

12 ECONOMIC ANALYSIS OF DISPOSAL OPTIONS

12.1 General Statement and Background of Cost Estimates

12.1.1 Uncertainty and Variance in Costs

Waste management companies provide aggregate cost figures (i.e. prices for disposal) on request. A large contract providing for several months for personnel and equipment can be obtained for as much as 15% to 20% below the initially quoted hourly rate. For example, a pressure treatment truck (a truck with a 10 m³ tank and high pressure pumping equipment) will rent for US\$45.00-50.00/hour (all price figures are from the year 2000), but on a guaranteed 10 hour/day, 6 days/week contract for three months, the company can expect to pay as little as US\$38.00-40.00/hr.

Recently, the concept of “one-stop-shopping” or “cradle-to-grave” sand management has been discussed in the industry. This approach involves contracting a single company handle all sand management, including stocktank cleaning, transportation, disposal, and handling of any ancillary wastes such as dirty water or sludge. The figure currently discussed for doing in an economically feasible manner is approximately \$65-70/m³. However, as yet there are no service companies that are prepared to commit to such an approach, and it may be difficult to institute in the oil industry.

In a “one-stop-shopping” approach, the service company must continuously try to achieve economies of scale, but the oil company is no longer bound by the same need. This means, for example, that the service company might be called in to clean a stock tank when there is less than a full load of sand, reducing efficiency. Also, oil companies have an expensive habit of wanting instant service once they call. If the service company is trying to achieve economies of scale, this need to respond immediately will mean extra mobilization costs, and the sand disposal costs will rise accordingly.

Nevertheless, there is a great deal of merit in “one-stop-shopping”. For the oil company, engineering costs and all in-house costs would be eliminated, and they would be able to do accurate forward cost analysis based on the sand production history of the wells. For the service company, economies of scale accrue with large contracts, reducing the number of stockpiles and the amount of handling, and making large and efficient disposal centers possible. Furthermore,

this would foster competition among service providers, to the benefit of the oil companies. The concept must be implemented in some form to make the produced sand waste management sector more competitive, and to establish clear cost predictions and cost control measures.

12.1.2 Corporate Cost Figures

Even when sand handling cost figures have been carefully compiled in-house, oil companies do not release their figures to the general public or to service companies. Also, oil companies do not have to release figures on the annual amounts of produced sand, slops, emulsion and other wastes they produce; only monthly figures on water and oil production from each well are required. It is therefore difficult to obtain realistic total cost figures from operating oil companies for handling waste sand on a per-cubic-metre of sand basis.

A company's economic assessment of its own produced sand waste management activities is complex and must include the following costs:

- Basic disposal costs (e.g. landfill, injection, or salt cavern cost/m³)
- Tank cleaning costs
- Costs of various transportation stages required to stockpiles, treatment centers, or disposal sites
- Unload and reload costs if stockpiles or storage sites are used
- Cost of building ecologically acceptable sites for management of water and slops that are generated at stockpiles, by spills, or through other activities
- Some proportion of stocktank purchase costs and other capital costs related to fixed assets involved in sand management
- Some portion of the well workover costs (this is clearly a “sand management” cost, but not necessarily a “waste disposal” cost, and its inclusion in cost analysis remains unclear)
- Engineering costs for planning and executing a waste handling system, as well as supervision costs for implementation and quality control (if wastes are third-party contracted, this cost becomes very small)

- Land use costs and land reclamation costs (e.g. the cost of keeping 10 ha as a waste management site, plus ultimate rehabilitation costs)
- Site preparation, management, and rehabilitation of stockpile and battery sites locations
- Long-term liability costs associated with environmental risk

The best figures currently available for sand management were presented in a confidential joint industry project carried out by a half-dozen oil companies for Alberta sites only. There was a wide variance among sites because of many factors, including:

- Different quantities of sand/bbl oil production, ranging from <1% by volume in the southern area near Provost and Hardisty to as much as 5-7% by volume at “steady-state” production in the Frog Lake, Elk Point and Bear Trap areas.
- Different haul distances to disposal facilities; in most cases, an intermediate stockpile was used.
- Different technologies for sand disposal (washing, injection, landfill, salt caverns, road spreading).

Overall, the following estimates are considered to be reasonable for the industry as a whole:

- Sand and other waste management costs account for 15-30% of OPEX⁸⁴, giving a cost of from CAN\$1.50 to CAN\$3.00 per barrel
- Well workover costs are 15-20% of OPEX
- The remaining 55-70% of OPEX includes product trucking (7-9%), fuel and power costs (6-10%), taxes, overhead, site maintenance and management costs, and so on.

Such figures alone do not reflect the fact that more sand generally means more oil, so that if sand handling costs are high, it is likely that wells are more productive and more profitable.

Conversely, a well with small-diameter perforations and a reciprocating pump producing only 2-4 m³/d may have lower sand management costs per barrel (little sand), but the well may not be economic because of the low production levels. Furthermore, different operating companies

⁸⁴ In reality, the range of sand management costs varies from 1-5% for those few horizontal wells that produce at high rates with minimal sand influx to as much as 40% for wells that consistently produce 8-10% sand by volume.

have substantially different OPEX, even in the same field, depending on the particular choice of technology and on the skills of the engineers and field operators.

12.1.3 Comparative NOW Disposal Costs in West Texas

Few comparative cost figures exist in the world because in Canada the sand waste volumes are large, the particular waste mix is unique (large amounts of dirty sand and emulsion), and factors such as population density and services differ substantially from other locations.

The only reasonably detailed study that exists is available from Argonne National Laboratory in the USA.⁸⁵ This cost analysis was carried out for the West Texas area in the late 1990's as part of a study of the environmental and cost suitability of salt caverns for waste disposal. Only a few cost figures are summarized here, and no effort is made to ensure that the techniques are "identical" to Canadian practices. The costs of tank cleaning, transportation, and stockpiling are apparently not included in the data provided. Therefore, in order to compare more directly with Canadian costs, approximately US\$25.00 to 30.00 has to be added to each category.

Table 12.1: West Texas Waste Disposal Costs

Disposal Method	Range of Costs per m ³
Land spreading	US\$35.00 – 85.00
Landfill or pit disposal	US\$15.00 – 22.00
Evaporation (suitable only for certain types of waste)	US\$15.00 – 20.00
Treatment and injection (liquid wastes only)	US\$42.00 – 70.00
Salt cavern disposal	US\$13.00 – 40.00

The amount of produced sand in West Texas is minimal compared to Canada, and much of this material referred to in the Table will be in the category of liquid NOW, including completion and treatment fluids.

⁸⁵ Visit website www.npto.doe.gov/saltcaverns or contact John Veil at jveil@anl.gov or phone 1 202 488 2450.

12.2 Stocktank Cleaning Approaches and Costs

The per-hour rental cost for mobile equipment controls the cost of tank cleaning and transportation to stockpiles or disposal. The following is a list of typical costs of equipment used in the industry (2001):

Table 12.2: Equipment Rental Costs, f.o.b. Lloydminster**

Type of Equipment	Common Use	Hourly rates, CAN\$
Small dump (LHD) truck, 10 m ³	Local site cleanup and hauling wastes to corporate stockpiles	CAN\$45.00
LHD unit, sealed tank, ~17 m ³ capacity	Local and highway hauling of produced sand	CAN\$55.00
Tandem trailer LHD unit, 30 m ³ capacity	Longer distance hauling of produced sand	CAN\$65.00
Tub truck, sealed 30 m ³ tub with cover, hydraulic dump, multi-axle	Transportation of sloppy wastes without spillage (used with auger tank cleaning)	CAN\$70.00-80.00
Oil tanker truck, 30 m ³ capacity, multi-axle	Oil transport from wells to local batteries or upgraders	CAN\$60.00-65.00
Water tanker truck, 12 m ³ capacity, no pressure	Water hauling from stocktanks to disposal well or tank	CAN\$55.00
Pressure treatment truck, 10 m ³ H ₂ O capacity	Operation of high pressure stingers and hoses	CAN\$65.00
Hydraulic auger truck	Hydraulic augering of sand from stocktanks into LHD units	CAN\$115.00-140.00
Vacuum truck, generally 17-20 m ³ capacity (limited to 13 m ³ sand legal limit)	Stocktank cleaning, spill cleaning, sludge cleaning from large tanks, etc.	CAN\$120.00
Front-end loader, 1 – 1.5 m ³ bucket capacity	Managing stockpiles, loading of LHD units and hoppers	CAN\$65.00
Dozer (D-7 to D-8 capacity)	Land clearing for eco-pit installation, managing stockpiles, site clean-up	CAN\$85.00-100.00
Excavator (hydraulic backhoe)	Site clean-up, ditching, trenching, general excavation of contaminated soil and slopes	CAN\$95.00 - CAN\$130.00, depending on size
Bobcat (small capacity loader)	Spill clean-up, local moving of small sand quantities	CAN\$45.00

****Lower rates are available for long-term contracts.**

12.2.1 High Pressure Jetting and Vacuum Trucks

The aggregate costs for a pressure and vacuum truck pair, commonly used together to remove sand from stocktanks, are approximately CAN\$165.00-185.00/hr for both units (with two driver-operators). Typically, the oil company will call the service provider and ask that a particular stocktank be cleaned of a load of sand. Usually, the stocktank cleaning trucks are called only when there is a full load of sand to be removed from the tank. Assuming 50 km mobilization distance, the following times are needed:

- For a vacuum truck, 3½ hours, based on one hour to the location, one hour loading sand, and 1½ hours to transport and dump the sand at the stockpile and return to base.
- For a pressure truck, 3½ hours, based on 1½ hours to get a load of water and go to the site, one hour stinging sand, and one hour to demobilize and return to base.

Assuming CAN\$165.00/hr and a full 13 m³ load of sand taken by the vacuum truck, unit costs to clean the stocktank and transport the material to the local stockpile are about CAN\$44.00/m³. This figure assumes a full load of sand and no delays or load restrictions on trucks. Note that to remove water from the stocktank is much less costly, requiring only an inexpensive tank truck with a small loading motor.

These sand handling costs can be reduced somewhat by careful planning so that mobilization and demobilization costs are spread over the cleaning activity for several tanks. If there are nearby disposal facilities, multiple wells on a single pad, or manifolded production to a single large tank, additional savings can be achieved. Nevertheless, even incorporating all reasonable efficiencies, the minimum cost for stocktank cleaning using a pressure truck and vacuum truck combination is about CAN\$37.50/m³. This figure will be used repeatedly later in this chapter to calculate the total costs of sand handling for various disposal technologies.

12.2.2 Auger Trucks and LHD Units

The combination of an auger truck and a sealed tub truck is more costly than the pressure truck and vacuum truck pair used to clean tanks, approximately ~CAN\$50.00/m³ rather than ~CAN\$40.00/m³. However, less emulsion may be generated, reducing ancillary costs required

for disposal. If a large LHD unit (17 m³) instead of a tub truck is used with the auger truck to clean tanks, the costs are somewhat lower, but in this case the sand must be relatively “solid”, and not sloppy. At this time, it is believed that the auger system, which is relatively new, will remain 10-20% more expensive than the vacuum truck and pressure truck combination, but competition may affect these values.

12.2.3 Better Ways to Clean Stocktanks

There are potentially better ways to empty stocktanks of sand with lower costs. If a cone-bottomed tank with a desander jet ring is used as the stocktank, and if the basal exit port for the sand slurry is at least 3 m above the ground (using a berm or a frame), it should be possible to slurry sand directly into a tub truck, reducing sand handling costs to about CAN\$30.00/m³.

Another method of reducing tank cleaning costs is to use flowlines from a group of CHOPS wells to a central large conical-base, D-ring stocktank that is mounted in an elevated position, as described above. Then, economies of scale and the elimination of multiple trucks should further reduce costs to about CAN\$20.00/m³. Many operators are reluctant to use flowlines because of the viscosity and the cold climate, but one operator has successfully used flowlines of up to 800 m. However, wells manifolded in this manner must be evaluated with a test separator for 48 hours each month.

Finally, if multiple-well manifolded production is feasible and if ~ 50-150 m³ of sand is collected daily at the site, it could be economically advantageous to establish a landfill, an injection well, or a salt cavern disposal facility nearby so that further handling and transportation charges would be unnecessary. In this case, the costs of stocktank cleaning and readying the sand for disposal could be as low as CAN\$15.00/m³.

12.3 Transportation and Handling Costs

12.3.1 Lease Stocktanks

The cost of a typical stocktank is given below for a vertical tank unit that is skid-mounted and truck transportable. Such a tank is usually fitted with several fluid withdrawal lines, contains a U-shaped fire tube for heating the contents, and is externally insulated.

Table 12.3: Stocktank Prices

Size of tank	Cost for a standard tank, f.o.b. Lloydminster, CAN\$	Cost for Envirovault tank, f.o.b. Lloydminster, Alberta, CAN\$
750 bbl (~120 m ³)	CAN\$25,000 – 30,000	CAN\$28,000 – 33,000
1000 bbl (~150 m ³)	CAN\$31,000 – 34,000	CAN\$34,000 – 37,000

The cost depends on client-stipulated fittings and number of draw points, types of ports and so on. A stocktank equipped with a conical bottom will be more expensive, as will an auger tank (about CAN\$9,000 extra). Larger vertical tanks are now available (1500-2000 bbl), particularly suitable for sites where several production wells are manifolded to the single main production tank.

The operating costs for a tank, exclusive of sand management, includes site maintenance plus fuel (natural gas from the well may be considered “free”) to keep the temperatures at 60-80°C. In Canada, this costs several thousand dollars a year (not counting OPEX) if a small natural gas line is available and must be used. If gas from the well annulus (or stocktank) is sufficient and can be counted on, only the opportunity costs have to be considered, but the tank must be equipped to capture and cycle the gas, with provision made for handling excess gas. If a propane tank is needed, costs are 50%-70% higher than if the regional natural gas network can be accessed.

In the cost analysis that follows, there is no component of costs for the stocktank, building the site for it, or the heating costs because there is no method of partitioning these costs to oil production, sand management, produced water management, etc. Because all methods use stocktanks, these costs are approximately the same in all cases, and can be left out of the analyses, dealing only with variable costs.

12.3.2 Sand Transportation

Once sand is in the company local stockpile, it has to be managed and transported to a disposal or treatment site. Vacuum trucks and tub trucks are never used for long distance hauling (>50 km) if it can be avoided because these units are more expensive and can carry less than a multiple axle LHD truck. Thus, all long-distance hauling of drained sand is carried out with

load-haul-dump units equipped with open tanks that are only partially sealed against bottom leaking.

Load-haul-dump (LHD) trucks are available in various sizes and at a wide range of rates, depending mainly on contract length. For example, an owner-operator whose 30 m³ LHD vehicle is on a one-year guaranteed contract with an oil company will charge an equivalent of CAN\$55.00 – 60.00/hr for an annual minimum 1800-2000 hours (additional hours charged at a pre-negotiated rate, as well as any hours beyond 10 hours a day or 48 hours a week).

As an example of transportation costs affecting sand disposal, consider the cost of delivering a 30 m³ load of sand (clean or oily) from a stockpile near Lloydminster to the Edmonton landfill. The mobilization time, loading time, two-way travel time and unloading time, assuming efficient operation, is a minimum of 7 or 8 hours. Unless there are two drivers, this limits the LHD vehicle to one trip per day. At a typical cost of CAN\$70.00/hr, using a highway LHD vehicle and delivering the load will cost ~CAN\$17.00/m³. This figure does not include stockpile management or loading costs. (If the landfill fees are included, the costs will be ~CAN\$39.00/m³.)

12.3.3 Stockpiling and Handling Costs

It is estimated that it costs CAN\$6-9/m³ of sand handled to manage the stockpile material in an environmentally acceptable manner. This includes site maintenance as well as reloading material using a front-end loader onto a LHD unit for transshipment (loading time is typically 20-30 minutes). This cost is a direct addition to all other sand management costs, and does not include vehicle mileage. Also, part of this cost is to clean up the liquids that are collected at the site, and truck them for disposal. A rule-of-thumb is that for every six truck loads of waste sand brought to a stockpile, one vacuum truck load of slops will have to be aspirated from the peripheral trench and trucked to disposal. Alternatively, stocktanks can be used for storing this material and skimming the oil. For purposes of cost comparison, a figure of CAN\$7.50 is used for stockpile management and handling.

12.4 Land Spreading and Road Spreading Costs

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:

- Lease stocktank cleaning costs
- Intermediate stockpiling costs such as winter storage for summer use
- Cost of reloading and transportation to the land-spreading or road-spreading site
- Engineering and supervision costs
- Cost of spreading the material in a relatively thin and relatively uniform layer on the disposal site
- Cost of plowing the material into the field or of compacting the material into the road.
- Possible cost of retained environmental liability.
- Costs for both land spreading and road spreading increase over time for the following reasons:
 - The haulage distance for road spreading increases as near-by roads are used first.
 - Farming operations are increasingly reluctant to accept solid NOW to place on fields.
 - Maintenance costs associated with roads that have been subjected to road spreading rise with time as the total length of such treated roads in a county increases.

As mentioned above, the detailed costs associated with these activities are difficult to calculate because many real costs (e.g. engineering costs) are often not included, and because there is no incentive to publish such costs externally. Nevertheless, it is believed that the following per cubic metre cost ranges are reasonable estimates:

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

The lowest costs for road spreading are associated with direct placement of the sand on roads using vacuum or auger trucks (this is rarely possible without an intermediate handling stage because of water contents and other factors).

Estimated Total Road Spreading Disposal Costs, CAN\$/m³

Cleaning stocktank of sand and transporting to a stockpile	CAN\$37.50
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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**

(**Depending partly on distance to the road that is being covered, or on the amount of ploughing, total sand management costs may vary from CAN\$85.00 - 105.00/m³)

No total disposal costs are given for land spreading or land farming; these methods will no longer be permitted in the future because of environmental concerns over long-term effects.

No cost analysis for incorporation of sand into road beds has been included. It has not been possible to obtain figures for this method, and the counties do not have an estimate of the value of the road bases so constructed. Nevertheless, it is believed that this is currently perhaps the cheapest alternative, roughly estimated as ~CAN\$75.00-80.00/m³ when the value of the road base is properly incorporated.

12.5 Landfill Costs

The best assessment of this cost is the all-inclusive price for pick-up and dumping that landfill operators at Marshall Saskatchewan are currently quoting for clients in the heavy oil industry, i.e. CAN\$26.00 - 30.00/tonne. This per tonne cost can be converted for comparative volumes of produced sand by using the same figure that the local industry uses for wet sand, a figure of 1.3 tonnes per cubic metre of sand.⁸⁶ Using this (unrealistically low) figure gives a disposal cost of CAN\$33.00 - 37.00/m³.

However, this cost is exclusive of the oil company's costs of cleaning the stocktanks of sand, stockpiling the sand (the landfill company will load from the company's stockpile), and long distance haulage fees. In other words, the quoted rates are for sand pick-up and disposal in a suitable class landfill within a certain haul distance. The costs for re-loading and transportation of sand from Lloydminster to the municipal landfill in West Edmonton are about CAN\$30.00 - 32.00/tonne (~CAN\$40.00/m³), including landfill dump fees in this case.

⁸⁶ The writer's own figures based on other considerations suggest that the conversion factor of 1.3 tonnes/m³ quoted by industry people should be much higher, at least 1.6 tonnes/m³.

This cost estimate for landfilling does not consider indirect costs to the oil company that may arise in the future. For example, if there is a problem with landfill leaks that contaminate groundwater, it appears that the oil company retains liability (although the issue remains to be tested in court). In addition, the withdrawal of land from high quality use carries future costs, although, in the Heavy Oil Belt of Canada, this is considered to be low because of the sparse population, the wide availability of poor grade land for landfill use, and the low cost of land.

Estimated Total Sand Disposal Costs in Approved Class II Landfills, CAN\$/m³

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\$85.00

(**Depending partly on distance to the landfill, and partly on different landfill dumping fees, costs will vary: CAN\$78.00 - 92.00)

Although no detailed figures have been published, Anadarko has discussed a total sand management cost for their Lindbergh wells of ~CAN\$90.00 for disposal in a Saskatchewan Class II landfill in Marshall, Sask., about 180 km from their stockpiles. Their figure appears reasonable, but it is not known if all aspects of design and facilities management are included, and the cost of retained liability during transportation and after placement is not accounted for (nor is it in any of the disposal methods that are analyzed).

Their analysis also indicates that the cost analysis presented above is somewhat optimistic. The writer recommends that Anadarko’s number of CAN\$90.00/m³ for landfill disposal be used in comparative cost analyses.

12.6 Sand Washing Costs

Sand washing has not proven economical in practice, as all three facilities have suffered either closure or economic difficulties. In the future it might prove economically feasible, provided that several conditions are met and provided that some advances in technology are implemented:

- Heat for water washing is provided “free” from some other source (e.g. hot water from a power plant or a nuclear station).

- The sand end product can be slurried directly into a near-plant tailings pond to avoid drying cost and stockpiling-load-haul costs.
- The oil recovery cannot only pay for itself, but can generate some income after cleaning.
- The dirty water generated during the washing process can be disposed directly without additional cleaning cycles (SFI™ or SCD seem to be the only alternatives).

The gate fees charged by the Bromley-Marr facility in Bonnyville for solid waste, mainly produced sand, were about CAN\$36.00/tonne in June 2000, which converts to ~CAN\$47.00/m³ using the same conversion factor as before.

Estimated Total Sand Disposal Costs in Bromley-Marr Washing Facility, CAN\$/m³

Cleaning stocktank of sand and transporting to a stockpile	CAN\$37.50
Stockpiling, site management and reload costs	CAN\$ 7.50
Transportation costs to the Bromley-Marr facility	CAN\$20.00
Bromley-Marr gate fees	CAN\$47.00
TOTAL**	CAN\$106.00

(**Depending partly on distance to the washing facility, actual costs will vary by ±CAN\$7.00.)

In evaluating these cost estimates, it must be remembered that washing facilities never operated profitably at a gate cost of CAN\$36.00/tonne. Projected markets for clean sand did not materialize, and likely never will at the scale required. As discussed in detail in the previous chapter, washing is not a true disposal method, and the costs to dispose or treat the three produced streams (sand, clayey water, oil) have proven to be substantial. Furthermore, at this time there is no commercial sand washing facility that accepts wastes, and a new facility in the future is unlikely.

12.7 Salt Cavern Placement Costs

12.7.1 Third-Party Operated Salt Caverns

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

Salt Cavern Disposal Facilities

Facility	Operator	Gate price per m ³ waste
Hughenden, AB	Newalta	CAN\$65.00/m ³
Unity, SK	Canadian Crude Separators	CAN\$65.00/m ³
Lloydminster AB	Husky Oil Ltd.	CAN\$80.00/m ³
Elk Point and Lindbergh, AB	Canadian Crude Separators	CAN\$65.00 (facilities started accepting waste in fall, 2000)

These fees are for a cubic metre of material, whether it is a liquid or a “solid” such as wet produced sand. This consideration becomes relevant when the pricing structure of deep well slurry injection is compared to the pricing structure of salt cavern disposal because injection service providers do not charge for the disposal of the make-up water to generate the injected slurry. It should also be noted that CAN\$65.00/m³ for disposal of high water content slops is an extremely expensive disposal option. There are far easier and cheaper ways to dispose of high water content slops simply by using large existing tanks to separate the phases and disposing of the water by deep well injection. However, if the slops are truly emulsions, this may be a cheap method to get rid of these difficult materials, compared with centrifugal, chemical and heat treatment.

If the oil company chooses not to transship the waste materials to a stockpile so that excess water and slops can drain, further cost reductions of CAN\$7.50 are effected. However, if vacuum trucks are first drained of excess water from tank cleaning before being sent to the salt cavern disposal facilities directly, they may spend extra time, and the vacuum truck may go to the facility with less-than-a full load. These details of cost variations are beyond the scope of this study.

The existence of a price structure does not always mean that the cavern is actually available for waste delivery, particularly if it is owned by an oil company that needs it for their own wastes.. For example, Husky Oil Ltd. has developed a salt cavern for wastes in Lloydminster in 2000, but this facility cannot meet their own needs in the near future, and they have not accepted wastes from third parties. Therefore, even though a posted price was given in 2000, the Husky facility is unavailable, and the small local producers have to seek alternative disposal approaches.

Finally, it must be mentioned that the salt cavern disposal operators are giving discounts to companies that commit all of their wastes to the salt cavern disposal facility. It is also likely that other volume discounts are being given. Thus, this cost analysis may reflect somewhat of an upper bound for actual long-term costs.

The provision of a unit cost for sand disposal implies that all additional and related costs are incorporated into the figure. The waste generating company can deliver it and “forget” it. As an example, the clear brine that is displaced from the cavern during sand placement must be either used (unlikely) or disposed of in a purpose drilled Class II injection well. The unit costs for this type of disposal are around CAN\$4.50 – 6.00/m³; this cost (as well as all other site management and cavern development costs) is included in the unit price that the salt cavern company charges to the oil company.

Realistic salt cavern disposal costs for produced sand must include all aspects of tank cleaning and transportation to the cavern site. As usual, these costs can be variable depending on haul distances and on the efficiency of the operating company in managing their stockpile.

Total Sand Disposal Costs in Dissolved Salt Caverns, CAN\$/m³

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

(**Depending partly on distance to the salt cavern facility, costs will vary from CAN\$110.00 - 130.00)

12.7.2 Use of Existing Salt Caverns

Abandoned or inactive salt caverns in Alberta and Saskatchewan have been converted for use as waste disposal facilities, but the specific unit cost per cubic metre of waste depends on many factors that are difficult to quantify. The following cost figures are estimates only.

The purchase cost for subsurface void space is roughly CAN\$ 2,500,000 to 5,000,000 for a volumetric capacity of 500,000 to 700,000 m³, leading to a purchase price of about CAN\$ 7.00/m³. There is no established regular bidding market for subsurface void space that would lead to a specific value. If a new cased well has to be drilled (the case in several salt cavern conversions), it will cost approximately CAN\$ 450,000. The building of all the storage facilities, blending unit, access, eco-pits, and other facilities will cost CAN\$ 4,000,000 or more. These bring the per-meter of cavern capacity (CAPEX costs) to about CAN\$15.00/m³. Additional fees are related to the operating expenses of the facility, including front-end loaders, pumps, power costs, and so on.

A complete cost analysis for generating a salt cavern for disposal is not available at the present time for the reasons mentioned previously. However, it is estimated that the cost is about the same as for purchase of existing salt caverns.

12.8 Slurry Waste Injection

Injection of certain types of NOW into a well on site means that the oil company itself must prepare and manage the site. The CAPEX above that associated with ordinary sand management includes checking the well with geophysical logs to ensure that it is in suitable condition for slurry injection, and re-perforating if necessary. The site has to be cleaned and organized so that the slurry injection system can be placed close to the wastes, and so that make-up water and the generated slurry can flow efficiently. However, other materials handling costs, such as providing water for mixing and injection and trucking slops and emulsion for disposal, are undertaken during all waste operations, and do not have to be “added” to the costs.

Slurry injection disposes of sand, but it also co-disposes approximately 4-6 m³ of wastewater for each cubic metre of sand. No additional fee is levied by the slurry injection company for this water disposal in their price structure. The wastewater provided by the oil company to the slurry unit can be untreated, unfiltered produced water or gravitationally separated water that otherwise would cost at least CAN\$6.00/m³ (about a dollar a barrel) for conventional disposal in a deep Class II disposal well. Other “liquid” streams such as fluidized tank bottom sludges, dirty slops, and emulsion are charged as sand because they have to be handled in the same manner as sand, requiring washing through the sieve and mixers, and blending to a suitable viscosity and density.

Therefore, in contrast to other methods such as sand washing and road spreading, 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 (CAN\$ 5.00 × 5 m³ of “dirty” make-up water per m³ of sand). This amount is deducted in all total slurry injection cost calculations.⁸⁷

12.8.1 Mobile Injection Unit Operating Costs

Allocating CAPEX on a per-cubic-metre basis turns out to be difficult; therefore the following assumptions will be used. It is assumed that a local disposal well site at which a mobile injection unit will be deployed will cost CAN\$150,000 (logs, perforating, workovers, etc.) and that the site will eventually be used for 30,000 m³ of sand, giving an estimated unit cost of CAN\$ 8.00/m³ when various factors are included. Site management using a 1.5 m³ front-end loader to load sand directly into the hopper-feeder will engender an additional CAN\$7.50/m³ in costs, as this unit must be available at all times on site. This amount is similar to the management and loading charges assumed for other stockpiles. Note that the sand storage stockpile should be the same as the stockpile for sand injection, as there is no need to allow the sand to drain to a chloride content below 3000 ppm. This reduces costs.

Mobile slurry injection unit use presents certain advantages for an oil company as it becomes possible to build and manage a series of small local stockpiles for produced sand. These stockpiles can be close to the CHOPS wells that generate the sand, so that the truck system that cleans the stocktanks can dump at the local stockpile without a long road trip. Furthermore, there is no additional cost associated with reloading and transshipment to large regional stockpiles, salt caverns, washing facilities, or road spreading sites.

Because of mobilization and demobilization costs, including equipment wear during transportation, mobile slurry injection unit charges⁸⁸ are a function of volume of waste to be disposed:

⁸⁷ A more precise estimate of the savings associated with water co-injection can only be achieved calculated within individual oil companies that have the OPEX data.

⁸⁸ SFI charges provided by Terralog Technologies Inc, Calgary Alberta.

For produced sand volumes <3000 m ³	CAN\$ 45.00 – 55.00/m ³
For produced sand volumes of 3000 – 10,000 m ³	CAN\$ 40.00/m ³
For produced sand volumes >10,000 m ³	CAN\$ 38.00/m ³

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

Cleaning stocktank of sand and transporting to a stockpile	CAN\$ 37.50
Well and site preparation and maintenance	CAN\$ 8.00
Site management and loading into SFI™ system**	CAN\$ 7.50
SFI™ mobile unit disposal fees (<3000 m ³)	CAN\$ 50.00
Credit for wastewater co-disposal	(CAN\$25.00)

TOTAL **~CAN\$ 78.00**

(**It is assumed that there are no additional transshipment charges for mobile injection unit use because it is operating on the oil company site adjacent to the produced sand stockpile.)

Given that the mobile injection unit disposal figure used was that quoted for smaller volumes (<3000 m³) it is reasonable to assume that the total costs of mobile injection unit disposal on site are about CAN\$ 78.00, without including the value of decreased long-term environmental liability. Likely, costs will be up to 10% lower in larger volume cases.

12.8.2 Static Dedicated Slurry Injection Site Operating Costs

If a company has a suitable site where the produced sand stockpile can be maintained on a long-term basis (3-5 years), sand injection costs can be reduced. On the other hand, some additional CAPEX and OPEX will accrue because of the need to establish a facility that can be partly weather-resistant (shelter and heating costs). In this estimate, the site costs have been increased to CAN\$15.00/m³ to account for this.

Total Sand Disposal Costs Using a Fixed Injection Site, CAN\$/m³

Cleaning stocktank of sand and transporting to a stockpile	CAN\$37.50
Well and site preparation and maintenance	CAN\$15.00

Site management and loading into SFIT TM system**	CAN\$ 7.50
SFIT TM permanent system disposal fees (>20,000 m ³ /yr)	CAN\$38.00
Credit for wastewater co-disposal	(CAN\$25.00)
TOTAL	~CAN\$73.00

(**It is assumed that there are no additional transshipment charges because the unit is operating on the oil company site adjacent to the produced sand stockpile.)

Fixed-site approaches appear to be the best approach for the oil company seeking to dispose of large sand volumes using injection methods, and total disposal costs of ~CAN\$70.00-75.00 are considered to be a reasonable estimate. However, only a few oil companies generate the volumes of sand on a steady basis to justify a fixed site. Most small operators deal with situations where only a few thousand cubic metres of sand are produced annually, and it may be more cost-effective to dispense with the intermediate stage of stockpiling if possible, and ship the LHD trucks loaded with sand from the stocktank directly to a custom slurry injection facility, or to another oil company's facility.

12.8.3 Central Integrated Disposal Facility for “Custom” Disposal

A central facility is designed to accept specific identified wastes shipped to the facility from a number of waste generators. Companies such as Anadime, Canadian Crude Separators and Newalta have fixed facilities to service all oil companies that deliver suitable and identified wastes to the gate of the facility.

Terralog Technologies has provided the following tentative prices for custom disposal of waste solids at a fixed site if this is created in the future:

CAN\$65.00/m³ for custom disposal

CAN\$62.50/m³ for waste volumes > 1700 m³/month

These projected values can be used to estimate the costs of custom “on-demand” disposal of produced sand at a central disposal site.⁸⁹

Total Sand Disposal Costs Using a Custom, On-Demand Facility, CAN\$/m³

Cleaning stocktank of sand and transporting to stockpile	CAN\$37.50
Reloading charges and transportation costs to the central facility	CAN\$15.00
Disposal gate costs	CAN\$65.00
Credit for waste water co-disposal	(CAN\$ 0.00)
TOTAL	CAN\$117.50

Evidently, the convenience offered by a custom disposal facility carries substantial additional costs, compared to on-site fixed slurry injection.

12.9 Costs of Other Approaches

Data are insufficient to allow detailed cost estimates for other possible waste treatment and disposal options such as thermal degradation, biodegradation and disposal, and so on. These options require specialized equipment, treatment cell maintenance, and so on, and are therefore costly. With the addition of various hidden costs, total costs for other approaches to produced sand disposal can be roughly estimated as >CAN\$130.00/m³. Because such facilities have never been attempted commercially, and are unlikely to be, even this estimate is uncertain, but considered to be low.

⁸⁹ At the present time, there is no detailed provision for the co-disposal of water, so a wastewater disposal credit is not included in the cost analysis.

12.10 Climatic and Geographic Issues

The long cold winters, hot dry summers, and relatively low-precipitation in the Canadian HOB place a number of constraints on sand disposal:

- Sand stockpile freeze up from October or November until April causes problems with loading, transportation and disposal of stockpiled material.
- From late April to the end of May, limits on axle loads because of thawing roadbeds restrict heavy equipment movement on secondary roads.
- During freezing weather, any type of aqueous waste treatment, such as slurry generation and injection into porous strata or salt caverns, has to be continuous and weather protected or the equipment cleared of water (using compressed air) after each use.
- Sunny dry summers dry the water from the surface of sand stockpiles, making the sand oil wet rather than water wet, and consequently more difficult to treat by washing.
- Cool ground temperatures restrict bacterial activity in HC decomposition processes such as land spreading.
- Cool temperatures during much of the year mean that additional energy has to be spent in heating stocktanks to 60-80°C, and that small diameter flow lines may not be feasible to carry heavy oil to a central facility because of the high viscosity.
- Year-round waste management activities generally require winterized equipment and lightly protected facilities (e.g. light enclosures maintained at 0-2°C).