The Water Technology Development Centre

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Clean Technology Facilities Support Program and Water Innovation Program

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AF	After Filter	**SQ**	Steam Quality
BD	Blowdown	**SQA**	Steam Quality Analyzer
BFW	Boiler Feed Water	**TAH**	Total Acidified Hardness
BIW	Bitumen in Water	**TDS**	Total Dissolved Solids
BS&W	Basic Sediment and Water	**TOC**	Total Organic Carbon
BW	Backwash	**TOE**	Technical Operating Envelope
bpcd	Barrels per calendar day	**TOI**	Total Inorganic Carbon
COSIA	Canada's Oil Sands Innovation Alliance	**TPH**	Total Petroleum Hydrocarbons
CPF	Central Processing Facility	**TSS**	Total Suspended Solids
CSS	Cyclic Steam Stimulation	**TST**	Tube Skin Temperature
CZ	Clarification Zone	**TQM**	Thermal Mass Flow Meter
DCS	Distributed Control System	**TWT**	Tube Wall Temperature
EB	Emulsion Breaking	**UA**	Heat Transfer Coefficient
FAC	Flow-Accelerated Corrosion	**UT**	Ultrasonic Testing
FTIR	Fourier Transform Infrared Testing	**USGPM**	U.S. Gallons per Minute
GHG	Greenhouse Gas	**WLS**	Warm Lime Softening
HLS	Hot Lime Softening	**WOR**	Water Oil Ratio
HPSS	High Pressure Steam Separator	**WTDC**	Water Technology Development Centre
H&S	Health and Safety	**Y'x'TP**	Year 'x' Test Plan
ILM	Interface Level Measurement		
KPI	Key Performance Indicator		
LOI	Loss of Ignition		
MagOx	Magnesium Oxide		
MW	Molecular Weight		
NDP	Nuclear Density Profiler		
NF	Nanofiltration		
NIR	Near Infrared Sensor		
OPEX	Operating Expense		
OIW	Oil in Water		
ORF	Oil Removal Filter		
OTSG	Once Through Steam Generator		
PSD	Particle Size Distribution		
PW	Produced Water		
PWC	Produced Water Cooler		
REB	Reverse Emulsion Breaker		
RMZ	Rapid Mix Zone		
RT	Radiography Testing		
RTD	Resistance Temperature Detector		
SAGD	Steam Assisted Gravity Drainage		
SMZ	Slow Mix Zone		
SOR	Steam to Oil Ratio		

Executive Summary

The Water Technology Development Centre (WTDC) was a live fluid test facility located at Suncor Energy Inc.'s (Suncor) Firebag Steam Assisted Gravity Drainage (SAGD) oil sands facility. This joint venture was completed by Suncor Energy Inc., Canadian Natural Resources Limited (Canadian Natural), Cenovus, and China National Offshore Oil Corporation (CNOOC), supplemented with funding from the Alberta Innovates Clean Technology Facilities Support Program and Water Innovation Program. The facility was the first of its kind in Alberta, where numerous pilots were designed, constructed, and operated simultaneously under a Joint Industry Partnership to extract valuable learnings for the provincial oil and gas industry.

As part of the Alberta Innovates contract, the WTDC Test Plan successfully designed, constructed, and executed 8 out of 10 proposed pilots. Each pilot was chosen with the goal of safely developing water technologies that reduce environmental impact, reduce capital and operating costs, increase reliability, and improve the sustainability performance of Alberta's thermal in situ oil sands projects so they can be competitive in a low oil price and low greenhouse gas intensity environment. The objective of the WTDC was to validate technologies through on-site pilot testing for near term commercial deployment at existing assets. While many pilots were able to identify a technologically superior solution to the incumbent methods, other results provided operators the confidence to continue operating using incumbent technologies, with some improvements. To date, the commercial uptake of the technologies has been low as many of the pilots remain in operation and the numerous results from the other piloting activities are still being processed internally. In addition, numerous challenges with the steam generator pilot have significantly slowed useful data generation from this important pilot.

Testing at the WTDC has had a measurable impact on technology gaps that exist for in situ thermal facilities. While the commercial impacts of these results can only be speculated as part of the current business environment, the project was able to identify chemical and physical improvements to the facilities that could improve GHG emissions, chemical consumption, equipment reliability, and equipment performance. Chemical vendors benefitted particularly, as they were able to develop and test new products that can be brought to market. Although uplifts were generally not realized to anticipated levels due to a variety of setbacks such as COVID-19, the project realized un-risked Bitumen production uplift of 1,500 barrels per calendar day, 20 permanent jobs, and the equivalent of 150 temporary 1-year duration jobs. The project provided many valuable learnings, and disproved the assumption that smaller pilots are easier to fabricate than full scale facilities. The WTDC was ultimately a success as it delivered on its target test plan, safe operation was achieved in a complex technology development facility, multiple years' worth of data was generated in a relatively short time frame, numerous lessons were learned on the overall technology development pathway in a multi-company collaborative environment, and pilot results with tangible financial and environmental benefits were identified.

Please note several pilots are still in progress as of February 2024, thus results included here are interim.

1 Introduction

The Water Technology Development Centre (WTDC) is a live fluid test facility located at Suncor Energy Inc.'s (Suncor) Firebag Steam Assisted Gravity Drainage (SAGD) oil sands facility. The project began operations on February 1st, 2019, with a vision to safely develop water technologies that reduce environmental impact, reduce capital and operating costs, increase reliability, and in general improve the sustainability performance of thermal in situ oil sands projects so that they can be competitive in a low oil price and low Greenhouse Gas (GHG) intensity environment. The WTDC was specifically designed to meet the substantial challenge that industry has in developing technologies past the lab or bench scale and to the on-site commercial piloting scale. An exterior photo of the WTDC is provided in Figure 1.

Figure 1: Water Technology Development Centre at Suncor's Firebag Steam Assisted Gravity Drainage (SAGD) facility.

The WTDC was supported by the Clean Technology Facilities Support Program and Water Innovation Program from Alberta Innovates, as well as by its contributing partners:

- Suncor Energy Inc. (Suncor).
- Canadian Natural Resources Limited (Canadian Natural).
- Cenovus Energy (Cenovus).
- China National Offshore Oil Corporation (CNOOC).

The contributing partners represent ~40% of Alberta's thermal in situ oil sands market, and all results from the WTDC will be shared with Pathways Alliance members. Therefore, future technology development will be material. Over 14 additional organizations collaborated through means of chemical and equipment supply and technology development.

1.1 Sector introduction

The average 2015-2017 production from existing thermal in situ oil sands assets in Alberta was ~1.18 MM barrels per calendar day (bpcd) and accounted for ~55% of the projected value in 2030 of ~2.16 MM bpcd [1]. The emissions from these assets are real and occurring now; they are not subject to future market conditions or final investment decisions. Barring extreme financial conditions, once the capital on a thermal in situ oil sands asset has been spent, that facility will continue to operate until end of life, typically 25 to 40 years.

1.2 Technology gaps

Significant environmental and economic performance improvements can be achieved by improving existing thermal in situ oil sands assets and infrastructure. The WTDC recognized the value creation potential of short-term incremental technologies that can be rapidly deployed at low cost. These technologies can increase production at low cost, improve asset availability, and lower operating costs while also lowering GHG emissions, reducing impacts of water use, improving waste management, and achieve minor land footprint reductions.

The WTDC was positioned to address an existing gap in technology development, which has limited, and is currently limiting, the implementation of incremental technologies. In the June 2017 report of the Standing Committee on Natural Resources, it was identified that "access to patient capital is one of the biggest barriers facing clean technology developers in the natural resources sector, especially through the so-called commercialization gap – i.e., the period between a technology's research and development phase and large-scale commercialization, when companies can expect to start making profit [2]. The WTDC filled the critical "on-site pilot testing facility" gap for qualifying surface facilities technologies for Alberta's thermal in situ oil sands (i.e., SAGD and Cyclic Steam Stimulation (CSS)) industry. It provided a ready-to-use, low cost, and collaborative means to test technologies with live fluids drawn directly from an operating plant (i.e., Suncor's Firebag SAGD oil sands facility) at a pilot scale that was intended to establish commercial viability. Slow, inefficient, and expensive on-site pilot testing exacerbates the challenges in moving from early-stage technology development to commercialization in the technology qualification process, but the WTDC eliminated this constraint for water technologies in the thermal in situ oil sands industry. The WTDC also served as critical infrastructure to close many knowledge gaps in the industry and therefore improve technical operating envelopes (TOEs) for both existing and breakthrough technologies. Using a dedicated facility for testing also reduced risk and disruption of producing assets (or operations).

2 Project Description

The original project term was five years, beginning February of 2019, but due to COVID-19 complications, some of the original test plans were extended by one year. As of February 2024, 5 pilots have been completed, and a total of 8 are projected to be completed by the end of 2024. 10 of those were funded through this Alberta innovates funding stream and are detailed in this report.

The objective of the WTDC was to validate technologies through on-site pilot testing for near term commercial deployment at existing assets. The WTDC Year 1 Test Plan (Y1TP) and Year 2 Test Plan (Y2TP), which received funding from Alberta Innovates and are the focus of this report, were centered on incremental technology development to improve the economic and environmental performance of the industry's existing assets. Key performance metrics used to measure the success of this project are discussed below as a part of the Project Results and Outcomes, Impacts, and Benefits.

The goals of the Y1TP were to:

- Reduce emulsion chemical costs through the Emulsion Breaking (EB) Chemistry Optimization Pilot (Pilot 3).
- Obtain real time data from online instrumentation to be proactive, optimize, and enable advanced process control and improve overall accuracy through the Oil in Water (OIW) Instruments Pilot (Pilot 4), the Interface Level Measurement Pilot (Pilot 11), and the Steam Quality Analyzer (SQA) Pilot (Pilot 9).
- Maximize steam quality through the Once-Through Steam Generator (OTSG) Steam Quality (SQ) Optimization Pilot (Pilot 7).
- Reduce Produced Water Cooler (PWC) cleaning frequency through the PWC Optimization Pilot (Pilot 5).
- Minimize OTSG blowdown carryover through the High-Pressure Steam Separator (HPSS) Optimization Pilot (Pilot 8).
- Increase reliability through many of the pilots listed above.

The goals of the Y2TP were to:

- Reduce water treatment chemical costs through the Warm Lime Softening (WLS) Pilot (Pilot 1).
- Achieve consistent high-quality boiler feed water (BFW) through the After Filter (AF) / Oil Removal Filter (ORF) Pilot (Pilot 2) and Pilot 1 WLS.
- Improve Water Cut Analyzers to enable optimization of steam utilization (Pilot 12).
- Increase reliability through many of the pilots listed above.

The Water Cut Analyzer Pilot (Pilot 12) was potentially linked to significant emissions reductions through steam to oil ratio (SOR) reductions. Currently, production engineers must manage steam allocation to the field using estimates with varying accuracy of water cut from well pairs. If accurate and low-cost methods of determining water cut could be achieved, this would open significant opportunities for field-wide SOR optimization, with potential SOR reductions up to 5% on a field-wide basis.

The following years' test plans are out of this report's scope, as they were not included as part of this funding. They include completion of further incremental technology testing in the Year 3 Test Plan (Y3TP) and beyond, such as continuation of Pilot 3 EB Chemistry Optimization, Pilot 7 OTSG Steam Quality Optimization, Pilot 5 PWC Optimization, and Pilot 12 Water Cut Analyzers. There will not be an additional public report discussing the Y3TP, as this effort was not supplemented by Alberta Innovates funding.

2.1 Pilot descriptions

Below is a brief technology-focused description of each pilot completed as part of the Y1TP and Y2TP. Results for each pilot are discussed in the Project Results section. Note that Pilot 10 is discussed briefly below and in Section 4. This pilot was originally proposed as part of the Y1TP, but was deferred to a later test plan year, as discussed with Alberta Innovates and confirmed with the Scope Change Request process. Pilot 10 is not included in the project metrics discussed in Section 6.

2.1.1 Pilot 1 Warm Lime Softening (WLS) Coagulant Flocculant Optimization

Completed July 2023.

Warm Lime Softening / Hot Lime Softening (WLS/HLS) is a central process in water treatment at most SAGD operating facilities. The performance of these units is heavily influenced by the coagulant and flocculant pair used and the reliability of the dry chemical feeds (e.g., lime, MgO, soda ash). This pilot aimed to optimize these variables, leading to operational cost reductions, reliability improvements, and potentially increased treatment capacity. The pilot utilized a small (150 mm diameter) warm lime softening system complete with wet/dry chemical feed and sludge recirculation systems. The unit designed through this pilot was a world class piece of pilot equipment that far exceeded the capabilities of any related pilot equipment available from global chemical suppliers. This design involved extensive collaborations with local institutions.

This pilot screened a wide variety of potential chemistries from several major specialty chemical suppliers with the following specific objectives:

- Gain experience reliably and successfully operating the equipment.
- Identify products which provide step change improvements in performance over traditional products.
- Improve boiler feed water quality resulting in less steam generator fouling and more efficient operation.
- Reduce coagulant/flocculant annual operating costs by 10%.
- Increase the ability to predict commercial scale performance by testing with live process fluids, and testing at greater scale, compared to traditional bench top jar testing.
- Provide opportunities for large chemical suppliers, who are not established in the SAGD marketplace, to test with live SAGD fluids, to increase product availability/selection for SAGD operating companies while spurring competition between chemical suppliers.
- Gain further insights into the WLS treatment process.
- Ensure that facilities have access to the most current and robust water treatment chemicals since available water resources are fixed and water re-use needs to be maximized.

2.1.2 Pilot 2 After Filter (AF)/ Oil Removal Filter (ORF) Enhancement

In progress as of February 2024.

Improved operation of After Filter (AF) and Oil Removal Filter (ORF) processes will improve performance of SAGD de-oiling and water treatment and provide improved reliability and reduced capital and operational costs (CAPEX / OPEX) for steam generation facilities. The goal of the pilot was to determine if it is possible to achieve higher filtration rates and/or improved water quality using alternative media beds with better performing media (rather than current anthracite and walnut shells). Operation at higher temperature than current processes (>85-90°C) was also considered as a route to assist in debottlenecking de-oiling and water treatment processes, reducing heat integration requirements (e.g., glycol and heat exchangers), and simplifying future greenfield SAGD CPF designs. The pilot utilized a dual-column filtration skid, complete with backwashing capabilities. The pilot unit designed was a world class piece of equipment that involved collaboration with a local company.

2.1.3 Pilot 3 Emulsion Breaking (EB)/ Reverse Emulsion Products (REB) Testing

Completed October 2022.

Currently, commercial emulsion breaker (EB) and reverse emulsion breaker (REB) chemicals applied to raw emulsion and diluent represent a large operating expense. This pilot tested alternative chemicals against the incumbent commercial products currently used at Firebag. This pilot began by inviting chemical suppliers to participate through a formal Request for Information (RFI) process, and the results of all chemical tests were interpreted by WTDC staff and each chemical supplier to determine the “best” EB/REB pairing based on agreed performance indicators. The pilot utilized the test separator that was pre-installed into the WTDC to perform this testing. Performance indicators included water quality, throughput, and chemical dosing requirements.

2.1.4 Pilot 4 Bitumen in Water (BIW) / Oil in Water (OIW) Analyzer

Completed September 2022.

Oil-in-water analyzers can be used to measure the free and emulsified oil content in produced water. For in-situ operations, they could be useful for identifying process upsets in the de-oiling process. This pilot tested three analyzer technologies: light scattering, ultrasonic acoustic, and UV fluorescence, with solvent extraction, with the purpose of identifying an analyzer or analyzers that are accurate and reliable at low single-digit ppm levels, compared to on-site laboratory analyses. This pilot used an instrument test loop to evaluate OIW analyzers, and their readings were compared to laboratory measurements using industry standard methods.

2.1.5 Pilot 5 Produced Water Cooler (PWC) Enhancement

Completed October 2022.

After primary oil/water separation, produced water must be cooled so further de-oiling and boiler feedwater treatment processes can be done at lower pressures and temperatures. During the cooling process, produced water contaminants such as dissolved solids (calcium, magnesium, and sodium), suspended clays, silica, suspended oil, and dissolved and undissolved organics cause scaling and fouling on the heat transfer surfaces. To reduce the operational cost and risk to production associated with scaling and fouling inside PWC’s, this pilot studied seven prevention technologies and seven mitigation (cleaning) strategies. After determining which of them were most promising, further testing was completed to determine if fouling was preventable, and to develop an optimum mitigation strategy for when fouling occurred. This pilot utilized a small and specially designed shell and tube style glycol cooler for this testing. This pilot also had significant overlap with Pilot 3 above as EB/REB selection is known to have a significant impact on PWC fouling. Coordinated piloting at the WTDC allowed investigators to take a comprehensive approach to solving this challenge.

2.1.6 Pilot 7 Once-Through Steam Generator (OTSG) 90% Steam Quality

Incomplete as of February 2024.

In the past, OTSG design and operation has been limited to an operating Steam Quality (SQ) of 80%. This operating envelope was used to reduce the risk of equipment damage caused by fouling/scaling and tube wall wetting leading to tube overheating. Higher SQs have become achievable with advancements in Boiler Feed Water (BFW) quality control, SQ control, and equipment design including tube metallurgy. This pilot was intended to enhance industry knowledge of the limitations of the current technologies and operating practices with the least risk to commercial operations. By being able to increase steam quality to 90% without risking any commercial operations, the ability to reliably operate at 90% steam quality could be validated. This pilot used a specially designed small-scale OTSG with 1-¼" diameter tubes, which unfortunately experienced numerous operating challenges over the course of the pilot. Further discussion on these challenges is provided below.

2.1.7 Pilot 8 High-Pressure Steam Separator (HPSS)

In progress as of February 2024.

A typical SAGD facility experiences blowdown carry over of ~5%, which can lead to corrosion in steam distribution and well systems and reduced heat recovery in the central plant. To develop a fundamental understanding of the causes for carry-over, this pilot tested assumptions used when testing vessels, challenged past designs, and studied fouling caused by organics and/or salts. This testing utilized the OTSG and the WTDC High Pressure Steam Separator (HPSS) and was intended to allow for the calculation of the actual average droplet size and its impact on fouling, allowing for recommendations to be made on improved HPSS internal processes to reduce carry over. This testing was also limited due to the OTSG operating challenges.

2.1.8 Pilot 9 Steam Quality Analyzer

In progress as of February 2024.

One of the most important key performance indicators (KPI) for in-situ thermal facility operation is OTSG steam quality. Operating the OTSGs efficiently at higher steam qualities not only increases the revenue but also reduces the environmental impact associated with water and GHG. Current steam quality measurement techniques are largely manual, are somewhat inaccurate, and take a long time to receive results due to their largely manual nature. This pilot was designed to test one way to remedy this issue, through accurate and reliable online steam quality measurement and controlling the OTSG by using real time steam quality data. Using accurate and real time steam quality measurement for OTSG control would enable safe operation of the OTSG closer to the maximum steam quality limits, which would result in higher steam production. This pilot also relied on the OTSG operation along with two different steam quality monitoring technologies, including optical technology with Near Infrared spectra data analyzed with Fourier Transform and mass flow measurement based on heat dissipation from a thermal probe.

2.1.9 Pilot 10 Blowdown (BD) Waste Management

Scheduled for fall 2024.

Nanofiltration (NF) of OTSG blowdown (BD) using membranes with high pH and temperature tolerance appears to be an effective treatment to improve water quality for recycle or reuse. This pilot was designed to leverage previous bench-scale studies to further de-risk blowdown nanofiltration, evaluate performance, and provide design criteria for full-scale design and deployment. The technical focuses were membrane permeate flux and recovery, trans-membrane pressure during operation/permeability, permeate quality (organic and inorganic removal), reject quality, overall recovery, back pulse and clean-in-place frequency. This technology could allow increased SAGD flow rates, reduce current process chemistry costs, reduce pigging frequency of OTSG's, and potentially increase steam production per OTSG by improving overall BFW quality. Unfortunately, due to time constraints, this pilot was not executed as part of the Y1TP or Y2TP.

2.1.10 Pilot 11 Level Interface Meter

Completed September 2023.

Interface level measurement (ILM) is vital for efficient separation of multi-phase emulsion in a facility's primary and secondary separation vessels. This pilot tested two new ILM technologies to provide reliable, accurate, and economic solutions for future ILM in the industry. These technologies were tomography and sonar-based level measurement, and they were tested against a baseline Nuclear Density Profiler (NDP). The results are intended to allow operators to select the new technologies which are best suited for their operation's unique conditions. This pilot utilized the WTDC Test Separator.

2.1.11 Pilot 12 Water Cut Analyzers

Completed June 2023.

Water cut analyzers measure the amount of water in an oil/water emulsion. After emulsion flow rate, water cut is the next most critical measurement to describe per-well production. Online water cut measurements at SAGD pads have generally demonstrated low accuracy using current microwave-based measurement technologies. This pilot was designed to develop improvements to existing water cut measurement techniques targeting +/- 1% accuracy, with SOR improvements being the main value driver for the project. Cation injection and highly representative sampling were the two techniques tested in this pilot, which leveraged natural water cut variability to compare performance and high and low water cut ranges. This pilot utilized an incumbent microwave-based analyzer technology and accurate sampling to evaluate the impacts of salt addition on the water cut measurement accuracy. The sampling was achieved through the installation and operation of a live sample station for Dean Stark analysis, which was compared to a "dead" sample station. The pilot also utilized the WTDC Test Separator to manipulate water cuts during the testing to understand impact on the full 0-100% water cut range.

2.2 Updates to project objectives

As communicated to Alberta Innovates and documented in the third Scope Change Request Form, the WTDC revised its pilot schedule compared to the original referenced in the signed funding agreement.

These changes have been forced by the 2020 low oil price environment and COVID-19 restrictions, as well as ongoing supply chain and regional labour market challenges. The project was delayed one year from the original test plan. Descriptions and durations of the delays are noted in Table 1. Despite the delays, the intent of the Y1TP and Y2TP, discussed above, was not changed throughout the course of execution.

Table 1: Descriptions and durations of delays to the WTDC original test plan.

Delay Category	Description	Delay Duration
Budget Limitations	Restructuring of Test Program in 2019/2020: Steam generation pilot delayed to Y5TP, Pilot 10 to Y5TP, Pilot 1, 2 to Y2TP, etc.	1 year
	Oil price crash significantly impacted annual test plan budgets.	1 year
Contracting	Longer than expected contract negotiations (e.g., Pilot 3)	1 year
COVID-19	COVID-19 required shutdown of facility.	6 months
Engineering & Procurement	Additional efforts required to work with new and small vendors.	6 months
	Longer than expected engineering timelines to address complexities.	3 months
	Longer than expected procurement.	6 months
	Longer than expected permitting processes for equipment (e.g., Pilot 4 CSA approval)	6 months
Labor Force	Limitations on labor force and camp capacity during Firebag turnarounds delayed pilot start dates.	3 months
	Limited labor force internally and in contractor workforce has extended timelines (e.g., for E&P, construction, scoping study prep, etc.).	3 months
Pilot 1	Complex system required more commissioning and start-up than expected.	3 months
	Equipment reliability issues and plugging early in the operation.	
	Longer than expected contract negotiations.	
Pilot 2	Complex system required more commissioning and start-up than expected.	6 months
	Equipment reliability issues.	

Delay Category	Description	Delay Duration
	Delays to coordinate with Pilot 1.	
Pilot 3	Longer than expected contract negotiations.	3 months
	Longer than expected procurement.	
	Many additional chemicals identified after start-up.	
	Challenges with chemical delivery systems.	
Pilot 4	Longer than expected procurement.	3 months
	Unexpected additional engineering design work was required to upgrade metallurgy and pumps.	
Pilot 5	Longer than expected procurement.	3 months
	Equipment reliability issues.	
Pilot 7,8,9	Equipment reliability issues (e.g., burner issues during commissioning).	1 year
	Inability to pig the OTSG	
Pilot 11	Equipment reliability issues	1 year
	Not many opportunities to lower interface level to test sonar unit	
	Permitting challenges with Nuclear Density Profiler NDP	
Pilot 12	Construction delay to labor force and camp availability constraints during Firebag turnaround.	3 months
	Delay to operating window due to conflicts with Pilot 11	

3 Methodology

The project utilized a complete indoor testing facility that was designed and constructed by the WTDC Members specifically for the purpose of testing new thermal in situ oil sands technologies. The facility brought numerous live fluids from the Firebag facility (e.g., raw emulsion, produced water, boiler feedwater, etc.), at typical operating temperatures and pressures. The facility also provided utilities required for operation of the pilots (e.g., HVAC, water, fuel gas, electricity, instrument air, glycol, etc.) and collected the waste streams from the pilots. Waste streams were returned to Firebag operations at low rates so as not to upset the main commercial process. Figure 2 shows an aerial view of the WTDC facility (foreground) exterior in relation to the Firebag facility (background). The WTDC facility layout is shown in Figure 3.

Figure 2: WTDC Facility Partial Overhead View.

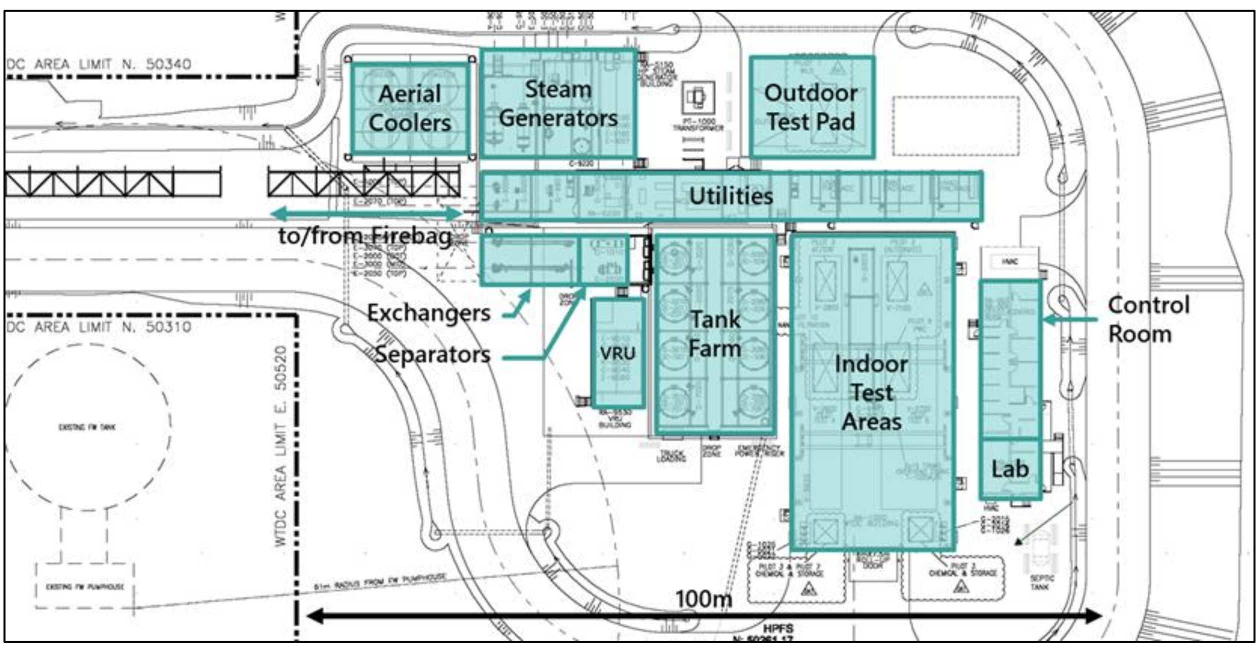

Figure 3: WTDC Facility Layout.

The facility had large bays which were available for installation of skid-based pilot equipment. The facility also included a large outdoor pad for pilot equipment too large to fit indoors. The WTDC had pre-installed equipment including:

- 5MW OTSG.
- High Pressure Steam Separator.
- Heat Exchangers.
- Storage tankage.
- Instrument Test Loop.

High level PFDs are available in Appendix A. The WTDC feed streams and waste headers are shown below in Figure 4 and Figure 5.

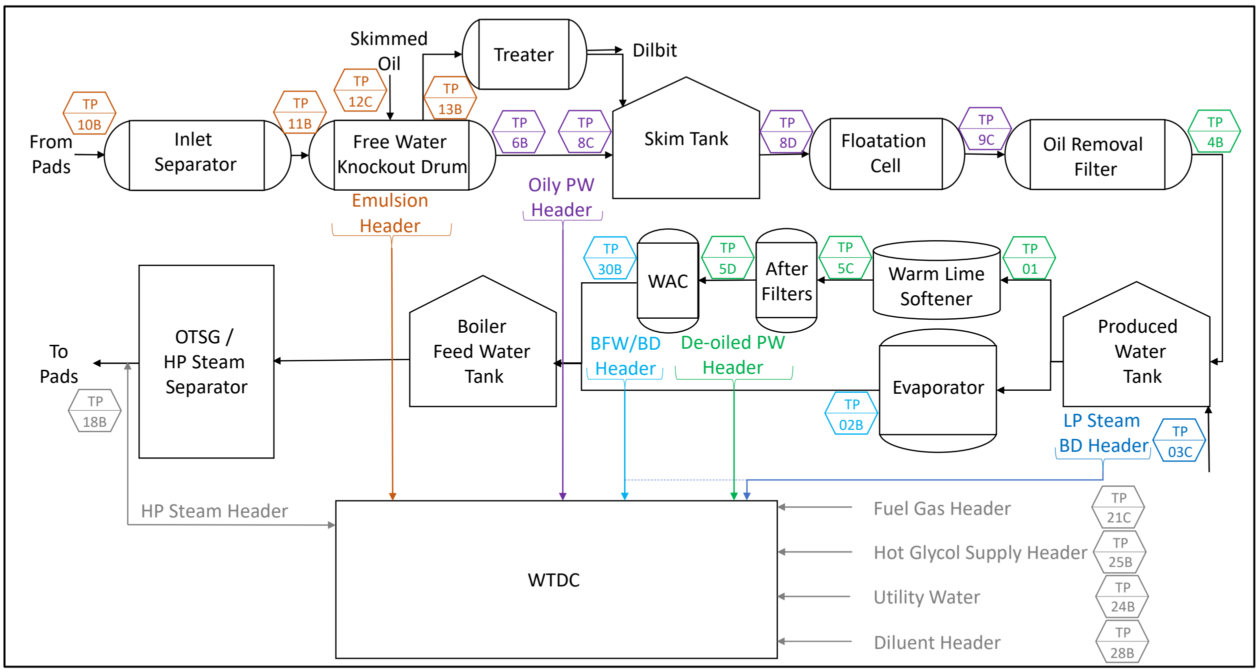

Figure 4: WTDC Suppler Header Diagram.

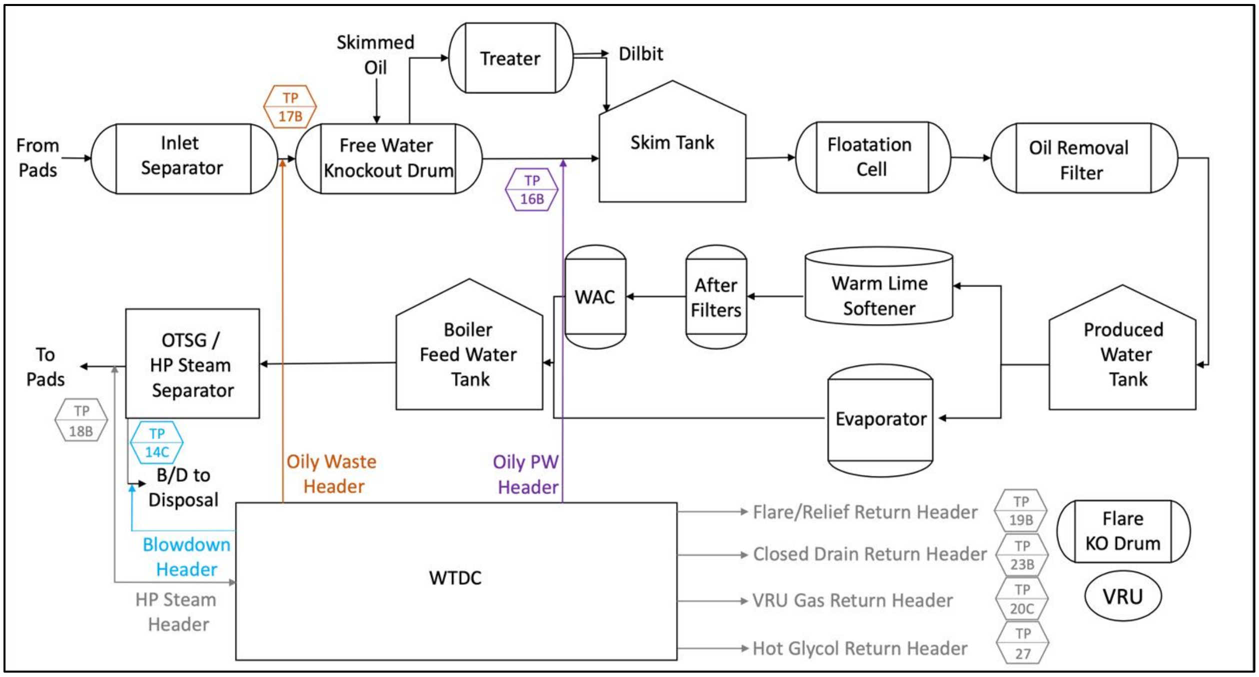

Figure 5: WTDC Waste Header Diagram.

The WTDC was operated by a full 24/7 operating staff, including foremen, day- and night-shift operators, and a staffed onsite laboratory, all dedicated to the execution of the WTDC pilots. An operations engineer was also dedicated to the project at all times. The Firebag Central Lab was available for conducting testing that the WTDC lab was not equipped to do.

The WTDC was managed by a Management Committee (ManCom), whose key responsibilities included strategic decision making, internal and external stakeholder management, commercial strategy, communications, legal, and annual budget approval. A separate Technical Committee (TechCom) was also established whose functions generally included 5-Year Test Plan development, technology evaluations, vendor engagement, pilot monitoring and reporting, and providing any technical direction required by WTDC operations. TechCom was typically comprised of members of the operations, technology, engineering, and pilot testing teams.

Each pilot had a dedicated pilot lead and co-lead responsible for the technology identification/selection, vendor engagement, scoping study development, pilot testing plan, engineering oversight, coordination with operations on the day-to-day execution of the pilot test plan, troubleshooting support, data analysis, and reporting.

Pilot engineering execution was generally managed by the Suncor Business Unit Projects (BUP) group, which worked with the tie-in engineering firm, HOCS, to execute the project detailed engineering.

4 Project Results

Key results of the WTDC include, but are not limited to, project specific metrics, which are provided in the Outcomes and Impacts section below. However, the metrics do not provide a complete picture of the benefits of the project to industry. A discussion of key results and learnings, including reasoning for variance between expected and actual performance, is presented here for each pilot.

4.1 Pilot results

Generally, piloting at the WTDC allowed for rapid testing of novel chemicals, equipment, and processes that will benefit future R&D planning and execution. The results and learnings generated by piloting small scale technology, provided per pilot below, will be valuable to the oil and gas industry in Alberta in various ways.

4.1.1 Pilot 1 Warm Lime Softening (WLS) Coagulant Flocculant Optimization

Completed July 2023.

The main outcome of the pilot was a step change performance improvement which was observed with the latest advanced coagulant and flocculant products as compared to more traditional products which have been used since the inception of SAGD. Innovative novel chemical packages can improve interactions with suspended particles of various charges improving overall WLS performance, resulting in a significant reduction in the overflow turbidity and particulate hardness thus improving boiler feed water quality which is expected to reduce steam generation fouling and improve efficiency.

Also, the best performance was achieved with the use of chemistries that were developed and tailored to the produced water present at the WTDC, confirming how important it is to support and progress technology advancement and development in the SAGD WLS and water treatment areas.

Commercial trials are encouraged as the implementation of newer chemical technologies in the SAGD water treatment industry has the potential to improve overall water treatment plant performance, further chemical optimization, and better boiler water quality yielding economic and environmental benefits.

4.1.2 Pilot 2 Oil Removal Filter (ORF) and After Filters (AF) Enhancement

In progress as of February 2024.

This trial was divided into several key phases, and a different media was tested each time. Four different phases of the trial have been performed to date. First, a baseline test was conducted to establish the performance of black walnut shell media in the WTDC facilities. In this phase, an upset test and backwash was also done to establish baseline performance surrounding those two events.

After this baseline, the second phase was started, where white walnut shells were placed in the variable column. A similar procedure was followed, first running the facility under normal operations. An upset test was also conducted here, as were several backwash cycles to clean the media. The performance of white walnut shells was slightly below that of the incumbent media, and the white walnut shells struggled to recover from the upset test compared to the black walnut shells. However, the cost of operating and maintaining filters that use white walnut shells is lower, therefore potentially making them a viable option in cases where adherence to strict parameters is not required.

In the third phase, a new type of media was used. This was a backwashable polymer coated media that is often used in treating streams with high oil content. In the trial, it performed below the standard set by the black walnut shells in both OIW and suspended solids. It is important to note that the difference in performance for the removal of oil was minimal. It did outperform the incumbent in turbidity removal, where it was significantly better. There is a chance, however, that some of this turbidity was oil that was not picked up by the oil analyzer. This could ultimately mean the turbidity removal improvement was not as high as it seemed. The media did seem to degrade over time, which was a conclusion found in other studies involving the media. With only turbidity removal being higher than the incumbent and due to the higher cost associated with implementing and maintaining this media, it is likely that this media would not offer any improvements worth pursuing at a commercial scale. However, the final recommendation would be pending a full economic evaluation based on site-specific conditions.

Finally, the filter aid phase of the trial involved adding chemicals to the media in different dosages and testing performance. This trial was done in both the ORF and AF configurations. In the ORF configuration, two different dosages were tested, and improvements were seen in both OIW and turbidity for both. The improvements in turbidity were more substantial and were higher relative to the incumbent when the dosage was lower. This could be because when in ORF mode, the filter is attempting to remove oil from the stream. This oil might be part of the turbidity that is being measured throughout the trial. The opposite was true for the AF performance, where the higher the dosage, the higher the removal levels. The largest difference from the black walnut shells in terms of relative performance was noted at a dose of 1.0 ppm, which was the middle dosage that was trialed. It was also noted that the pressure differential seemed to increase more substantially with higher doses, potentially leading to more frequent backwash requirements which could harm the filters efficiency and water usage levels.

Through the work done in the trial to date, it has been demonstrated that improvements can be made to the backwash cycle, offering potential optimization opportunities for the process. As well, through the media tested, it has been proven that there are ways to further increase the efficiency of water treatment in SAGD facilities, and such opportunities will continue to be available in the future as the technology surrounding filtration improves further. Depending on the properties and the situation, some media seem to offer more specialized performance gains, making them better suited for certain applications relative to others.

4.1.3 Pilot 3 EB/REB Testing

Completed October 2022.

Thirty-two demulsifier products from three different chemical suppliers were considered. Outside of the WTDC, this is equivalent to approximately 10 years of commercial testing. Demulsifier products from two suppliers were identified as front runners. However, one of their products should be supplemented with a third product, as needed, to improve performance.

Pilot testing provided operating companies with an indication of future commercial scale performance and lowers the risk of commercial trial failure. This approach identified a greater product selection for operating companies, which will allow for reduced operating expenses. One supplier’s demuslifier products well proven and met pilot dilbit dehydration and OIW specifications at equal or lower doses than products from other suppliers, though with shorter PWC runtimes. Products from multiple suppliers showed potential to address the problem of PWC fouling. However, newer products may generate poorer water quality and/or dehydrate worse than the incumbent. These risks must be considered prior to proceeding with any commercial trials.

4.1.4 Pilot 4 BIW/OIW Analyzer

Completed September 2022.

Three OIW analyzer technologies were evaluated for this pilot, including light scattering, ultrasonic acoustic, and UV fluorescence with solvent extraction. These three technologies have been incorporated into commercial online analyzers to measure OIW and analyzers using these technologies have been used commercially elsewhere in the oil and gas industry.

None of the online analyzers achieved the KPI's related to accuracy, in comparison to the on-site laboratory measurement of OIW using UV fluorescence with solvent extraction. The performance of the analyzers was inconsistent, but there were periods when the light scattering and ultrasonic acoustic analyzers both trended with lab OIW measurements. The trending was stronger with the WLS Feed process stream as compared to the ORF Outlet process stream. Also, the light scattering and ultrasonic technologies have the potential to measure suspended solids as well as OIW, and that was evident during the pilot.

The cleaning and re-tuning of the light scattering and ultrasonic acoustic analyzers were effective in restoring performance. The operation of the recirculation pump, which led to a higher velocity in the test header, led to cleaning intervals of up to 3 months for the light scattering and ultrasonic acoustic analyzers. The maintenance on the UV fluorescence with solvent extraction was excessive; the technology still holds promise, but the analyzer design was not robust enough for the application.

The learnings from off-site FTIR OIW measurements were limited. It was noted that the FTIR OIW measurements were generally higher than the on-site OIW measurements using UV fluorescence with solvent extraction.

4.1.5 Pilot 5 Produced Water Cooler (PWC) Enhancement

Completed October 2022.

The strengths and weaknesses of each approach to reducing/mitigating the effects of PWC fouling were investigated and tested. This pilot also achieved approximately 10 years' worth of commercial trials in the timeframe of the pilot.

The most attractive technology to address the PWC fouling problem was found to be improved specialty chemicals (i.e., demulsifiers and/or antifoulants), as these chemicals can be implemented relatively quickly and require little to no additional capital investment, while promising improvements based on results observed during pilot testing. The second most promising technology investigated was coatings, which also provided significant PWC runtime gains and appear to have potential for further commercial implementation.

Work on improved specialty chemicals should continue to be advanced and further refined through additional pilot and commercial trial testing, followed by full-scale commercial implementation. Other approaches tested, such as flow reversal and glycol, may also have merit and should not be ruled out, provided that technical and commercial barriers to implementation can be worked out, as multiple approaches could be combined for greater overall impact.

4.1.6 Pilot 7 OTSG 90% Steam Quality

Incomplete as of February 2024.

The WTDC OTSG was commissioned and started up in December 2020. The unit experienced multiple operational challenges throughout the course of the project, which have been communicated to Alberta Innovates in previous Progress Reports. In August 2022, the OTSG was shut down, as enough baseline data had been gathered on tube skin temperature, OTSG pass pressure drop, stack temperature, BFW and BD chemistry, UT, and via tube cut-out destructive analysis. The plan was to mechanically clean the OTSG before moving to 90% SQ. However, due to OTSG design constraints and difficulty finding a pigging company that could successfully perform pigging of the small inside diameter tubes in the OTSG, the pilot was put on hold until an engineering solution could be implemented. Until an appropriate engineering solution is determined for tube cleaning, the OTSG will continue to operate for testing anti-scaling, antifoulant, and corrosion inhibitor agents at lower SQ conditions (~75%).

Learnings from the baseline work confirmed that OTSG operation at ~80% SQ results in tube corrosion in both convection and radiant sections. Under deposit pitting, the corrosion mechanism was most prominent in all analyzed tubes, whereas flow-accelerated corrosion (FAC) was observed only in the OTSG steam exit elbow.

Although BFW quality is not a key performance indicator (KPI) for this pilot, it is one of the most critical aspects to control and minimize both fouling and corrosion in the OTSGs. Specifically, pH is one of the factors largely influencing corrosion mechanisms and the stability of the magnetite layer. A pH less than 9.5 in BFW is recommended for OTSG operation, particularly for the 90% SQ trials. Tightening the pH control was found to be critical to maintain OTSG integrity. More studies targeting water treatment system design and operation, online instrumentation, blowdown management, etc. are recommended.

4.1.7 Pilot 8 High Pressure Steam Separator (HPSS)

In progress as of February 2024.

Despite all OTSG issues, attempts were made to determine the amount of carry-over experienced during the OTSG operation. The 2022 timeline was selected as it represents a period of relative steady system performance. The carry-over calculation was based on the laboratory results for conductivity. The estimated carry-over was approximately 10%.

This methodology had some limitations, but regardless of the limitations observed with the HP Separator carryover calculation, it can be established that this phenomenon is present based on the average numbers obtained. Currently, specialty sample points are being installed in the HP steam header, and it is expected that once the sample points are available, the carryover rate and calculation results will be confirmed.

4.1.8 Pilot 9 Steam Quality Analyzer

In progress as of February 2024.

In this pilot, two novel technologies were tested to measure online steam qualities: the Optical Near Infrared (NIR) sensor and the combination of the Thermal Mass Flow Meter (TQM) and vortex meter. The Optical NIR sensor leaked right after the calibration runs which caused significant damage to the skid electronics and other instruments. The redesigned and refabricated Optical NIR also leaked after the calibration runs, indicating potential integrity risks operating at high pressure and high-temperature conditions. The Optical NIR sensor steam leaks significantly impacted the test schedule including TQM tests. The Optical NIR test was discontinued and only TQM tests were continued.

Some changes were made to the TQM configuration to improve the accuracy. The calibrated runs with TQM results measured SQ values were within ±2%. The preliminary tests were promising but the long-term performance of TQM needs to be understood better with continued tests.

4.1.9 Pilot 10 Blowdown Waste Management

Scheduled for fall 2024.

As previously communicated to Alberta Innovates, due to schedule constraints, Pilot 10 was not executed within the funding window and has been pushed out to future testing. As such, no results are available to report.

4.1.10 Pilot 11 Level Interface Meter

Completed September 2023.

Two novel technologies were tested in this pilot using trial versions of the products. Issues were identified with the equipment after the installation and commissioning, and the pilot faced challenges with the reliability of manual sampling, which is subject to human error. In addition, the technologies faced extended regulatory approvals and required replacement due to damage, which in turn delayed the test plan and reduced the accuracy of comparison between different technologies.

Due to the constraints and interruptions in testing, it is difficult to draw meaningful conclusions from the Pilot 11 testing. It does appear that when the devices are working properly, they provide meaningful data on ILM. In particular, the tomographic technology provides a visual of what is going on in the vessel, which can lead to unique insights for operations. The sonar technology also trended reasonably well when the interface level could be drawn down to its operating level, but more data is required to confirm if it could replace the NDP technology. It is believed that with further product development and commercial sized installations, the technical challenges experienced at the WTDC could be resolved.

4.1.11 Pilot 12 Water Cut Analyzers

Completed June 2023.

The primary objective of this pilot was to assess the impact of enhanced sampling techniques and salt addition on water cut measurement accuracy using raw, degassed emulsion from Suncor’s Firebag Plant

92. The pilot demonstrated that accurate water cut measurement is possible using existing microwave-based technologies. However, strategies to improve measurement accuracy were largely unsuccessful, and the main opportunity for improvement lies in proper installation, highly representative sampling, and ensuring adequate velocities across the analyzers. Measurement accuracy can be improved from +/-20% to at least +/-5% with the implementation of these strategies. The improvement in measurement accuracy could result in a 3-4% reduction in SOR, leading to a direct 3-4% reduction in greenhouse gas (GHG) emissions related to steam generation.

It has been demonstrated that while salt addition has a significant impact on microwave-based water cut measurement, it does not appear to be a robust strategy for improving water cut measurement accuracy.

5 Key Learnings

As documented in Progress Report 1 and 2, the WTDC learned valuable lessons through planning, construction, and operation of the Y1TP pilots, which have been compiled into an internal "lessons learned" presentation and are being utilized to improve future test plan years. Pilot learnings were communicated to the WTDC partners on at least a monthly basis, and each partner is independently exploring implementation of these learnings within their commercial facilities. In addition, the WTDC executed a formal group "lessons learned" session to identify key learnings from the initial testing period and plan how to utilize these learnings moving forward. Learnings from all these exercises along with a few additional insights are summarized below.

5.1 Role definition

There was potential to increase the efficiency of the pilots with more detailed roles and responsibilities of the pilot lead and co-lead, for each stage of pilot development and execution (i.e., scoping studies, communicating results, etc.). This would be especially important during long term projects such as the WTDC, as it is critical to plan for personnel changes.

5.2 Stakeholder engagement

Limitations on human resources and available budget can result in some stakeholders not being engaged, not enough time for parties to develop a full understanding of pilot complexities, and inability to complete thorough review processes. Due to the long-term nature of the project and altered business environment, the pace of pilot development was sometimes impacted by availability of internal resources.

5.3 Communications between management and technical committees

Avoiding duplication of meeting content between ManCom and TechCom was identified as an important efficiency. This was achieved through clear documentation on roles and responsibilities of team members and the purposes of each committee. It was also found that having one representative from each of the partners that sat on both the management and technical meetings was helpful to maintain clear communication between the two. The WTDC benefitted from having the "WTDC Vision, Goals, and Stewardship" document, as it clearly aligned the efforts of the partners. Additional value could have been realised in reviewing this document with the entire team more regularly to facilitate agreements on “goal posts” for pilots during test phases.

5.4 Resourcing and partner commitment

Since the funding for the WTDC came from high levels of the partnership companies, it was helpful to offer site tours and webinars to demonstrate the capability of the facility. It was found that site tours often exceeded visitor expectations. Additionally, it is important to work budget reforecasting into the contractual agreement, especially with the inherent volatility in the oil and gas industry. Frequent communication that was transparent about priorities and capabilities helped align test plans against resources, budgets, and interests. The WTDC also found synergies in the workload and created more focused test plans. A suggestion for any future collaborations is to commit to a set annual operating expenditure range in the commercial agreement.

5.5 Number of pilots to tackle to per year

Scheduling should be done conservatively. It is critical to balance utilization, value, resources, and budget. Post COVID-19, the start-up was phased due to health requirements, but it ended up being beneficial for all pilot test plans.

5.6 Engage new vendors early

The WTDC found challenges with certifications (e.g., CSA, Nuclear Safety Board), working with pre-commercial products, and working with international vendors. Many of these challenges resulted in contracting lag. Performing proactive test planning in the future would early engagement of vendors. Something to consider is to have boiler plate contracts that are “good enough” rather than prolonging negotiations to get the "perfect”" agreement in place. It is also noteworthy that vendor contracts with the consortium included more complex negotiations than would be expended if the vendor were negotiating with a single company.

5.7 Challenges in pilot design and Scale-up complexities

Despite smaller scale and cost, the design and engineering of pilot skids were found to be more complex, time-consuming, and expensive, on a relative basis, than executing similar commercial technologies. In part, this occurred because local engineering, procurement, and construction (EPC) companies were geared towards quickly turning over standard designs for commercial projects. The WTDC pilot projects, by definition, were unique and required significantly more engineering expertise to execute well. Standard equipment or metallurgy that are often available for commercial projects were often not available for the smaller pilot sizes. Much more thought, effort, and design reviews were required to deliver pilot projects. The WTDC partners found that there were very few resources that could carefully examine the scale-up complexities associated with each pilot. Assessing these complexities was critical to ensure successful operation and the translation of pilot results to the full-scale commercial operation.

The WTDC OTSG is an example of a critical piece of equipment that was hampered by pilot design and scale-up complexities. These included issues with the burner and ultimately the inability to mechanically clean the smaller 1” boiler tubes, even though this was specified as a requirement in the original design. Commercial SAGD boilers have 3-6” tubes and mechanical cleaning of these tubes is critical to long term operation. Furthermore, several online meters and probes that were of interest to the WTDC could not be utilized on the 1” tubes due to the small size. The ability to test designs in Pilot 8 was also limited due to the small size of the WTDC high pressure steam separator.

Conversely, the Pilot 1 and Pilot 2 equipment were very well designed and performed according to expectations. The WTDC membership was much more involved in the design of these pilots, which likely contributed to their success. Pilot 1 involved collaboration with several local institutions. Government support to improve provincial capabilities in this area is recommended.

5.8 Cost, time, and effort required to deliver on pilot scopes

Due to several of the factors outlined above, the effort required to deliver each pilot scope was much higher than originally anticipated. Although some efficiencies were gained through experience, the unique nature of each pilot posed challenges and the overall improvement in efficiency that was anticipated by executing multiple pilot projects was likely not realized.

5.9 Gaps between smaller scale R&D and WTDC

Many individuals, both within and outside, the thermal in situ oil sands industry underestimate the complexity of the process fluids involved in the process. The oil-water emulsions and boiler feed water chemistries are some of the most complex in the global oil and gas industry. Although many useful programs have been developed through the Pathways Alliance to provide more insight into these complex chemistries, a gap was identified, and still remains, between that fundamental work and the WTDC pilot programs. For the Y1TP and Y2TP, no results were available from any of the smaller scale R&D programs, and it appeared that not all vendors fully understood the complex chemistries present in SAGD. Continued government support for these smaller scale R&D programs is recommended.

5.10 Hurdles to commercial implementation

Several of the WTDC pilots yielded results with commercial implementation potential (i.e., Pilot 1, 3, 4, 5, 9, 11). However, given the current industry environment, the cost to implement some of these technologies has been found to be too high to proceed. For example, this applies to Pilot 5 PWC; even though multiple options were shown to improve performance, many of them were too expensive to implement commercially in a brownfield facility in the current industry environment.

5.11 Source high quality, vetted components

The WTDC offered an opportunity to identify and source high quality components for use in the pilots. In cases where high quality components could not be procured, the WTDC offered the opportunity for vendors to further develop and engineer higher quality products. This ultimately benefited industry as whole.

5.12 Collaboration

In the process of planning, designing, building, and operating the WTDC, there were nearly unprecedented opportunities for collaboration amongst competing operating companies. During the planning and design of the facility, substantial agreements were developed, and engineering resources came together to identify common gaps and goals. There was also significant collaboration in the project execution aspects as well. During test plan development, numerous experts shared their own company's technology investigations and found common threads that were ultimately carried forward for piloting. The partners then also had to collaborate on pilot objectives and a detailed test plan that met all the member company objectives.

5.13 Safely operate a complex thermal in situ testing facility

Another important, but often overlooked, learning in the context of testing facilities which the WTDC demonstrated is that a complex technology development facility can safely operate multiple technologies simultaneously while connected to an operating host facility. This is important, as most of the pilots were one-off designs without any former operating experience with the equipment. New operation procedures and practices had to be developed through the WTDC project to ensure Operator safety. During the entire duration of the WTDC, there were no significant safety incidents.

5.14 Piloting Execution

During the course of the Project, there were numerous lessons learned about how to execute pilots successfully. Some notable examples are related to the following:

- Engagement of a highly capable, yet focused, engineering firm was important:
- It was important for the engineering firm to be invested in the success of the facility (i.e., they stood to gain significant and continued business from the ongoing success of the WTDC).
- It helped that the engineering firm was not overly large and distracted by other, higher budget projects.
- C&SU (spares): it was important to have spares for long-lead equipment, as the spares became a critical schedule factor. It was clear early in the project that this would need to be carefully evaluated for every pilot; this was done very well in later pilots.
- Resource forecasting was also critical early in the pilot planning phases to ensure success; the WTDC members did this very well as it became obvious that some of these smaller pilots required significant engineering and operational resources, relative to their size.

5.15 Avoiding duplication of effort

One key benefit of the WTDC was that member companies avoided what likely would have been significant duplication of technology testing. Many member companies had been considering pilot testing of similar technologies and had industry proceeded without the WTDC, there would have been significant duplication of effort. This would have meant fewer dedicated resources, less collaboration, and much greater difficulty for vendors to meet expectations. Overall, the speed at which knowledge was developed would have slowed significantly without the WTDC.

6 Outcomes and Impacts

The WTDC project had a measurable impact on technology gaps that exist for in-situ thermal facilities. It was able to identify chemical and physical improvements to the facilities to improve chemical consumption, equipment reliability, and equipment performance. These improvements will result in capital and operating cost benefits and environmental performance improvements, which will ultimately improve economics and further the industry as a whole. Additional specifics are highlighted in the following sections. Metrics defined at the beginning of the project in the "AI CE Work Plan and Budget" table are reported on in the tables below.

6.1 Project Success Metrics

Key results of the WTDC include, but are not limited to, the following project specific metrics, provided in Table 2 below. Not all metrics can be directly measured, and, due to the challenges with the pilots as highlighted previously, not all targets were definitively reached. Furthermore, as previously mentioned, the commercial uptake of the technologies to date has been low as many of the pilots remain in operation and the numerous results from the other piloting activities are still being processed internally.

Table 2: Project Success Metrics

Metric	Target	Actual
GHG Reduction	5.9 kg CO2/bbl bitumen risked at 70%	4 kg CO2/bbl bitumen
Net Present Value (NPV) Improvement	+$41MM (brownfield) +3% RR $238MM (greenfield)	~ $100MM (risked)
Water Use	< 0.5 bbl H2O/ bbl bitumen	Minor improvements
Land Reduction	25% land reduction	Negligible
# Pilots Delivered per Year	4 - 10	4 (average)
WTDC Operating Budget	~$10M / year	~$8.5M / year
# of WTDC Participants	6 - 7	4-6*

**Based on starting the WTDC with six partners and ultimately being reduced to four through acquisitions.*

6.1.1 Emissions Metrics

The GHG benefits associated with the SQ uplifts is perhaps the biggest target miss and that was largely due to the significant number of OTSG delays experienced over the course of the Project. However, thanks to the water cut analyzer pilot, SOR improvements have allowed some credit to be taken for GHG reductions and the WTDC OTSG is now operating. Despite the OTSG related challenges, it is still felt that SOR and SQ improvements would yield values in the range of the previously envisioned targets. Furthermore, commercial plants have already begun pushing SQ into the mid-80% range and therefore, the expected benefits are currently being partially realized by industry. Accounting for OTSG operational improvements and SOR improvements, it is estimated that the WTDC pilots will contribute to a reduction in GHG emissions of 4-7% wherever they are implemented, with potential to achieve reductions greater than 7% as SQ is pushed higher. It is also assumed that uptake of these benefits across industry will begin in 2025, as opposed to 2021 which was originally assumed while setting the GHG emissions reduction targets.

6.1.2 Financial Metrics

Net Present Value (NPV) improvements also do not quite meet original targets; as above, this can be attributed to pilot delays and lack of time to fully implement results commercially. The inability of the OTSG to run as expected had a significant negative impact as well. However, it is worth noting that even if piloted technologies were determined to be unsuitable for commercial implementation, this in itself is a valuable learning. There is value in knowing what to avoid and not duplicating efforts within the rest of industry. The value of this knowledge does not map directly to a performance metric.

Overall, however, even though there were significant delays, the Project did meet expected targets with respect to the budget and the number of participants. It can therefore be argued that the project was successful and delivered its expected scope as committed to. Financial and environmental benefits from the WTDC are expected to further increase over time as the remaining pilots are completed and commercial development plans are finalized. It is also noted that only two of the five-year test plan results are discussed in this report, and the WTDC membership and industry as a whole will see further economic and environmental improvements from the results generated from the full five-year test plan.

6.2 Clean Energy Metrics

Although six pilots from the Y1TP are currently operational and several are generating learnings which are noteworthy for the WTDC partners, it is too early to comment conclusively on changes to the project-specific and implementation-specific targets for most clean energy metrics. Most metrics are based on future uptake of piloted technologies by industry, and the WTDC's progress against these targets cannot be assessed at this time. The WTDC's performance against the Clean Energy Metrics is summarized in Table 3 below.

Table 3: Clean Energy Metrics

Metric	Target	Actual	Justification
$ in Clean Technology	$29,250,000	$34,918,834	This result is positive, indicating that the WTDC partners supported more development in clean technology than originally planned.
$ Future Investment	Unknown	Unknown	This will be a function of commercial uptake, which is difficult to assess at this time.

Metric	Target	Actual	Justification
# field pilots/demonstrations	10	10	The Y1TP and Y2TP were modified from the original proposal to Alberta Innovates, as communicated in Scope Change Request Forms.
# of Publications	• 20 - 80 patents • 10 - 50 best practice, standard lab procedure, and technical operating envelope recommendations	• 2 patents • 20 best practices • 9 presentations • 3 public profiles • 1 conference paper	No new patentable technologies or innovations were identified as part of the project due to using primarily vendor-supplied equipment. Therefore, the WTDC members themselves applied for very few patents.
# Sector HQSP trained	100+	40	Not as many resources were allocated to the project as originally envisioned; mostly engineers and operators worked on the project.
# Existing Sector HQSP jobs retained	100 – 200	40	Most HQSP that are currently involved in the project have been retained.
# new jobs created from project	273	150	Only personnel involved in executing the project and/or the technologies themselves have been included.
# projected new jobs created from future deployment	None	Unknown	This will be a function of commercial uptake, which is difficult to assess at this time.
# Patents filed	20 – 80	2 (Pilot 3)	See above regarding publications.

Metric	Target	Actual	Justification
Partnership agreements / MOUs?	Yes	Many	An agreement was signed between WTDC partners (Research Services and Technology Sharing Agreement). Multiple contracts/agreements/MOUs were signed with vendors and other companies related to piloting.
# New products/services created	1	>10	Vendors were able to develop new products, particularly the chemical vendors.
# actual GHG emissions reductions from project	0	0	The future deployment of piloted technologies is expected to result in GHG emissions reductions (see metric below). GHG emissions are not expected to drop at the WTDC facility itself during the test plan.
# projected GHG emissions reductions from future deployment (to 2030). (Commercialization / Implementation Target)	9 mega tonnes/year, assuming Incremental technology benefits begin in 2021 and a risked, 50% uptake GHG reduction by 2030 by adoption of WTDC incremental technologies.	2 - 3 mega tonnes/year	The actual assumes a 4 – 7% reduction is achieved, although as noted greater benefits are possible with finalization of the OTSG pilots. This also assumes uptake of technologies begins in 2025, as opposed to 2021 which was assumed in the original target.

6.3 Program Specific Metrics

The majority of Program Specific Metrics are related to commercialization of piloted technologies in the long term, and therefore the WTDC's progress against these metrics cannot be assessed at this time, especially considering the current business environment. Thus, the project's chance of success in meeting commercialization targets has been estimated as High, Medium, or Low, as summarized in Table 4.

The “# of End Users participating” metric target is still six to seven. As of November 30, 2022, the WTDC effectively remains a four-member organization (i.e., Suncor, Canadian Natural, Cenovus, and CNOOC). However, the WTDC has had success engaging additional participants for individual pilots.

Table 4: Program Specific Metrics.

	Commercialization Target	Chance of Success (H/M/L) & Justification
% Improvement of overall water use efficiency	• 36% (unrisked) • 25% (risked at 70%)	L *OTSG failed to perform to expectations.*
$ intensity cost reduction on commercial deployment	• $21/ bbl	*N/A* *$21/bbl was the assumed netback price used in the economics. No improvements were stated related to this item.*
# energy intensity reduction	• 7.5% steam production increase • GHG target of 50-55 kg CO2/ bbl-bit • Improving asset availability to 96%	L *OTSG failed to perform to expectations.*
# of barrels of new resource unlocked	• 1629 bpcd (risked) • 2327 bpcd (unrisked)	H *The successful water cut analyzer pilot will contribute to new resources being unlocked.*

7 Benefits

Many of the benefits have already been discussed as part of Project Results and Outcomes and Impacts. They are summarized once again below.

7.1 Economic benefits

Generally, the uplifts that were proposed when the WTDC began were not realised to the originally anticipated levels. Challenges included: equipment reliability issues, OTSG performance issues, higher engineering and technical design complexity, slower execution of test plans, slower commissioning and start-up, and an ambitious workload of the number of pilots per year. As noted previously, financial, and environmental benefits from the WTDC are expected to further increase over time as the remaining pilots are completed and commercial development plans are finalized. The actual resulting benefits are:

- Un-risked Bitumen production uplift of 1,500 barrels per calendar day.
- 20 permanent positions created.

- The equivalent of 150 temporary 1-year duration engineering, fabrication, and construction jobs created.

The lower uplifts are associated with many of the key learnings included in Section 55. In particular, the assumption that smaller pilots were "easier" turned out to be inaccurate, which was an important learning for the project. Smaller pilots like Pilot 1 and 2 turned out to have more complex designs and required very non-standard equipment for one-off designs. Engineering companies struggled with designing these unique pilot units and needed more expertise than was expected. In some cases, technical design was completed to the required scale, but it ended up taking longer and being more costly than anticipated.

For most pilots, commissioning and start-up took longer than expected. This is partially because smaller equipment can be more prone to upsets than larger equipment, and therefore takes longer to achieve a stable operating state.

The WTDC ambitiously set out to complete 10 small scale pilots in Year 1. The amount that can be done in one year with a team of this size, in a space of this size, is more realistically in the four to five pilot range.

A general finding has been that the economic barriers to commercially implementing improvements in brownfield plants is high. This has recently been exacerbated by post COVID supply chain issues and overall cost increases to deploy projects in the field. Infrastructure and human resource solutions to the lower costs of executing projects in the oil sands regions would enable more brownfield projects with both economic and environmental benefits to be realized. Piloting at the WTDC has yielded numerous scientific and engineering results of interest, but these aren't necessarily being implemented due to do the current business environment, impacting the resulting uplifts. It remains too early to determine if the WTDC will have the anticipated impact on "moving the dial" of the commercial and economic state of the industry. However, piloting has improved the understanding of presence/absence of suitable technological alternatives, and gaining the understanding of how to improve future piloting activities has been incredibly valuable.

7.2 Environmental benefits

As detailed above in Section 6.2 Clean Energy Metrics, GHG reductions associated with Steam Quality uplifts would have made the largest environmental impact if realised to full capacity. Although the pilots did not realise the targeted GHG reductions, there is potential for environmental benefits to be realised in future commercialization.

7.3 Social benefits

This project provided entrepreneurship opportunities for local engineering firms, technology pilot fabricators, and chemical suppliers. The opportunities are not limited to the operational period, as many of these firms were able to test and extract learnings that allowed them to improve their products and develop experience working with their customers to deliver high quality products which will be used in other applications.

The WTDC also supported Albertan communities by providing high quality employment and training, thus indirectly supporting an improved quality of life for employees, their families, and communities.

7.4 Building innovation capacity

One of the key outcomes of the Project was to further the thermal in situ industry's ability to bridge the gap between other technology identification efforts of industry collaborative groups (i.e., the Pathways Alliance) and the path to commercialization through piloting. Organizations like the Pathways Alliance work with industry and academia to bring ideas from inception to bench scale, serving as the early part of the technology funnel. The WTDC then became the mechanism through which these technologies and ideas could be tested to at least commercial demonstration level, and in some cases, fully commercial. In this way, the project has had a direct and observable impact on the industry's ability to innovate and commercialize ideas by acting as the industry's "technology funnel". The combined Pathways-WTDC mechanism has enabled a systematic and streamlined approach to collaboration and technology vetting.

8 Recommendations and Next Steps

As noted previously, the Year 1 and Year 2 test plans are not yet fully completed, and the WTDC member companies continue to look for opportunities to implement value adding initiatives commercially. These WTDC advancements must compete against the background of other technology and development initiatives made by the member companies, some of which are significantly larger in scope and more mature in their overall development.

It is anticipated that all, or at least the majority of, the test plan reports will be contributed to the Pathways Alliance, thereby expanding the potential commercial scope and uplift of the technologies tested at the WTDC. Three of the four WTDC member companies are also Pathways Alliance members and are applying lessons learned from the WTDC to improve early-stage R&D activities that occur in COSIA (Canada's Oil Sands Innovation Alliance), Pathways Alliance's innovation arm.

Technology piloting is ongoing at the WTDC in 2024, as discussed. Testing of a similar nature should be explored in the future, but the specific requirements are changing as the industry changes and the focus is turning to GHG reduction techniques. A critical component to consider for future testing is the transferability of the results to various facilities, as this significantly impacts the scale of possible commercial benefits.

The next steps for this work, apart from sharing results with the Pathways Alliance, is to initiate commercial demonstrations and/or deployments at partner facilities. The results from this work will be valuable to COSIA members and could allow COSIA members to complete additional commercial demonstrations at their own facilities. The choice of demonstration is dependent on the companies' own priorities.

9 Knowledge Dissemination

WTDC participants have already participated in various conferences and written communications regarding piloting. This final report summarizes key results and learnings from the Y1TP and Y2TP. Final technical reports for each pilot have also been prepared and the learnings from piloting will be shared with COSIA via equitable contributions of final reports. Work on other test plan years is ongoing, and the results will be shared with COSIA as well.

The WTDC has completed testing for 8 pilots so far in the Y1TP and Y2TP. Two patents have been filed (Pilot 3), four prototypes have been developed (Pilots 2, 5, 9, and 11), best practices and standard laboratory procedures have been recorded (e.g., bitumen in water analysis), and technical operating envelope (TOE) specifications have been refined (e.g., OTSG SQ Optimization).

9.1 Current status

Below is a summary of the WTDC's external communications to date. Overall, reception to these communications has been positive. At conference presentations, audience members appeared to be engaged in the presentations and asked numerous questions to learn more about the test facility.

9.1.1 Completed conference presentations/posters

Conferences and associated presentations or posters completed as of February 2024 include:

Squires, M, Perdicakis, B. 2021. The Water Technology Development Centre (WTDC). Presentation given at Alberta Innovates Water Innovation Program webinar (online), December 6, 2021, Calgary, AB, Canada

Bourgeois, J.C. 2021 Water Tech Talk: WaterNEXT Industry Matchmaking – Resource Sector. Presented on behalf of the WTDC as part of an industry panel. May 5, Calgary, AB, Canada (virtual)

Reinders, T. 2020. CRIN Water: Building Connections Within the Water Innovation Ecosystem. Presented on the WTDC as part of a CRIN (Clean Resource Innovation Network) webinar, September 16, Calgary, AB, Canada (virtual)

Squires, M. and Sobey, B. 2018. COSIA Water Technology Development Centre, WTDC – A Live Fluids Test Center to Solve Current Produced Water Technology Challenges in the areas of Water Deoiling, Softening, Filtration, Steam Generation, and Heat Integration. Presentation given at Canada's Oil Sands Innovation Alliance (COSIA) Innovation Summit, June 7-8, Calgary, AB, Canada

Sobey, B., Perdicakis, B., and Bernar, R. 2018. Canadian Thermal Oil Industry Water Technology Development Center – Purpose, Design and Vision. Paper and presentation submitted to the International Water Conference, November 4-8, Scottsdale, AZ, USA

Perdicakis, B. 2019. The Water Technology Development Centre (WTDC) – Year 1 Test Plan. Presented at Alberta Innovates' Water Innovation Program Forum, Edmonton, AB, Canada

Squires, M. 2019. The Water Technology Development Centre (WTDC) Overview. Presented at the Canadian Heavy Oil Association (CHOA) Fall Conference, November 6-7, 2019, Calgary, AB, Canada

Squires, M., Perdicakis, B. 2020. The Water Technology Development Centre (WTDC). Presentation given at COSIA Associate member event (online), June 4, 2020, Calgary, AB, Canada

Squires, M., Perdicakis, B. 2020. The Water Technology Development Centre (WTDC). Presentation given at CHOA Edmonton member event (online), June 25, 2020, Calgary, AB, Canada

9.1.2 Completed reports & other publications

The WTDC was featured in an internal publication from Global Affairs Canada, the Alberta water treatment technology factsheet. Although not available publicly, this factsheet will be utilized by Global Affairs staff to attract investment and partnerships within the Alberta water sector. Other reports and publications completed as of February 2024 include:

Ashcroft, K. 2018. Innovation Profile: Basil Perdicakis and the Water Development Centre. Published in the Canadian Association of Petroleum Producers (CAPP) Context: Energy Examined magazine. Calgary, AB, Canada

JWN staff. 2019. Meet the 2019 Daily Oil Bulletin Energy Excellence Award champions. Published online by JWN May 3, 2019, Calgary, AB, Canada

Perdicakis, B. 2018. Full Project Proposal (FPP) Form: Clean Technology Facilities Support Program. Funding application submitted to Alberta Innovates (on behalf of the WTDC), November 15, 2018, Edmonton, AB, Canada

Perdicakis, B. 2018. Full Project Proposal (FPP) Form (Technology Development). Funding application submitted to Alberta Innovates' Clean Energy Division (on behalf of the WTDC), November 2018, Calgary, AB, Canada

Perdicakis, B., McGregor, M., Gerbino, AJ., and Petersen, M. 2019. High Temperature Reverse Osmosis Membrane SAGD Process Design Assessment. Published at the 2019 International Water Conference (Paper # IWC 19-61), Orlando, Florida, United States of America

9.2 Future Knowledge Dissemination

The WTDC will continue to participate in conference presentations as opportunities arise. No presentations are scheduled in the upcoming reporting period at this time. Further informal site visits for pilot leads and employees of the WTDC partners are planned in the future. It is believed that COSIA and Pathways Alliance members will find the most value in the learnings generated by the WTDC. Information will be shared with those entities via equitable contributions, working groups, etc., and it is expected that pilot technical reports will be shared with those groups. Participants will aim to publish additional papers documenting future testing results, but can make no formal commitment to do so at this time.

10 Conclusions

The key messages to be taken away from the WTDC project can be summarized as follows:

- The WTDC was the first facility of its kind in Alberta, and the learnings generated by piloting small scale technology will be valuable to the oil and gas industry in Alberta.
- Numerous pilots were operated simultaneously and safely for the duration of the Project.
- The level of collaboration on technology was very high, perhaps approaching the level of collaboration observed during the Alberta Oil Sands Technology and Research Authority (AOSTRA) in this industry and contributed to the continued success of the Pathways Alliance and COSIA.
- Testing that could have taken up to 10 years if executed within a commercial facility was accelerated and completed within just over two years.

- The WTDC Project successfully delivered 8 out of the 10 pilots that fell under agreement with Alberta Innovate within the funding timeframe, with an 80% success rate.
- Significant design and operational issues with the OTSG hindered the successful execution of two key pilots, on which much of the project benefits were based.
- Commercial uptake of the technologies has been low to date, driven by the industry's shift away from developing new projects to sustaining current projects.
- Numerous schedule delays were encountered throughout the project due to equipment reliability issues, supply chain issues, complex designs, and the COVID-19 pandemic.
- While some pilots were unable to identify a technologically superior solution to the incumbent methods, there is still significant value in this knowledge. It lends operators the confidence to continue operating using incumbent technologies, with some improvements.
- Significant duplication of testing by member companies was avoided, potentially saving millions of dollars.
- Financial and environmental benefits from the WTDC are expected to further increase over time as the remaining pilots are completed and commercial development plans are finalized. It is also noted that only two of the five-year test plan results are discussed in this report, and the WTDC membership and industry as a whole will see further economic and environmental improvements from the results generated from the full five-year test plan.

The WTDC was ultimately a success, as it delivered on its target test plan, safe operation was achieved in a complex technology development facility, multiple years' worth of data were generated in a relatively short time frame, numerous lessons were learned on the overall technology development pathway in a multi-company collaborative environment, and pilot results with tangible financial and environmental benefits were identified, with ultimate benefits to the industry and province expected to increase over time.

Appendix A PFD's

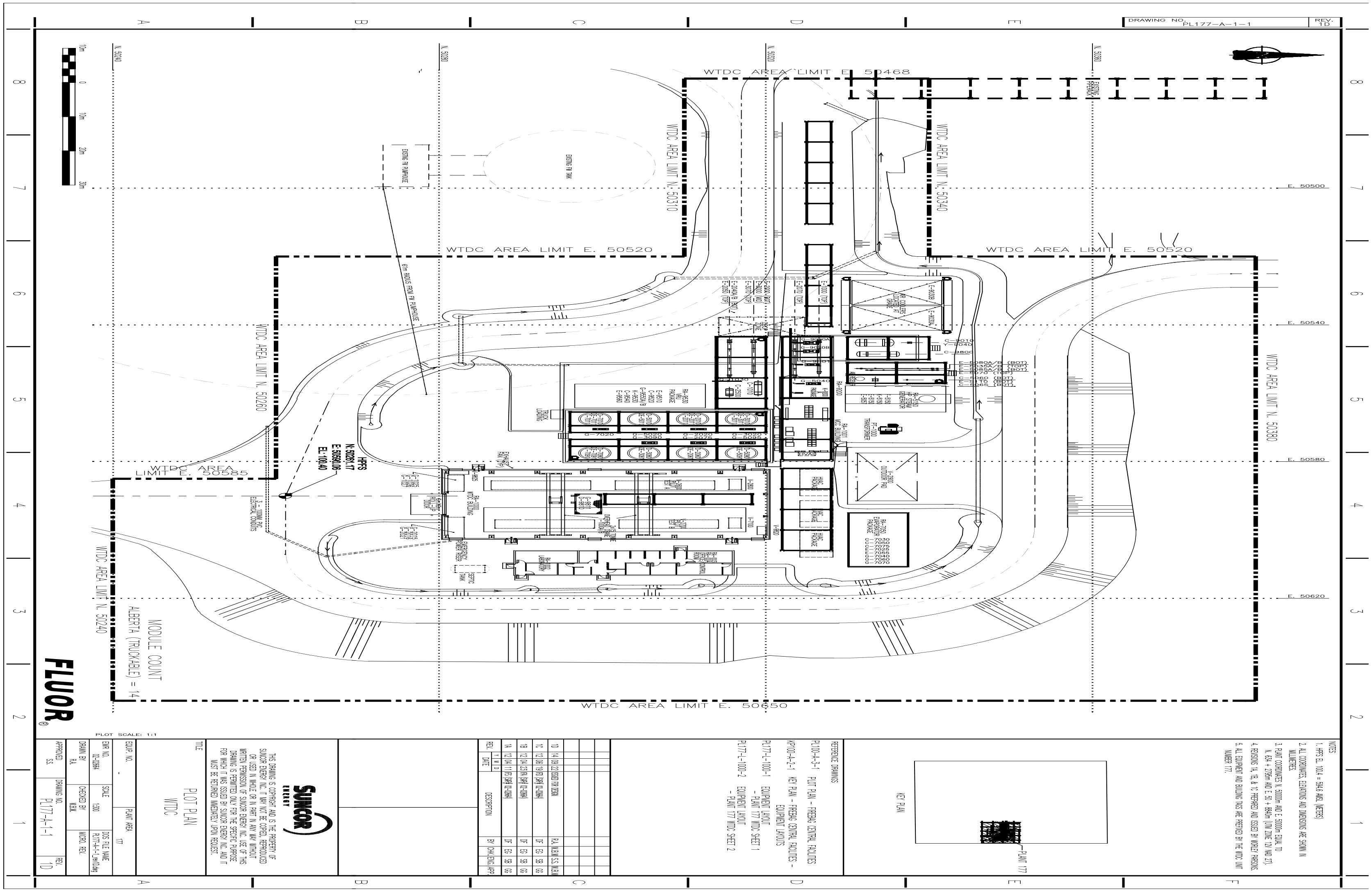

Figure 6: WTDC PFD.

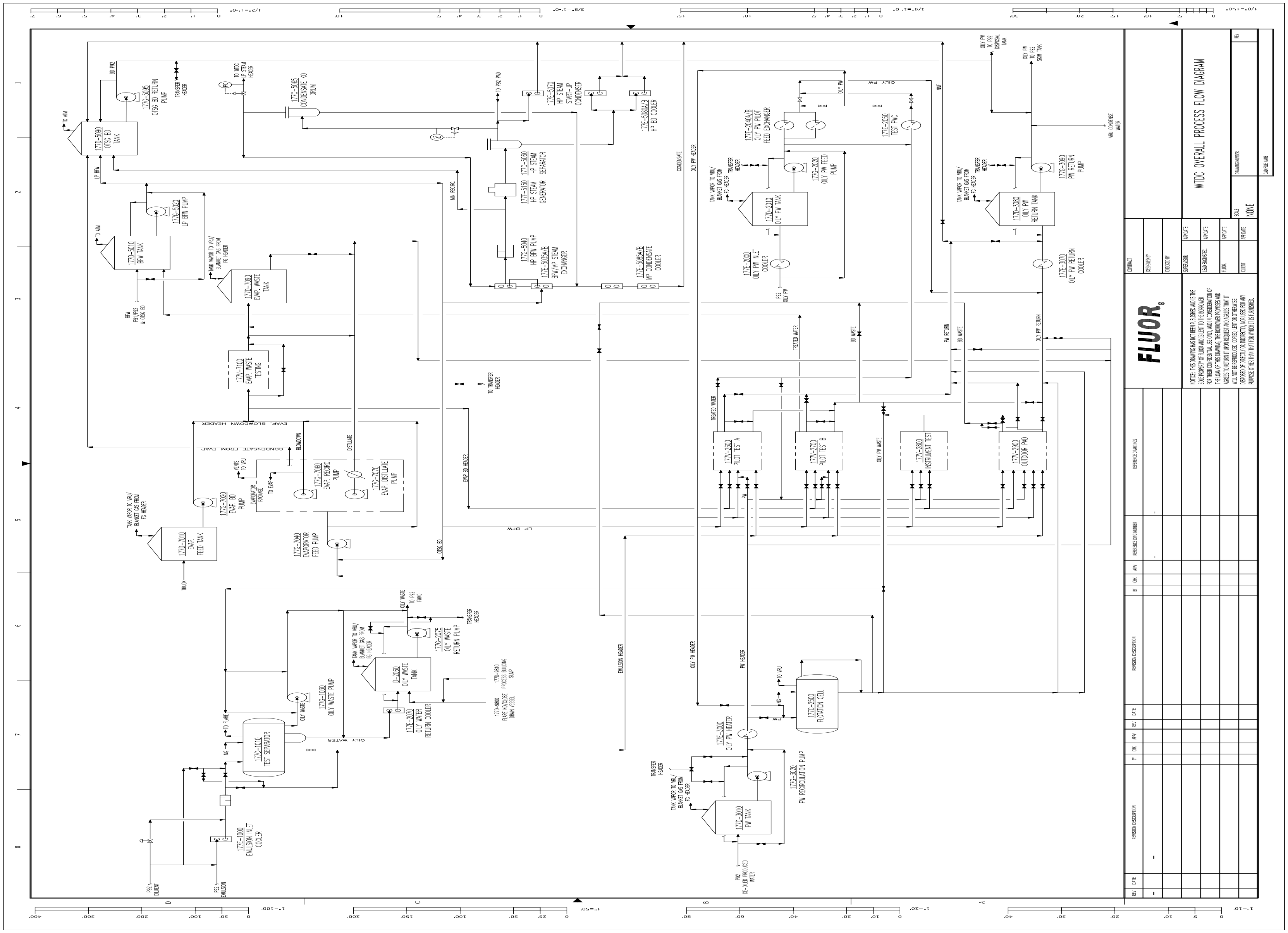

Figure 7: WTDC PFD.