

Oil sands: backfill for tailings management

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Abstract

Oil sands mining has traditionally been large-scale operations using either truck and shovel or steam-assisted gravity drainage (SAGD) applications. This has meant that exploration and mining of oil sands has focused on large deposits that justify the use of the existing infrastructure and technologies. These large-scale operations also create large areas of land disturbance and have historically generated significant volumes of tailings and process-affected water that need to be managed. There is a new approach that is targeting smaller-scale deposits that do not meet the requirements of either truck and shovel or SAGD. These smaller deposits are often located in pockets, with four to five deposits being co-located in a general footprint, and they are generally closer to the surface than traditional SAGD deposits. The concept is to focus on underground extraction from the surface without the disturbance of truck and shovel and without the infrastructure of SAGD. The concept also allows for the tailings generated after extraction to be used as the feed material for backfilling the underground void.

This paper will be one of a series of papers presenting the alternative mining method being developed for small-scale oil sands mining and the backfill strategy to both manage tailings generated from the extraction process and preserve the stability of the underground operations. In addition, the test results from the initial backfill recipe development will be discussed along with the conceptual design for backfill delivery.

Keywords: *backfill, paste, alternative mining methods, near-surface voids, oil sands*

1 Introduction

Historically, oil sands mining has been executed in large-scale operations by either the truck and shovel (surface mining) method or the steam assisted gravity drainage (SAGD) method (Oil Sands 2021). Oil sands are a mixture of sand, water, clay and a type of crude oil called bitumen that is too thick to flow on its own. Oil sands deposits are found globally, including in Venezuela (Dusseault 2001), the United States (Crysdale 1988), Russia, and Canada. Canada is home to the Alberta oil sands, the fourth largest proven crude oil reserve in the world, which stretches across three regions: Athabasca, Cold Lake and Peace River. Together these three regions encompass a total area of over 142,000 square kilometres (National Resources Canada [NRCAN] 2022).

Among the Alberta oil sands, approximately 20% of the reserves are shallow enough to make use of the mining (truck and shovel) method. Most surface oil mines have sand deposits that are less than 50 m below surface, however, they can be as deep as 75 m (Oil Sands 2021). The surface mining method uses large trucks with scoops to extract the oil sands and it is then transferred to facilities where the bitumen is separated from the sand prior to the bitumen being upgraded and refined.

The other 80% of the oil sand reserves in Canada are at a depth too far from surface, greater than 75 m, to use truck and shovel, and hence make use of the SAGD (in situ) method. The in situ method is advantageous in that many wells can be drilled from a small surface location, with a massive reduction in the total land disturbance as compared to the truck and shovel method. However, there is substantial infrastructure required for SAGD operations. This infrastructure is required to produce steam. The SAGD method is executed by drilling pairs of horizontal wells approximately 400 m below surface to the oil sand reserves. The top well injects steam into the oil sand reserves to heat up the bitumen and separate it from the sand. The

bitumen is then pumped back up to the surface through the secondary well. On the surface, the bitumen is treated, and the water is separated out and re-used in the process (NRCAN 2022).

There are considerable environmental challenges associated with both traditional oil sands extraction methods. The truck and shovel method results in the production of tailings, which need to be managed to maintain chemical and geotechnical stability and immobilise any constituents of concern. It also requires a large area of land for the external tailings facility (ETF). There are also permitting and environmental regulations that must be followed, in addition to the operational and closure requirements for ETFs. Trucking also uses large amounts of diesel fuel for transport of the oil sands. In SAGD it is the large amounts of natural gas used for warm water extraction that create environmental hurdles from a greenhouse gas emissions perspective (NRCAN 2022).

The new method of oil sands extraction discussed in this paper targets mid-depth oil sand reserves and can be applied to smaller-scale oil sands reserves that do not meet the requirements for truck and shovel or the SAGD method. The primary target area is 'the Middle' deposit, which is approximately 6% of the Athabasca oil sands and covers 9,600 km², with 102B barrels of oil in place.

The new technology being developed has a focus on extraction without the required land disturbance of truck and shovel and the mass infrastructure of the SAGD method. Called gravity-assisted bitumen extraction (GABE™), it is a patent-pending process for net-zero bitumen recovery and extraction that will eliminate the requirement for tailings facilities and reduce greenhouse gas emissions while utilising waste streams from other industrial processes.

In addition to reduction in land use and greenhouse gas emissions as compared to traditional oil sands methods, GABE™ is also designed to incorporate the use of tailings in the backfill. The tailings produced from the oil sands extraction will be combined with a binder to create a paste backfill to fill the underground voids created from oil sands extraction.

This paper will discuss the conceptual design of the mining method along with preliminary laboratory data for the paste backfill recipe and the conceptual layout/distribution system for the paste backfill.

2 Gravity-assisted bitumen extraction

2.1 Bitumen extraction

GABE™ is a new oil sands extraction technology that is designed to access 'the Middle' zone, which is classified as the area that is too deep for the surface mining method and too shallow for the SAGD method. This method allows for the recovery of bitumen without the use of large mining equipment or the need to generate steam to heat the bitumen.

To start the GABE™ process, a traditional directional drilled well is drilled with 13" conductor pipe, 11" intermediate casing and 9-5/8" production casing. The last 20 m of well uses a unique half-moon casing. The well is completed with a 9" diameter auger that has a special underreamer to create a larger hole (Figure 1). The auger works to de-stabilise and break down the underground oil sand formation (Dusseault & Morgenstern 1977). Once the formation has been destabilised, the auger is used to pull back and transport the oil sand and water back through the well to the surface.

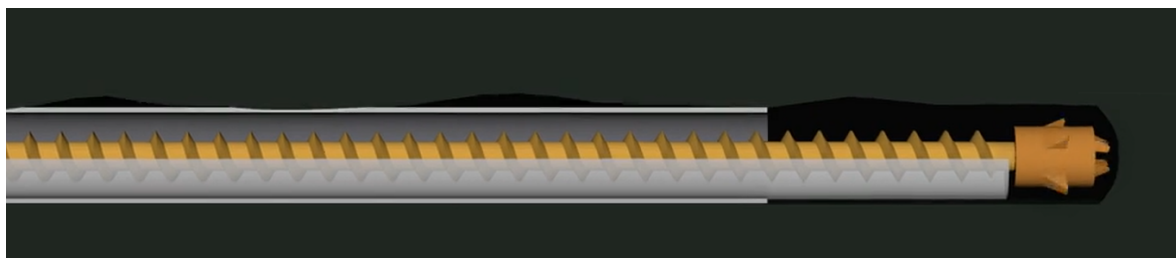
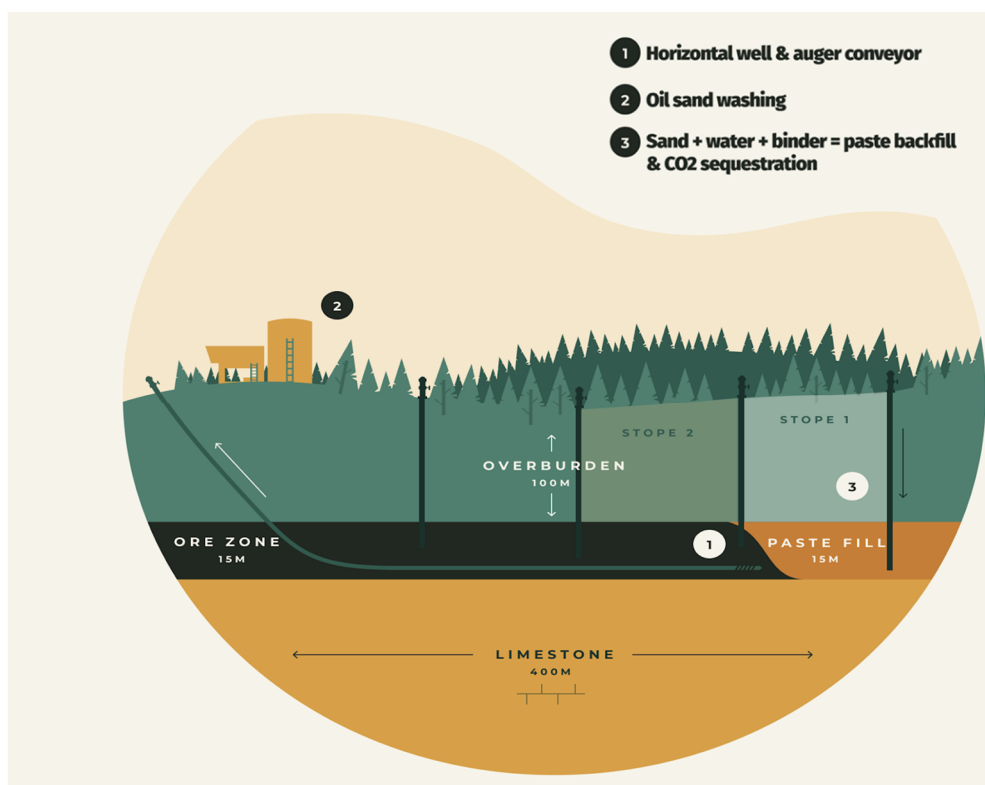


Figure 1 Preliminary schematic of the auger arrangement showing the half-moon casing

The techniques used for the oil sand recovery are similar to those used in block caving or tunnelling principles but, rather than keeping the tunnel open, the purpose of the reaming is to allow the tunnel to collapse in a controlled way (Figure 2a). The vertical boreholes shown in Figure 2a are for delivery of paste backfill. Once the tunnel has collapsed, the auger can transport the collapsed oil sand to surface for processing. In other words, the cavity will keep collapsing and increasing in size as the auger retreats and transports the oil sands to the surface. Because of the typical depths of the deposit from the surface it is unlikely that sinkholes will occur, however, surface subsidence is a risk (Stone 2014); the purpose of the backfill is to avoid this. The entire concept can be seen in Figure 2b.



(a)



(b)

Figure 2 (a) Preliminary schematic of the auger and void development in the near-surface oil sand deposit; (b) Overall concept of the near-surface oil sands recovery

2.2 Bitumen separation

Once transported to surface, the oil sands are then washed in a single-pass warm water and chemical process based on Dr Karl Clark's separation method. This involves warm water washing, otherwise known as mechanical separation, for a once-through bitumen extraction process.

To separate the bitumen from the sands, the oil sands in the tanks are mixed with 60°C water. The mixing with warm water causes the oil sands to separate into layers where the densest material, the sand, sinks to the bottom and the water rises to the top. Unlike other oil products, oil from the Athabasca oil sands is denser than water but less dense than the sand; therefore it ends up in a middle layer that must be extracted. After the addition of warm water there is a kneading process of the oil sand until the pulp reaches a temperature of approximately 80°C, when it is then mixed into a turbulent stream of circulating water. The circulating water passing through the sand distributor washes the pulp in a large quantity of warm water, termed the separation cell, at a temperature of 85°C. This process creates a froth that is 55% bitumen, 40% water and 5% solids. From the separation cell, the oil floats as a froth on the top of the water and can then be skimmed off.

The warm water extraction process only requires a 1:1 ratio of water to oil sand to recover 80% of the bitumen. In comparison, the industry average is a 3:1 water to oil sand ratio, which means that the GABE™ technology provides a considerable amount of water savings.

2.3 Environmental

As compared with the traditional oil sands bitumen extraction methods, there is an immediate reduction in emissions from 71 to 22 kg CO₂e/bbl (69% lower). In addition to these direct benefits, there is the potential for an additional 15% reduction by using electrification of selected processes. The remaining 16% reduction (from 11 to 0 kg) to produce net-zero emissions is achieved by the sequestration of CO₂.

3 Backfill

3.1 Backfill process description

Upon the completion of the bitumen separation process, the froth product will have 40% water and 5% solids material remaining after the bitumen is skimmed off. Instead of disposing of this by-product in an ETF, the useable portion of aggregate will be screened off and re-used and/or sold. The remaining portion of solids will be mixed with recycled water and a binder to create a paste backfill. The paste backfill recipe is undergoing testing at the time of writing this paper and aims to use a blended binder of ordinary Portland cement (OPC) and cement kiln dust (CKD) which is waste product from the cement industry.

The paste will be pumped to a vertical well and deployed down into the end of the horizontal section to fill the underground void left from the oil sands recovery (Figure 3). As the oil sand formation is recovered, the well casing and auger are pulled back to facilitate continued extraction. This process is repeated every 100 m along the 1,000 m horizontal well section. For wider deposits, variation on the process will be explored e.g. moving some distance laterally in the deposit and drilling another well.



Figure 3 Preliminary schematic of the backfill delivery into the void space left by the auger extraction

3.2 Backfill as a sink

In addition to providing geotechnical stability to the underground void and redirecting tailings material underground, there is another opportunity being explored related to using the backfill as a CO₂ sink. The process involves sourcing CO₂ from offsite capture projects and then diffusing it into the paste backfill to create limestone crystals which will sequester the CO₂ in a similar fashion to concrete sequestering processes.

3.3 Backfill test results

The first step in any paste backfill laboratory program is to assess the potential for the feed materials, e.g. tailings, to make a good backfill. Materials received in the laboratory for testing included two samples of tailings: coarse sand tailings and whole tailings. These two materials were run through an index property testing program which helps identify the 'fingerprint' of the materials. This helps to baseline the materials, and is followed by other tests, such as rheology, that assess the ultimate performance of the paste backfill.

3.3.1 Index properties

The specific gravities of the coarse sand and whole tailings were 2.60 and 2.72, respectively. The particle size distributions (PSD) are shown below in Figure 4. The PSD of the whole tailings sample is fine and will likely require blending. Given the presence of some clay minerals, the performance of the whole tailings in terms of settling, strength gain, etc. will also likely benefit from blending with the coarse sand tailings.

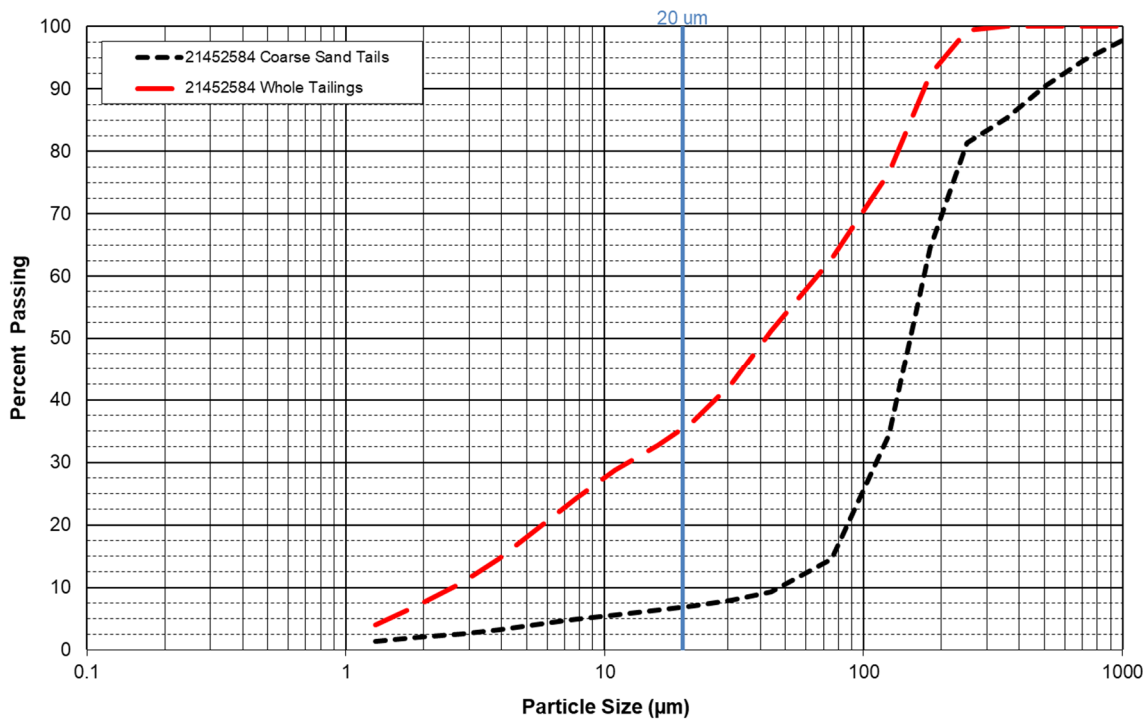


Figure 4 PSD for coarse and whole tailings

Residual bitumen in the samples was measured using the conventional Dean Stark method and was recorded as 1.17 and 2.08% in the coarse and whole tailings samples, respectively.

The x-ray diffraction (XRD) analysis of the tailings’ samples and the cement kiln dust is shown in Figure 5. The tailings are predominantly quartzite, with the balance comprising a few clay minerals.

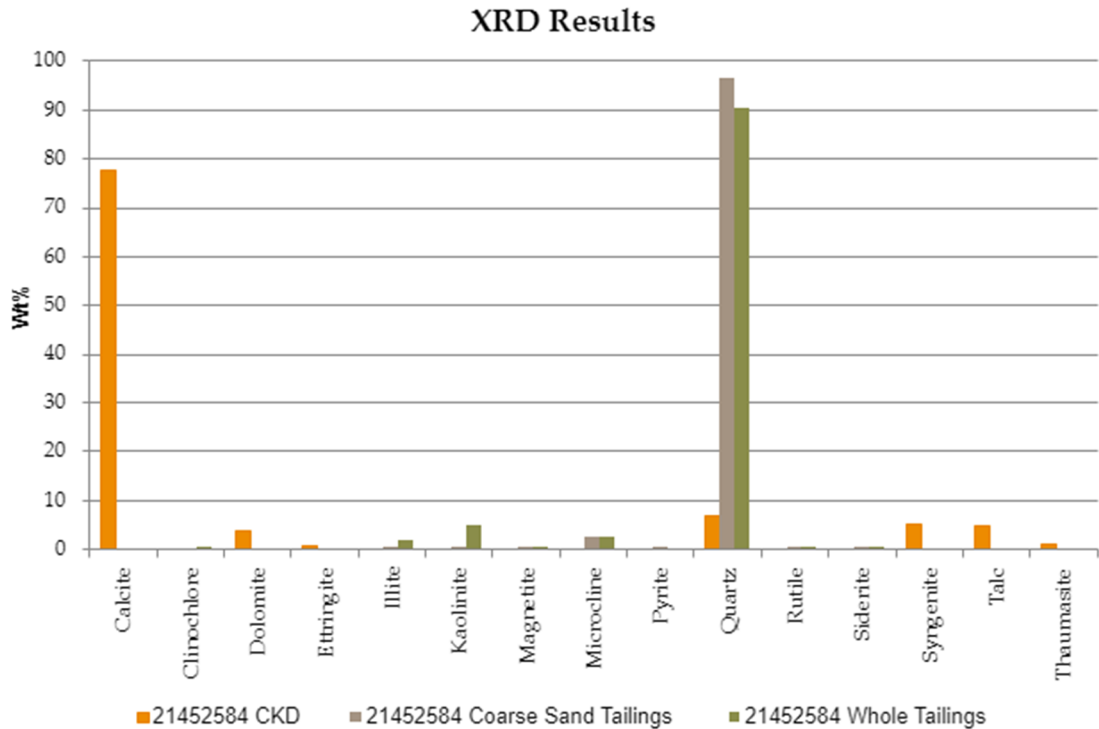


Figure 5 XRD results

The index property assessment generally indicated that both tailings' samples have the potential to make a good paste backfill.

3.3.2 Rheology

Rheology testing was undertaken to assess the paste backfill ability to flow and move through the void space created by the auger extraction. A slump test was performed using a standard slump cone with a height of 300 mm, a bottom diameter of 200 mm and an upper diameter of 100 mm. Figure 6 is from the whole tailings.

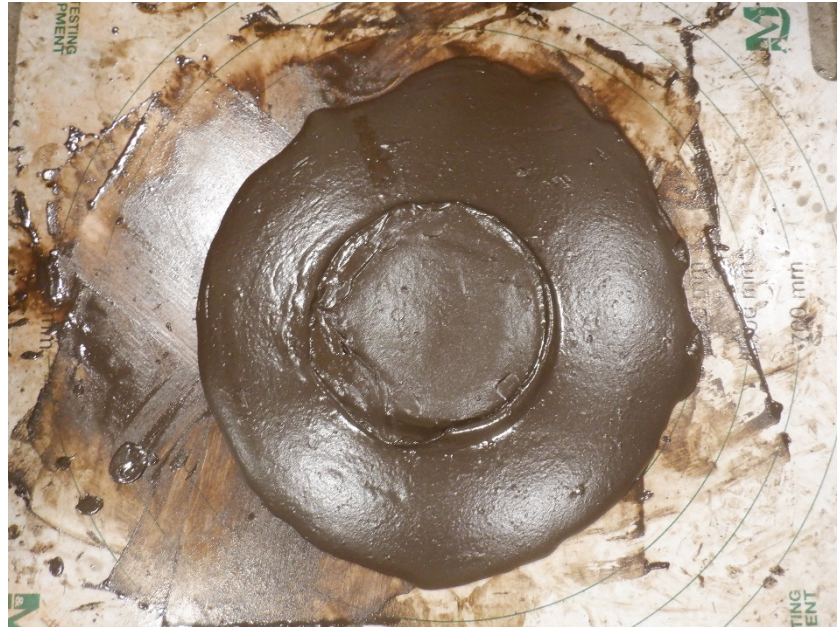


Figure 6 178 mm (7") slump test for whole tailings

The slump versus solids curve is in Figure 7 and shows the whole tailings are moderately sensitive to water addition.

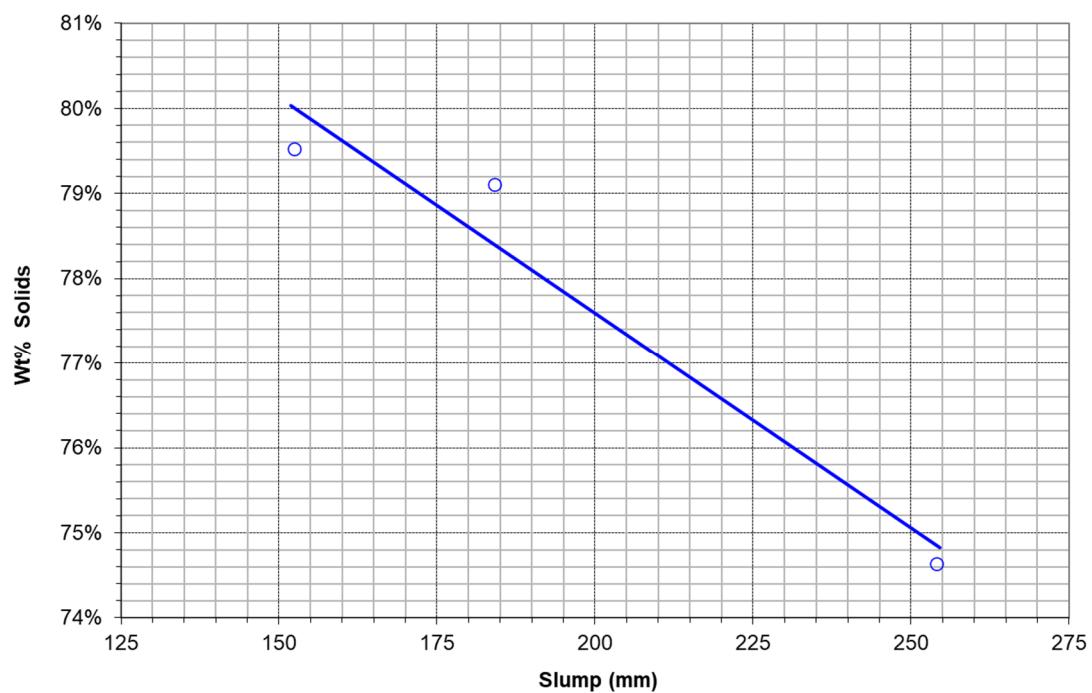


Figure 7 Slump versus solids curve

3.3.3 Unconfined compressive strength

The unconfined compressive strength (UCS) program was undertaken to assess the strength gain potential of the paste backfill. Several different recipes and binder types were tested, and the results are shown in Table 1. The 28 day strength targets are still being developed for various configurations of the underground void spans but will be a minimum of 200 kPa and likely will be higher.

Table 1 UCS test matrix and results

Mix design	Feed type	Slump	Binder content	Binder type	UCS (kPa)					Comments
					1	3	7	14	28	
1	50/50 C:W	7"	5%	OPC	61	184	95	NA	111	Baseline
2	50/50 C:W	7"	5%	CKD	0	0	0	0	0	CKD comparison to OPC
3	70/30 C:W	7"	10%	CKD	0	0	0	0	0	High coarse
4	30/70 C:W	10"	7%	CKD	0	0	0	0	0	High fines
5	50/50 C:W	7"	10%	95CKD/50PC	TBD	TBD	TBD	TBD	TBD	–

C:W = coarse tails:whole tails

The goal of the UCS program was to maximise the use of the CKD. However, the results show that no strength was obtained with CKD alone. With CKD being less reactive, additional activators/alternative binders will need to be explored in additional testing. A binder blend of CKD/OPC was therefore tested as well. The early results are promising.

4 Future work

In order to prove some of the concepts in the GABE™ process a pilot test is being undertaken with three main objectives:

- Confirmation of the 85% reduction in CO₂ emissions as compared to surface mining and thermal extraction methods.
- Confirmation of land use reduction compared to surface mining operations.
- Confirmation of the 1:1 water-to-sands extraction process.

The pilot will consist of one well with a 1,000 m-long horizontal section, which is planned to be the commercial length. The auger will be installed and will be able to open the hole to commercial sizes to confirm that the diameter of the hole will lead to oil sands collapse. The target production rate for the pilot is half of the commercial rate, at 22 m³/h oil sand recovery. The pilot well is expected to produce approximately 700 bbl per day. Pilot activities will also include onsite warm water extraction, paste backfill, CO₂ sequestration and surface monitoring.

The pilot is projected to take place in 2023 and span approximately 12 months. The production targets for the GABE™ pilot are 21,000 bbl of bitumen over approximately 30 days with an intensity of 22 kg CO₂e/bbl before CO₂ sequestration in the paste backfill. Paste backfill will sequester an additional 11 kg CO₂e/bbl.

5 Conclusion

Oil sands mining has conventionally been implemented in large-scale operations by either surface mining or SAGD applications. Exploration and mining of oil sands have an emphasis on the larger deposits that justify the use of these existing technologies and the major infrastructure that is associated with them. GABE™ is a new innovative technology that will expand the opportunity for oil sands recovery to ‘the Middle’ zone, drastically reduce greenhouse gas emissions, reduce land disturbance and remove the requirement for tailings ponds. Additionally, GABE™ has a much lower capital costs option that can be applied to smaller-scale oil sands deposits that are not currently economically feasible with traditional extraction methods.

The GABE™ pilot project will be a critical milestone to determine the future possibilities available for a widespread implementation of GABE™. This is the beginning of major development in oil sands extraction technology that will bring about a greener and more expansive future for the oil sands industry.

References

- Crysedale, BL 1988, *Bitumen-Bearing Deposits of the United States*, US Geological Survey Bulletin 1784, viewed 22 January 2022, <https://pubs.usgs.gov/bul/1784/report.pdf>
- Dusseault, MB & Morgenstern, NR 1977, *Shear Strength of Athabasca Oil Sands*, Department of Civil Engineering, University of Alberta, Edmonton.
- Dusseault, MB 2001, ‘Comparing Venezuelan and Canadian heavy oil and tar sands’, *Proceedings of the Canadian International Petroleum Conference*, Canadian Institute of Mining, Metallurgy & Petroleum, Westmount, viewed 21 January 2022, https://www.researchgate.net/profile/MauriceDusseault/publication/254538101_Comparing_Venezuelan_and_Canadian_Heavy_Oil_and_Tar_Sands/links/55db0dd708aeb38e8a8a458d/Comparing-Venezuelan-and-Canadian-Heavy-Oil-and-Tar-Sands.pdf
- National Resources Canada 2022, *Energy Fact Book 2022-2023*, Natural Resources Canada, viewed 25 January 2023, https://natural-resources.canada.ca/sites/nrcan/files/energy/energy_fact/2022-2023/PDF/Energy-factbook-2022-2023_EN.pdf
- Oil Sands Magazine 2021, *Oil Sands Emissions by Extraction Method: Busting Myths on GHG Intensity*, viewed April 2021, <https://www.oilsandsmagazine.com/news/2021/3/18/oil-sands-emissions-by-extraction-busting-myths-on-ghg-intensity>
- Stone, D 2014, ‘The evolution of paste for backfill’, in Y Potvin & T Grice (eds), *Mine Fill 2014: Proceedings of the Eleventh International Symposium on Mining with Backfill*, Australian Centre for Geomechanics, Perth, pp. 31–38, https://doi.org/10.36487/ACG_rep/1404_0.3_Stone