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New Oil Sands Technology to Meet the Challenges of Climate Change and Tailings Management

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ABSTRACT

Recent events are shaping the emerging environmental landscape for Canadian oil sands mining operations. Alberta's Climate Change Leadership Plan (CCLP), the UN Paris Conference and the Canadian government commitment/support to limit global CO_2 impacts will require oil sands miners to significantly reduce their GHG emissions and intensities. Further, the industry will be stewarding towards a revised Tailings Management Framework (TMF) that aims, in part, to sustainably control tailings volumes. These are significant challenges and opportunities for the industry in earning their social license to operate.

Titanium Corporation has developed an 'end-to-end' suite of technologies to remediate oil sands froth treatment tailings that offer important reductions to greenhouse gas and volatile organic compound emissions and allow tailings avoiding tailings ponds altogether, enabled via novel and innovative recovery of contained hydrocarbons. These CVW^{tm} technologies generate revenue through the recovery of lost commodities, including bitumen, solvent and valuable heavy minerals such as zircon and those bearing titanium dioxide, in addition to offering attractive operational cost savings, fit-for-reuse water, heat integration and positive economics.

Implementation of the Company's CVW^{tm} technologies allows for the reduction of more than 80% of current fugitive methane, and up to 70% of VOC, emissions at oil sands mines. This represents a reduction in GHG emissions intensity by ~10% or up to 3-5 megatonnes of CO_2e annually across the industry, and is a significant contribution to the annual 12 megatonnes of methane emission reduction target set by the CCLP. With the hydrocarbons effectively removed and recovered, efficient tailings management performance is realized that allows for direct deposition into a reclamation landscape without passive settling in a tailings impoundment. As such, Titanium's technology is also well aligned with the key tenets of the Alberta's Directive 85 and can assist the industry in achieving important sustainability advancements that are consistent with advancing global expectations.

KEY WORDS

Oil Sands, Froth Treatment Tailings, Climate Change Methane, Water, Tailings Management

INTRODUCTION

Since their beginnings in the late 1960's oil sands mining operations have been producing tailings slurries as part of the water based extraction methods utilized to recover bitumen. These slurries are clarified in tailings impoundments which, in part, have served as a significant source of water that can be recycled in the extraction process. The fine grained solids contained in the tailings slurries slowly sediment in the ponds to form mature fine tailings (MFT). MFT has been identified as problematic to mine reclamation due to challenges in consolidation.

A portion of MFT emanate from *froth treatment tailings*; these represent about 10% of the total tailings slurry volume yet contain a plurality of environmental issues. Perhaps the most significant is the presence of process solvent (naphtha) that serves as a substrate for methanogenesis in tailings ponds, a source of volatile organic compound (VOC) emissions, a relatively large concentration of lost bitumen, pyrite leading to acid rock drainage and a concentration of radioactive minerals. This stream, by nature of their hydrophobicity, also concentrates valuable heavy minerals such as zircon and leucoxene.

The Alberta government has been monitoring and regulating the management of tailings and their impoundment for decades. In particular, with froth treatment tailings, the naphtha loss intensity, as barrels of solvent lost relative to every thousand barrels dry bitumen produced, has been limited to a maximum of approximately four bbl/kbbl. In 2009, the Energy Utilities Board issued Directive 74, which mandated tailings fines capture and a timeline towards mine reclamation (Houlihan et al., 2010). More recently, Alberta issued their 2015 Climate Leadership Plan, which calls for an increase to the carbon levy with emphasis on methane emissions reductions given the relatively potent global warming potential. At the same time, the Canadian Council of Academies issued their special report on oil sands tailings, noting that froth treatment tailings are 'toxic' (Newell et al., 2015) due to their relatively high hydrocarbons (including process naphtha) concentrations. This report goes on to cite Titanium's CVW^{tm} technology as the solution to abating the environmental impacts of froth treatment tailings. In 2016, the Alberta Energy Regulator (AER), after consultations with industry and the public, replaced Directive 74 with Directive 85. This new directive makes for provisions to conduct tailings management with respect to relevant environmental issues, including GHG emissions and acidification with specific mention, perhaps for the first time, of froth treatment tailings.

Titanium Corporation's CVW^{tm} technology has been developed to remediate froth treatment tailings and provide manifold environmental benefits including significant GHG emissions reductions. The technology provides benefits that are consistent with current and emerging views of the public and key stakeholders.

ABOUT TITANIUM'S TECHNOLOGY SOLUTION

Through the support and cooperation of industry and Government, Titanium Corporation has developed a suite of practical technologies for the remediation of froth treatment tailings. Titanium has followed a proven development path which involved progressive testing through laboratory, on site piloting through to large scale demonstration piloting at the NRC CanmetENERGY test facility at Devon Alberta. The Canmet facility is dedicated to the development of new oil sands technologies and is the principal site for the testing of froth treatment process technologies by oil sands industry operators.

Titanium is an Associate Member of Canada's Oil Sands Innovation Alliance (COSIA), the oil sands industry's organization dedicated to accelerating the adoption of new environmental technologies. Titanium's technology is a prioritized technology for froth treatment tailings in COSIA's Tailings Technology Roadmap (Sobkowicz, 2012). In this study, COSIA evaluated over 600 unique technology solutions for oil sands tailings. A final total of 48 were prioritized and included Titanium's CVW^{TM} technology, the only technology developed to process froth treatment tailings with additional environmental benefits (GHG emissions reductions) and diversified resource recovery. **Figure 1** illustrates Titanium's technology development pathway and the broad collaboration with expert research, university, engineering, testing and oil sands firms.

REMEDIATING OIL SANDS TAILINGS BEFORE DISCHARGE INTO TAILINGS PONDS

Titanium's CVW^{tm} process applies proven technologies to remediate froth treatment tailings prior to discharge to tailings ponds. Froth treatment tailings are intercepted and reprocessed to economically produce trafficable deposits in an enhanced manner due to the efficient recovery of tailings hydrocarbons. The *cleaned* tailings are efficiently thickened, allowing for water recovery and heat integration, and then deposited in thin lifts to achieve attractive deposition strengths. In addition to

enhanced dewatering and heat integration, GHG (and VOC) emissions reductions are achieved through the efficient end-of-pipe hydrocarbons (bitumen and process solvent) recovery, thereby preventing methane formation in tailings ponds via microbial methanogenesis. High quality hydrocarbon products (solvent and diluted bitumen) are recovered from tailings and returned to the existing oil sands upgrading facilities. Heavy minerals are recovered and processed into final minerals products for export to world markets. The CVW™ process reduces the volume of tailings discharged to ponds and also reduces the concentration of hazardous materials (radioisotopes) at oil sands mining sites. The generalized process flow-sheet is shown in **Figure 2**.

A combination of tailings processing by Titanium's concentrator followed by proven thickening and drying processes would avoid the need for impoundment of froth treatment tailings. A number of industry adopted tailings management technologies tested very effectively for processing the tailings exiting Titanium's concentrator during demonstration piloting at CanmetENERGY. A conceptual layout of Titanium's froth treatment tailings management operations using standard industry technologies for thickening and drying (which could include other proven technologies) is shown in **Figure 3**.

THE REMOVAL OF BITUMEN AND SOLVENT CONTRIBUTES TO IMPROVED TAILINGS REMEDIATION

The Company's CVW™ technology solution for froth treatment tailings utilizes practical technologies that are in operation at commercial scale in other applications in the oil sands industry. These technologies, adapted to froth treatment tailings, have been demonstrated to recover hydrocarbons (bitumen and solvents) from froth treatment tailings. Once the hydrocarbons are removed, the cleaned tailings have been demonstrated to thicken more effectively during testing at CanmetENERGY's tailings testing facility.

The contained hydrocarbons in oil sands tailings adversely affect fines/clays particle interactions by coating particles and reducing flocculant efficacy, which result in 'softer' mature fine tailings that hold more water and ultimately impede trafficability and reclamation efforts. Substantial removal of bitumen results in an increase in settling behaviours of fluid fine tailings (Klein, 2014). Removing hydrocarbons from froth treatment tailings opens opportunities for multiple benefits including:

- Enhanced dewatering of froth treatment tailings (improved trafficable deposits).
- Reduction in flocculant application and overall usage (higher efficiency and reduced costs).
- Efficient recovery of hot water (heat recovery/recycling/reduced river water usage).
- Integration of heat from the recovered water (reducing site-wide energy intensity)
- Deposition of over 35 million tonnes annually of froth treatment tailings solids (including 15 million tonnes of fines that would contribute to MFT).
- Recovery of up to 50 million cubic meters of fit□ for□reuse water
- Reduction of natural gas consumption (currently used to re□heat process water) by approximately 240 million cubic meters annually with attendant cost and GHG reductions.
- Recovery of heavy minerals concentrates (processed into minerals products).
- Reduction of the radioactive content of deposited tailings by up to 80%.

In addition to enhancing the practical management of oil sands tailings and to helping slow the growth in mature fine tailings volumes, recovering hydrocarbons from froth treatment tailings results in a number of other environmental benefits:

- Reduced greenhouse gases (tailings ponds represent a significant source of oil sands mining GHG emissions due to the microbial methanogenesis of solvent deposited from froth treatment tailings; Holowenko et al. 2000).
- Reduced VOCs (light hydrocarbons in solvents are volatized into the lower atmosphere causing emission harmful to human health).

Titanium's tailings technology has been extensively tested during four years of demonstration piloting at large scale for industry and Government at the NRC CanmetENERGY oil sands test facilities in Alberta. Development of this new technology has been supported through private Canadian investment of over $70 million plus grant funding of $12 million from the Governments of Alberta and Canada. Major

oil sands companies participated in a consortium with Sustainable Development Technology Canada (SDTC) in the demonstration piloting of Titanium's technology. The results achieved by CVW^{tm} have been reviewed and validated by the Canadian Oil Sands Innovation Alliance (COSIA) and oil sands producers.

ENHANCED DEWATERING AND THICKENING

The tailings from Titanium's CVW processes can be characterized by low hydrocarbon concentrations, ranging between 0.2 and 0.4% by mass, and a significant fraction of solids classified as fines (less than 45 microns, with a typical d_{90} up to 75% - 99%). The low hydrocarbon concentrations are achieved through innovative flotation, solvent extraction and distillation operations. The particles contained in Titanium's tailings have been classified based on their physical properties with the majority of fine/coarse heavy minerals reporting to the heavy minerals processing streams. The resultant tailings, in advance of dewatering, are similar to mature fine tailings in terms of particle sizing (Revington et al., 2016) but have significantly less bitumen than MFT. The reduced bitumen content contributes to enhanced dewatering with a three-fold increase in hydraulic conductivity, which becomes more pronounced as the solids concentration increases (fines void ratio decreases), and allows for the deposition to reach higher solids concentrations (Chow et al., 2013). This response may be augmented by an optimal sand to fines ratio of approximately three (Morris and Williams, 1997; Mikula et al., 2010) for some of Titanium's tailings.

A recent University of Alberta research suggests that dewatering is optimized when the residual bitumen content is between 0.2% and 0.5% (Klein et al., 2014). Titanium's tailings are ideally suited for accelerated dewatering when subjected to conventional tailings management processes. In addition to the thickening (**Figure 4**) and thin lift operations described below, Titanium's tailings responded well to conventional centrifugation and rim ditch processing. Due to the reduced bitumen content of the tailings, CanmetENERGY centrifugation resulted in significantly greater solids concentrations in the produced solids cake at over 57% at polymer dosages of 300 ppmw or less. This compares to 50% solids in the solids cake at more than double the flocculant dosage for conventional MFT (Mikula et al., 2010). In rim ditching operations at CanmetENERGY (3 m^3 test shown in **Figure 4**), Titanium's tailings released over 60% of the contained water during the drainage phase. The average resultant deposition during the ditching phase was 47% solids, with a surface vane shear stress in excess of 15 kPa. This performance was achieved at a polymer dosage of only 100 ppmw.

CanmetENERGY confirmed superior performance during its deposition studies of Titanium's tailings produced during the Company's demonstration piloting (2010-2014), noting that Titanium's tailings reach a critical deposition strength (5 kPa) at lower solids concentrations of 50%, relative to the 65-70% required with typical MFT (Mikula et al 2010). Approximately 67-80% of the water contained in Titanium's CVW^{tm} tailings, ex hydrocarbon processing, can be recovered at elevated temperatures in Titanium's thickening operation that utilizes low flocculant concentrations of 200-400 ppmw (Mikula et al., 2010) to increase solids concentration of the thickened product to up to 50% by weight from the ~10% value in tailings. The accelerated thickening operation, allows for significant direct heat recovery opportunities with fit for reuse water produced at 70°C.

Based on demonstrated performance at CanmetENERGY, Titanium's thickening operation on cleaned froth treatment tailings would facilitate the recovery of approximately 50 million cubic meters of water industry wide. The produced water was of sufficient quality for subsequent re□use as process water, enabling direct integration of contained heat, or to offset fresh water draw from the Athabasca River in use as low grade utility applications. The produced water from the thickener can be further upgraded to remove dissolved organics by more conventional advanced oxidation processes (Kasperski, 2011).

The thickened tailings can then be directly subjected to conventional thin□lift drying to produce trafficable deposits. The thin lift performance of Titanium's thickened tailings is superimposed on data collated by Alberta Innovates – Technology Futures (AITF) in their recent study (Chow et al., 2013), as shown in **Figure 5** with Titanium's thin lift data given as solid red squares.

These results confirm superior performance of Titanium's thickened tailings relative to industry MFT in achieving attractive and meaningful strength at lower solids concentrations. As per the superseded AER Directive 74 (McFadyen, 2009) and the current AER Directive 85 (Ellis, 2016), depositions must reach a shear strength of 5 kPa (shown as the lower horizontal red line labelled 'D074 5 kPa' in **Figure 5**). Titanium's thin lift deposit reaches this target at a fines concentration of just over 60%, compared with 72% for typical fluid fine tailings. This superior performance is achieved at significantly lower flocculant dosages than required by typical fluid fine tailings.

The Titanium thin lift performance was achieved by applying a total flocculant dosing of 330 ppmw. This compares favourably to the work cited by AITF (Chow et al., 2013) which utilized over 1000 ppmw of polymer flocculant and coagulants to achieve similar results. A number of relevant

precedents also support an average flocculant dosage of about 1000 ppmw (**Table 1**).

The removal of hydrocarbons from froth treatment tailings facilitates accelerated dewatering, leading to auxiliary environmental benefits of heat integration and reduced land use impacts (described above). In addition, the low residual hydrocarbon concentrations extant in Titanium's process tailings yield additional operating cost benefits. One such benefit is the enhanced efficacy of flocculants used in the process. Flocculants are utilized to promote faster settling through induced particle□particle attachments. These flocculants are designed to adsorb to clean silica and minerals surfaces. Those surfaces that are contaminated with a layer of organics, including hydrocarbons such as bitumen and diluent, do not interact as efficiently, leading to higher flocculant consumption in the tailings management process. This is the basis for estimating the cost benefit of Titanium's process related to lower flocculant dosing. A survey of public disclosures, from oil sands operators in describing their commercial and demonstration experiences, chemical companies and third party expertise, indicates typical flocculant dosing in treating tailings in the range of 500 to 1500 ppmw.

A combination of processing by Titanium's concentrator and proven thickening and drying processes would avoid the need for tailings pond impoundment of froth treatment tailings. A number of industry adopted tailings management technologies tested effectively for processing tailings exiting Titanium's concentrator during demonstration piloting at CanmetENERGY.

MANAGING PYRITE

Pyrite is a natural constituent of oil sands ore, comprising about 0.5% of the total mineral matter with a wide ranging occurrence in the McMurray formation with deposition concentrations of up to 10% (Kaminsky, 2008) and represents the most abundant of the iron bearing minerals. Pyrite is a naturally hydrophobic mineral that is preferentially wet by bitumen froth and, consequently ends up in tailings following bitumen froth treatment cleaning operations utilizing process naphtha. Recently, it has been identified that thickened froth treatment tailings may contribute to acid rock drainage, an emerging environmental issue in commercial oil sands production, during deposition (Kuznetsov et al., 2015). Titanium's heavy minerals production process actively targets pyrite (32x micrograph in **Figure 6**) for removal in a dedicated process stream. Over 95% of the pyrite contained in froth treatment tailings can effectively be segregated from froth treatment tailings (Moran and Doiron, 2013; Kruger, 2013), significantly reducing potential for acid mine drainage issues in tailings management.

REDUCING TAILINGS POND VOLUMES

Titanium's technology materially reduces the volume of froth treatment tailings entering tailings ponds and has the potential to totally eliminate any deposit of this stream into ponds. Through the recovery of bitumen, solvents, heavy minerals and recycled water, over 50% of the tailings volume is recovered and there is an opportunity to immediately thicken and remediate the balance. This would result in a reduction of material entering tailings ponds of over 100 million cubic meters annually when implemented at all current operating sites. Industry wide annual cost savings potential could be in the range of $100 million based on an Alberta Energy Research Institute (AERI) commissioned study on the cost of tailings management practices which included options such as thickening, composite tailings and centrifugation of pond tailings (Devenny, 2010). In this study, a number of environmental factors were considered such as land disturbance, creation of fluid tailings, fit□for release water treatment and end□of□mine closure costs as well as operational expenses, earthworks and general tailings management (transport of materials, recycling water).

REMOVAL OF HAZARDOUS WASTE (RADIOACTIVE MATERIALS)

Naturally occurring radioactive material (NORM) is concentrated by the oil sands extraction process and discharged to tailings ponds in froth treatment tailings. Radioactive material has been found to be concentrated in tailings ponds and has been identified as hazardous waste. In 2012, the Alberta Government's Alberta Innovates, Energy and Environment Solutions, as part of their Oil Sands Tailings Bitumen Recovery study (Chow et al., 2013), identified the issue of NORM occurring from oil sands froth treatment tailings discharge to tailings ponds. The report, which was co-produced with the Canadian Oil Sands Innovation Alliance (COSIA), recommended with regard to NORM build up:

> "*The existing froth tailings deposits be characterized and that process methods to reduce or manage these loadings be given a high research and development priority*."

Titanium's processing offers a solution for the removal of radioactive material from froth treatment tailings. Heavy

minerals deposits throughout the world contain NORMs and are safely handled in the normal course of processing. During the Company's demonstration piloting, up to 80% of the radioactive material was removed from froth treatment tailings streams and handled within NORM limits by the minerals recovery process. **Figure 7** shows the removal efficiency of the CVW^{tm} process for the various radioactive isotopes (NORM) in oil sands froth treatment tailings.

ENVIRONMENTAL BENEFITS: REDUCING GHG AND CLIMATE CHANGE FORCING METHANE EMISSIONS

Oil sands tailings ponds are generators of GHG emissions caused by the decomposition of hydrocarbons contained in oil sands tailings. Titanium's CVW^{tm} suite of technologies includes innovative and novel extractive and distillative processes to remove hydrocarbons (solvents and bitumen) from froth tailings streams. Titanium's technology has been extensively tested and demonstrated over a four year period using fresh oil sands froth treatment tailings provided by oil sands operators. After CVW^{tm} processing, the tailings contain non measurable amounts of residual naphtha (solvent) and bitumen as determined by the independent analytical firm Maxxam Analytics. Based on extensive test results, this new technology would achieve "game changing" improvements for the oil sands industry, reducing solvent losses to 0.7 barrel per 1,000 barrels of bitumen production, representing a more than 75% improvement on current practices which allow 4 barrels of solvent release per 1,000 barrels of bitumen production. This improvement translates directly into GHG emission reductions which may exhibit a range commensurate with atmospheric volatilization of solvent resulting in VOC emissions from froth treatment tailings. University of California studies determined methane emissions from tailings ponds represent 55% of carbon dioxide equivalent releases from oil sands mining fugitive sources (Yeh et al., 2010). Implementation of Titanium's technology would reduce solvent losses to tailings ponds in the range of 75%, resulting in a reduction of up to 1.4g CO_2e per MJ of bitumen produced. Absolute industrywide CO_2e emissions would be reduced by approximately 3 - 5 megatonnes per year.

Figure 8 shows (in the right hand last two bars) the potential to reduce oil sands "Mining" GHG's using CVW technology, to a level in line with other heavy crudes.

Climate Change-Forcing Effects of Methane (source: ICF International: Economic Analysis of Methane Emission Reduction Opportunities in the Canadian Oil and Gas Industries, September 2015):

"Different greenhouse gases persist in the atmosphere for different lengths of time and have different warming effects, and thus have different effects on climate change. In order to compare them, the scientific community uses a factor called the global warming potential (GWP), which relates each GHG's effect to that of CO2, which is assigned a GWP of 1. The science and policy communities have historically looked to the Intergovernmental Panel on Climate Change (IPCC) assessment reports as the authoritative basis for GWP values. The currently accepted values are from the IPCC Fifth Assessment Report (AR-5). CO2 emissions are the primary driver for climate change over the long term, due to their long lifetime in the atmosphere. Because stabilizing climate will require deep cuts in GHG emissions, GWP values are most commonly expressed on a 100-year time horizon. The 100 year GWP is the standard value used by Environment Canada and other federal, provincial, and international agencies to measure GHG emissions. On a 100-year basis, methane is assigned a GWP of 34 by the AR-5. This means that one tonne of methane has the same effect as 34 tonnes of CO2 over 100 years. However, the Canadian GHG inventory uses a 100-year GWP of 25, as specified by the UNFCCC inventory protocol. Some GHGs, including methane, have a stronger climate-forcing effect than CO2 but a shorter lifetime in the atmosphere (12 years for methane). In order to evaluate the short-term effects, the GWP is also calculated on a 20 year basis. On a 20 year basis, the AR-5 assigns methane a GWP of 86. Most countries, including Canada and the EPA Greenhouse Gas Reporting rule as of 2013 use the AR-4 100 year GWP of 25 for methane. The AR-4 20 year GWP for methane is 72. The GWPs for methane per the AR-5 are 34 for 100 years and 86 for 20 years."

ENVIRONMENTAL BENEFITS: REDUCING VOC EMISSIONS IMPROVING AIR QUALITY IN ALBERTA

Implementing Titanium's CVW^{tm} technology will result in major reductions of VOCs at oil sands mining sites. This innovative technology to recover solvents and reduce emissions is the result of Titanium's research programs in collaboration with leading scientists at Gas Technology Institute in Chicago and Dr. Ding Yu Peng of the University of Saskatchewan, a world renowned thermodynamics researcher. In mining oil sands extraction, the froth treatment process is the single point where solvent is added to bitumen froth and therefore represents the main source of release of solvent and VOC's into the atmosphere. Unlike GHGs, VOCs enter the lower atmosphere and are hazardous to human health.

Under current regulations, up to 4 barrels of solvent may be discharged to tailings ponds for every 1,000 barrels of bitumen production. This can result in 235,000 – 600,000 barrels of solvent entering tailings ponds and the atmosphere each year at individual sites and over 2.0 million barrels across the sector.

Titanium's technology has been demonstrated to recover in the range of 75% of the solvents in froth treatment tailings. Preventing solvents entering the ponds and atmosphere translates directly into reduced emissions. Associated VOC emissions would be reduced by approximately 75% through the implementation of Titanium's CVW^{tm} technology. Based on scientific calculations of the VOCs created by solvent release (Dyer et al., 2008), this would equate to industry-wide VOC reductions potential of over 50 kilotonnes annually. Titanium's technology represents an economic "bolt on" solution to significantly reduce VOCs without modification or risks to existing oil sands froth treatment processes.

WATER CONSERVATION

Removing bitumen and solvent from froth treatment tailings creates the opportunity to directly recycle and conserve water. The key to recovery and reuse of the hot tailings water is removal of hydrocarbons (bitumen and solvents) that prevent the water from being directly reused in oil sands processes. In Titanium's process, bitumen is recovered from froth treatment tailings utilizing a combination of proven large scale processes including cyclones, flotation and solvent extraction. In demonstration piloting at CanmetENERGY, the technology successfully recovered 85% of the contained bitumen. Solvent was removed from the process tailings using a novel distillation operation. Titanium's technologies reduced the hydrocarbon concentration in the tailings stream from ~2% down to ~0.3% by mass. The low residual hydrocarbon levels result in accelerated dewatering of the process tailings, allowing both the recycle of hot water and achieving the heat recovery potential of this tailings stream as described below.

In the Company's suite of technologies to remediate froth treatment tailings, the cleaned process tailings exit the tailings solvent recovery unit at about 95°C. Of the original volume, approximately 93% report as a slurry containing 20% solids, characterized by a d_{90} of 45 microns, to a thickening operation. Due to the relatively low hydrocarbon concentrations and elevated temperatures, accelerated dewatering of the tailings slurry is achieved. Extensive testing of thickening and other tailings management options were independently tested by CanmetENERGY in integrated and continuous testing during the Company's demonstration piloting. Due to the efficient thickening, cleaned water can be recycled at a temperature of about 70°C. Up to 80% of the contained water is recovered with a low suspended solids concentration of 0.2%. The improved quality of the water could also be utilized in certain other services such as gland seal that currently source fresh river water (reducing river water withdrawal). Operating cost saving would be realized, equivalent to the costs of heating an equivalent amount of cold pond tailings water and additional GHG benefits achieved by reducing the emissions caused by the heating process.

CREATING ECONOMIC VALUE AND DIVERSIFICATION FOR ALBERTA

Recovering valuable resources currently lost in froth treatment tailings would create additional economic value for the oil sands industry (even in a low oil price environment) and economic growth and diversification for Alberta, while reducing environmental impacts.

Heavy Minerals Recovery: Titanium's technology has unlocked the opportunity for Alberta to create new economic value and diversification with a new minerals industry and increased exports. The heavy minerals in the Athabasca oil sands deposits are concentrated by the oil sands extraction process and rejected in froth treatment tailings. These mineral resources are currently lost in tailings ponds.

Titanium's CVW^{tm} technology has been demonstrated to recover commercial quantities of valuable heavy mineral concentrates from froth treatment tailings and cost effectively process the concentrates into final zircon and titanium products. The final Athabasca mineral products are dry sands which would be containerized and transported to North American and international markets by truck, rail and ocean vessels. The carbon footprint of Athabasca mineral products from tailings would be low relative to other world supply sources which require energy intensive mining and extraction. Zircon is an essential ingredient in the manufacture of ceramic tiles, zirconium chemicals, metals and other related products produced during demonstration piloting. Titanium is used in the manufacture of paint, plastics, paper and metals. Market testing of titanium and zircon product samples (from Titanium's demonstration piloting) has been conducted in China, where the samples were independently evaluated as very suitable for markets. Based on current world prices, new revenues of approximately $100 million per year at each oil sands site would be created, with industry wide potential of $400 million per year. A new minerals industry would create new capital investment, jobs, taxes and royalties for Alberta.

Bitumen Recovery from Tailings: Froth treatment tailings contain bitumen that is currently lost in tailings ponds. At naphtha based froth treatment process mining sites, 2-3% of

the original bitumen is lost in froth treatment tailings and at paraffinic froth treatment sites, approximately 7-8% of bitumen is rejected in froth treatment tailings. Titanium's CVW^{tm} technology has been demonstrated to recover 85% of the bitumen lost in froth treatment tailings. CVW^{tm} would recover in the range of 6,000 barrels per day or 2.2 million barrels annually at individual sites and over 25,000 barrels per day industry-wide (about 10 million barrels per year). The operating costs of recovering tailings bitumen are estimated to be well below $10 per barrel and this recovered bitumen would have a low carbon footprint as there would be no incremental GHGs associated with mining and extraction. A range of economic modeling indicates attractive returns on capital employed to build the new tailings processing facilities based on the values of recovered resources, environmental benefits, low capital and operating costs and ancillary savings in a number of areas including heat recovery and tailings management.

CONCLUSIONS

Titanium Corporation's CVW^{tm} technologies are well aligned with emerging public interests and are ready for implementation to deliver significant sustainable benefits for the oil sands industry and Alberta.

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TABLES

Table 1. Flocculant dosages used to dewater oil sands fluid fine tailings. The lead and./or support organizations are listed along with a brief description of the application and the flocculant dosage utilized.

Organization	Description	Flocculant dose (ppmw)
DOW Chemicals[1]	high throughput thickening of oil sands tailings	1500
Residue Solutions[2]	mud farming with modified amphirols	1150
U of A/Syncrude[3]	Suncor cyclone overflow, thickened tailings	1100
Kemira[4]	Polymer flocculated oil sands MFT	1000
Syncrude[5]	centrifuging flocculated tailings	800
Royal Dutch Shell[6]	Atmospheric Fines Drying (AFD) experience	780□910
University of Alberta[7]	thickening of MFT; impact of bitumen	500
University of Alberta[8]	thickening of froth treatment tailings	450
Titanium Corporation	**Thickening/thin lift drying**	**200-400**

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High-Throughput Techniques", Third International Oil Sands Tailings Conference, Edmonton, Dow Chemical Company, 12 pp.

[2] Munro, L.D., and D. Smirk (2013), "Mud Farming of Fine Tailings – Application and Benefits of MudMaster Technology", Tailings and Mine Waste 2013, Banff, Residue Solutions, 10 pp.

[3] Jeeravipoolvarn, S. (2010). "Geotechnical Behaviour of In-Line Thickened Oil Sands Tailings", PhD Dissertation, Department of Civil and Environmental Engineering, University of Alberta, 431 pp.

[4] Fenderson, T., S.G. Thakurta, A. Mahmoudkhani, P. Watson, Y. Wu, K. Stewart (2013), "Understanding dewatering limits of polymer flocculated oil sands mature fine tailings", Tailings and Mine Waste 2013, Banff, Kemira, 15 pp.

[5] Spence, J., B. Bara, J. Lorentz, R. Mikula, J. Lee, R.D. Lahaie, R. Cameron, R. Donahue and N. Wang (2014), "A centrifuge process for dewatering oil sands tailings", Canadian Patent 2824543, Syncrude Canada Ltd.

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[7] Klein, C., D. Harbottle, L. Alagha and Z. Xu (2013), "Impact of Fugitive Bitumen on Polymer-Based Flocculation of Mature Fine Tailings", Canadian Journal of Chemical Engineering, **91**(8), 1427-1432

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FIGURES

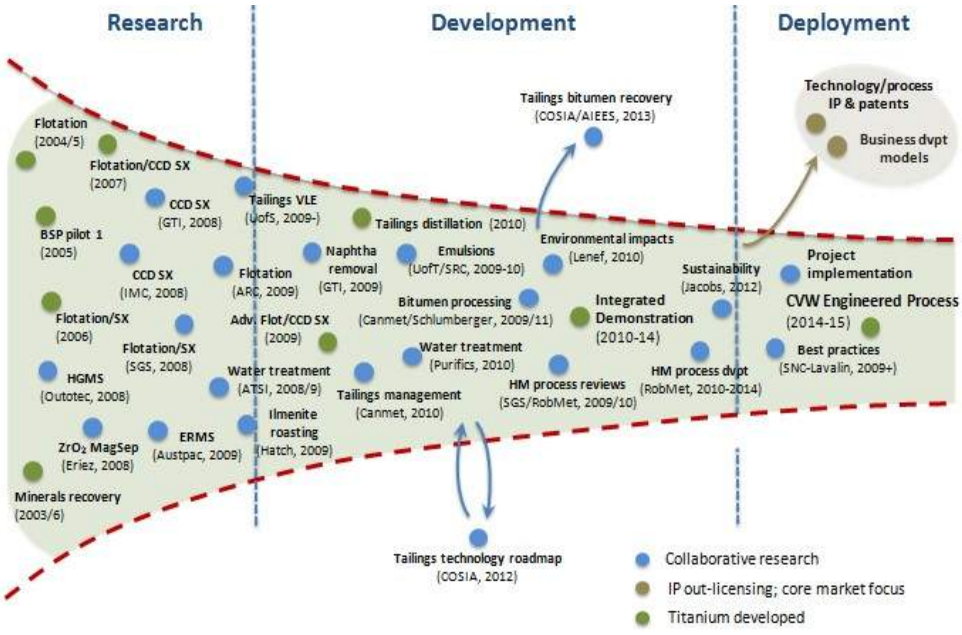

Figure 1. Funnel diagram showing elements of the open innovation research and development pathway for Titanium Corporation's CVW[tm] technology.

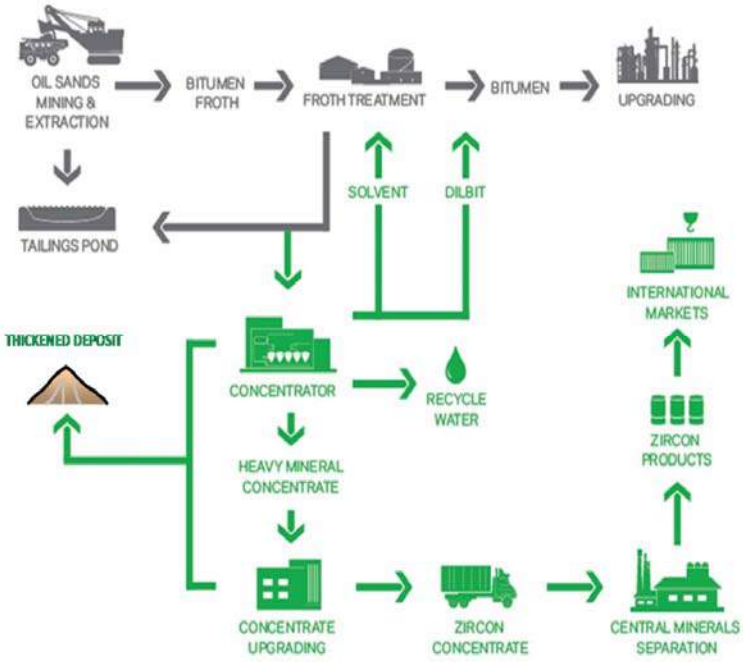

Figure 2. Generalized schematic showing how Titanium Corporation's CVW[tm] technology process blocks (in green) integrate with an existing oil sands mining operation (in grey).

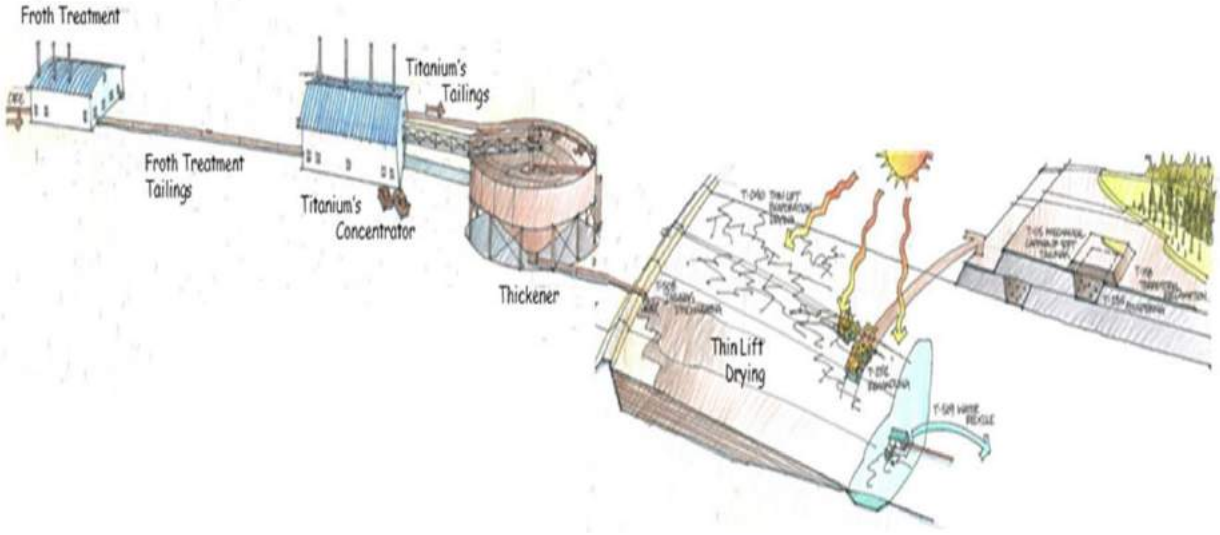

Figure 3. Conceptual drawing of Titanium's CVW[tm] tailings management technologies designed to provide an 'end-to-end' solution for direct dry reclamation of froth treatment tailings slurries. (adapted from: Sobkowicz, J.(2012), "Oil Sands Tailings Technology Deployment Roadmaps: Project Report – Volume 1, Project Summary, Report to Alberta Innovates – Energy and Environment Solutions", File 17-235-22, Thurber Engineering).

Figure 4. Photographs depicting the processing of Titanium's fine fluid tailings in a thickener and rim ditch process at CanmetENERGY's tailings testing facility.

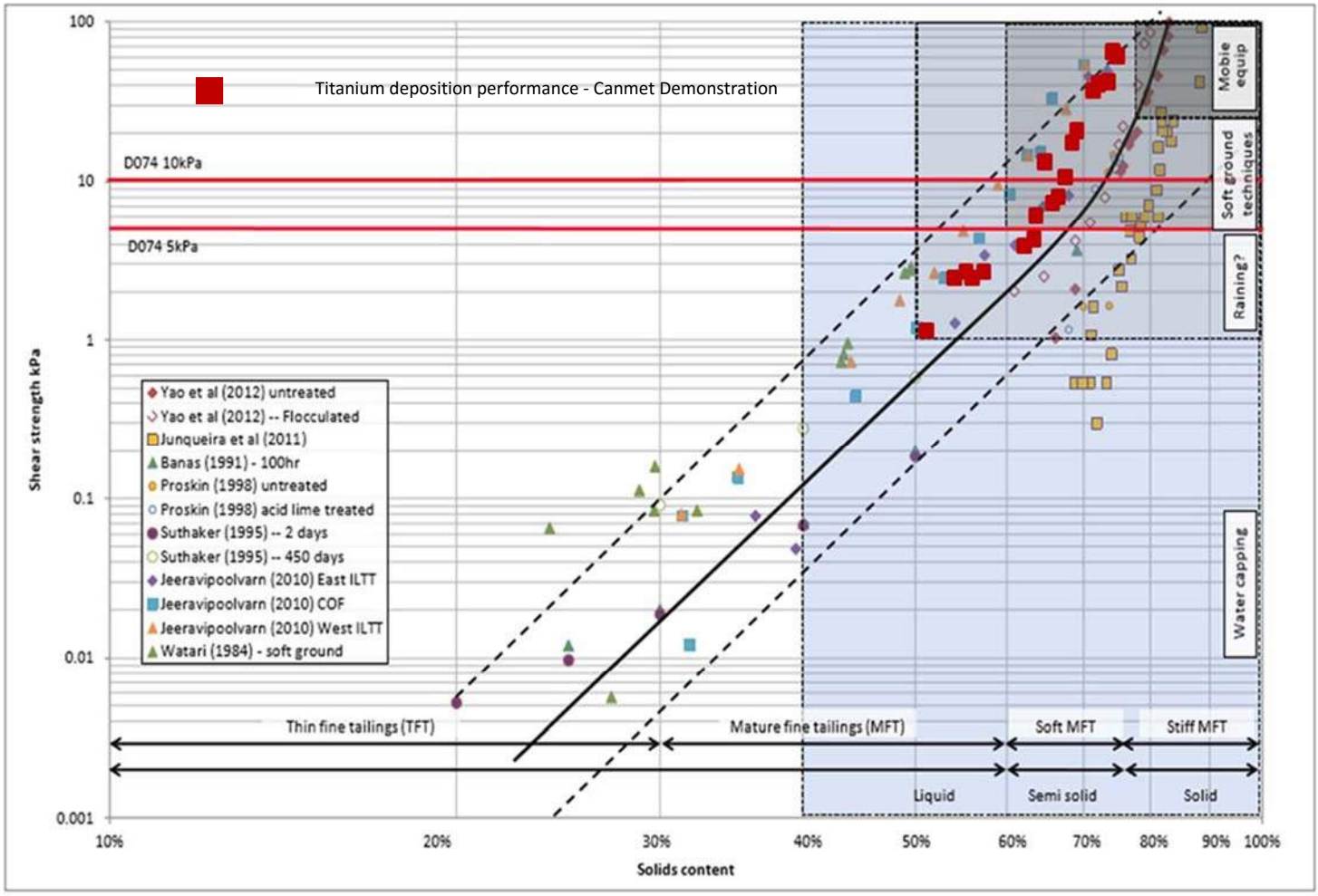

Figure 5. The shear strength of Titanium's fluid fine tailings in dry lift depositions with relevant comparative data. Titanium's tailings performance is given as the solid red squares. Graph adapted from Chow, R., G. McKenna, S.M.K Win and J. Journault (2013). "Recovery of Bitumen from Oil Sands Tailings Streams and Deposits: Potential Opportunities and Benefits", HOOS-16156-2013, Alberta Innovates Technology Futures; and Bromwell Engineering Inc. (1983). "Geotechnical Investigation of Mildred Lake Oil Sand Tailings Sludge Disposal, Consultants report prepared for Syncrude Canada Ltd", Lakeland, FL, pp. 119.

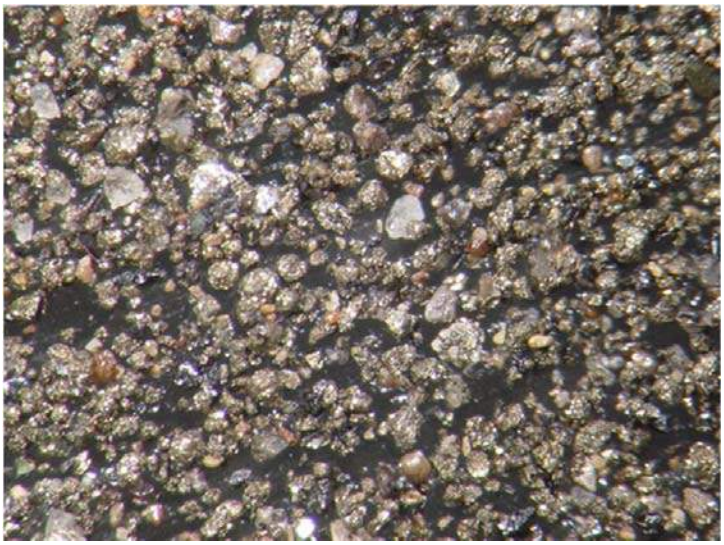

Figure 6. Micrograph (32x) of pyrite enriched stream processed out of froth treatment tailings by Titanium Corporation technologies.

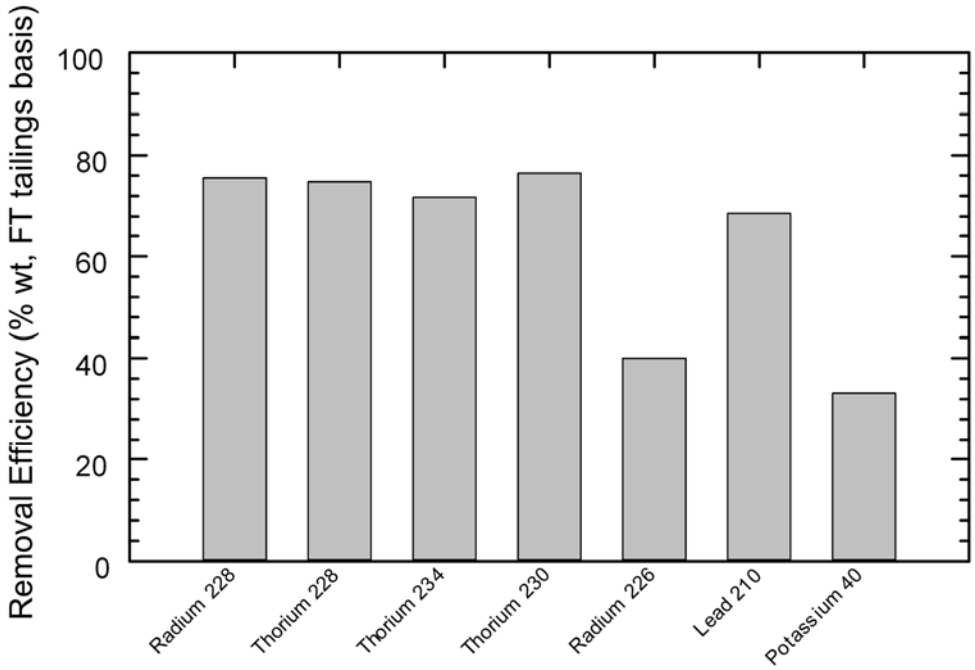

Figure 7. Removal efficiency of radionuclides from oil sands froth treatment tailings via Titanium's CVW^{tm} tailings remediation technologies.

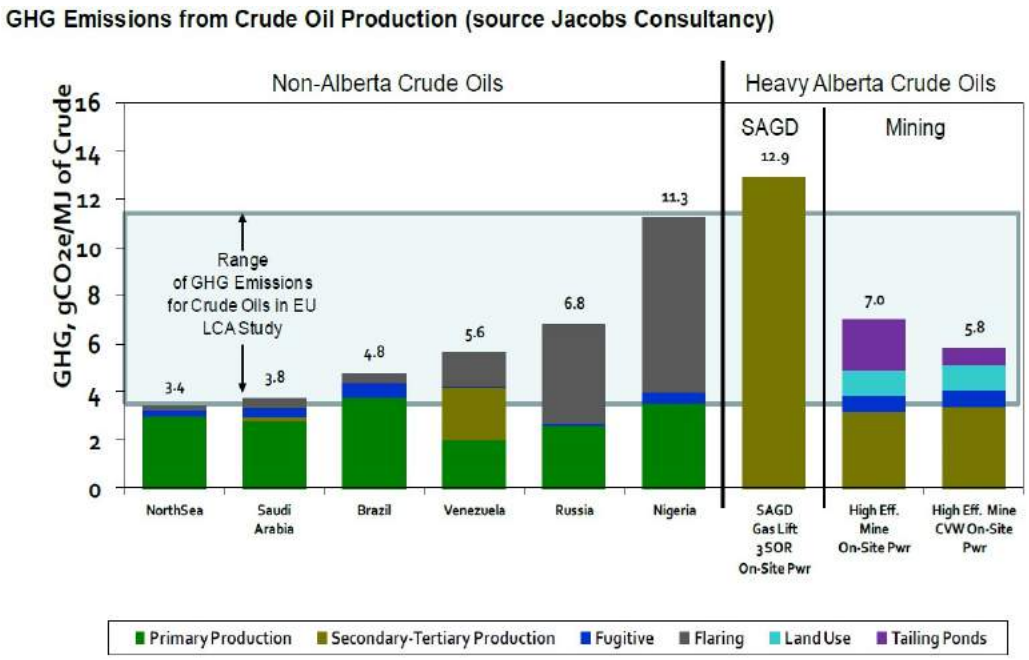

Figure 8. GHG emissions of crude oil production by region and operation. The right-most data set indicate the impact of Titanium's CVW^{tm} technologies,