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I. Introduction.

Oil in Alberta has been traditionally one of the main resources on which the province’s economy was always based. In today’s conditions, while the reserves of conventional oil are constantly diminishing, the production of heavy oil and bitumen associated with oil sands deposits will increase dramatically in the coming years. Over $15 billion have been invested in oil sands projects over the past five years and construction is under way at several new or expansion projects. This will increase the production of oil to 50% of Canada’s output and 10% of total North American production of oil in the following 5 years. The oil sands projects together with other oil & gas developments account for almost 67% of all major projects listed by Alberta Economic Development in their Inventory of Alberta Major Projects in August 2003. Among other aspects incurred by these grand scale investments like infrastructure or energy supply, environmental issues are also challenges that have to be considered in establishing the strategy for a sustainable development in the area maintaining a rich and healthy environment for future generations.

Recognizing the increasing importance of the cumulative environmental impacts, the Alberta Department of the Environment has developed a Regional Sustainable Development Strategy (RSDS). This strategy, and the oil sands companies' cooperation and involvement, have been noted by the Alberta Energy Utilities Board as important elements in granting regulatory approvals for the various oil related projects.

The extraction processes based on technologies like SAGD or CHOPS (Cold Heavy Oil Production with Sand) associated with the oil sand industry generate large amount of sand-wastes with no commercial value that constitutes into a serious
environmental concern if improperly disposed. Currently used and potential future technologies to dispose these wastes will be described in the present paper along with costs incurred and other economical implications that have to be considered by any project developer in the field.

II. Environmental issues associated with oil solid waste disposal.

In the last years, oil sands industry became an increasingly major driver behind the economic activity in Alberta. While contributing to the economic well being of the province through long-term employment creation, purchases of goods and services, and payment of taxes and royalties, oil sands industry expansion also places stresses and risks on the biophysical environment. Increasing oil sands activities will increase the amount of land disturbed and the production of waste and emissions. All projects are required to conduct an Environmental Impact Assessment as part of their regulatory approval process and more and more emphasis is being placed on the cumulative effects assessment.

Both sets of extraction methods, the mining processes and the in situ recovery generates large amount of wastes that have no commercial value and represent a threat to the environment if not managed properly. Although in the mining projects, most of the solid waste is used in the land reclamation process that follows after the oil sand extraction there are important quantities of waste sand that have to be disposed in other locations. These wastes are mainly the following:

- Large volume of sand containing 1%-5% oil related substances by weight. Approximately 30-40 kg of sand are generated by every cubic meter of oil produced.
- Stable emulsion, consisting of a mixture of water, bitumen, different diluents and fine-grained sand particles and clay. Approximately 3-5 kg of emulsion are generated for each cubic meter of oil produced.
- Tank sludge, consisting of a mixture of emulsion, additional asphaltenes and fine-grained sand.

These waste products if not managed properly are responsible for destructive effects on the surrounding environment affecting the land, water and air.

The main harmful effects associated with the oil sand wastes are presented below:

- Surface disturbances produced by waste sand deposits and tailings ponds.
- Emissions of VOC and Total Reduced Sulphur compounds from the tailings ponds and waste disposal sites are also a concern to nearby residents. VOC (Volatile Organic Compounds) are a major contributor to odour and ozone formation affecting the air quality in the neighborhood.
- Changes in water quality of streams, rivers, lakes and underground water due to potential leaks from the tailing ponds or waste disposal sites under the effect of precipitations.

The human and wildlife habitats on the adjacent areas are affected by higher than normal concentration of acidity and heavy metal deposition on soil and vegetation. This represents a serious threat for fish, wildlife and human health in general. Mitigation of these risks involves the timely identification of the issues, information sharing among all stakeholders, and cooperation in finding the optimal method for waste disposal that minimizes the risks and the associated costs.
III. Methods of Disposal and Treatment of Sand Waste.

Disposal of huge volumes of wastes is a crucial aspect of the oil sand industry simply considering the costs incurred. Not of less importance are the environmental ramifications with long term implications in the quality of ground water and surface conditions. Currently there are two sets of methods to be considered in waste management: disposal methods and treatment methods. While being more expensive, the treatment technologies attempt to produce a fully “rehabilitated material”, easier to dispose.

A. Disposal Methods.

1. Sand Waste Stockpiling

Because of its simplicity it was used on a large scale. Large sand stockpiles can be seen in many locations. When initially disposed the sand contains approximately 20% formation water and 2-6% oil by weight. Because rainfall can help mobilize chlorides in the aqueous phase and dissolve small amounts of hydrocarbons, environmentally suitable storage sites with groundwater protection are now generally required in the form of “Ecology Pits”. In general these are temporary storage locations for sand in transit to a permanent disposal site. In order to set an “eco-pit”, the topsoil is removed and placed in a stockpile for future reclamation. Subsoil is graded into a flat-bottomed pit surrounded by berms approx. 1 m high. A shallow ditch is installed on the inside of the berm to trap all liquid from the produced sand stockpile. A membrane of fibre HC-resistant flexible polimer fabric is placed on the bottom of the eco-pit and on the inside slopes of the berms to prevent any leaching from the sand stockpile into the grand. A single entrance specifically designed to intercept any liquid run-off is built to allow equipment traffic No
protection against wind-mobilization of particulates is implemented because the oil content of the sand usually provides resistance to wind erosion. Conservation authorities require careful monitoring of ground water around stock piles using a set of wells drilled around the stock pile from which samples are periodically withdrawn.

A typical design for a 04- 1.0 ha eco-pit is presented in Fig. 1.

FIG. 1: Cross-Section of an Ecology Pit for Sand Stockpiling
(Source: Alberta Energy – Publications: Oil Sands –CHOPS. Author – Dr. Maurice Dusseault)

2. Sand Disposal by Road Use and Land Spreading
   Disposal of produced sand by spreading on roads or fields is a practice used from 1950’s or perhaps even earlier. A more recent option is to incorporate sand into a carefully designed mix for road base construction.

   a. Road Spreading

   It was widely used in the past on the gravel roads in Alberta and Saskatchewan because the sand with its oil contention tends to reduce dust on the roads. The produced
sand has been taken from companies’ stockpiles and transported on different roads where it is spread in a layer generally no more than several inches thick.

*Advantages:*

- Rapid and economical method, simple technology, no need for special facilities.
- Oily sand is an excellent dust suppressor for dirt and gravel prairie roads.
- Long-term scientific monitoring indicates that there is no significant negative environmental impact if the spreading is done properly.

*Disadvantages:*

- Runoff from the oily sand on the roads can affect the local ground water.
- With increased quantity of sand as the heavy oil production rises, operators have to go farther and farther from the stockpiles thus increasing costs are incurred.
- No liquids, slopes, sludges or emulsions can be directly disposed.
- The sand is not a good road material if not used in a designed mix.

Waste spreading on the roads is no longer viewed as a viable long-term strategy. Provincial regulatory authorities have expressed concerns over the possibility as the quantities of disposed sand increase.

**b. Sand Incorporation into Road Bases**

Produced sand and other oily solid wastes can be used as part of road base construction material for new roads of industrial and local interest. The mix of approx 50% produced sand and 50% sized gravel with additional heavy oil or asphalt and elemental sulphur (also a “waste” if there is little market demand for it) showed reasonable stability for long-term traffic. The sulphur and small amount of additional asphalt help encapsulate the oil and residual chloride in the hot mix as it is compacted.
Advantages:

- The produced sand is now a useful material, rather than being disposed as waste.
- The leachable components of the heavy oils on the sand are encapsulated by the additional asphalt and sulphur.
- Sulfur, another material of little commercial value is used at the same time.
- Immediate reduction of costs of disposal because the sand is used as a construction material. Most economical disposal option at the present time.

Disadvantages:

- The number of kilometers of additional roads that will be available is limited by local demand and availability of municipal financial resources.
- The long-term durability of the road-base mix unknown more study is needed.
- Transportation costs rise with distance.

c. Land Spreading.

“Land spreading” usually refers to a once-only application of waste to a field or to a non-cultivated land. The placement of oily solid wastes on the land surface and incorporating it into the soil horizon is basically a process of uncontrolled biodegradation. Biodegradation is highly effective for HC contaminated soils, provided that most of the HCs are of low molecular weight (light aromatics and short chain aliphatics) and is less effective for high molecular weight and sulfur-rich HCs. Nevertheless, particularly in clayey soils, the addition of several inches of sand-sized material improves the texture and air-flow capacity of the soil, improving the crop bearing capabilities of heavy (clay-rich) soil. Approximately 330,000 m³ of sand
produced in 1997 would require about 14-15 square kilometers if placed at a thickness of 25 cm.

A version of the method known as “land farming” method was used in the past in permanent facilities where the surface of the land was carefully managed to accept repeated applications of waste. The regulatory authorities are not permitting new land farming or spreading at this time, and it is likely that it will never again be permitted.

**Advantages:**

- Land spreading has been used for decades throughout North America, and is a well recognized method for disposal, of NOW (Non-hazardous Oilfield Wastes).
- Providing that disposal fields are nearby, land spreading can be relatively economical, although more expensive than the previous methods.
- In the right applications, produced sand can be beneficial to soil.
- No negative consequences on animals or crops have yet been recorded.

**Disadvantages:**

- Must be approved by the EUB, as it is classified as a regulated disposal facility, with requirements for measurements and monitoring.
- Incur additional costs for land spreading and mixing with the natural soil.
- Environmental liability remains high because of potential contamination problems in the adjacent groundwater, despite the approval of regulatory agency.
- No liquids, slops, sludges or emulsions may be disposed of in this fashion.
- Degradation of the HC’s is slow, unless specially-designed bacteria are added.
3. Permanent Landfill Placement

According to EUB regulations, solid NOW materials can be disposed in Class II oilfield landfills (and also in Class 1b landfills, although this would constitute underutilization of such facilities).

Class II landfills meet design, monitoring and maintenance specifications for non-hazardous oilfield materials as specified by provincial environmental authorities. In Alberta, NOW landfills can be used for moist but solid wastes like wet sand but not for liquids, slops, aqueous sludges or emulsions. Approved landfills may be found throughout Alberta, operated by towns, counties, or commercial organizations. Design, management, monitoring and closure of landfills are regulated (by EUB in Alberta).

Advantages:
- Landfills are a relatively secure disposal method for NOW. There are decades of experience with Class II landfills.
- The technology is straightforward and no complex facilities are required.
- Land values in the heavy oil area are low, and there are many sites of little agricultural potential that could be made into Class II landfills.

Disadvantages:
- Landfills do not eliminate environmental liability, as there is a risk that potable aquifers might become contaminated in the future (Fig. 2).
- Obtaining a permit for a Class II landfill for massive sand disposal requires site investigation a management plan that meets the needs of all the local stakeholders.
- Additional costs are associated with stockpiling and transporting produced sand to approved landfills that may be at some distance from the production field. (See Fig. 2.)

**Fig. 2: Issues Arising in Class II Landfills.**

(Source: Alberta Energy – Publications: Oil Sands –CHOPS. Author – Dr. Maurice Dusseault)

4. **Salt Cavern Placement of Produced Sand**

Salt cavern disposal has definite advantages over all other disposal methods. Because of the extremely low permeability of the salt strata and the tendency of a salt cavern to slowly close, it is technologically feasible to place and isolate toxic wastes permanently at a cost far less than with other toxic waste disposal methods. This is important since in addition to NOW, heavy oil production and upgrading operations generate small amounts of DOW (Dangerous Oilfield Wastes), and these are extremely expensive to treat. The large cavern acts as a huge and effective fluids and solids gravitational treatment and segregation tank. The salt strata to be used for disposal of toxic wastes should be no
shallower than 500-600 m to eliminate any risk of interaction with groundwater. They should be relatively thick, continuous and suitable for creation of caverns.

The process of waste placement is schematically presented in Fig 3.

**Fig.3: Salt Cavern Waste Placement and Management**

To develop a solution cavern for waste disposal, conventional oil well drilling is used to drill to the base of the cavern. The well is cased and cemented below the top of the salt bed and one or two concentric tubings are hung in the casing. Unsaturated water is circulated through the centre tube and brine passes up the annulus between the centre tube and the well casing. Seven volumes of fresh water are required to dissolve one volume of salt. Storage purpose created caverns, typically have volumes of 200,000 m$^3$ to 500,000 m$^3$ and are well separated from adjacent cavities. After the waste disposal (liquid waste, brine and solid waste), in time the salt strata will absorb the free fluids and will close around the waste deposit insulating it. The physical processes involved and the
geological characteristics of the suitable salt strata lead to the conclusion that biosphere contamination is highly unlikely and the salt cavern placement is perhaps the most secure disposal method. (see Fig. 4).

**Fig. 4: Salt Cavern Closure on Solid Wastes.**

5. **Slurry Injection of Solid Sand and other Oilfield Wastes**

Slurry Fracture Injection (SFI) was developed in Alberta and Saskatchewan as an alternative to surface disposal methods for produced sand. The method involves injection under conditions of continuous fracturing of a slurry of waste sand and water into a stratum that is either a depleted reservoir or permeable oil-free water sand. The water used to generate the slurry can be produced water or slops. A small proportion of emulsion can be included. It is important that an appropriate stratum and injection well be available. The bed must have a minimum 5-6 m thickness of permeable sand to allow unimpeded injection (high k= injectivity value) and radial drainage. Low permeability neighboring strata to insulate the stratum in which the waste is injected as well as a low
resistance to fracture propagation in order to reduce the pressure requirements during the injection, are prerequisites for the successful application of the method. The process is schematically presented in Fig. 5 below.

Fig 5: Slurry Fracture Injection into Stratified Sediments, Alberta.

The well bores are cemented after injection of waste is completed. The cementation’s role is to create a pressure seal around the well bore to prevent liquid migration between the cement and the rock.

B. Treatment Methods

1. Sand Washing Approaches

Washing removes oil and generates sand that is sufficiently clean to place in a landfill or for secondary industrial use. However, sand washing is not sand disposal: once washing is complete, three streams remain for disposal: sand, oil and “dirty water”. Thus, sand washing must be considered an intermediate stage in the disposal process. Washing
approaches can be roughly divided into thermal and non-thermal methods, although hybrid approaches are possible. Various methods have been experimented at the Alberta Research Council and various laboratories. Only thermal methods have been used at full scale but because of the high variance in sand composition (varying levels of oil and water concentration) none of them proved to be technically feasible.

2. Produced Sand as Industrial Feedstock

In principle, produced sand can be used directly as it is or cleaned to meet specifications for industrial use. For direct use two possibilities proved technical feasibility: cement powder manufacturing, or using sand as part of asphalt-based surface paving material.

Produced sand along with clay, oil and residual water has been used successfully as a feedstock for the cement plan in Edmonton. Although technically feasible, the amount of sand that could be used in one year is only a small fraction of the amount of sand produced in the oil industry. In addition, oil industry sand would have to be delivered to the cement plant for only a few dollars per tone in order to displace other sources of sand.

Produced sand with oil still on the grains can be used directly in asphalt-concrete for road surfacing. When oily sand is added to asphalt concrete mixes, the oil becomes incorporated as part of the asphalt (road tar) component of the asphalt concrete, and the sand as part of the solid mineral matter. However, quality issues occur with only small increases of heavy oil concentration in the asphalt mix and the demand for road asphalt sand is limited in the oil sand region.
3. Other Treatment Options

Similar to washing, these are methods designed to destroy, alter or decompose the contaminating agents in the waste so that it meets standards permitting easy disposal or secondary use. The major alternatives are thermal decomposition, biodegradation and chemical treatment. Although successful in laboratories, none of them proved to be feasible at the industrial scale.

a. Thermal Decomposition

There is a number of thermal decomposition technologies that are designed to either directly burn the oil from the sand, or cause it to react with an oxidant that eliminates or greatly reduces the oil content. All these methods involve passing the sand through an insulated kiln where the thermal process takes place on a feed-through basis.

b. Biodegradation Cells

In laboratories, batch mode oil product decomposition has been demonstrated to be technically feasible. Oily sand can be placed in cells with reasonably controlled conditions, (nutrient and bacteria supplied, oxygen made available, etc.). In these conditions, rapid degradation of even difficult materials takes place, often in just a day or two. In the field, nutrient and oxygen access are more problematic, temperatures cannot be optimized, and other natural and man-made factors complicate treatment.

c. Chemical Treatments

No large-scale chemical treatments for oily produced sand are known. The same difficulties encountered in other processes (large volumes, small amounts of oil in the sand, type of oil, etc.) act against chemical treatment. Any chemical that could react with
the oil to produce totally benign products (gases, or solid material that cannot be leached) is likely to be expensive.

IV. Economic Analysis of Disposal Options

1. Uncertainty and Variance in Costs.

In general oil companies do not release their figures to the general public. Also, oil companies are not required to release figures on the annual amounts of produced sand, slops, emulsion and other wastes, only monthly figures on water and oil production from each well are required. It is therefore difficult to obtain realistic total cost figures for handling waste. Recently, the concept of “one-stop-shopping” has been introduced in sand management. This approach involves contracting a single company to deal with all aspects of sand management, including stock-tank cleaning, transportation, disposal, and handling. The figure currently considered as economically feasible is approximately $65-70/m.\textsuperscript{3}. Using a different approach, the estimates for the waste management cost in correlation with the total operating costs account for 15-30 % of operating expenses resulting in a cost of CAN$1.50 to CAN$3 per barrel.

The variance of the estimates is mainly caused by the different levels of production and technologies involved in different projects.

2. Comparative costs for Non-hazardous Oilfield Wastes (NOW) disposal.

Few comparatives cost figures exist in Canada, given the large waste volumes and the particular mix of the waste (no variety of methods applied).

A reasonable study was provided by the Argonne National Laboratory in U.S.A. The cost analysis was carried out for the West Texas area in the late 1990’s and the estimated costs per m3 are presented in the Table 1. The amount of produced sand in West Texas is
minimal compared to Canada, and the material considered can be classified in the category of liquid NOW, including completion and treatment fluids.

Table 1: West Texas Waste Disposal Costs

<table>
<thead>
<tr>
<th>Disposal Method</th>
<th>Range of Costs per m3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Spreading</td>
<td>US$ 35.00 – 85.00</td>
</tr>
<tr>
<td>Landfill or pit disposal</td>
<td>US$ 15.00 – 22.00</td>
</tr>
<tr>
<td>Evaporation (suitable only for certain types of waste)</td>
<td>US$ 15.00 -20.00</td>
</tr>
<tr>
<td>Treatment and injection (liquid wastes only)</td>
<td>US$ 42.00 – 70.00</td>
</tr>
<tr>
<td>Salt Cavern Disposal</td>
<td>US$ 13.00 -40.00</td>
</tr>
</tbody>
</table>

(Source: Alberta Energy – Publications: Oil Sands –CHOPS. Author – Dr. Maurice Dusseault)

3. Cost Estimates for Land Spreading and Road Spreading

A detailed cost analysis of the true cost of road spreading and land spreading for disposal of oily sand involves assessment of the following factors: leasing stock-tank cleaning costs, intermediate stockpiling costs, cost of reloading and transportation to the land-spreading or road-spreading site, engineering and supervision costs, cost of spreading the material, cost of plowing the material into the field or of compacting the material into the road. Costs for both land and road spreading increase over time because the haulage distance for road spreading increases as near-by roads are used first.

The estimates of per cubic meter are as follows:

Land spreading costs: ~CAN$26.00 - 40.00
Road spreading costs: ~CAN$30.00 – 38.00 if the site is near (<5 km)
   ~CAN$45.00 – 70.00 for distant sites.

If all the costs are considered:

Cleaning stock-tank of sand and transporting to a stockpile: CAN$37.5
Stockpiling and reload costs: CAN$ 7.50
Road or land spreading, grading and maintenance (assume 80 km distance) CAN$53.00
**TOTAL** CAN$98.00
4. Cost Estimates for Landfilling

The total disposal costs in approved Class II Landfill in CAN$/m³ are as follows:

- Cleaning stocktank of sand and transporting to a stockpile: CAN$37.50
- Stockpiling, site management and reload costs: CAN$ 7.50
- Landfill haul and dump fees: CAN$40.00
- TOTAL: CAN$85

5. Salt Cavern Placement Costs

The most reliable cost figures are those charged by salt cavern management corporations for disposal of slops, sand, and other permitted NOW wastes (Table 2).

**Table 2: Salt Cavern Disposal Facilities**

<table>
<thead>
<tr>
<th>Facility</th>
<th>Operator</th>
<th>Gate price/m³ waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hughenden, AB</td>
<td>Newalta</td>
<td>CAN$ 65.00/m³</td>
</tr>
<tr>
<td>Unity, SK</td>
<td>Canadian Crude Separators</td>
<td>CAN$ 65.00/m³</td>
</tr>
<tr>
<td>Lloydminster AB</td>
<td>Husky Oil Ltd.</td>
<td>CAN$ 80.00/m³</td>
</tr>
<tr>
<td>Elk Point and Lindberg, AB</td>
<td>Canadian Crude Separators</td>
<td>CAN$ 65.00/m³</td>
</tr>
</tbody>
</table>

(Source: Alberta Energy – Publications: Oil Sands –CHOPS. Author – Dr. Maurice Dusseault)

The costs presented above did not include all aspects of tank cleaning and transportation to the cavern site. Total costs are variable depending on distances and on the stockpile management cost.

Average estimates (CAN$/m³) are given below:

- Cleaning stocktank of sand and transporting to a stockpile: CAN$37.50
- Stockpiling and reload costs: CAN$ 7.50
- Transportation costs from stockpile to salt cavern: CAN$15.00
- Salt cavern gate fees: CAN$65.00
- TOTAL: CAN$125.00

6. Slurry Waste Injection Costs

The slurry injection cost analysis must include the “saving” associated with the co-disposal of wastewater, which would otherwise be an additional cost item for the oil
company. This saving is estimated to be an average of CAN$ 25.00 per cubic metre of sand disposed. This amount is deducted in all total slurry injection cost calculation.

**Total Sand Disposal Costs Using a Mobile SFI™ System, CAN$/m³**

<table>
<thead>
<tr>
<th>Cost Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaning stocktank of sand and transporting to a stockpile:</td>
<td>CAN$ 37.50</td>
</tr>
<tr>
<td>Well and site preparation and maintenance:</td>
<td>CAN$ 8.00</td>
</tr>
<tr>
<td>Site management and loading into SFI™ system:</td>
<td>CAN$ 7.50</td>
</tr>
<tr>
<td>SFI™ mobile unit disposal fees (&lt;3000 m):</td>
<td>CAN$ 50.00</td>
</tr>
<tr>
<td>Credit for wastewater co-disposal:</td>
<td>(CAN$25.00)</td>
</tr>
<tr>
<td><strong>TOTAL ~:</strong></td>
<td><strong>CAN$ 78.00</strong></td>
</tr>
</tbody>
</table>

7. **Sand Washing Costs**

The gate fees charged by the Bromley-Marr facility in Bonnyville for solid waste (produced sand), were used for the following estimates (CAN$/m³)

<table>
<thead>
<tr>
<th>Cost Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaning stocktank of sand and transporting to a stockpile:</td>
<td>CAN$37.50</td>
</tr>
<tr>
<td>Stockpiling, site management and reload costs:</td>
<td>CAN$ 7.50</td>
</tr>
<tr>
<td>Transportation costs to the Bromley-Marr facility:</td>
<td>CAN$20.00</td>
</tr>
<tr>
<td>Bromley-Marr gate fees:</td>
<td>CAN$47.00</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td><strong>CAN$10</strong></td>
</tr>
</tbody>
</table>

8. **Estimates for costs of other approaches**

There is insufficient data to allow detailed cost estimates for other possible waste treatment and disposal options such as thermal degradation, biodegradation, etc. These options require expensive specialized equipment and are therefore costly. Because such facilities have never been attempted commercially, total costs can only be roughly estimated as >CAN$130.00/m³.
V. Conclusions

Currently, the technologies to dispose the solid waste from generated in oilfield activities are limited to landfill placements, salt cavern disposal and slurry fracture injection. Other technologies are either economically not feasible (very expensive) or do not eliminate all the risks for the environment.

The underground disposal methods also solve the problem of liquid waste that can be deposited together with the solid waste. Salt Cavern Disposal appears to be the safest method currently in use to dispose toxic and hazardous solid and liquid wastes.

For a better monitoring of waste disposal EUB should require that all operators report the volumes of sand produced and disposed as well as monitoring data regarding the quality of environment from the from the disposal sites.

Research should be encouraged and supported in the field to improve the current technologies and increase the efficiency and effectiveness of waste management processes in the future.
References:

1. Alberta Energy – Publications: Oil Sands –Canadian Oil Production with Sand in the Canadian Heavy Oil Industry. Author – Dr. Maurice Dusseault). Chapters 4, 10, 11, 12, 13 + Recommendations. 


3. Alberta Energy: Alberta’s Oil Sands: The New Paradigm, Authors: Paul Precht and Carmen Rokosh 

4. Alberta Energy and Utilities Board website