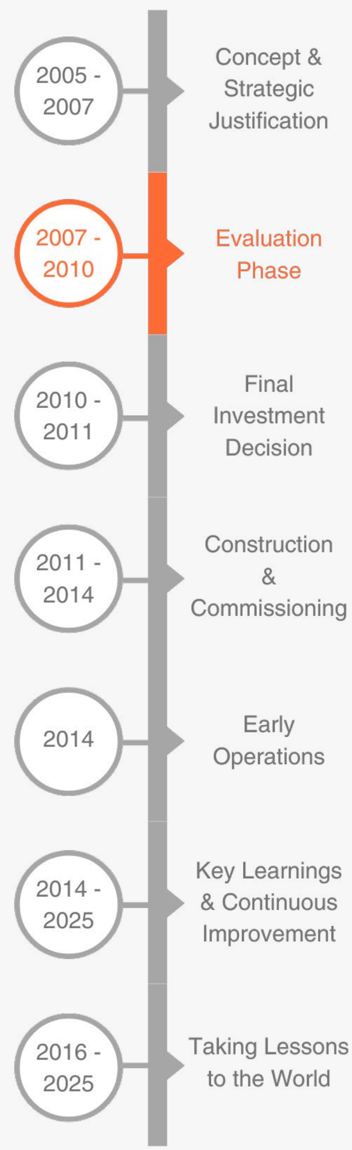
The initial project phases involved extensive feasibility studies to assess the technical and economic viability of retrofitting Unit 3 with carbon capture. Many of the preliminary evaluations considered SaskPower's research and pilot projects dating back to the 1980s. These studies examined technology applicability to operations, their cost implications, engineering challenges, and potential benefits.

SaskPower built upon the feasibility analysis with a Front-End Engineering Design (FEED) study to identify the appropriate capture technology for BD3. In 2007, the decision was made to proceed with post-combustion capture technologies that could provide operational flexibility for capturing $CO_2$ and supplying it to EOR operators. However, post-combustion $CO_2$ capture technologies had not been demonstrated at a commercial scale, so it was necessary to undertake an extensive analysis of potential options that could be scaled to the requirements of the project.

After a thorough review of technologies through a competitive proposal process, SaskPower selected Shell's Cansolv® amine-based capture technology. Although there weren't commercial demonstrations of post-combustion capture $CO_2$ projects, Cansolv® technology had been demonstrated at scale for the capture of sulphur dioxide ($SO_2$), providing more confidence in the applicability to be scaled and integrated into BD3 operations, which would require the capture of both $SO_2$ and $CO_2$.

With the capture technology selected, the project team continued to refine the project scope for greater certainty regarding costs, technical feasibility, and risk management. The design of the capture facility was an iterative process due to the concurrent refurbishment of the power plant to extend its operational life and integrate with the capture system. This analysis uncovered several technical opportunities to further optimize the integrated facility. A process optimization study assessed the impact of the amine solvent regeneration pressure on the power generated from the power plant and found that although higher steam pressure improved $CO_2$ separation, it came with the trade-off of lowering the power output from the plant. However, the higher regenerator pressure also lowered

BD3 ICCS PROJECT TIMELINE



the power requirement for the capture system, therefore, the team was able to find an optimum $CO_2$ regeneration pressure that maintained the efficiencies of the integrated plant outputs.

These updates were beneficial in identifying the optimal conditions suitable for capture plant operation and power generation. The final product from the FEED study was a process design package from the technology licensor, which fed into the detailed engineering design phase of the project.

Section 4

# Final Investment Decision

Following the FEED phase, the project execution team initiated the process to finalize the design and construction plans for both the power plant and capture facility with detailed engineering. To support the decision of whether or not to proceed with the investment, SaskPower initiated a third-party technology and investment review to assess and refine:

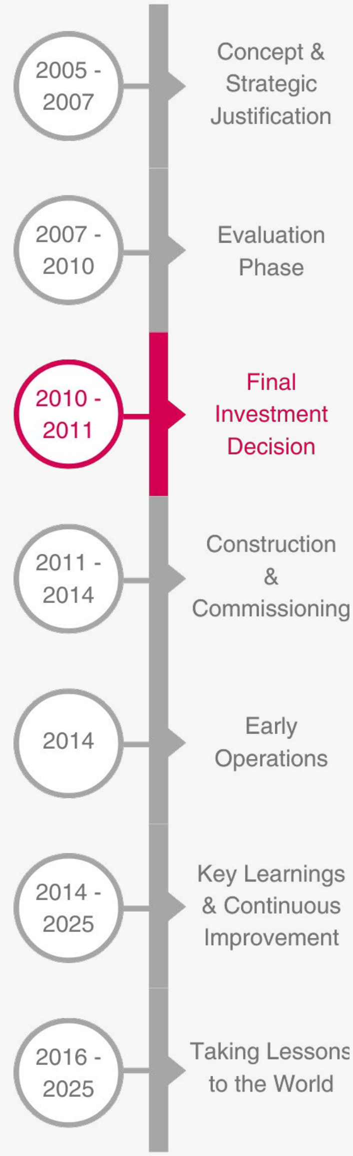
- Design information for the BD3 retrofits and the $SO_2$/$CO_2$ capture systems,
- Capital cost estimates for the entire project,
- Major contracts for project development,
- Schedule for implementation,
- Potential for sales of $CO_2$ in proximity to the project site,
- Both existing and projected expenses associated with the operation and maintenance of the project,
- The status of and compliance with permits and approvals, and
- Recommendations for minimizing risks related to project management.

With the successful completion of the third-party review by Chicago-based engineering design and infrastructure firm R.W. Beck, SaskPower reached a Final Investment Decision (FID) for the ICCS project in mid-2011, marking a major milestone for the organization and the province.

Given the scale and complexity of executing the power plant upgrade alongside the capture plant development, SaskPower established separate project teams, each with its own project managers to eliminate challenges associated with oversight and overlapping of resources during project design and implementation.

Over the years following project completion, the insights gained from the detailed navigation of early-stage development and progressing a project from conception to FID have been of significant interest to international knowledge-sharing initiatives.

BD3 ICCS PROJECT TIMELINE



# Section 5

# Construction & Commissioning

## 5.1 Full-Chain CCS Project Development

The execution of the construction phase was especially complex given that the project required construction across the entire CCS value chain from capture through to injection. To ensure the operations ran as smoothly as possible, significant consideration was given to each phase of the CCS process.

To fully grasp the learnings and optimizations throughout the construction phase and subsequent years of operations, it is essential to understand the path of the flue gas throughout the ICCS system, as shown in Figure 2.

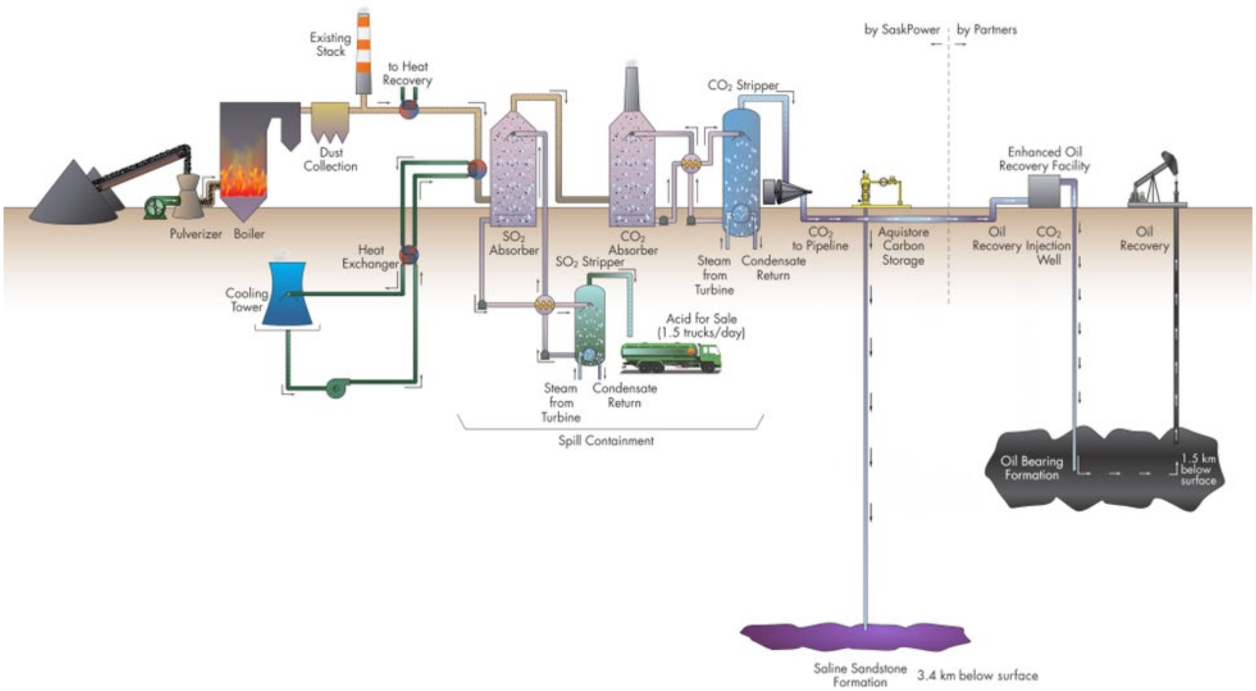



*Figure-2: BD3 ICCS Full Value Chain*

The flue gas treatment process operates in two sequential stages following pre-treatment, first targeting $SO_2$ removal, followed by $CO_2$ capture. This approach allows for efficient emissions reduction and recovery of by-products for revenue generation.

The flue gas is pre-treated to remove fine particulates with existing electrostatic precipitators before it enters the $SO_2$ capture train, where the amine-based desulphurization system removes 99% of $SO_2$, enabling the conversion of this compound into sulphuric acid.

After desulphurization, the flue gas moves to the $CO_2$ capture train, where $CO_2$ is removed using an amine solvent in an absorber. The $CO_2$-rich amine solution is then directed to a stripper, where the amine is heated to release the $CO_2$. This regeneration process allows the amine to be reused in the absorber, maintaining an efficient continuous cycle of $CO_2$ capture. The separated $CO_2$ is dehydrated and compressed to about 2500 psi to meet the pipeline operating conditions and moisture requirements.

The majority of the final $CO_2$ product is transported by pipeline for utilization in $CO_2$-EOR operations at nearby oil fields. There, the $CO_2$ is injected into an oil-bearing geological formation to aid in extracting additional oil from the reservoir, with the injected $CO_2$ permanently stored in the reservoir.

The remaining $CO_2$ is transported by a 2 km pipeline to the Aquistore site for injection and storage into a deep saline sandstone formation at a depth of approximately 3.4 km. The Aquistore site is owned and operated by SaskPower. PTRC Sustainable Energy is a partner and contracted by SaskPower to provide measurement, monitoring and verification (MMV) and ongoing research at Aquistore.

## 5.2 Construction Optimizations

Construction began in the spring of 2011, delivering significant economic and employment benefits to the region. At its peak, the project employed 1,700 workers, supporting local businesses and reinforcing Saskatchewan's position as a leader in energy innovation. Given the scale and complexity of the project, meticulous coordination was required between engineers, contractors, and regulatory bodies to ensure seamless integration of the capture facility with BD3's existing operations. The complex construction project was divided into four distinct but related projects, scheduled to ensure equipment was installed in order of use:

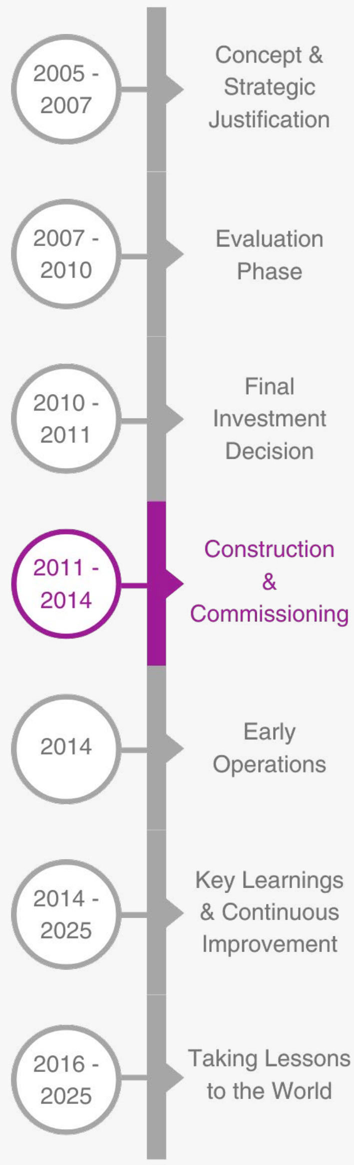
- Power plant upgrades and replacements (Early-2012 to Mid-2013)
- Cansolv® $SO_2$ and $CO_2$ capture plant (Late-2012 to Mid-2014)
- Integration of the Power Plant with the Capture Plant (Mid-2013 to Early-2014)
- $CO_2$ pipeline to injection sites (Mid-2013 to Mid-2014)

Construction was completed by the end of summer 2014, with the project being turned over to operations, capturing $CO_2$ from the flue gas stream for the first time. This achievement reflected the efforts of nearly a decade of planning, research, and execution.

The total project cost was CAD$1.5 billion. This achievement was especially notable given the challenges typically associated with projects of this scale and the added pressure on costs due to significant competition for labour in a period of rapid growth for the Canadian oil and gas sector, alongside high prices for construction materials.

The project employed several methodologies to handle risks associated with manpower and construction efficiency to mitigate potential cost

BD3 ICCS
PROJECT TIMELINE



overruns and delays. By staggering construction projects, the project managers could better plan for resource allocation. To optimize construction activities, SaskPower actively sought opportunities to prefabricate and modularize key equipment to reduce on-site labour demands further and improve quality control.

Components such as the $SO_2$ and $CO_2$ absorbers were too large for prefabrication and had to be built on-site, leaving other smaller units to be assessed for modularization. For example, the flue gas ducting and $CO_2$ stripper were prefabricated and assembled on-site, as shown in Figures 3 and 4. This strategy reduced the labour field requirements that would have been required for on-site construction and allowed construction and prefabrication to occur simultaneously, minimizing delays and reducing rework.

*Figure-3: Prefabricated Flue Gas Ducting*

*Figure-4: Prefabricated $CO_2$ Stripper*

SaskPower also constructed portions of the $CO_2$ off-take pipeline network, which was a first for the company. A pipeline was constructed by SaskPower from the capture facility to a metering station, with the remaining section of pipeline to nearby oil fields for EOR constructed by the off-taker. The pipeline to Aquistore is also owned and operated by SaskPower and was designed to be capable of handling the entire volume of captured $CO_2$ product from the CCS facility if necessary in the future. These sections were designed with routes that minimized environmental impact in collaboration with stakeholders from local communities, and the pipelines are equipped with state-of-the-art monitoring systems to ensure safe and reliable operations.

## 5.3 Commissioning & Transition to Operations

Prior to the commissioning and successful transition from project development to full-scale operations, SaskPower undertook a comprehensive operationalization strategy to train and prepare staff to handle new operations, alongside managing risks and initiating appropriate safety measures.

Given the long history of operations at BD3, most of the staff had a background in power engineering and were experienced in operating power plants. However, the CCS system and integration with existing operations required a new set of skills for the operators. To manage this process, a training needs analysis was conducted to determine the scope of additional chemistry and other process operations knowledge needed to operate the capture facility. These findings were captured in a training matrix developed for all trade experts working in the capture plant, such as process and field engineers, mechanics, instrumentation technicians, and electricians. Together with the technology licensor and suppliers of key equipment, comprehensive training documentation was prepared, including a “Train the Trainer” program, which promoted knowledge sharing and learning within the team.

A critical feature of this training program was the inclusion of a high-fidelity simulator, which provided realistic performance using a fully functional human machine interface (HMI), allowing trainees to familiarize themselves with the capture process and respond to changes in a similar manner to actual process operations. The simulator included the physics of the equipment and control interface being used for the power plant, capture facility and Aquistore, ensuring that operators were well-positioned to succeed once the project was commissioned.

Alongside the in-depth training, SaskPower ensured processes were safe and compliant with regulatory requirements. This was demonstrated by the formation of a safety task force in 2012, which was led by SaskPower’s corporate safety department. Throughout the project development, Hazard and Operability Studies (HAZOPs) were executed on major capture plant systems through a third-party review to ensure operational readiness. These HAZOPs remained a priority following the start-up of the capture plant, where they were conducted to identify deficiencies with safety components and provide appropriate upgrades, which have proved to be critical for CCS processes that were new to operations staff.

During this phase, detailed operating manuals supplied by various vendors for different equipment were converted to Standard Operations Procedures (SOPs) for the capture facility. This was a new approach for SaskPower’s power generation division and has since been adopted in many other SaskPower operations.

The transition to operations for the BD3 ICCS project highlighted the benefits of planning for the transition early in the project. Early initiation provides ample time for thorough staff training and ensures that all operational procedures and protocols are rigorously assessed. Continuous review of these procedures has been essential to keep them current and effective.

Section 6

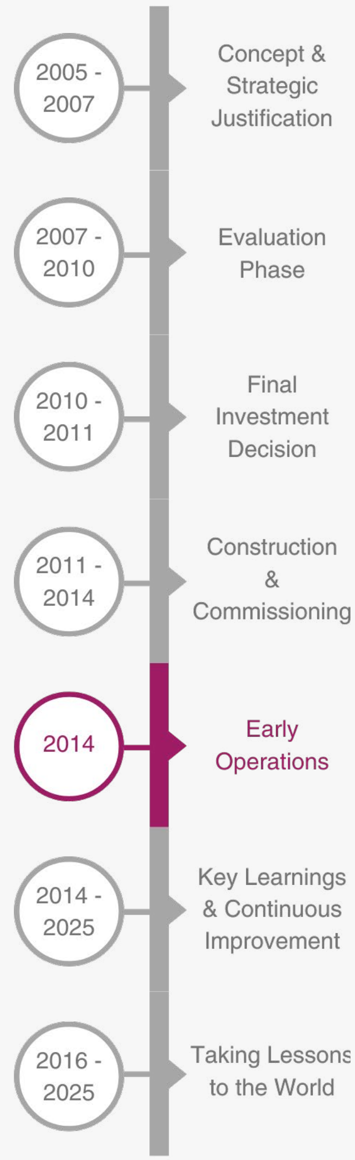
# Early Operations

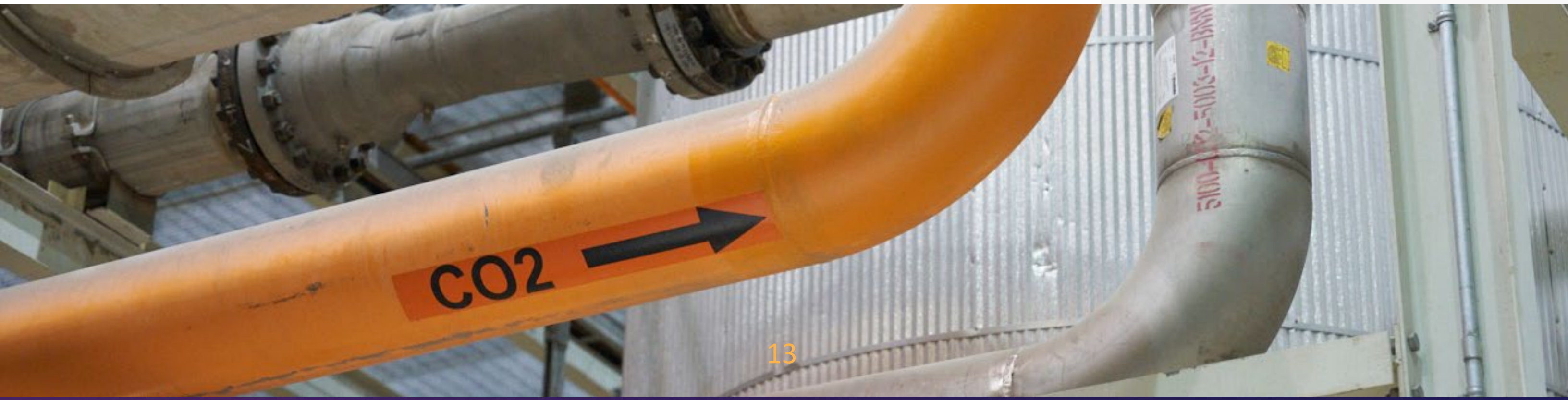
Most first-of-a-kind projects face unexpected technical challenges, requiring companies to continuously look for opportunities to improve the performance of the facility. For the BD3 ICCS project, the main initial operational priorities focused on $CO_2$ capture efficiency and overall reliability. Through technical assessments, continuous improvement and process optimizations, performance of the facility has improved over its operating life.

One of the key takeaways from the early operational phase was the importance of incorporating redundancy and flexibility in plant design. Equipment failures can result in taking entire systems offline, leading to reduced reliability of the capture plant. By implementing redundant components and isolation systems, the BD3 ICCS facility significantly reduced downtime and enabled online maintenance, reducing the risk of full system shutdowns. For example, redundancy was added to various processes to address early heat exchanger operational shortcomings, such as the $SO_2$ lean/rich amine heat exchangers, $SO_2$ reboiler, and $CO_2$ absorber wash water coolers. These changes directly resulted in increased heat exchanger performance and process stability. Additional capacity was also provided for the closed-loop cooling water heat exchanger system, enabling online cleaning of the redundant heat exchangers.

The effectiveness of these types of enhancements is evident in the improvement of BD3's actual capture rates, as shown in Figure 5. This graph illustrates that the plant's performance was consistent and later achieved a $CO_2$ capture efficiency of more than 90% for the partial flue gas stream diverted to CCS. Although the facility experienced an extended outage during 2021 and 2022 due to a compressor motor failure and subsequent compressor cooler leaks, these were isolated equipment issues. The reduced $CO_2$ captured during this period was directly related to the decreased volume of flue gas sent due to the outage.

BD3 ICCS
PROJECT TIMELINE



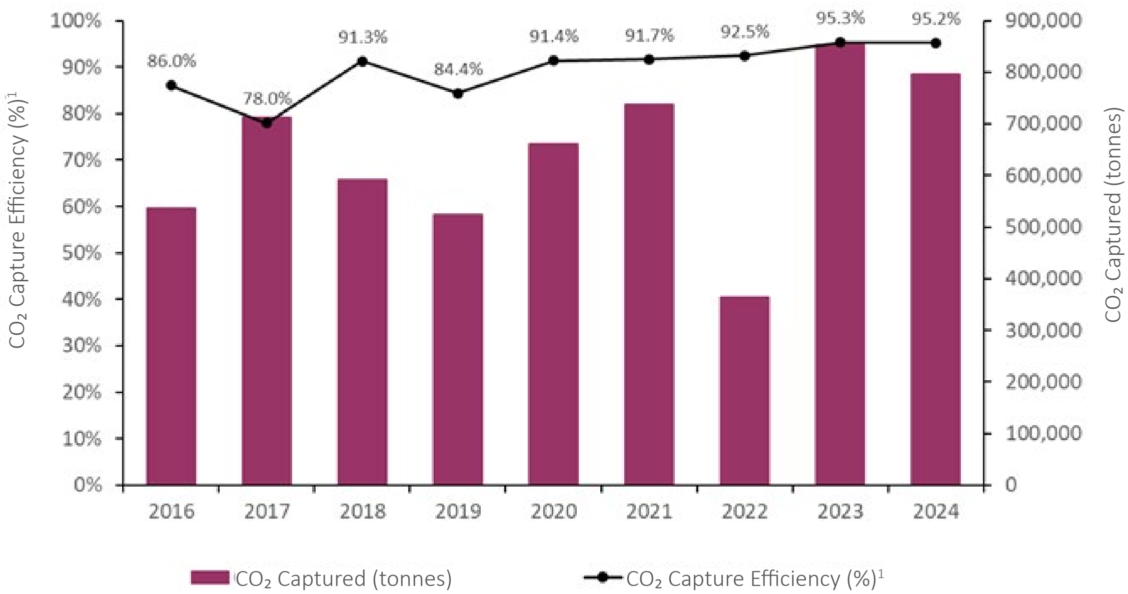



*Figure-5: BD3 ICCS Performance Profile*
*(Yearly performance reflects the fiscal period, April 1 through March 31 of the reporting year)*[1]

Coincident with the actions taken to improve plant efficiency, the BD3 ICCS facility was designed to allow continued power plant operations in the event of issues with the capture facility or during different operating modes. This was a key design feature and is evident in Figure 5 (i.e., lower $CO_2$ coincides with lower flue gas volumes sent to the capture plant). The design incorporated two different modes of operation as a risk mitigation strategy to manage downtime if there were outages in the capture plant. A key component of this was the use of diverter dampers, allowing flue gas to be directed toward either the original BD3 stack when the capture plant was not operating, to the capture facility, or a combination of the two (partial bypass). The flexibility of this operational mode provides an example of efficiencies through integration for future plants looking to retrofit existing operations with CCS.

In addition to incorporating flexibility into the plant design, the project team made additional early operational adjustments to improve the plant's performance and reliability:

| Opportunity | Corrective Action | Operational Learning |
|---|---|---|
| Reduce particle build-up impeding overall $CO_2$ capture | Upgraded the Electrostatic Precipitator (ESP) | ESP upgrade removed more impurities from flue gas before entering the capture system, significantly reducing challenges with plugging and equipment failures |
| Replace the original concrete amine storage tank | Replaced with double-walled stainless-steel tank | The upgraded tank enhanced the longevity, integrity and reliability of the storage tank |
| Early detection of system $CO_2$ leakage | Installed monitoring system for cooling water pH | This system can mitigate the risk of high-pressure $CO_2$ leaking into the cooling water, which could cause corrosion and fouling |

1 Yearly performance reflects the fiscal period, April 1 through March 31 of the reporting year. The $CO_2$ capture efficiency considers only the portion of flue gas diverted to the capture facility and utilizes data at normal operating conditions, excluding turndown, startups and shutdowns.

Section 7

# Key Learnings & Continuous Improvement

Throughout the ten years of operations since the BD3 ICCS facility was first commissioned, SaskPower has continued to innovate and seek opportunities to improve the project. Given the first-time nature and scale of many of these technical challenges, the BD3 ICCS facility has been at the forefront of numerous technical and planning achievements that continue to shape the CCS projects being developed across the globe.

## 7.1 Detailed Flue Gas Characterization

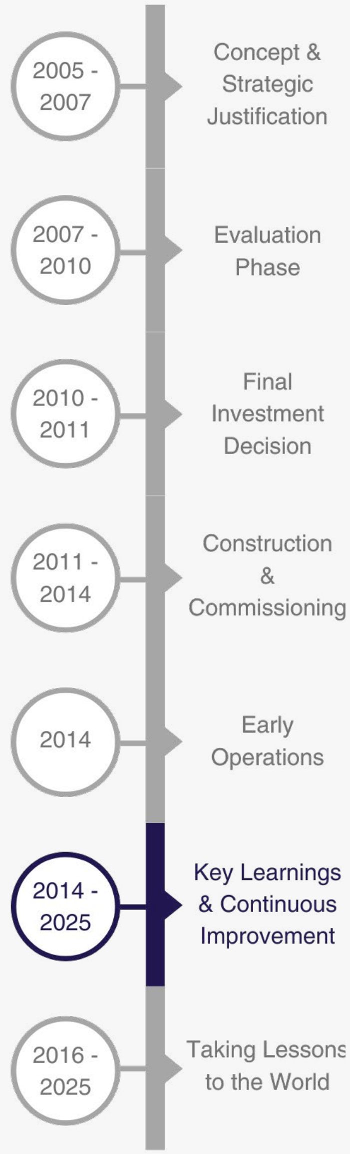
During the development of the BD3 ICCS project, the capture system design and pretreatment processes were based on existing flue gas testing data that was used for demonstrating regulatory compliance of the flue gas “waste stream” being emitted from the power plant prior to CCS.

However, the extensive operational experience has highlighted how important it is to understand the constituents of this “waste stream” and the interactions between flue gas impurities and the capture system technology. Performing early, detailed characterization can reveal more information about the composition of the flue gas that is not included in conventional flue gas testing. Having the detailed characterization information could help steer appropriate technology choices and mitigation options during the design phase. Some of these impurities react directly with the solvent or act as catalysts or precursors for the formation of other species that may have adverse effects on amine health and capture efficiency. For instance, impurities such as sulphur compounds, nitrogen oxides, and particulates can lead to the degradation of the amine solvent, reducing its efficiency and increasing operational costs.

In efforts to continuously optimize and improve capture efficiency at the plant, SaskPower undertook additional tests to better understand flue gas impurities and reduce amine degradation. This continues to be a priority at the facility to ensure efficient operations and compliance with environmental standards. With insights from these tests, the project team continues to advance the removal of contaminants quickly to avoid damage to the capture system.

These experiences highlight the importance of early and detailed flue gas characterization to enable customized solutions tailored to the specific characteristics of the flue gas being treated. By addressing these issues proactively alongside continued advancement of capture technologies,

BD3 ICCS PROJECT TIMELINE



future CCS projects can ensure that the $CO_2$ capture system operates efficiently and effectively, minimizing environmental impact and maximizing the long-term viability of the CCS project.

## 7.2 Pilot Testing and Scale-Up

To support the BD3 ICCS project decision-making process, SaskPower conducted pilot testing at their Emission Control Research Facility (ECRF), located at the Poplar River Power Station, shown in Figure 6.


*Figure-6: Emission Control Research Facility (ECRF) at the Poplar River Power Station*

The pilot testing focused on energy efficiency as it related to the performance of capture solvents and the required heat for regeneration. The insights from the pilot were invaluable prior to the successful 7000:1 scale-up to commercial operations. However, subsequent operational learning has highlighted the importance of strategic pilot planning with clearly defined objectives and respective processes to test them.

For future CCS projects, piloting should prioritize potential flaws and sensitivities within the capture system and understand their impact on the capture process. Consequently, given the subsequent operational findings, it would have been beneficial to focus on the impact of flue gas constituents on capture efficiency alongside the evaluation of solvent performance metrics, such as capture efficiency and the heat of regeneration. Additionally, the efficacy of selected cooling systems and other operational units must be evaluated to ensure the system's robustness.

While the pilot testing phase lasted three months , an extended pilot testing phase (such as six months to a year) would have enabled the collection of a more comprehensive range of data on project-specific intricacies. Some operational challenges, such as the impact of amine degradation, take time to manifest and may not be observed during short pilot testing periods. This extended testing period allows for a better understanding of long-term performance and the identification of potential issues that may arise over time.

Ultimately, a more robust pilot testing phase could have accelerated BD3's path to optimal performance during full-scale operations, potentially resolving inefficiencies before full-scale commissioning, including:

- Increased mechanical reliability, leading to fewer unplanned outages and reduced downtime by identifying opportunities to build-in redundancy and/or remove potential maintenance bottlenecks,
- Improved long-term capture efficiency by addressing potential solvent degradation early, and
- Enhanced process reliability, leading to fewer disruptions and subsequently lower maintenance costs in the facility's initial years.

## 7.3 Thermal Integration

With variable energy demands from fluctuations in flue gas flow, CCS projects can see significant benefits from efficient heat utilization and integration between the host plant and the capture facility. By effectively integrating heat sources and sinks, the amount of external energy required can be minimized, leading to cost savings and improved environmental performance.

At BD3, a comprehensive study was conducted to determine the optimal point for extracting suitable steam from the steam cycle to supply energy to the capture plant. Although this added complexity to the design and necessitated modifications to the existing turbine, it presented a more efficient solution compared to adding an auxiliary boiler or exacting steam from other less efficient points in the process. This arrangement eliminated the expanded footprint and associated capital and operational costs of an auxiliary boiler.

Heat recovery at the BD3 ICCS facility was achieved with the installation of a Flue Gas Cooler (FGC). The FGC extracts heat energy from the high-temperature flue gas before it enters the capture facility, reducing the amount of cooling water needed to decrease the temperature of the flue gas. The heat extracted from the flue gas in the FGC is used to heat the condensate stream in the power generation steam cycle before it enters the boiler, which would otherwise require generated steam for its conditioning. Mechanical Vapour Recompression was used to recover heat as steam from the regenerated $CO_2$ solvent, reducing the steam requirement from the host plant.

By leveraging advanced control systems and real-time data analysis, operators can dynamically adjust energy flows to match variations in flue gas conditions, further enhancing the system's overall efficiency and reliability.

## 7.4 Absorber Emissions Monitoring and Waste Emissions Management

As a first-of-a-kind project with a large number of stakeholders, ensuring the entire integrated facility was environmentally safe was of paramount importance. Significant effort was devoted to waste handling and the management of potential emissions from the capture facility. These new challenges necessitated the development of innovative techniques and protocols for measuring and monitoring absorber emissions.

When the BD3 ICCS facility was built, there were few regulatory or permitting limit guidelines for amine emissions in Saskatchewan, Canada and other industrial regions worldwide. However, in Norway, the Technology Centre Mongstad and the Norwegian Institute for Climate and Environmental Research (NILU) have conducted extensive research on emissions from amine-based capture systems. SaskPower incorporated these learnings and undertook additional testing of the proprietary Cansolv® amine technology to confirm that the research and guidelines on best practices for managing amine emissions would apply to the BD3 facility.

To ensure the environmental safety and effectiveness of the capture facility, SaskPower developed a central chemistry laboratory tasked with reliably sampling and measuring emissions of amines and other degradation products from the absorber stack. This required designing and developing specialized stack sampling equipment. SaskPower worked closely with the Netherlands Organization for Applied Scientific Research in the development of sampling equipment from prototype through to the creation of new probes and systems that proved to be reliable and effective in emissions measurement.

The amine technology licensor had provided an overview of the expected waste streams, which was updated as operational data was collected and used to create transportation protocols that didn’t exist prior. Additionally, the project resulted in the creation of  information sheets for the safe handling of spent amines and other waste chemicals from the capture facility.

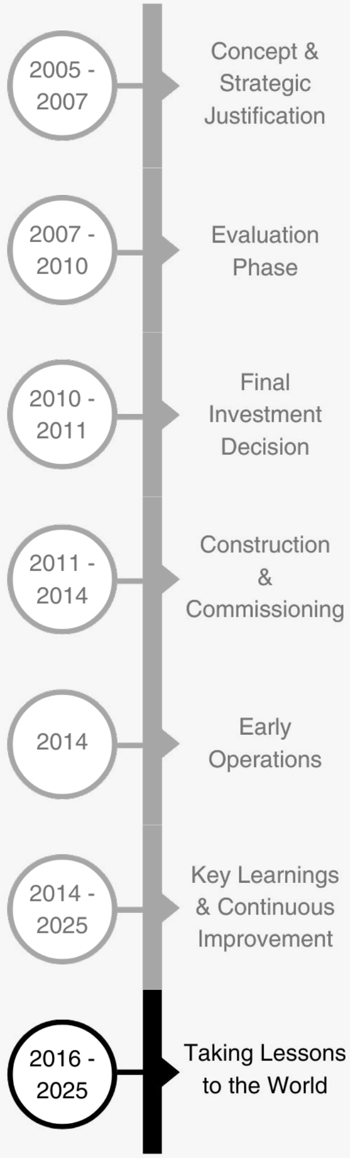
A key lesson learned from this experience was the importance of collaboration between the project owner, regulatory bodies, research institutions, the selected licensor, and other relevant stakeholders to innovative solutions for first-time problems.

Section 8

# Taking Lessons to the World

The BD3 ICCS project has played a role in advancing the global CCS industry, serving as a real-world case study of innovation, resilience, and scalability. Over the past decade, the facility has demonstrated the feasibility of integrating CCS technology into existing infrastructure and effectively reducing carbon emissions while maintaining reliable energy production. The knowledge and experience gained from this project have transcended the power industry, with the BD3 ICCS project providing an adaptable business model applicable across numerous high-emitting industries. Because of this, the journey from initial conception through execution and now ten years of operations continues to be shared globally, contributing to the development of the next generation of CCS projects.

BD3 ICCS
PROJECT TIMELINE



## 8.1 Creation of the International CCS Knowledge Centre

With significant interest in understanding the lessons learned from the BD3 ICCS project development, SaskPower partnered with BHP to establish the International CCS Knowledge Centre (Knowledge Centre) in 2016. Leveraging the learnings from the BD3 ICCS project, the Knowledge Centre has become a hub for expertise in CCS, providing comprehensive guidance to global CCS stakeholders. The Knowledge Centre's initiatives have included workshops, conferences, advisory services and site tours, which have facilitated the exchange of best practices and technological advancements across industries and regions. Global delegations from numerous countries, including those in Europe, Asia, and the Americas, have visited the BD3 facility to observe its operations firsthand, with Figure 7 highlighting the broad reach of the project, which hosts over 200 visitors per year. One of these highlights is partnering with the IEA Greenhouse Gas R&D Programme (IEAGHG) to support the International CCS Summer School, which attracts young professionals in every facet of the CCUS value chain from around the world.

These visits have catalyzed international collaboration, inspired a new workforce, aided CCS project development and contributed to policy development in regions seeking to achieve ambitious climate goals.

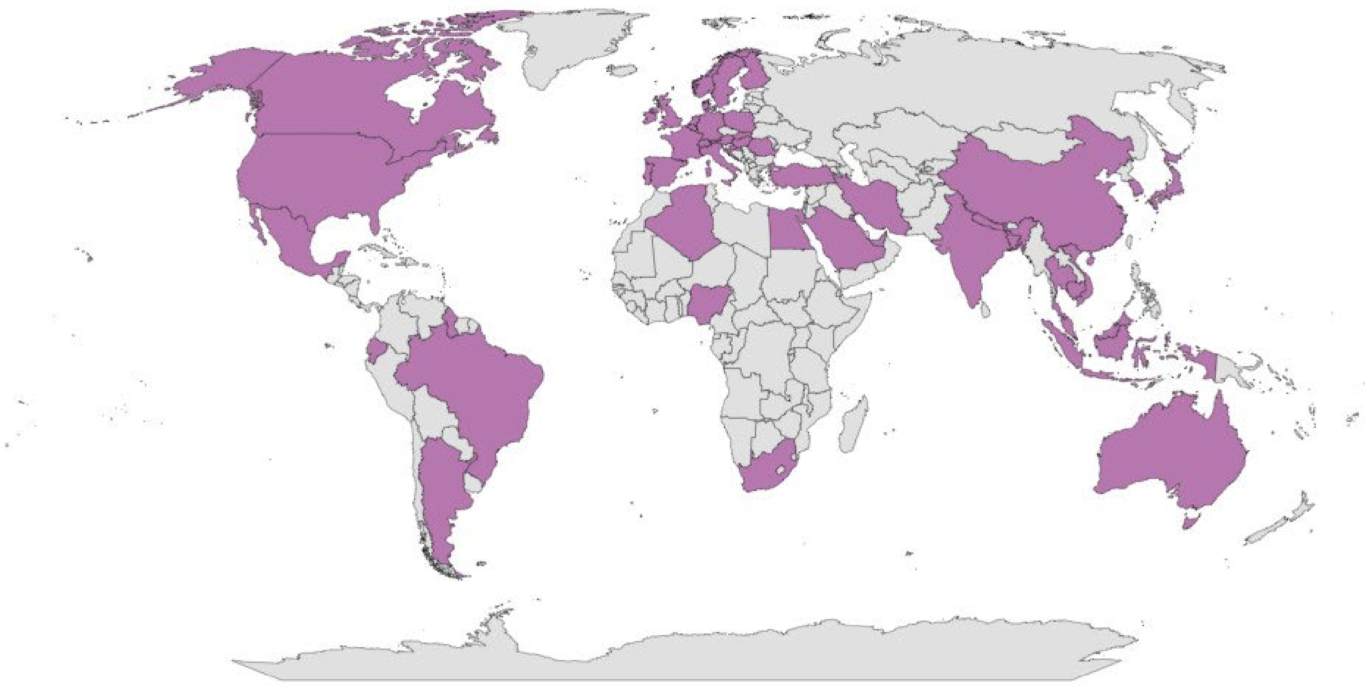


*Figure-7: Locations of Visitors to the BD3 CCS Facility Since its Inception*

## 8.2 Applying Knowledge to Next-Generation CCS Projects

The Knowledge Centre has taken key lessons learned from the BD3 ICCS project to influence the next generation of CCS projects, serving as independent and neutral, technical advisors to provide detailed FEED study reviews for international projects. By refining process design, optimizing equipment specifications, and modelling long-term operational performance with specialized first-hand experience, these early-stage evaluations reduce risks and improve cost predictability for future projects.

The operational experience detailed in this report has provided the Knowledge Centre's experts with a unique perspective to uncover opportunities and risks for projects that might go unchallenged in initial technical and economic feasibility studies. For example, the Knowledge Centre has built upon BD3's success with modular construction techniques to advise on optimization strategies for second-generation CCS projects to further streamline deployment and reduce capital costs.

Additionally, the Knowledge Centre has evaluated the applicability of advanced system configurations that are being developed to improve energy efficiency and low-carbon power integration (being able to operate with renewables providing intermittent generation). These innovations would enable future CCS installations to achieve greater performance while seeking to improve capture efficiency and reduce environmental impacts. Innovations in heat integration and water management are further enhancing the environmental performance of CCS-equipped power plants, ensuring they remain competitive in a low-carbon energy landscape.

In addition to power generation, the Knowledge Centre has played a pivotal role in expanding the application of CCS for hard-to-abate sectors, including cement and steel production, and evaluating opportunities to improve upon BD3's successes.

These industries are among the largest industrial sources of $CO_2$ emissions globally, with limited alternatives for deep decarbonization due to the inherent nature of their production processes. The cement industry, for example, accounts for approximately 7% of global $CO_2$ emissions. Drawing on BD3's operational insights, the Knowledge Centre demonstrated that CCS could be effectively integrated into cement manufacturing without disrupting production processes. By adopting advanced heat integration strategies and optimizing system configurations, detailed FEED studies have shown that capture rates of up to 95% of $CO_2$ emissions could be achieved, significantly reducing the carbon footprint of cement production.

The Knowledge Centre has adapted operational strategies from BD3 to address the unique challenges of industrial CCS applications. Managing variable plant loads, an issue encountered in power generation, can be mitigated in cement production through innovative energy solutions such as combined heat and power systems. These approaches enhance process efficiency while ensuring stable capture operations, even during maintenance periods.

Economic and environmental analyses have shown that CCS can be deployed cost-effectively in these hard-to-abate sectors. In cement production, the captured $CO_2$ can be used in concrete markets, enabling net-negative emissions by offsetting emissions in concrete production. In the steel industry, there are significant opportunities for thermal integration with high-temperature processes across the value chain to improve the efficiency of CCS integration and support the sector's transition to lower-carbon production methods.

By extending the applicability of CCS beyond power generation, the Knowledge Centre is paving the way for large-scale deployment in essential industries critical to modern infrastructure. These advancements not only reduce greenhouse gas emissions but also ensure the economic sustainability of the cement and steel sectors, supporting long-term industrial competitiveness.

## 8.3 Catalyzing the Canadian CCS Landscape

The Knowledge Centre partnered with Emissions Reduction Alberta (ERA) to advance large-scale CCS projects through the Carbon Capture Kickstart program. Launched in July 2022, the program allocated CAD$40 million in funding to support pre-construction design and engineering studies for 11 CCS projects spanning a variety of industrial sectors, including power generation, cement, fertilizer, forest products, and oil and gas. With the first-hand knowledge and experience from BD3, the Knowledge Centre provided up to 200 hours of consulting support to reduce the risk and maximize the value of these projects for Albertans, with some of the key impacts from the initiative including:

| Highlights | Impacts |
|---|---|
| Leveraging Lessons from BD3 | Many of the Kickstart projects incorporated insights and best practices from BD3 and other CCS initiatives to improve performance, lower costs, and enhance scalability |
| Technical and Financial Risk Reduction | By providing consultation services and technical advice, the Knowledge Centre helped reduce uncertainty in project design and implementation, enabling near-term final investment decisions |
| Cross-Industry Knowledge Sharing | The parallel execution of 11 studies created invaluable opportunities for cross-learning, as projects tackled challenges unique to their respective industries |
| Strategic Policy Support | The program's outcomes have helped to unlock future funding mechanisms, fostering a favourable environment for CCS development |
| Economic and Environmental Impact | Projects supported by the Kickstart program are expected to significantly contribute to Alberta's economy while addressing industrial emissions |

The report, Lessons Learned from 11 industrial CCS FEED Studies, provides a more detailed summary of the key learnings from the Carbon Capture Kickstart Program.

The Knowledge Centre's expertise and collaboration with ERA exemplify the critical role of knowledge-sharing in advancing CCS technology. By reducing technical and financial barriers, the Carbon Capture Kickstart program helped accelerate the deployment of commercial-scale CCS solutions, contributing to global decarbonization efforts and supporting Canada's leadership in climate innovation.

Section 9

# Conclusion

The Boundary Dam Unit 3 CCS facility stands as a testament to the transformative potential of carbon capture and storage technology. Through continuous innovation, operational refinement, and knowledge sharing, BD3 has laid the foundation for the next generation of CCS projects across multiple industries.

Beyond its technical achievements, BD3 has been instrumental in shaping the global CCS landscape. The insights gained from the design, construction, and operation have informed large-scale industrial decarbonization projects across industries and geographies. The establishment of the International CCS Knowledge Centre has further amplified BD3's impact, fostering international collaboration, policy development, and the acceleration of CCS deployment worldwide.

As industries and governments seek pathways to net-zero emissions, BD3 provides a proven model for integrating CCS into existing infrastructure. Its lessons have helped reduce project risks, lower costs, and improve system efficiencies, making CCS more accessible. The ongoing dissemination of these insights ensures that the pioneering efforts at the BD3 ICCS facility will continue to drive innovation, helping to secure a sustainable and lower-carbon future


# Acknowledgments

This report was made possible through the support and funding of key organizations dedicated to advancing CCS technology. We acknowledge the contributions of the IEA Greenhouse Gas R&D Programme (IEAGHG), the United States Department of Energy (U.S. DOE), and Natural Resources Canada (NRCan). Their commitment to fostering innovation and collaboration in the field of CCS has played a pivotal role in driving progress and enabling projects like BD3 to serve as a global benchmark for carbon capture initiatives.

The International CCS Knowledge Centre expresses deep gratitude to BHP, SaskPower, and the Government of Saskatchewan. Financial support from both BHP and SaskPower ensures the lessons from BD3 reach a wide audience through reports like this. In the fall of 2014 SaskPower 's Boundary Dam Power Station became the first power station in the world to successfully use CCS technology. They have spent a decade openly sharing operational realities. The ongoing collaboration between SaskPower, BHP, and the Knowledge Centre provides the practical experience required to reduce global GHG emissions and deploy carbon capture.