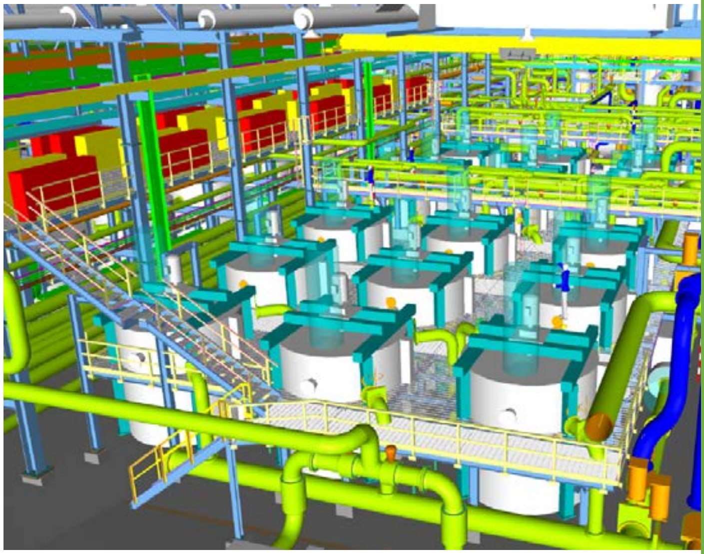
2019

Reducing Methane Emissions and other Environmental Impacts from Oil Sands Tailings and Ponds – Deployment of Sustainable Technology

Emissions Reduction Alberta Project O160140

Non-Confidential Project Report

March 22, 2019



Titanium Corporation

Executive Summary

Titanium Corporation's Creating Value from Waste (CVW™) process is being evaluated for implementation for the first time at a commercial scale at Canadian Natural's Horizon site north of Fort McKay in Northern Alberta. This process will recover residual bitumen and diluent, extract valuable mineral products from Horizon's froth treatment tailings stream and provide meaningful environmental benefits, including significant fugitive methane emissions avoidance.

The Front-End Engineering Design (FEED) phase was co-financed by Titanium Corporation, Canadian Natural and Emissions Reduction Alberta. The engineering was completed by an integrated team at Stantec, which developed the designs for both the Concentrator Plant (CP) and the Mineral Separation Plant (MSP) – with the main Process and Mechanical design of the MSP plant developed by IHC Robbins of Brisbane in Australia. The Concentrator Plant is responsible for hydrocarbon recovery and minerals stream conditioning and is comprised of conventional oil sands technologies, including cyclones, flotation, solvent extraction and distillation. The Minerals Separation Plant produces valuable minerals products, including concentrates of zircon and titanium-bearing minerals through the utilization of conventional minerals dressing equipment. All technologies have been uniquely designed and configured for oil sands tailings processing and have been validated through extensive piloting.

The FEED project was completed on budget and on schedule by February 2019. Select pre-FEED activities were executed to provide project definition, including site location and preliminary utilities sourcing. Two studies were also commissioned to examine technical aspects of the project. An experimental tailings settling program provided key data for the CVW™ Horizon thickener design. A modelling activity by Coanda validated (with design recommendations) the scalability, in terms of mass and phase transfer, of the CVW™ distillation units.

The FEED technical design was completed between April and October 2018, with the Total Installed Cost (TIC) estimate developed from October to December 2018. Project optimization and subsequent conditioning of the cost estimate was executed in between December 2018 and February 2019. This details all key tie-ins such as produced diluted bitumen and cleaned tailings. Further, a reckoning of utility requirements and sourcing has indicated that Horizon supply is largely sufficient with the inclusion of a dedicated steam boiler and associated cooling/water treatment.

The CVW™ Horizon project will recover hydrocarbons, bitumen and diluent, from froth treatment tailings. The resultant CVW™-processed tailings have been demonstrated to exhibit enhanced settling and flocculation behaviours that lead to efficiencies in tailings management performance. An optimized thickener has been designed to transition CVW™ tailings into the Horizon tailings management planning, offering a potential solution for the Horizon froth treatment tailings.

Titanium's CVW™ technology has the potential to deliver significant GHG emissions avoidance and reductions upon implementation at Canadian Natural's Horizon oil sands facility. These CVW™ Horizon project emissions have been estimated and include CVW™ process emissions, tailings pond methanogenic emissions avoidance as well as upstream avoidances from Horizon bitumen production and mining. A stoichiometric model developed by Alberta Environment and Parks, has been adopted to assess methane and carbon dioxide emissions avoidance from ponds due to reduced naphtha deposition from froth treatment tailings afforded by CVW™ implementation. Horizon mine face degassing and bitumen production offsets allows for recovered bitumen contributions from CVW™ Horizon and have been estimated on a functional equivalency basis against Horizon design production rates. The resulting GHG emissions profile is presented below.

Benefits (t CO2e/yr)	2023	2024	2025	2026	2027	2028	2029	2030	2050
TP Methanogenesis	0	0	0	642,787	642,787	642,787	642,787	642,787	642,787
Bitumen Production FE	89,319	89,319	89,319	89,319	89,319	89,319	89,319	89,319	89,319
Mine Face Degassing FE	3,849	3,849	3,849	3,849	3,849	3,849	3,849	3,849	3,849
CVW Process	(177,569)	(173,584)	(169,558)	(168,925)	(165,974)	(165,131)	(164,498)	(163,665)	(151,743)
Total Benefit (t CO2e/y)	(84,401)	(80,416)	(76,390)	567,030	569,981	570,824	571,457	572,290	584,212
Cumulative Benefit (t)	(84,401)	(164,817)	(241,207)	325,823	895,804	1,466,628	2,038,085	2,610,375	17,826,083

Implementation of CVW™ at Horizon can result in a net reduction and avoidance of GHG emissions of 567,000 tonnes CO_2e annually in 2026, growing to 572,000 tonnes CO_2e per year by 2030 and 584,000 tonnes CO_2e per year by 2050 due to CVW™ process emissions efficiencies. By 2050, the cumulative benefit of the CVW™ Horizon project could reach 17.2 million tonnes CO_2e. Other air quality benefits, including volatile organic compound emissions reductions, may also be realized.

The FEED technical design was optimized to identify cost efficiencies. The optimization largely involved a revision of the Minerals Separation Plant to produce a non-magnetic concentrate rather than zircon and titanium products. Other notable optimizations included a cost-reducing change in Concentrator Plant cooling water equipment and the isolation of the thickener. An optimized integration design for implementation of CVW™ technology at the Horizon site. A conditioned and optimized AACE Class 3 capital cost estimate has been developed for the CVW™ Horizon project. The optimization also included removal of the thickener and select cost savings changes in the Concentrator Plant. This cost has been developed from budgetary costs of tagged equipment with vetted build-ups to estimate other direct and indirect costs. This cost estimate will serve as a base case for next steps in the project's development. The estimate has been reviewed by Canadian Natural estimators to ensure consistency with other Horizon construction projects. The cost estimate has been reviewed by independent 3rd Party estimation experts and the associated P_{50} contingency was developed by independent consultants.

Titanium Corporation, along with partners Canadian Natural and Emissions Reduction Alberta, have successfully completed the FEED project for implementation of CVW™ technology at Canadian Natural's Horizon mine. The next steps for the project include economic modeling, business model definition and agreement, AER application submission, financing and detailed engineering.

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Project Description

Titanium's "CVW™ Horizon" project is a first-of-kind sustainable technology designed to create value through high value resource recovery while remediating oil sands froth treatment tailings. The project will be jointly conducted and implemented with Titanium's industry partner, Canadian Natural Resources Ltd. CVW™ is a clean technology that remediates oil sands froth treatment tailings, recovering contained hydrocarbons (bitumen, diluent) and preventing their release into tailings ponds and the atmosphere. The release of these hydrocarbons into ponds causes methane formation, a major source of fugitive emissions in the oil sands industry. The recovery of diluent, an upgraded product from bitumen processing, from froth treatment tailings will avoid fugitive methane formation from tailings ponds and provide environmental benefits including enhanced tailings management. Additional benefits include valuable minerals recovery (zircon and titanium-bearing minerals) creating a new minerals industry and significant economic diversification beyond bitumen and export markets for Alberta. This phase of the CVW™ Horizon Project encompassed the front-end engineering design (FEED) for a full-scale commercial installation of Titanium's CVW™ technology at Canadian Natural's Horizon oil sands oil sands processing and mine site.

This $10.2M ($5 million of ERA funding) project is a Front-End Engineering Design (FEED) toward commercial implementation of Titanium's Creating Value from Waste™ (CVW™) sustainable technology at CNRL's Horizon oil sands site. Titanium and CNRL with support from various contractors will conduct the FEED for implementation of CVW™. The first commercial implementation of CVW™ at CNRL Horizon will pave the way for industry wide implementation. The process will reduce the volume of hydrocarbons rejected to tailings ponds and avoid related fugitive methane emissions to support targeted reduction of methane in Alberta and Canada. In parallel, the process will also create a froth treatment tailings (FFT) stream that is more amenable to existing tailings deposition technologies.

This FEED will benefit future engineering FEEDs and installations of CVW™ at other oil sands sites. The CVW™ process is standardized to retrofit at all brown-field sites and several of the integration points will be similar for all sites. Both factors will reduce the cost and increase the efficiency of the future CVW™ installations and accelerate the proliferation of this sustainable technology for the benefit of all stakeholders and the environment.

CVW™ technologies remediate oil sands froth treatment tailings, recovering lost hydrocarbons (bitumen and solvents) and preventing their release into tailings ponds and the atmosphere. Reducing the release of these hydrocarbons will avoid and diminish methane formation in tailings ponds, an issue reported in numerous science-based studies by researchers, government scientists and industry operators. Implementation of CVW™ will also avoid emissions of Volatile Organic Compounds (VOCs) and Secondary Organic Aerosols (SOAs).

In addition to the recovery of lost bitumen and solvents, CVW™ will recover valuable mineral products from oil sands tailings, creating a new minerals industry for Alberta. Recovery of these valuable commodities will create economic growth, jobs, royalties and taxes while delivering significant environmental benefits for Alberta and Canada. CVW™ has been extensively piloted for industry operators, Alberta and Federal oversight agencies. The technology is now ready for detailed engineering of a first commercial implementation at Canadian Natural's Horizon site and subsequent proliferation throughout the industry.

Introduction and Background

CVW™ fills a gap in the oil sands mining process by recovering valuable lost commodities from froth treatment tailings, reducing environmental impacts (particularly methane emission from tailings ponds) and improving the quality of tailings enabling more efficient tailings remediation. The following describes how CVW™ delivers these important benefits. In the oil sands mining extraction process, bitumen froth is cleaned using a hydrocarbon solvent (naphtha or condensate) which reduces its viscosity allowing for the release of contained water and solids. The rejected water, solids, bitumen and solvent comprise the froth treatment tailings that serve as feedstock to the CVW™ process. Residual amounts of bitumen and solvent are lost in froth treatment tailings. The lost solvent currently enters tailings ponds where methanogenic fermentation of the solvent results in fugitive methane emissions. These solvent losses are also a major source of VOC emissions at oil sands sites. The key to abating fugitive methane emissions from tailings is to prevent process solvent from froth treatment tailings from entering tailings ponds. Titanium's CVW™ technology efficiently recovers process solvent from froth treatment tailings, reducing losses to tailings ponds and resultant methane emissions by approximately 80%.

The CVW™ process utilizes a number of component technologies that have been developed by Titanium internally and at research institutions in Alberta and across North America. The current technologies were selected following an extensive R&D campaign that evaluated several options. During the R&D phase which commenced in 2004, Titanium adopted an open innovation technology development model, contracting with best available research organizations in addition to building a $7 million oil sands tailings and minerals pilot facility at the Saskatchewan Research Council campus in Regina. Technology development programs began with an emphasis on heavy minerals recovery from froth treatment tailings including on-site pilots at Syncrude's Mildred Lake mine in 2005 and 2006. Starting in 2007, technology development advanced to hydrocarbons extraction and environmental remediation at Company facilities and together with third party expert organizations including Alberta Innovates, CanmetENERGY, SGS (a global testing and verification firm), GTI (the Gas Technology Institute, a leading research/development organization), the Saskatchewan Research Council, a number of Canadian Universities and several other contributing organizations. From 2010 until 2014, the developed CVW™ technologies were brought together at CanmetENERGY facility in Devon, Alberta, and demonstration piloted on an integrated and continuous basis at significant *industry-platform* scale (1:20). The demonstration piloting programs received financial support from Alberta Energy and Sustainable Development Technology Canada (SDTC). An SDTC Consortium comprised of Canadian Natural, Syncrude and Suncor cooperated with the programs providing tailings and technical review. Titanium has invested over $80 million in the development of CVW™ including valuable funding of $3.5 million from Alberta Energy, $6.5 million from SDTC, $1.4 million in Alberta government SR&ED refundable tax credits and $0.4 million from the National Research Council IRAP program.

CVW™ demonstration piloting results have been verified by independent firms, oil sands operators and government agencies. Piloting results confirm hydrocarbon recoveries of over 80% (bitumen and naphtha), recovery of commercial quantities of valuable heavy minerals (titanium-bearing and zircon), improved tailings remediation and improved quality water[1]. In the Canadian Oil Sands Innovation Alliance (COSIA) 2012 Tailings Technology Roadmap[2], an initiative supported by Alberta Innovates – Energy and Environment Solutions (AI-EES), the Company's CVW™ process was identified as a 'prioritized' technology, ranking number 16 out of over 600 technologies reviewed. CVW™ was the only

[1] Moran, K. (2013). "Sustainable Remediation of Oil Sands Froth Treatment Tailings: SDTC Project 1449 Final Report", Titanium, 117 pp.
2 Sobkowicz, J. (2012). "Oil Sands Tailings Technology Deployment Roadmaps. Project Report – Volume 1", Thurber Engineering, 243 pp.

technology identified that provides value-added resource returns while achieving important environmental improvements. The Council of Canadian Academies, in a 2015 study for Natural Resources Canada, recognized the importance of dedicated remediation of oil sands froth treatment tailings, citing Titanium Corporation's CVW™ as the lone identified solution[3]. CVW™ potential for co-production of valuable heavy minerals in addition to significant environmental benefits was emphasized. Full lifecycle carbon accounting has been conducted by independent experts[4, 5, 6,] verifying the significant net GHG emissions reductions potential of commercial implementation of the technology. In 2016, Titanium's CVW™ technology won the Global Petroleum Environmental Show Environmental Innovation Award, was an award finalist at the World Heavy Oil Congress.

Technology Description

Titanium's 'Creating Value from Waste' (CVW™) is an innovative end-of-pipe technology designed to intercept oil sands froth treatment tailings (FTT) before discharge to tailings ponds and fully remediate the tailings, recovering valuable bitumen, solvents and minerals. The solvents and bitumen are a major source of methane emissions and other environmental impacts when deposited in tailings ponds. CVW™ performs a series of physical separation processes, described below, which utilize large scale proven technologies, uniquely modified and configured for processing froth treatment tailings. The CVW™ technology is comprised of a Concentrator Plant (Bitumen Recovery, Naphtha Recovery, HMC production, optional Tailings Management) and a Minerals Separation Plant.

Bitumen Recovery: The froth treatment tailings stream (the feed to the CVW™ process) is initially fed into cyclones which separate the tailings feed into coarse minerals (+50μ) and fines (-50μ) fractions. Bitumen is recovered from the fines fraction by flotation and solvent washing in a counter-current decantation circuit achieving approximately 85% recovery of bitumen that is currently lost in the froth treatment tailings stream and ponds. The cleaned tailings streams are then processed to recover lost solvent using steam distillation.

Naphtha Recovery: The naphtha recovery circuit is enhanced due to the removal of bitumen from the froth treatment tailings, altering the tailings liquid-vapour equilibrium to achieve superior performance of the distillation units and realize significant GHG emissions avoidances. The resulting distilled tailings have 'below detection limits' concentrations of residual naphtha. This important processing stage recovers valuable refined product that can be used to improve the quality of synthetic crude oils from bitumen upgrading processes. Further, the residual naphtha release from oil sands extraction would be reduced significantly, by approximately 80%.

HMC Production: A heavy mineral concentrate is produced from the cyclone coarse fraction using selective flotation. Bitumen is then removed from the mineral surfaces using multistage counter-current solvent washing. The tailings streams are processed to recover any lost solvent using distillation (see Naphtha Recovery). The recovered hydrocarbons contribute to the total amounts stated in the Bitumen

[3] Newell, E. and S. Vaughn (2015). "Technological Prospects for Reducing the Environmental Footprint of Canadian Oil Sands: The Expert Panel on the Potential for New and Emerging Technologies to Reduce the Environmental Impacts of Oil Sands Development", Council of Canadian Academies, 252 pp.

[4] Flint, L. (2011). "Oil Sands Mining Emissions Reduction Potential in Conjunction with Minerals Recovery", Lenef Consulting, 28 pp.

[5] Conestoga-Rovers & Associates (2011). "Updated SMART Report: Prepared for Sustainable Development Technology Canada", 38 pp.

[6] Keesom, B., D. O'Brien and J. Blieszner (2013). "Impact of the CVW Process on WTW GHG Emissions and VOCs from Mined Bitumen", Jacobs Consultancy, 30 pp.

Recovery circuit. The produced heavy minerals concentrate is then transported to a Minerals Separation Facility.

Tailings Management: This treatment operation may be integrated with the operator's existing tailings management facilities or separate FT tailings facilities. Tailings management after CVW™ processing of FT tailings is highly efficient due to the low residual hydrocarbon values[7] leading to accelerated dewatering in thickening processes. The thickened tailings slurry may be then highly amenable to depositional processes.

Minerals Separation: The heavy minerals concentrate is processed through conventional minerals electrostatic and magnetic separation technologies, uniquely configured in CVW™ to produce valuable mineral products. The production of these minerals represents a diversified export market for Alberta and creating additional value in new oil sands products.

Figure 1 illustrates the integration of Titanium's CVW™ technology, comprised of the Concentrator Plant (Area 6) and the Minerals Separation Plant (Area 7) with oil sands mining extraction operations:

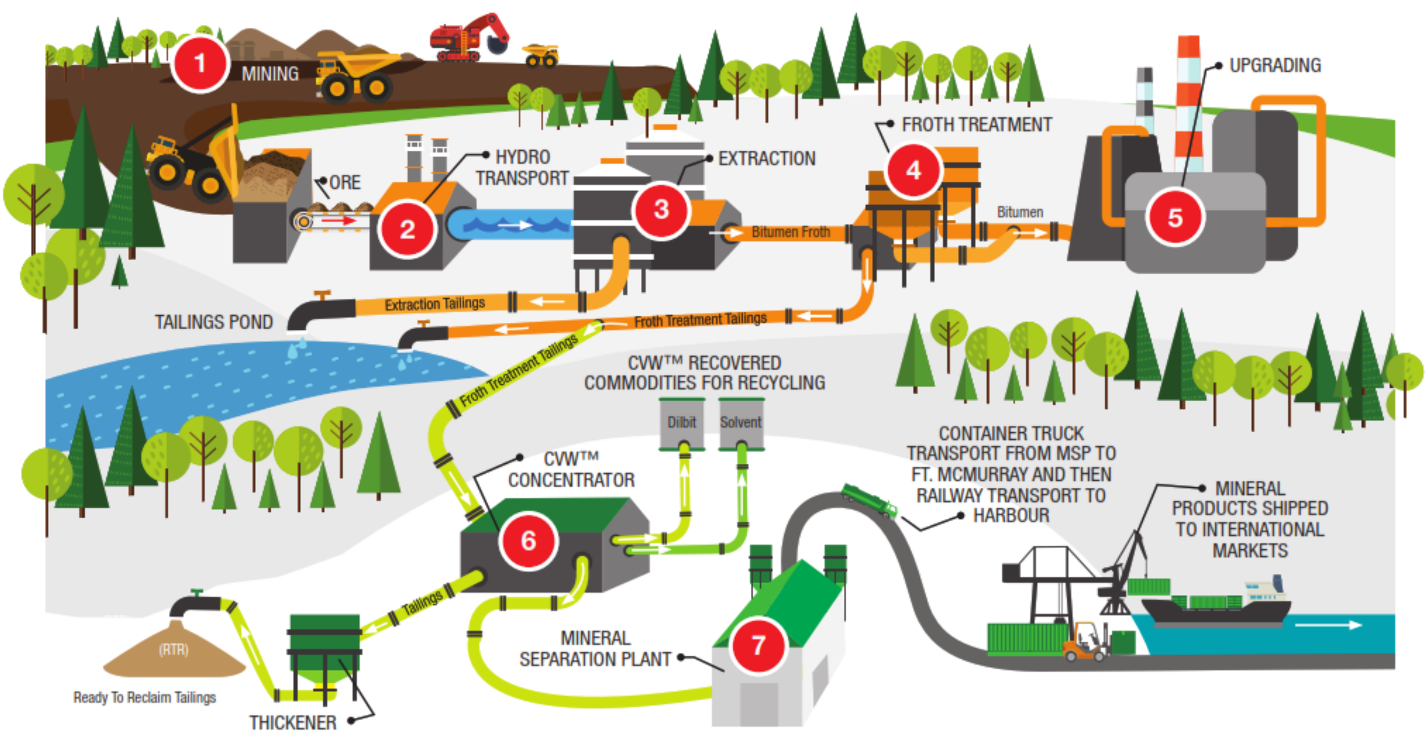

Figure 1. Titanium's CVW^{TM} technology and integration at an oil sands site.

[7] Mikula, R., K. Dickson and J. Elias (2010). "Dewatering Treatment Options for Titanium Corporation Naphtha Froth Treatment Tailings", Division Report 2010-092-CF, CanmetENERGY, 34 pp.;

Project Goals

Titanium's CVW™ technology has undergone extensive, sequential research and development and demonstration piloting validation. The remaining technological matters to be finalized are related to the commercial implementation of the technology, including both GHG emissions reductions benefits confirmations and important site-specific integration engineering. The remaining business areas involve project de-risking and value engineering to move the project to commercialization. The FEED of the proposed ERA project for a first commercial implementation of the technology is designed to de-risk the project and address remaining incremental technology opportunities; these include optimizing water and tailings integration opportunities and confirming associated additional methane and GHG emissions reduction benefits while optimizing energy integration of tie-ins as outlined in the previous section. The project goals are summarized as follows:

(a) Generate a capital cost estimate for implementation of CVW™ technology at Canadian Natural's Horizon oil sands mine (CVW™ Horizon) project in a front-end engineering design (FEED) project. FEED is a necessary step towards commercializing engineered projects and sanctioning for commercial development. Key activities of the FEED will identify potential cost reduction and operational efficiency opportunities while advancing the technology to a sanctioning decision, including refinement of the capital costs to an AACE Class 3 confidence level and completion of extensive process, operational and project risk reviews. Select activities will be executed in advance of the FEED to provide project (site location, utilities identification, engineering contract awards) and process definitions.

(b) Assess the net impact of the CVW Horizon project on GHG emissions. Recovering naphtha (solvent) from froth treatment tailings will result in the avoidance of subsequent fugitive methane releases from tailings ponds. Titanium Corporation has been working with independent expert consultants to evaluate the impact of reducing the amount of process diluents (solvents) discharged to tailings impoundments and the resulting methane emissions reductions. Titanium's CVW™ technology will deliver tailings ponds methane emissions avoidances related to naphtha recovery from process tailings of ~80%[6, 8]. Further GHG emission reductions will be sought through the integration of hot water recovered from the cleaned CVW™ tailings as well as other efficiencies and value improvement practices identified in the engineering design of the integrated CVW™ Horizon facility.

Work Scope Overview

The Front-end Engineering Design (FEED) includes some aspects of earlier project life cycle phases and is developed into five milestones, including early stage FEED activities (or Pre-FEED) of Concept Finalization and Design Basis criteria establishment and additional FEED phases. The FEED plan includes Contractor Project Management, Project Controls, Procurement Services and Engineering (early studies, process, civil, buildings, mechanical, piping, instrumentation and controls, electrical, process quality assurance and safety). The following describes typical engineering work-flow activities and deliverables to be produced during the program:

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8 Flint, L. (2013). "The Environmental Impact of Applying Titanium Corporation's CVW Technology to Froth Treatment Tailings from Oil Sands Mining-Based Bitumen Recovery", Lenef Consulting, 39 pp.

Milestone 1 - Planning & Pre-FEED: FEED engineering contractors were only engaged after Q1 2018. Prior to their engagement, Titanium Corporation and Canadian Natural will jointly conduct pre-FEED studies that include facility location, tie-in point reviews and selections and inter-facility materials handling aspects. Options for both the hot water heat integration and tailings management integration and optimization will be explored. The nature of the hot water integration, whether direct or indirect and post-heat transfer uses for the water will be considered. The project team will consider options to process clean tailings generated by CVW™ technologies in existing or planned fluid tailings management processes. Based on the outcome these studies and selections, detailed scopes of work will be compiled for the concentrator and the mineral separation plant FEED engineering contractors, to be used in the request for proposals (RFPs) to the engineering contractors. Locally based engineering contractors will be selected based on cost, quality of personnel, previous project history and understanding of the scopes of work. Milestone 1 is therefore defined as the end of these pre-FEED activities.

Milestone 2 - FEED Milestone 1: Engineering will deliver final discipline specific design criteria's and process flow diagrams (PFD) as well as heat and material balances necessary to develop a more refined plant definition. Further plot plan optimizations to be made and issued for review. Product and marketing studies will be initiated.

Milestone 3 - FEED Milestone 2: Engineering contractors will deliver full mechanical equipment lists (datasheets and specifications) and will also have identified major long lead equipment. Piping and Instrumentation diagrams (P&IDs) will have been issued and the relevant control system architecture for each facility will be issued for review.

Milestone 4 - FEED Milestone 3: Relevant HAZOP and HAZID studies will have been completed by the contractors, based on the issued P&IDs. Electrical single line drawings (SLDs) will have been issued, together with electrical and instrumentation equipment. Final material selections will also have been incorporated into designs. All piping routings will have been finalized, preliminary stress calculations completed and plant layout drawings issued for review and coincided with 3D model and constructability reviews.

Milestone 5 - FEED Milestone 4: The final outcomes report will be issued to ERA, together with a summary on GHG emissions avoidance projections. The relevant FEED engineering reports will also have been issued as final, together with Class III capital and operating cost estimates, based on engineering material take-offs produced from the 3D Model and other engineering drawings and lists.

The key project milestone dates are shown below (**Table 1**):

Table 1. ERA Project O160140 Work Scope, Schedule and Key Deliverables.

Milestone #	Task	Start Date	End Date	Key deliverables
1	Pre-FEED	June 3/2017	Mar 30/2018	Horizon Utility Tie Points and Facility Location Studies completed, FEED Scopes of Work completed, RFPs issued, Contractor Selection completed, Contract Formation and award.
2	FEED Milestone 1	Mar 30/2018	June 30/2018	Design Criteria's formulated, Heat and Material Balances completed, Process Flow Diagrams (PFDs) issued. Initial Plot Plans issued for review.
3	FEED Milestone 2	June 30/2018	Sep 30/2018	P&IDs issued for review, Mechanical Equipment lists issued, Control system architecture issued for review
4	FEED Milestone 3	Sep 30/2018	Nov30/2018	Electrical and Instrumentation Equipment Lists issued, Single Line Diagrams issued, Routings finalized, HAZOPs completed, final Material Selection completed.
5	FEED Milestone 4	Nov 30/2018	Feb28/2019	Final Control Designs, Material Take-offs, 3D model completion, Class 3 Estimates developed, and Final Outcomes Report issued.

Outcomes and Learnings

Titanium's CVW™ Horizon FEED project (ERA O160140) has been completed on time and on budget. Further all project milestones were also achieved as planned. The Front-end Engineering Design (FEED) includes some aspects of earlier project life cycle phases, including early stage FEED activities (or Pre-FEED). The project outcomes are described through pre-FEED activities (**Table 1**). Specific focus and attention are given to the capital cost estimate and greenhouse gas study. The project financial outcomes are also summarized.

Pre-FEED Activities

Milestone 1 deliverables are all considered completed. The key deliverables advanced during the reporting period for Milestone 1 (Planning and Pre-FEED) and Milestone 2 (FEED Milestone 1) include the facility location studies, Horizon utility tie points identification and FEED contractor selection. In addition to these planned activities, two studies were commissioned to provide process definition for the project. The first study was to examine the settling behavior of tailings processed through the CVW™ process. The second study was to model the performance of the CVW™ naphtha recovery units with a view towards scalability.

Location

A preferred location for the CVW™ facilities, comprised of the Concentrator Plant (Hydrocarbons recovery, Heavy Minerals Concentrate (HMC) production and tailings processing) and the Minerals Separation Plant (for production of mineral sands), has been identified. This location is immediately south/southeast of the Horizon froth treatment plant and was chosen due to its proximity to both the froth treatment plant and the process and utility tie-in locations (**Figure 2**). The site location is bounded on the south by the Horizon mine setback. A minimum spacing between the facilities is provided to account for hydrocarbon zone classifications.

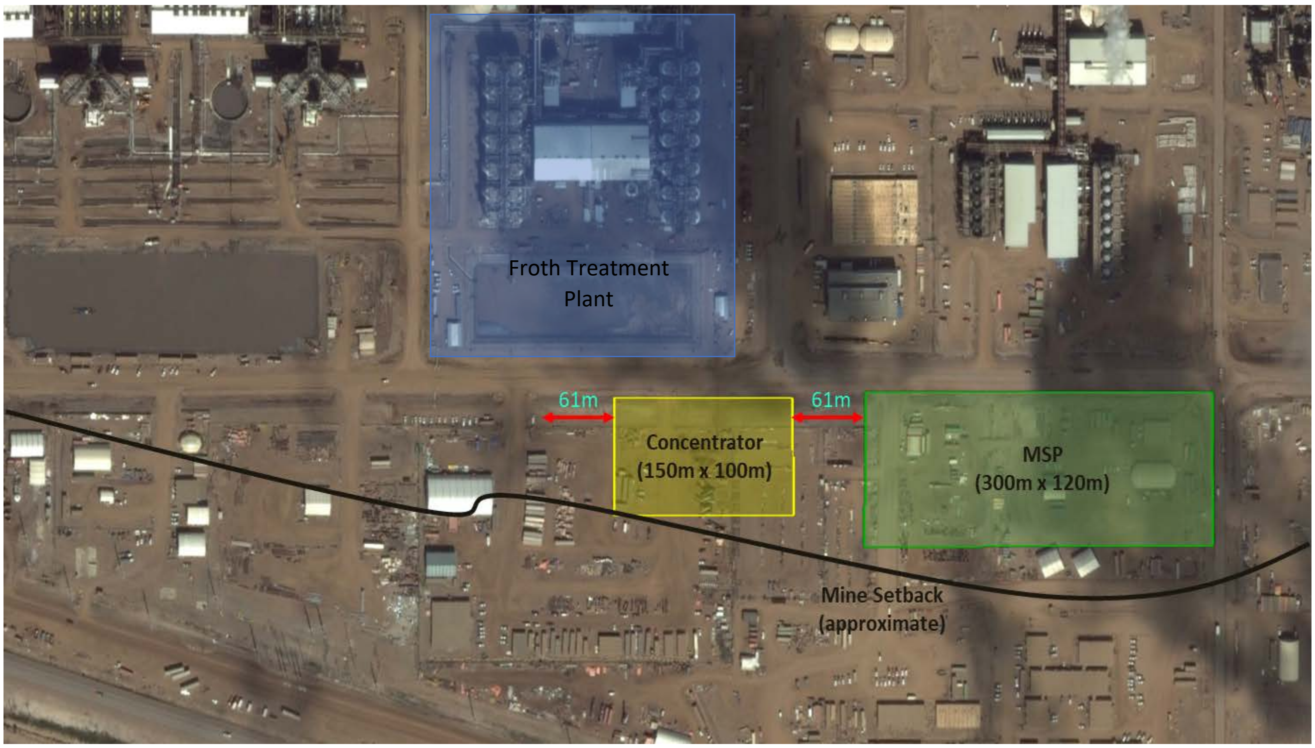


Figure 2: CVW Facility locations within Canadian Natural's Horizon site. Plant locations and footprints are approximate. Note that the thickener facility is to be located west of the Concentrator.

The project team, comprised of Canadian Natural and Titanium management and technical specialists conducted a survey of the type and amount of various utilities required to support a CVW™ installation at Horizon as well as the practical locations at which these may be sourced. Almost all identified utilities can be sourced from existing Horizon infrastructure. The two key exceptions include low pressure steam and cooling capacity. Following FEED, the Horizon CVW™ project now contemplates a once through stream generator to provide ~150 tonnes per hour of low pressure steam and a water cooling system sized for ~2000 m^3 of cooling water to handle demand from both the Concentrator Plant and Minerals Separation Plant. Further, it has been determined that hot water recovered from CVW™ tailings following a thickening operation cannot be integrated into the Horizon process utility systems.

Studies

The project team identified two studies for kick-off during the pre-FEED phase of the project. The first was to determine performance metrics for the thickening of CVW™ tailings and provide sizing data for the thickener; this work was conducted by SNF. The second study was to address the scalability of the CVW™ Tailings Distillation Unit with respect to liquid pool mixing and phase transfer. This study involved computational fluid dynamic modelling executed by Coanda Research and Development Corporation (Coanda).

Engineering Contractor Selection

Two Scopes of Work documents were prepared as part of a Request for Proposal process to select the local engineering contractors required for the Concentrator Plant and the Minerals Separation Plant. These scope documents specified that the Engineering Contractor shall be responsible for the execution, quality and accuracy of all front-end engineering design (FEED) Work, for the CP and MSP, as necessary to support Class III capital and operating estimates, and produce engineering deliverables that can support the start of detailed engineering, including Work performed by any required Subcontractors, eg. HAZOP facilitation. The successful engineering contractors were to develop an engineering execution plan and engineering execution schedule, procurement and contracting strategy and plan, construction execution plan including a modularization plan, a level III construction schedule, and a preliminary commissioning plan with definition of systems and completion sequencing. Further, the engineering contractors were responsible for any studies, Titanium approved third party reviews or any Titanium approved specialized consulting contracts required to complete the FEED. These include the GHG emissions estimates that are contemplated under this project. Note that the process engineering for the Minerals Separation plant was sole-sourced to IHC Robbins out of Brisbane, Australia due to their extensive expertise in development of heavy minerals processing facilities, process development work on Alberta tailings resources and their knowledge of the Titanium Corporation projects.

Request for Proposals were issued to pre-qualified local engineering firms with invitations to submit packages for either the Concentrator Plant, Minerals Separation Plant and/or a combined effort comprising both plants. The pre-qualified engineering firms were identified based on oil sands experience and included SNC-Lavalin, Wood (formerly AMEC), Stantec and Worley Parsons. All these firms have a significant presence in Calgary. The successful engineering firm was to work closely with IHC Robbins, who executed the minerals process engineering for the Minerals Separation Plant. Proposals were received from all invited participants; these proposals were reviewed by the project team based on both cost and quality of the proposal. Stantec's 'combined' proposal (both Concentrator and Mineral Separation Plants) was selected as optimal and the project team formally awarded the FEED engineering scope to Stantec in early April 2018. The Stantec project team includes senior and experienced engineers with good oil sands experience.

FEED Activities

Titanium Corporation's Creating Value from Waste (CVW™) process is being evaluated for implementation for the first time at a commercial scale at Canadian Natural's Horizon site north of Fort McKay in Northern Alberta. This process will recover residual bitumen and diluent and will also extract valuable minerals from Horizon's Froth Treatment tailings stream. The Front End Engineering Design (FEED) phase was co-financed by Titanium Corporation, Canadian Natural and Emissions Reduction Alberta. The engineering was completed by an integrated team at Stantec, which developed the designs for both the Concentrator Plant (CP) and the Mineral Separation Plant (MSP) – with the main Process and Mechanical design of the MSP plant developed by IHC Robbins of Brisbane in Australia.

The FEED project was completed from April to December 2018. The technical design was completed between April and October 2018, with the Total Installed Cost (TIC) estimate developed from October to December 2018. Optimization exercises were conducted in January and February 2019. The project's FEED report[9] details the various deliverables (drawings and documents) developed for the FEED design – by plant and discipline – and also details what items have not been addressed, or where additional work is required during Detailed Engineering.

Engineering Design

The CVW Horizon project encompassed the Concentrator Plant (CP) and the Mineral Separation Plant (MSP), with tie-ins to Canadian Natural's Horizon plants. It represents the first application of Titanium's Creating Value from Waste (CVW™) technology to treat the Froth Treatment Tailings stream generated at Canadian Natural's Horizon site to extract residual hydrocarbon as well as a premium grade zircon sand (minimum 66.0% ZrO_2) and a high-grade titanium oxide bearing sand (Hi-Ti) product, containing at least 88% TiO_2.

The CVW Horizon FEED project encompasses the Concentrator Plant (CP), the Mineral Separation Plant (MSP) and tie-ins to Canadian Natural's Horizon site (**Figure 3**). Canadian Natural assigned plant number 25 to the CVW Horizon project. Plant 25 encompasses the common site wide scope of work, 25A is for Concentrator Plant (CP), 25B is for Mineral Separation Plant (MSP). Two additional codes were created for thickener system: 25C for the thickener and related equipment, 25D for the thickener underflow corridor and booster pumps.

The CP scope covers:

- Plant 25: The high-voltage system and transformers, tie-in to existing power lines, Emergency Dump Pond (EDP), interplant corridor as well as the external tie-in corridor up to 100 Ave, site preparation and grading, fire water ring main, site wide communications and control….
- Plant 25A: The CP building including the primary processing circuits, utility buildings flare
- Plant 25C: The thickener was separated into a dedicated plant area
- Plant 25D: the thickener underflow system. The tailings pipeline together with the booster pumps and pumphouse is excluded from the FEED scope and was included in a separate DBM.
- Plant 26: The tie-ins and the corridor to Plant 26
- Plant 79: The tie-in to the firewater header north of the CVW Horizon plot space.

The MSP (Plant 25B) consists of a large number of process steps, including spirals, magnetic separators, electrostatic separators, belt filters, driers, etc. The process separates out the valuable minerals from the coarse stream received from CP to produce a premium grade zircon sand (minimum 66.0% ZrO_2) and a high-grade titanium oxide bearing sand (Hi-Ti) product, containing at least 88% TiO_2. All rejects from the MSP are returned to the CP thickener/existing tailings lines. The MSP (Plant 25B) scope covers the MSP building, the Main Office & Control Room, the laboratory, the stockpile building and the structures south of the MSP building.

[9] Vashist, Y. (2018). "CVW Horizon FEED Report", Document No. 25-RPT-GE-0001-00, Rev B, Project No. 110903262, Stantec, 141 pp.

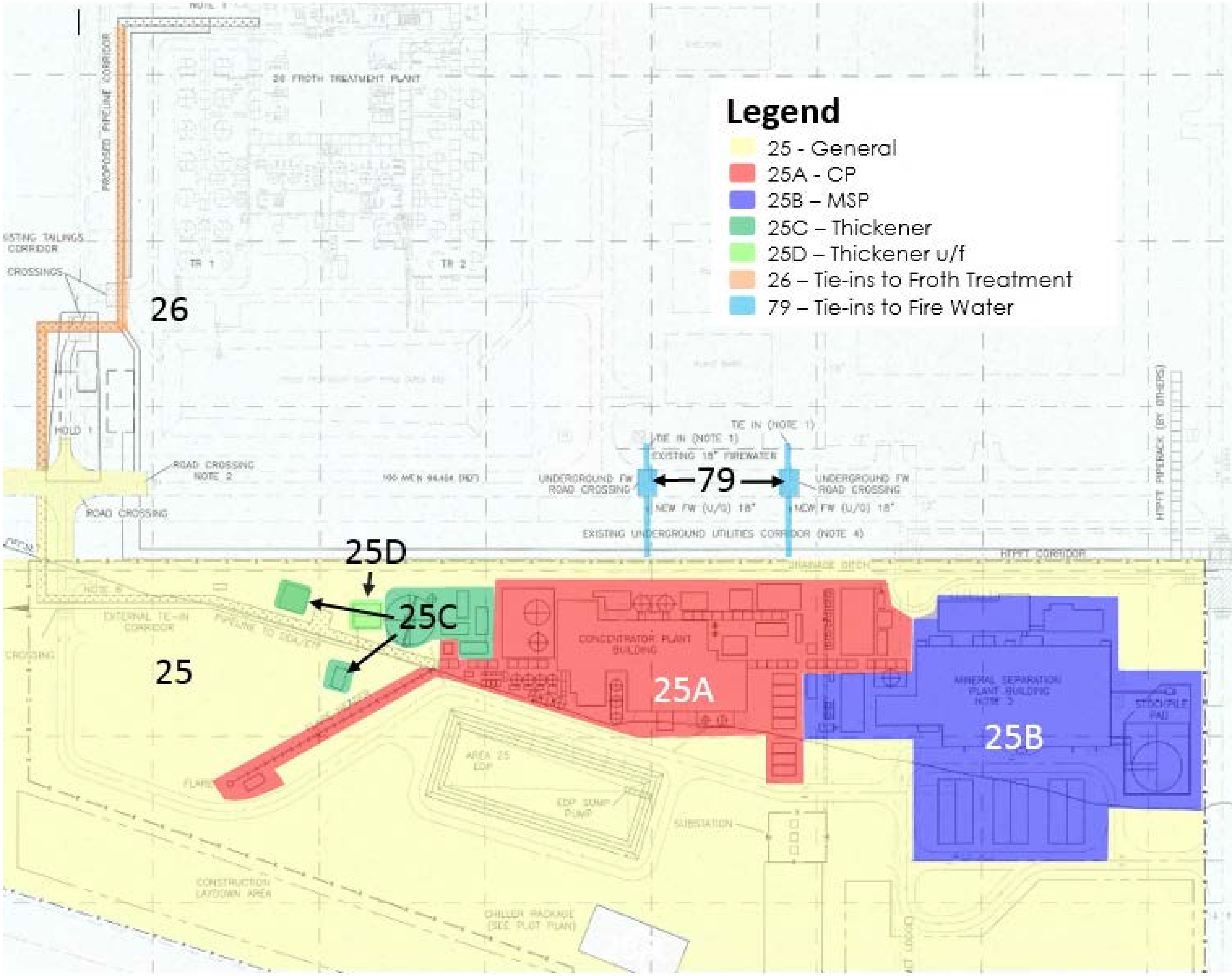


Figure 3. Major Plant Areas for the CVW Horizon Plant.

The project risks were managed via a Project Risk Register. An initial brainstorming session was held with all discipline leads early in the project to identify possible opportunities and risks associated with the CVW Horizon project. Subsequently, the identified risks were added to the Risk Register and a mitigation strategy was developed for each risk. Monthly meetings were held to review the register and the mitigation strategies to ensure that the risks were managed where possible. Project Decisions were managed via a Decision Log. Where initial decisions had to be changed, new decisions were recorded to replace the outdated decisions. The log indicates which decisions were superseded, by showing the initial decision with struck through text together with a reference to the new decision. All engineering deliverables, including discipline specific reports (process, mechanical, electrical, technical safety…) and the 3D model reside as appendices to the FEED report[9]. Note that most ERA O106140 Project Key Design Criteria were met (**Table 2)**.

Table 2. ERA 0160140 Project Key Design Criteria, adapted from ERA FO160140 Contribution Agreement.

Project Design Criteria	Target	FEED
Bitumen recovery	85%	86%
Solvent recovery	78%	80%
Heavy minerals rec.	70%	83%
Solvent loading	5%	5%
Steam loading	2%	4%
Water recovery	80%	-
Concentrator Reliability	92%	98%

The bitumen recovery was confirmed in the Concentrator Plant heat and material balance. Note the solvent recovery has been recast on a froth treatment tailings basis and reflects the naphtha volumes that are prevented from deposition into tailings ponds due to CVW™ processing. The minerals recovery value was increased in the optimized concentrates flowsheet described below (see Capital Cost section). Steam loading remained at pre-project rates due to additional heating requirements and thermodynamic limitations. Water recovery was deemed not feasible for CVW™ Horizon. The Concentrator Plant reliability was matched to the Horizon froth treatment plant (~98%) as a result of the FEED Class of Plant Study.

Concentrator Plant

The Concentrator Plant (CP) basis of design is 2,500 tonnes/h of tailings slurry feed from the Naphtha Recovery Unit (NRU) in Plant 26. Given that a purpose of this stage of engineering was the development of the Class 3 cost estimate, the decision was taken to focus on one design case which is outlined in the design basis criteria (DBC). This design case was chosen to be the case with the highest bitumen content and a normal expected heavy mineral content and a higher fines grading split (SFR = 1.0). SFR studies were completed to determine the capability of the process to handle changes in the feed from the NRU. The design basis criteria (DBC) is actively linked to the H&MB calculations, which populate the H&MB summary. The Concentrator Plant (CP) is comprised of the following circuits (**Figure 4**):

- Primary Cyclone
- Fines (Bitumen Recovery)
- Coarse (HMC Production)
- Area 10 Cyclones
- Thickener
- Combined Tailings
- Process water, Gland Water and Flushing

Three dimensional model snapshots of the Concentrator Plant are shown in **Figure 5** and **Figure 6**. The cut for the NRU (froth treatment) tailings primary cyclone was set at 35 µm and the coarse d50 was set at 100 µm. Diluent recovery in the TDUs is currently a set value based on the specific operating conditions derived from experimentally determined vapour-liquid equilibria and Titanium's pilot plant data. To link the operating conditions in the TDUs to recovery requires multiple variables to be considered and several different data plots to be referenced. This calculation is not currently included in the FEED H&MB.

The plant has been designed fit-for-purpose based on the agreed-to design case in the DBC. There has been a 15% design factor added into the fines circuit based on the hydraulic losses of water; the fines streams are so dilute that using the SRC Bingham model does not add any additional accuracy. It is assumed for the coarse tailings in the SRC model that each pipe could experience 50% of the design flow and this has been accounted for in the velocity calculations and sizing of each line. The pressure drop was used to calculate pump TDH with preliminary layouts to calculate equivalent lengths of both suction and discharge piping. This will need to be updated and verified in detailed design.

The fines circuit of this process is water driven and changes in solids content have minimal effect - less than 3% based on the SFR (solids to fines ratio) study. The coarse circuit has a little more change (upwards of 7%) however based on the pumps selected there is adequate pumping capacity to handle these variations.

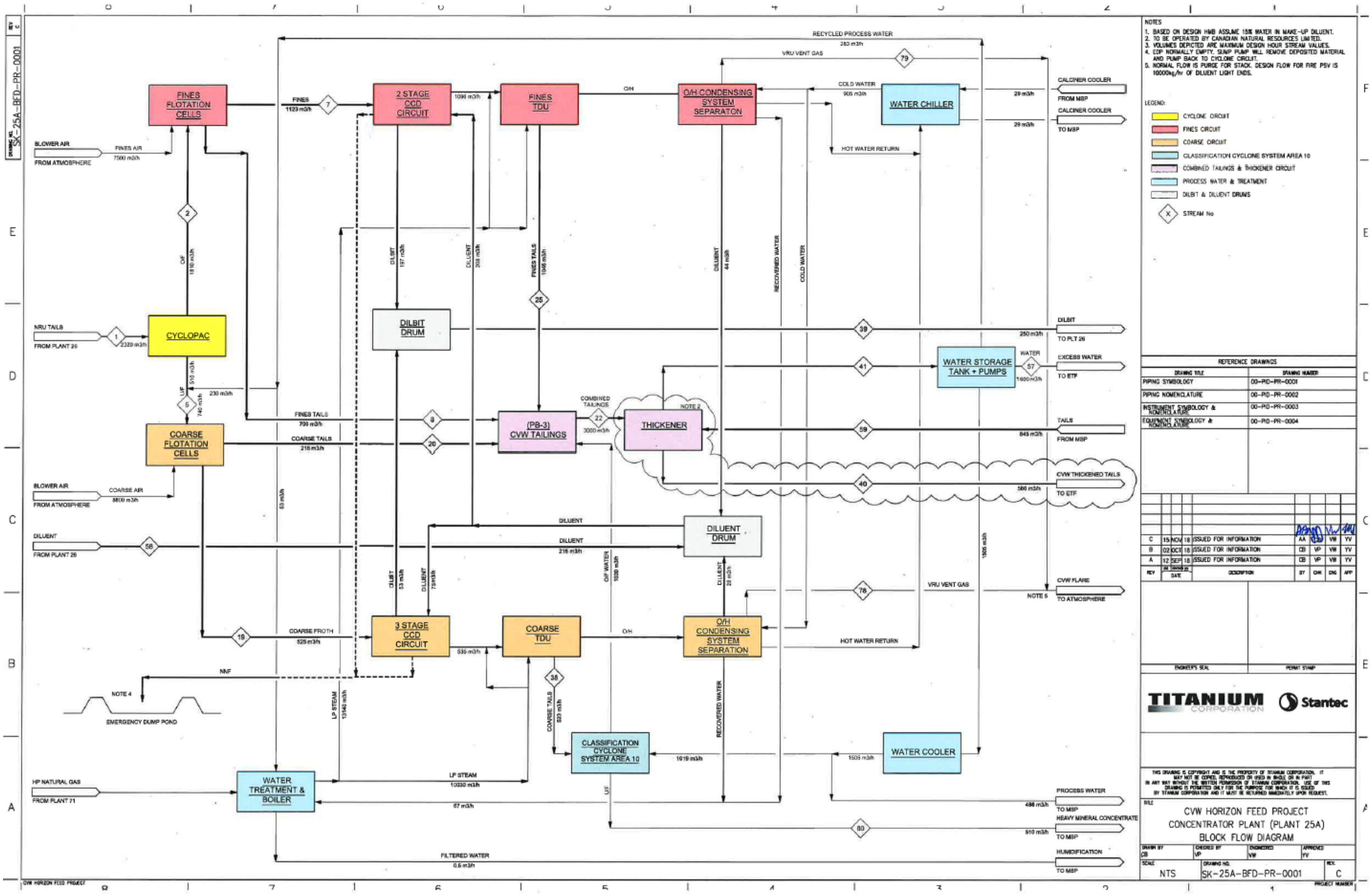


Figure 4. Block flow diagram of the CVW[TM] Horizon Concentrator Plant (CP).

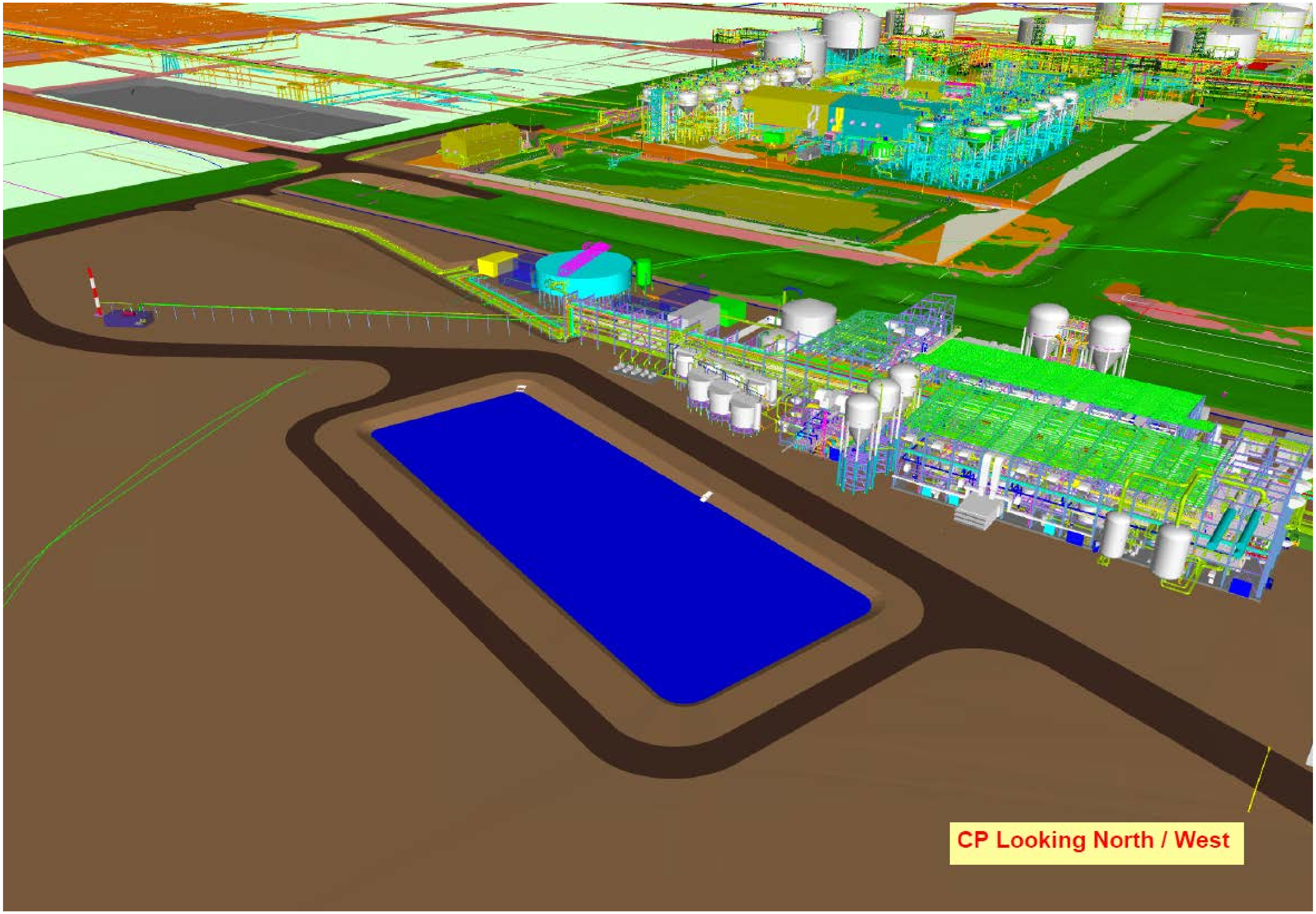


Figure 5. 3D model snapshot of the Concentrator Plant; view from south-east.

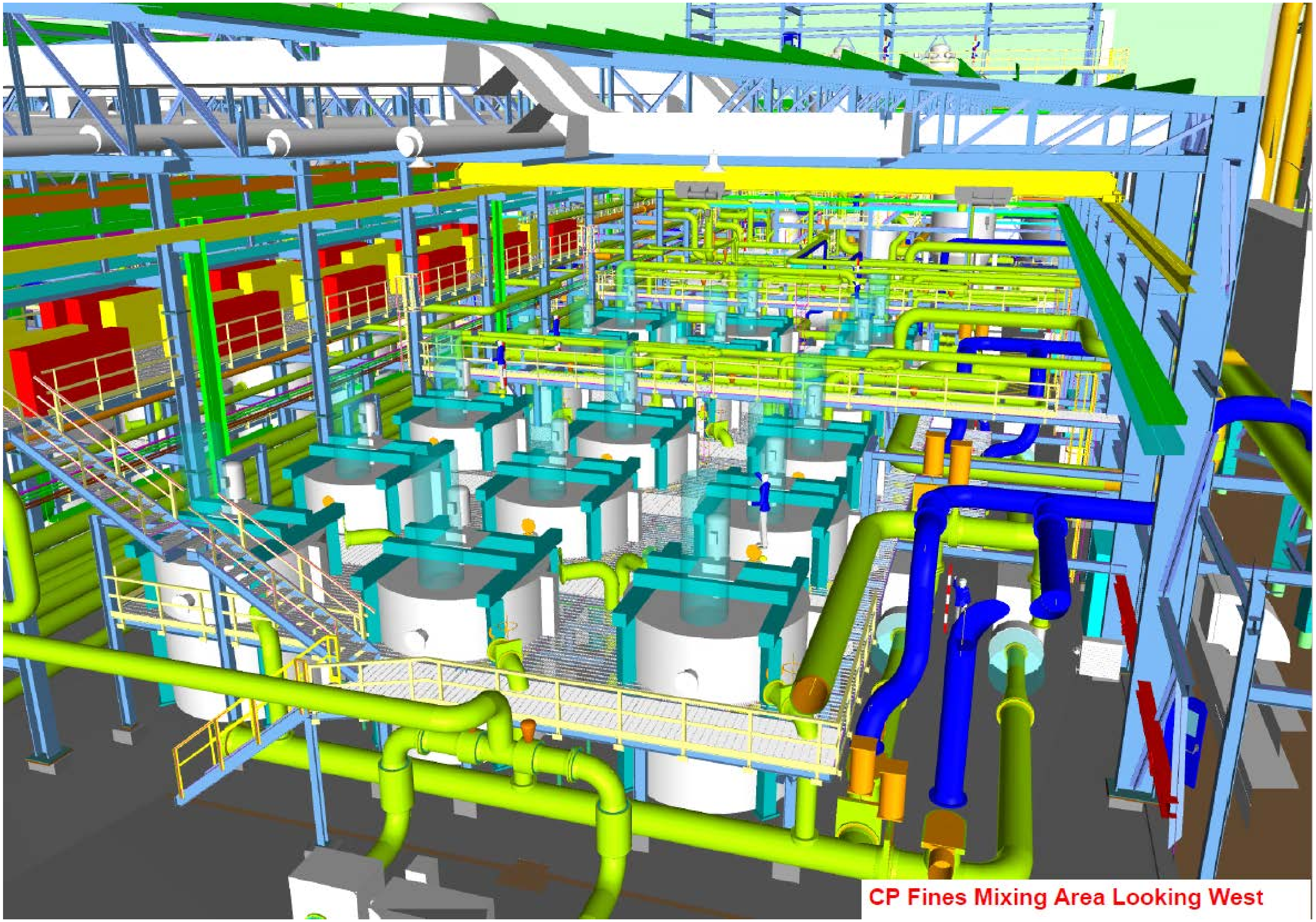


Figure 6. 3D model snapshot of the Concentrator Plant's Fines CCD mixing hall; view from east.

Minerals Separation Plant

The MSP consists of a large number of process steps, including spirals, magnetic separators, electrostatic separators, belt filters, driers, etc. The process separates out the valuable minerals from the coarse stream received from CP to produce a premium grade zircon sand (minimum 66.0% ZrO_2) and a high-grade titanium oxide bearing sand (Hi-Ti) product, containing at least 88% TiO_2. All rejects from MSP are returned to the CP thickener.

IHC Robbins based the design of the MSP on an instantaneous flowrate of 190 t/h of solids from CP. The maximum design rate of 205 dry t/h corresponds to a maximum rate of 2,500 tph of slurry received from Horizon Froth Treatment Plant 26 Trains 1 & 2 combined. This rate is encountered for 2-3 weeks during ramp-up following a major Canadian Natural plant shutdown.

The MSP Feed Preparation area (Area 10) was relocated to the Concentrator Plant (CP) during FEED. The 25B tags were maintained for FEED and the costs were based on the equipment sizes and costs provided by IHC Robbins. The costs associated with this area were included in the CP section of the estimate. As such, the actual feed to MSP will now be the Cyclone underflow stream rather than the Cyclone Feed stream that IHC Robbins had considered. According to the CP H&MB, at a CP feed rate of 2,500 t/h of total slurry, the MSP Feed Preparation Cyclone feed rate will be 1,287 t/h of total flow and 194 t/h of solids. 184 t/h of solids report to the Cyclone underflow and report to the MSP. The major plant equipment contained within the Process Plant is summarised as follows (**Figure 7**):

- Area 15: Gravity Upgrade Circuit (GUC);
- Area 20: Magnetic Separation Circuit (MSC);
- Area 25: Non-Mag Gravity Circuit (NGC);
- Area 30: Primary Dry Circuit (PDC);
- Area 35: Wet Zircon Circuit (WZC);
- Area 45: Dry Zircon Circuit (DZC);
- Area 50: Hi-Ti- Flotation Circuit (HFC);
- Area 55: Hi-Ti Dry Circuit (HDC);
- Area 51: Flotation reagents
- Area 60: Zircon Calcining Circuit (ZCC);
- Area 85: MSP process water system including: All bins, tanks, pumps, piping, etc. for the local distribution of process water (process water supply to the building from the CP).

Snapshots of the Minerals Separation Plant from the 3D model are shown in **Figure 8** and **Figure 9**.

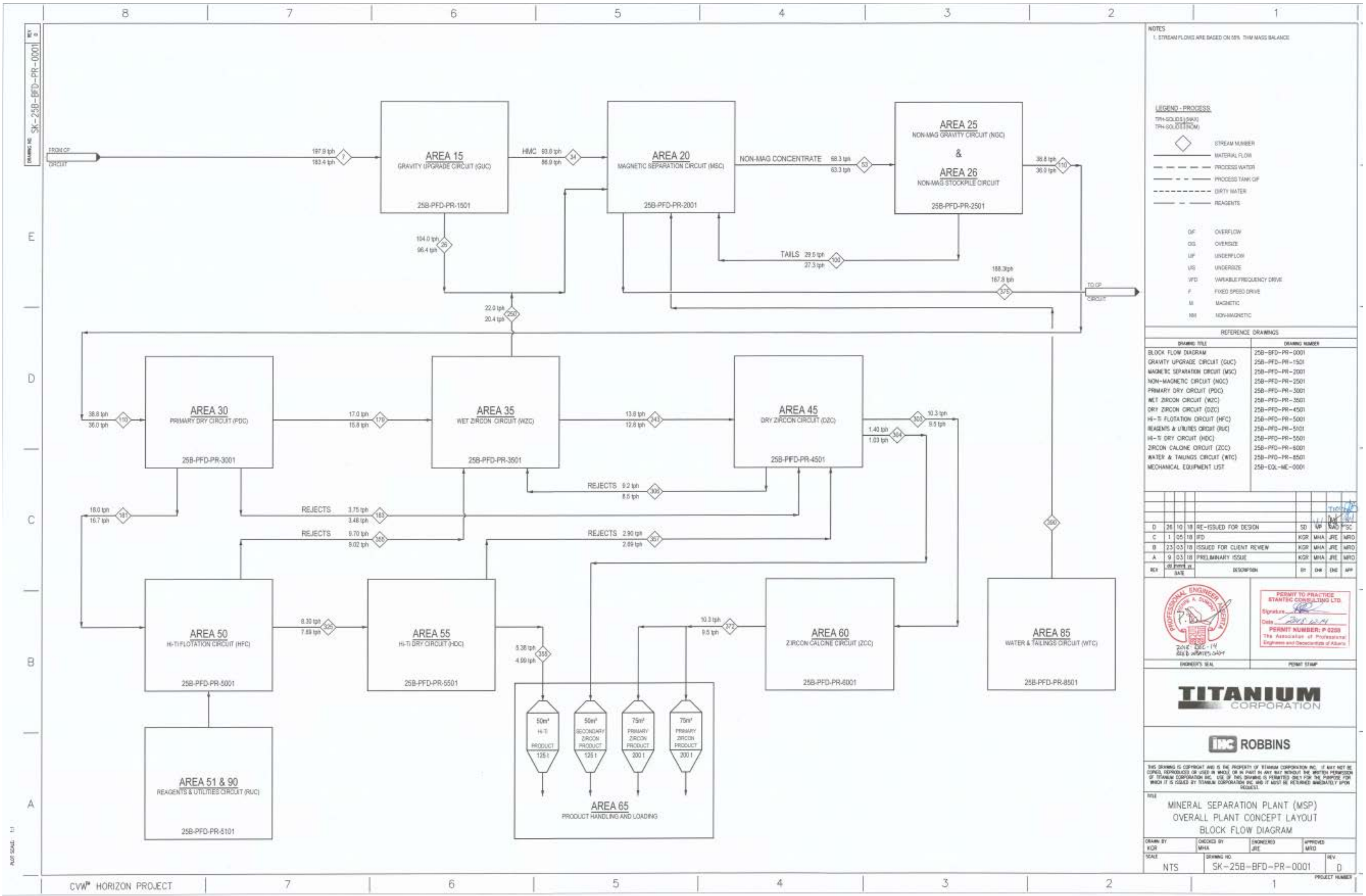


Figure 7. Block flow diagram of the CVW™ Horizon Minerals Separation Plant (25B).

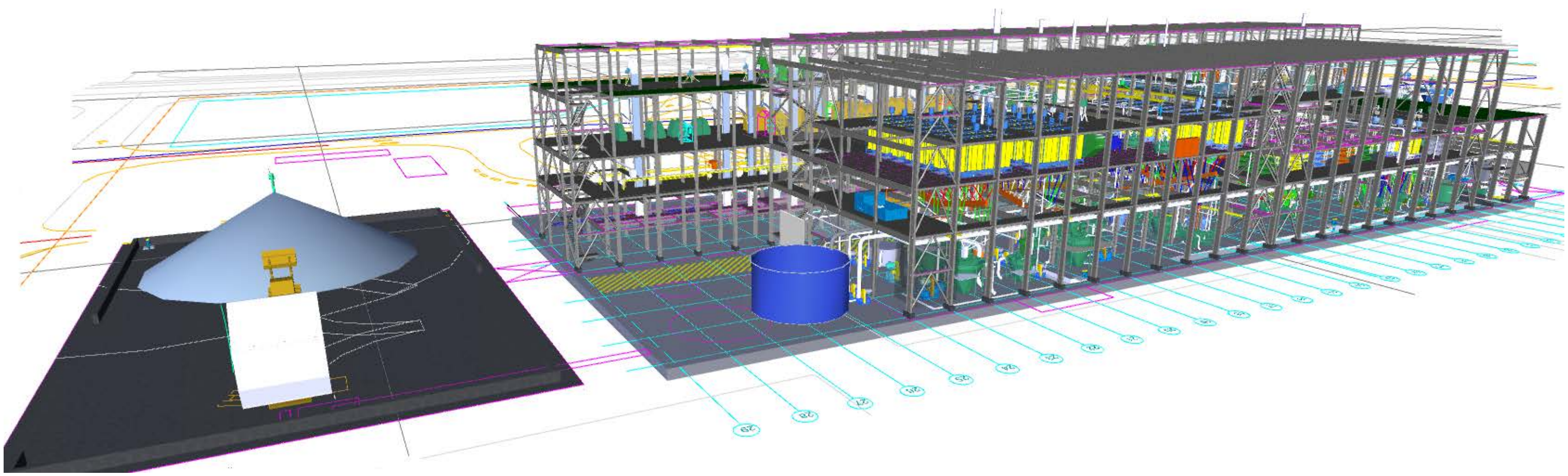


Figure 8. 3D model snapshot of the CVW^{TM} Horizon Minerals Separation Plant (25B).

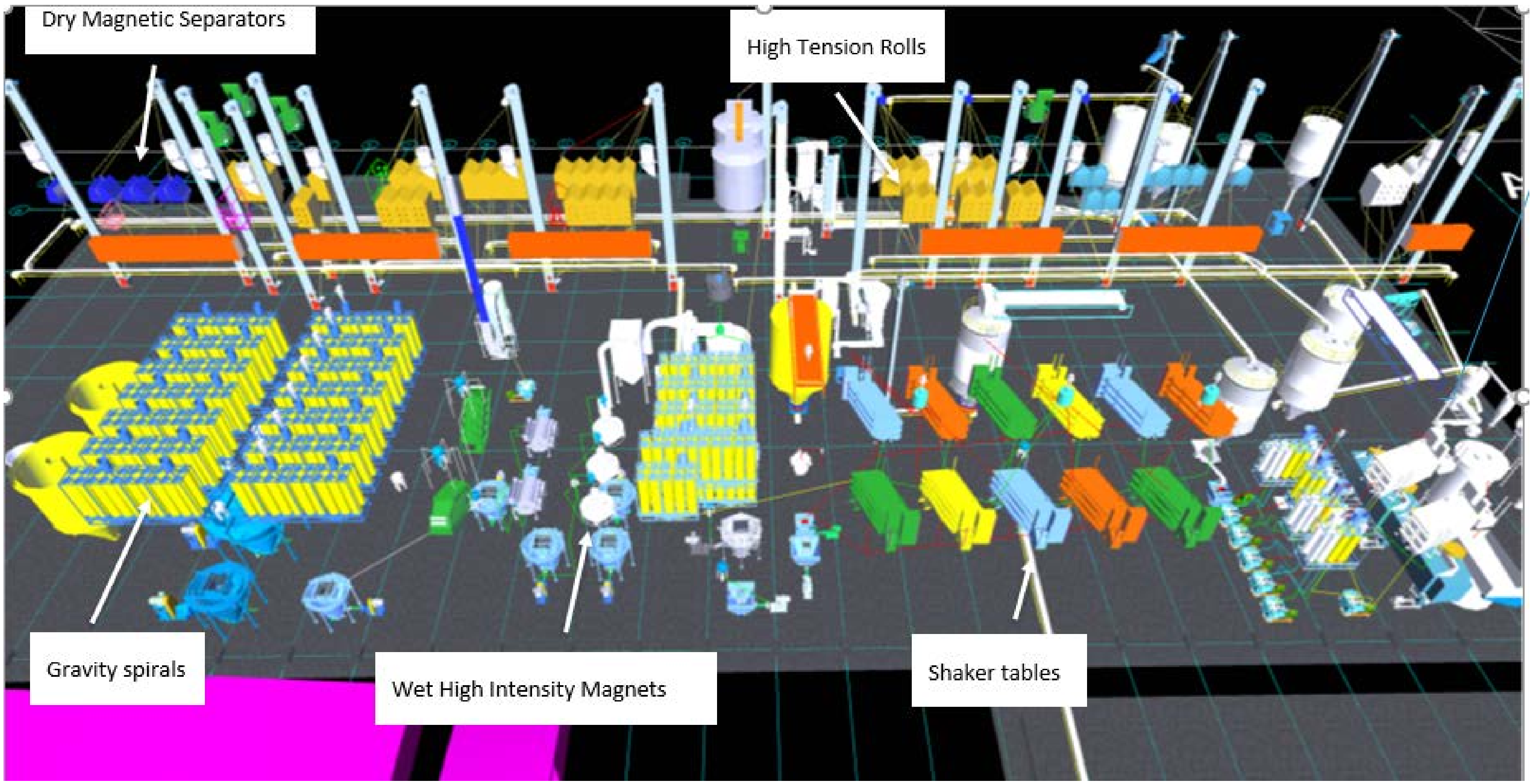
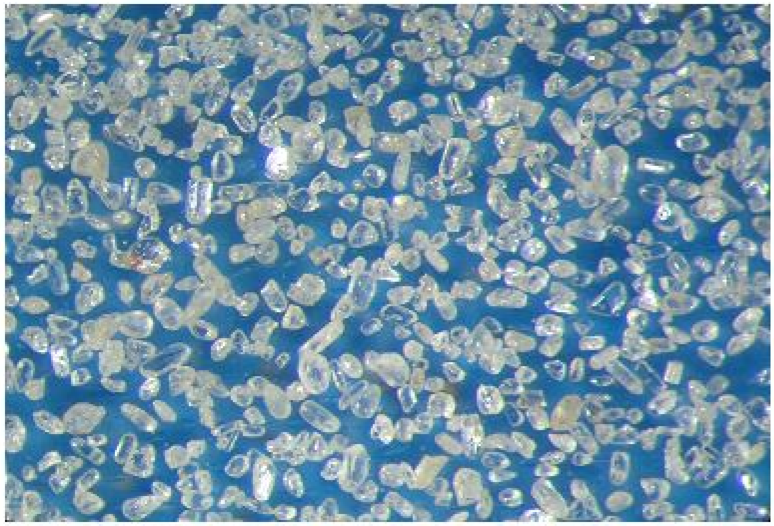
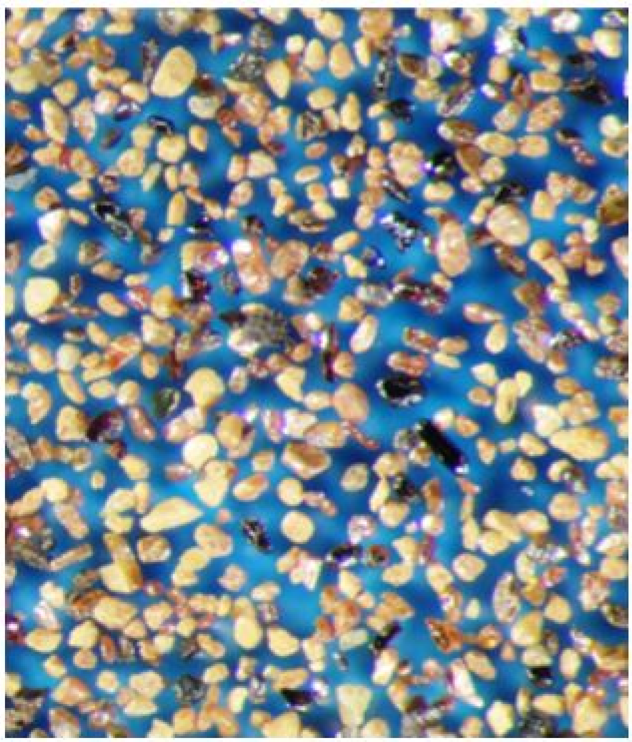


Figure 9. 3D model snapshot of the CVW™ Horizon Minerals Separation equipment.



Zircon Product



HiTi Product

Figure 10. Micrographs of mineral products of CVW^{TM} Minerals Separation Plant. The HiTi product is a blend of ilmenite (black particles), leucoxene (brown particles) and rutile (red/rose particles) with a TiO_2 content of up to ~90%.

Cost Estimating Methodology

The Basis of Estimate (BOE)[10] is the defining document for the TIC estimate. It is based on the Estimate Execution Plan but includes more details on Stantec's factors and allowances used in the estimate, exchange rates, labour rates, etc., together with assumptions made by the disciplines in deriving the Material Take Offs (MTO). The BOE was developed by Stantec in consultation with Canadian Natural's estimating group.

The estimate is a Class 3 Capital Cost Estimate in compliance with AACE (Association for the Advancement of Cost Engineering) requirement. This was confirmed and/or adjusted with the results of the Risk Analysis, which was developed by an independent expert in Risk management with Canadian Natural project staff attending. The estimate was completed to the level of accuracy in accordance with AACE International Recommended practice No. 18R-97 Cost Estimate Classification System Guidelines. This estimate reflects an expected accuracy range of +15%/-15% with confidence level @ P50.

For the Concentrator Plant (CP), the work covers the entire scope from flowsheet, heat and mass balance development, equipment sizing, P&ID development, Electrical and I&C design, Civil Structural and Architectural design, etc. right through to the development of MTOs and the Class 3 estimate. Disciplines involved in this part of the work are Process, Mechanical, HVAC, Piping, Electrical, Instrumentation & Controls, Civil / Structural / Architectural, Environmental and Technical Safety. For MSP, Stantec has received the Process and Mechanical design, as well as a 3D model (incorporating the equipment, some Piping and a preliminary structure) from IHC Robbins in Australia. Stantec is responsible for checking that the Process and Mechanical deliverables meet all Canadian and applicable Canadian Natural standards. Stantec is also responsible for the Utilities design as well as the Electrical, Civil, Structural, Architectural, HVAC deliverables associated with the MSP plant, including the office & control room building, etc.

The FEED phase specified a Class 3 facility design and construction cost estimate to support Titanium Corporation/Canadian Natural's internal approval process and regulatory requirements. The estimate will also be used to establish control budgets that are used for reviewing vendor quotes, engineering and construction contractor bids, and providing a starting point for the Cost Control process. Stantec has compiled the Class 3 estimates for the following facilities:

- Concentrator Plant (CP) including associated utilities and buildings
- Minerals Separation Plant (MSP) including the laboratory and the Office & Control Room
- The Thickener (as a separate item from CP)
- Thickened Tailings (Thickener underflow pumps only)
- General Plant infrastructure, including
    - Tie-ins to the Canadian Natural Main Plant and Utilities
    - The External Tie-in Corridor and Inter-plant Corridor
    - Fire Water System

The estimate is based on material take-offs (MTOs) generated by the engineering disciplines and confirmed by the respective Project Engineer. The MTO will include item description with quantity, unit, specification and WBS. MTOs from all engineering disciplines (civil, concrete, piling, structural, building, mechanical. Piping, electrical, and instruments) utilized to assemble direct costs.

[10] Motwani, M. (2018). "Estimate Basis", Document No. 25-RPT-PC-0002 Rev C, Project No. 10903262, Stantec, 40 pp.

All quantity takeoff data provided is as per the area breakdown according to WBS in "neat" (excluding allowances) quantities, reflecting the count or measure that is generated by modeling tools and take-offs from FEED phase engineering/ project documents for items not included in the models. The estimate is assembled using a detail quantity method based on MTOs generated by each engineering discipline team. The MTOs reflecting detailed breakdown of civil, concrete, piling, building, equipment, piping, structural, electrical, and instruments quantities will be utilized to assemble direct costs. The MTOs are generated according to area breakdown for every site and by discipline, and follow the work breakdown structure.

The cost estimate includes all direct and indirect field costs. Other cost such as engineering costs, construction management costs, owner's costs, etc. included in the cost estimate on the summary sheet as provided by the appropriate source if required. Project direct costs were developed by the Stantec estimating department based on MTOs provided by Stantec engineering disciplines, vendor firm quotations, budget quotes, subcontract rates from Stantec in-house data, and productivity factors and wage rates provided or agreed by the Titanium. Installation hours will be assembled based on John S. Page's Man-Hour Manuals/NECA 3 Manual of Labour Units with a productivity factor applied that reflects Northern Alberta site conditions. Direct costs are assembled by discipline based on direct labour, shop/module labour, material, tagged equipment, module and subcontractor costs. Subcontractor unit costs indicated under the "Supplier Contract" column on the estimate detail sheet covers supply and installation costs. Subcontractor pricing is mainly used for civil, piling, painting, coating, and insulation work. These costs are based on unit pricing composed of assemblies of vendor pricing, historical data, equipment productivity and efficiency norms, and labour productivity factors based on site conditions. Subcontractor unit pricing is inclusive of overhead and profit and excludes living out allowance (LOA), travel costs and travel time costs, which are captured separately in the indirect costs of the estimate.

Construction indirect cost is based on the construction execution plan, contracting strategy and preliminary schedule of the project. It was primarily bottoms-up to align with construction contracting strategy, in consultation with Titanium where applicable and rest was based on historical factored allowances.

The estimate was prepared using MS Excel and assembled using Stantec's *Opinion of Probable Cost* template. The estimate was structured and assembled in accordance with the breakdown structure (WBS, Discipline, and Mod/GF/BF/Retrofit coding).

Optimization: As the FEED project progressed select optimization activities were undertaken that had material impacts on the project Capital Cost. The primary change was a re-working of the Minerals Separation Plant to produce a non-magnetic concentrate rather than zircon and HiTi products. This was viewed as a more cost effective means to export valuable product to international markets. Subsequent refining to finished zircon and/or HiTi products can be accomplished at lower costs outside the Fort McMurray region. The 'Non-Mags Study'[11] provides the definition for this modified minerals process. The changes to the MSP involved the removal of Area 30 (Primary Dry Circuit), Area 35 (Wet Zircon Circuit), Area 45 (Dry Zircon Circuit), Area 55 (Hi-Ti Dry Circuit) and Area 60 (Zircon Calcining Circuit). Areas 50 (Hi-Ti Flotation Circuit) and associated Area 51 (Reagents) have been re-sized and repurposed for pyrite removal with a relocation between Area 20 (Wet Magnetic Circuit) and Area 25 (Non-Magnetic Gravity Circuit). The feed to repurposed Area 50 (Pyrite Flotation Circuit) is the non-magnetic

[11] Hicks, B. (2019). "MSP Non-Mag Concentrate (NMC) Study", Document No. SK-25B-RPT-PR-001, Rev B, Project No. 110903262, Stantec, 16 pp.

product stream from Area 20. The Area 50 flotation concentrate serves as the feed to Area 25. A complete description[12] is provided in the FEED documentation. Other key optimizations involved the replacement of the propane chiller system in the Concentrator Plant with a more cost-effective air-driven cooler along with the relocation of select process equipment outside of buildings. These optimizations are reflected in the capital cost estimate.

Financial Report

Titanium's ERA project (CVW™ Horizon FEED) was completed on time and on budget. Each milestone target was met and the phased expenditures are presented in **Table 3**.

Table 3. Summary of CVW™ Horizon FEED project milestones and expenditures. The ERA funds does not reflect the 20% hold back contingent on successful project close out.

Milestone	Task	Start Date	End Date	Proponent Funds	ERA Funds	Total Funds
1	Pre-FEED & Contractor Selections	June 3/2017	Mar 30/2018	$537,690.22	$537,690.22	$1,075,380.43
2	FEED Milestone 1	Mar 30/2018	Jun 30/2018	$1,183,624.36	$1,183,624.36	$2,367,248.72
3	FEED Milestone 2	June 30/2018	Sep 28/2018	$1,493,172.49	$1,493,172.49	$2,986,344.97
4	FEED Milestone 3	Sep 30/2018	Nov 30/2018	$1,068,847.04	$1,068,847.04	$2,137,694.08
5	FEED Milestone 4	Nov 30/2018	Feb 28/2019	$680,211	$680,211	$1,360,422
Total				**$4,963,545.11**	**$4,963,545.11**	**$9,927,090.22**

The approved project budget was $10,190,000 with 50% contribution from Emissions Reduction Alberta (ERA), 30% provided by Canadian Natural and the balance contributed by Titanium Corporation. These values included in-kind labour support from both Canadian Natural and Titanium. The final project cost was $9,927,090, which is approximately 2.6% under budget. The final ERA contribution of $4,963,545.11 is subject to Milestone 5 approval and required 20% holdback as of March 22, 2019.

[12] CWA (2019). "Process Narratives, CVW™ Horizon Project, Titanium Corporation Inc.", Doc. No. SK-25B-GE-PR-0001, Rev D, IHC Robbins, 11 pp.

Greenhouse Gas and Non-GHG Impacts

Titanium's CVW™ technology has the potential to deliver significant GHG emissions avoidance and reductions upon implementation at Canadian Natural's Horizon oil sands facility. These CVW™ Horizon project emissions have been estimated[13] and include CVW™ process emissions, tailings pond methanogenic emissions avoidance as well as upstream avoidances from Horizon bitumen production and mining. A stoichiometric model developed by Alberta Environment and Parks[14], has been adopted to assess methane and carbon dioxide emissions avoidance from ponds due to reduced naphtha deposition from froth treatment tailings afforded by CVW™ implementation. Horizon mine face degassing and bitumen production offsets allows for recovered bitumen contributions from CVW™ Horizon and have been estimated on a functional equivalency basis against Horizon design production rates. The resulting emissions profile is presented below in **Table 4**.

Table 4: CVW™ Horizon Emissions Profile.

Benefits (t CO2e/yr)	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2050**
TP Methanogenesis	0	0	0	642,787	642,787	642,787	642,787	642,787	642,787
Hot Water Integration	0	0	0	0	0	0	0	0	0
Bitumen Production FE	89,319	89,319	89,319	89,319	89,319	89,319	89,319	89,319	89,319
Mine Face Degassing FE	3,849	3,849	3,849	3,849	3,849	3,849	3,849	3,849	3,849
CVW Process	(177,569)	(173,584)	(169,558)	(168,925)	(165,974)	(165,131)	(164,498)	(163,665)	(151,743)
Total Benefit (t CO2e/y)	(84,401)	(80,416)	(76,390)	567,030	569,981	570,824	571,457	572,290	584,212
Cumulative Benefit (t)	(84,401)	(164,817)	(241,207)	325,823	895,804	1,466,628	2,038,085	2,610,375	17,826,083

Methanogenic emissions avoidance (~5.75 kg CO_2e/bbl) is not recognized until three years following CVW™ start up to account for migration of deposited froth treatment tailings to the active zones in the pond and allow for reaction kinetics. This methane avoidance corresponds with a minimum naphtha loss intensity of ~0.6 bbl naphtha per thousand barrels of bitumen produced; this value may not reflect average values experienced with normal plant operational variances. CVW™ process emissions (~1.5 kg CO_2e/bbl in 2026), comprised of natural gas consumption and electrical loads, are based on emissions factors from Canada's 2018 National Inventory Report. (Note: adjustments due to MSP optimization not reflected). The process emissions decrease with time due to increased 'efficiency' of electrical generation. Bitumen recovery from CVW™ Horizon may lead to Horizon bitumen production emissions

[13] Bozorgian, A. (2019). "Study Report on Potential GHG Emissions Resulting from CVW Horizon Project", Doc. No. SK-25-RPT-PR-001, Rev B, Project No. 110903262, Stantec, 19 pp.

[14] Burkus, Z. (2014). "GHG Emissions from Oil Sands Tailings Ponds: Overview and Modelling Based on Fermentable Substrates", Environment and Parks.

avoidances (operations and fugitive) of ~0.8 kg CO_2e/bbl. The net benefit of CVW™ implementation at Horizon is estimated at approximately 567,000 tonnes CO_2e annually (2026), or about 5.0 kg CO_2e/bbl of bitumen produced. Cumulative CVW™ Horizon emissions avoidance/reduction grows to ~326,000 tonnes CO_2e in 2026, 2.6 million tonnes CO_2e by 2030 and 17.8 million tonnes CO_2e by 2050.

Recovery of hot water from process tailings was contemplated in this project. However, after detailed consideration by the project team, tailings heat recovery and integration was deemed not feasible for the CVW™ Horizon project. Dry tailings options, intended to support additional methanogenic emissions avoidances, were also determined to be not feasible due to inconsistency with tailings management planning.

Value engineering emissions reductions were sought through process efficiencies and optimized utilities management. Some benefits were gained through the elimination of pumps throughout the Concentrator Plant. Process emissions reductions realized in the FEED study were reflected in the net CVW™ process emissions calculations.

The Horizon oil sands processing plant and mine are operating at near full capacity. Accordingly, the Horizon upgrader is unable to process additional bitumen recovered by CVW™. To integrate the CVW™ Horizon bitumen production with the Horizon operations, the Horizon mining and bitumen production functions can be reduced by an equivalent amount, or approximately 2.5%. The results in two additional emissions avoidances in those related to Horizon bitumen production and fugitive emissions related to mine face degassing.

The CVW™ Horizon process emissions have been estimated largely from tagged equipment lists generated during the project FEED exercise. These emissions are resulting from electrical consumption and natural gas loads from all plant areas (Concentrator Plant (25A), Minerals Separation Plant (25B), Thickener (Plants 25C/D) and utilities and water (Plant 25)). Based on electrical and natural gas emissions factors from the 2018 Canadian National Inventory Report[15], the FEED study estimates total process emissions of 168,926 tonnes CO_2e per year in 2026. Note that process emissions are reduced each year to 2034 due to improved electrical emissions factors resulting from adoption of a more sustainable mix of energy sources (*c.f.* **Table 4**). The largest contribution to the 2026 process emissions is the Concentrator Plant steam consumption (106,778 tonnes CO_2e per year) followed by the MSP electrically-sourced emission (20,848 tonnes CO_2e per year); these account for ~76% of the process emissions. Note the MSP process emissions do not reflect the optimized plant and will be a conservative estimate.

Value engineering benefits in process related GHG emissions reductions are evident for the Concentrator Plant (CP). The FEED study found several efficiencies in the CP, largely through the reduction of underflow pumping systems that were replaced with flow restriction devices. This has resulted in a reduction in electrically-sourced GHG emissions reductions of almost 38% when the adjustments for process flowrates and electrical efficiency are factored.

Air Quality

The direct recovery of process diluents from hot froth treatment tailings prior to deposition in tailings impoundments avoids emissions of flashed VOCs and secondary organic aerosols (SOAs). Flashing of diluent from Froth treatment tailings account for a majority of oil sands mining VOC emissions. Froth

[15] (2018). "National Inventory Report, 1990-2016: Greenhouse Gas Sources and Sinks in Canada".

treatment tailings are currently deposited into tailings ponds at ~70˚C to 95˚C and approximately 5%-30% of the diluent mass can volatize into the atmosphere. CVW™ distillation can reduce tailings VOC emissions. Environment Canada recently reported on the potential health hazards of secondary organic aerosol (SOA) precursor emissions at oil sands mining sites[16]. A significant source of SOA precursors is volatized emissions from diluents being discharged to tailings ponds and the atmosphere from froth treatment tailings[17]. As with VOC's, Titanium's CVW™ may reduce SOA prevalence.

Land and Water

By removing the plurality of hydrocarbon from froth treatment tailings, tailings management processes work more efficiently with lower operating costs and lower environmental footprint to potentially deliver 'ready-to-reclaim' solids depositions. Titanium's CVW™ processes can reduce pond deposition of froth treatment tailings as the clean thickened tailings could meet general depositional requirements at lower flocculant dosing while achieving acceptable geotechnical characteristics.

Overall Conclusions

Titanium Corporation's Creating Value from Waste (CVW™) process is being evaluated for implementation for the first time at a commercial scale at Canadian Natural's Horizon site north of Fort McKay in Northern Alberta. This process will recover residual bitumen and diluent, extract valuable minerals from Horizon's froth treatment tailings stream and provide meaningful environmental benefits, including significant fugitive methane emissions avoidance.

The Front-End Engineering Design (FEED) phase was co-financed by Titanium Corporation, Canadian Natural and Emissions Reduction Alberta. The engineering was completed by an integrated team at Stantec, which developed the designs for both the Concentrator Plant (CP) and the Mineral Separation Plant (MSP) – with the main Process and Mechanical design of the MSP plant developed by IHC Robbins of Brisbane in Australia.

The FEED project was completed from April to December 2018. The technical design was completed between April and October 2018, with the Total Installed Cost (TIC) estimate developed from October to December 2018. Project optimization and conditioning of the cost estimate was executed in between December 2018 and February 2019. The main conclusions of the CVW™ Horizon FEED study include:

- An optimized integration design for implementation of CVW™ technology at the Horizon site. This details all key tie-ins such as produced diluted bitumen and cleaned tailings. Further, a reckoning of utility requirements and sourcing has indicated that Horizon supply is largely sufficient with the inclusion of a dedicated steam boiler and associated cooling/water treatment.
- Implementation of CVW™ at Horizon can result in a net reduction and avoidance of GHG emissions of 567,000 tonnes CO_2e annually in 2026, growing to 572,000 tonnes CO_2e per year by 2030 and 584,000 tonnes CO_2e per year by 2050 due to CVW™ process emissions efficiencies. By 2050, the cumulative benefit of the CVW™ Horizon project

[16] Liggio, J. et al. (2016). "Oil Sands Operations as a Large Source of Secondary Organic Aerosols", Nature, 534, 91-94.

[17] Liggio, J., personal communication with K. Moran, June 14, 2016.

could reach 17.2 million tonnes CO_2e. Other air quality benefits, including volatile organic compound emissions reductions, may also be realized.

- The CVW™ Horizon project will recover hydrocarbons, bitumen and diluent, from froth treatment tailings. The resultant CVW™-processed tailings have been demonstrated to exhibit enhanced settle and flocculation behaviours that lead to efficiencies in tailings management performance. An optimized thickener has been designed to transition CVW™ tailings into the Horizon tailings management planning, offering a potential solution for the Horizon froth treatment tailings.
- A conditioned and optimized AACE Class 3 capital cost estimate has been developed for the CVW™ Horizon project. This cost has been developed from budgetary costs of tagged equipment with vetted build-ups to estimate other direct and indirect costs. This cost estimate will serve as a base for next steps in the project's development.

Next Steps

Titanium Corporation, along with partners Canadian Natural and Emissions Reduction Alberta, have successfully completed a FEED project for implementation of CVW™ technology at Canadian Natural's Horizon mine. This FEED details the integration complexity and identifies a capital cost for the CVW™ Horizon project at full commercial rates. The next steps for the project include:

- Economic Modeling: Titanium and Canadian Natural will work together to refine economic models that incorporate the optimized, conditioned capital costs with anticipated resource production and environmental benefits to fully define the project.
- Project Scope: Following the economic modelling, Titanium and Canadian Natural must agree on a project definition and business model that provides benefits to both parties.
- AER Application: This application will be revised based on the agreed project scope. The recently completed FEED updated critical elements of the application, including the air quality and noise studies, based on the project options.
- Financing finalization: Titanium will work with partners to define the financing for the project. Certain financing from government agencies is advancing and may provide significant leverage for this first-of-kind sustainable project.
- Detailed Engineering: The final phases of engineering will begin as the financing for this work comes together. The project will then transition to procurement, construction and commissioning of the CVW™ installation at the Canadian Natural Horizon site.

The oil sands mining sector has been grown from its founding over 40 years ago, from a relatively small industry in the 1970's through the 1990's to very rapid expansion and growth in this century. The sectors resource base is expected to support stable production and some growth for the next 4-6 decades. World energy demand including oil demand is forecast to increase 30% by 2040. The oil sands are a vital resource for Canada and the world, representing the world's 3rd largest oil reserves (165 billion barrels) and over 50% of the world's accessible reserves. It is estimated the oils sands sector will contribute $1.7 trillion to the Canadian economy over the next 10 years and over 220,000 Canadian jobs rely on the oil sands.

Critical factors for both sustainability and profitability of the industry are reducing the industry's environmental footprint, particularly GHGs and tailings ponds, and reducing operating costs, all areas where Titanium's CVW™ technology will deliver improvements and benefits.

The market entry plan to advance Titanium's CVW™ technology from its current TRL8 to commercial implementation involves executing the commercial prototype project deployment at the Canadian Natural Horizon site as proposed in this application. The current FEED phase was completed in February 2019 and will be followed by a final decision on sanctioning of a commercial implementation project jointly by Titanium and Canadian Natural. While the business structure has not been finalized, Titanium and Canadian Natural have done extensive financial modeling of business structures and held associated discussions.

All of the industry operators have cooperated with Titanium during CVW™ technology development and are well aware of the technology and its benefits. Titanium has worked with all of the oil sands operators including the industry SDTC Consortium for demonstration piloting. Full piloting results and engineering have been provided to the operators and proposals made for implementation at their sites. Titanium is one of the first associate members to join COSIA, the oil sands industry organization formed to facilitate the sharing of environmental technologies and ideas. COSIA membership has enabled on-going communication with the operators. It was expected that only one operator would step forward as the first adopter with other operators as second/subsequent adopters.

Canadian Natural has stepped forward as the industry first adopter as illustrated by a page on its website describing the CVW™ Horizon project as a D4 New Technology that is being deployed. As first adopters, Canadian Natural and Titanium and Titanium are taking all of the risks of a first-of-kind complex technology implementation, paving the way for industry wide adoption. Titanium and Canadian Natural are seeking risk sharing funding from governments for the first installation of CVW™ technology, which will be a very important factor in reaching a Final Investment Decision (FID) to sanction the full project.