A Screening Study

of

Oil Sand Tailings Technologies and Practices

Prepared for

Alberta Energy Research Institute

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By

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The Rock Doctor

March 2010
Executive Summary for Part A – Screening Study of Oil Sand Tailings Technologies

This report documents the results of a scoping study undertaken to provide insight on the potential of alternate technologies to:

- Reduce fresh water make-up needs in oil sand extraction and processing.
- Facilitate projects qualifying for a timely reclamation certificate.

The study started with a literature review, interviews with practitioners in the business and data collection on specific technologies. Existing operations were studied in sufficient detail that detailed case studies could follow.

Five cases were studied in detail: 1) a conventional oil sand plant producing fluid tailings; 2) a thickener case capable of producing paste; 3) a CT add-on capable of solidifying fluid tailings; 4) a centrifuge case capable of producing waste that approaches a solid state; and 5) a ‘Dry Tails Case’ - centrifuge treatment followed by the addition of “dry swelling clay” to provide final drying.

A generic platform was created so designs could be prepared for each technology using a common base. Projects were then designed for each technology that included plant layouts, process flow diagrams, material balances, operating and reclamation plans. Activities were defined in sufficient detail that cost differences between the technologies could be identified and compared.

Environmental liabilities were treated as costs by assuming that funds, equal in value to the liability, were deposited in a Trust at the time the liability was created. Four liabilities were booked in this manner: land disturbance, solidification of fluid tailings, water treatment at closure, and establishing a fund to finance closure.

Capital, operating costs, and preparation for closure were highest for case five and least for case one.

Results: Conventional economic assessment based on cash flow vs time favours cases from one to five, with one the preferred case. Those cases defer reclamation, minimize expenditure, transfer liabilities to future generations and do not advance the project toward closure. Economic assessment based on cash flow that recognizes reclamation liabilities as they are created favours cases from five to one with five the preferred case. Those cases invest in progressive reclamation, avoid tailings build-up and advance the project toward closure.

Conclusions:
1. Traditional economic analysis that discounts cash flow over long periods of time is misleading.
2. Traditional economic analysis of project options has misled management.
3. Economic screening should recognize liabilities as they are created. Otherwise, discounting will reduce the value of the reclamation liability, resulting in conclusions that are misleading.
4. The centrifuge solid waste case looks promising and should be explored in detail.
Part A – Study Cases
Screening Study of Tailings Reclamation Options

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Appendices are provided in Report B
A. Introduction to combined Reports A and B

This report documents a study undertaken to provide insight into the potential of alternative tailings technologies to:

- Reduce fresh water make-up needs in oil sand extraction and processing.
- Facilitate projects qualifying for a timely reclamation certificate.

The core program involved studies of four different tailings technologies and comparing their potential.

The work was undertaken under AERI contract 2008-0326. Richard Nelson, Manager of Water Use and Renewable Energy at the Alberta Energy Research Institute, was the AERI contact.

The report is organized into two parts.

Part A deals with the screening study of alternative tailings technologies. It documents how the technologies were studied, results obtained, water use, relevance to reclamation and closure, how the technologies were compared, and results of the screening process.

Part B provides background information about mineable oil sand projects, and specifically the tailings and reclamation components. The background on oil sand is essential to understanding the complexities of oil sand development. The novice reader may wish to read Part B first.

Support information is provided in the appendices.

Back up spread-sheets document material balances, full life cycle production, activities and costs for each technology studied. The spread sheets also contain the tailings forecast model, and the economic models that were used to evaluate the technologies. Electronic versions of those spread sheets are available from AERI.

Most of the work was performed by Dr David Devenny P. Eng., P. Geol. who works through his firm, the Rock Doctor. Brian Raymond P. Eng. of Raymond Mineral Dressing provided support and undertook the study on the Dry Tails case. The Dry Tails study involved a design and cost estimate for a facility to centrifuge fluid tailings, and then add “dry swelling clay” to achieve the density and strength desired for reclamation.

All information used in the study comes from public sources. An extensive literature review accompanied the study. The report does not have a specific section on the literature review. References are noted throughout the report.
A.1 Introduction to Report A

This section concentrates on the main screening study of alternative tailings technologies.

The study started with a detailed review of three projects and technologies:

1. The original Syncrude base plant because it represents early practice and provides a suitable base for additional processing technology such as CT.
2. The Total application for commercial development (Total, (2006 a & b) because it describes a thickener based approach and provides a detailed material balance. The information offers insight to thickener based paste and heat recovery.
3. The RTR/Gulf technology was piloted in 1980. It is a centrifuge based approach that produces solid waste with no tailings pond.

The three projects were studied in sufficient detail that representative flow sheets and material balances could be developed for each. The review provided valuable insight into oil sand operations. It also indicated that each project is unique and reflects different geology, design and operating philosophy. Those differences make it very difficult to compare projects.

A generic site platform was developed on which projects representing the different tailings technologies could be developed and compared. With the generic platform, differences would be due to the technologies, not differences in ore body characteristics or management style.

Next a representative project was developed for each tailings technology. Information developed included a process flow sheet, mass balance, a brief development and reclamation plan, and finally a list of work and cost vs. time so economic comparisons could be made.

The study of capital and operating costs focused on differences between technologies. If one technology used a different approach then the work and costs associated with that difference were identified.

Areas where major differences occurred included:

- Construction of earth structures to contain waste,
- Water use and heat loss,
- Tailings processing, transportation and reclamation costs,
- Reclamation costs including:
  - Land reclamation,
  - Fluid tailings reclamation,
  - A fund for water treatment prior to release at the time of closure,
  - A fund to pay for closure operations after operations cease.
Reclamation costs were treated as though deposits, equal in value to reclamation liabilities, were made to an environmental trust at the time reclamation liabilities were incurred. In practice, reclamation of disturbances was linked directly to production.

Technologies studied in detail included:
1. Base case technology, equivalent to Syncrude at start-up,
2. Thickener based technology that allows the production of paste and thickened tailings:
   - Stand alone thickener,
   - Thickener plus hydrocyclones,
3. CT based technology that can work on MFT alone or as an add-on to an existing facility:
   - CT applied to external MFT (from a pond),
   - Ct applied to fines derived in-plant,
   - CT capacity added to an existing facility,
4. Centrifuge technology offering the potential for solid waste.
5. Dry tails technology – a centrifuge case that adds “dry” swelling clay to extract the final bit of water from centrifuged tails to ensure the product meets density and strength targets. This case has a high probability of meeting target requirements for water content and strength.

A.2 The Generic Platform

A generic platform was developed to provide a common platform on which projects representing different technologies could be developed.

Site features are listed in Table A.1. Development plans are listed in Table A.2.

Projects employing different technology were designed for use on the generic site. The projects are listed in the previous section.

This was a screening study, undertaken to compare the performance of different technologies. Detailed design and cost estimates were outside the intended scope. However, the projects were studied in sufficient detail to reveal performance, operating, and cost differences. The focus was on big factors that affect tailings. Full cycle plans were developed for each project so the ability to qualifying for a reclamation certificate could be appraised.

Table A.1 Features of the generic site.

- A mineable oil sands site with normal available infrastructure.
- The ore body geology is amenable to development without onerous special needs.
Part A - Study Cases
Screening Study of Tailings Reclamation Options.

- Normal extraction processes work satisfactorily.
- The ore body is 50 m thick and is covered by 50 m of overburden.
- Characteristics of the ore and its constituents are summed below:

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight %</th>
<th>Weight per cubic metre (tonnes)</th>
<th>Volume in one cubic metre</th>
<th>Density/ specific gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitumen</td>
<td>11%</td>
<td>0.231</td>
<td>0.229</td>
<td>1.01</td>
</tr>
<tr>
<td>Water</td>
<td>5%</td>
<td>0.105</td>
<td>0.105</td>
<td>1.00</td>
</tr>
<tr>
<td>Fines</td>
<td>16%</td>
<td>0.336</td>
<td>0.127</td>
<td>2.65</td>
</tr>
<tr>
<td>Sand</td>
<td>68%</td>
<td>1.428</td>
<td>0.539</td>
<td>2.65</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>2.100</td>
<td>1.000</td>
<td></td>
</tr>
</tbody>
</table>

- Overburden is 50 m thick and is composed of
  - Surface muskeg 0 to 2 m thick,
  - Weak surface soil within the top 5 m,
  - The remainder is glacial till, 25% of which contains material derived from Clearwater clay/shale.
- The surface vegetation, ecology, and wild life are typical for the Northern Boreal region.
- There are no archaeological features that could impede development.
- All local residents support development.

Table A.2 Development plans
- An integrated project that produces 100,000 bbl per day of synthetic crude oil.
- The project places overburden and process waste in surface storage facilities for the first 6 years. Then the waste management operations move into mined out areas.
- The plant extracts 90% of the bitumen from the ore processed.
- Progressive reclamation is practiced as soon as it is practical to do so.
- Operations continue for 30 years.
- The project is designed to qualify for a reclamation certificate within 15 years after production operations are concluded.

Table A.3 lists specific criteria used to appraise each project.

Table A.3 Appraisal criteria used to appraise each tailings technology study case:
- Specific merits of each technology:
  - Relative volume of waste,
  - Energy efficiency,
  - Water use requirements,
  - Probability of meeting project goals for closure.
- Feasibility of qualifying for a timely reclamation certificate.
Part A - Study Cases
Screening Study of Tailings Reclamation Options.

- Contingency plans needed to meet project goals for closure.
- Economic assessment

The economic assessment was based on estimates for differences in capital, operating costs and managing timely reclamation obligations. Components:
  - Capital and operating costs,
  - Cost of building water retaining structures for those technologies that required them,
  - Cost of installing and operating different equipment in extraction and tailings facilities,
  - Heat loss,

Environmental obligations:
  - Reclaiming disturbed land,
  - Converting fluid tailings to a solid material suitable for reclamation,
  - Establishing a fund to treat water prior to release,
  - Establishing a fund to pay for closure activities.

A.3 The generic site and its development

Figure A.1 shows the layout of the generic site.
Normal site development is planned. If the development activity is common to all study cases there is no need to estimate the cost. However, if one project operates in a different manner, the cost of that activity is needed for comparison.

The study cases have different needs for four aspects of site development:

1. Work on the above ground tailings pond commences two years ahead of planned start-up. The starter dyke is constructed of material derived from stripping overburden in the mine area. Some projects do not require the full tailings facility. Consequently, the work and cost associated with building the surface tailings facility was determined.

2. Some projects rely heavily on CT processing to reduce inventories of MFT. To offset a shortage of sand to support CT activities, they use other construction materials to build retaining dykes. Resulting differences in facilities are indicated by Figure B.21 in Report B. There is a cost associated with those changes. As a result, the use, and cost, of alternative construction materials was determined for projects that use CT technology.

3. Process waste is stored in the mine after year 6. Fluid waste requires containment dykes capable of retaining fluid waste. Waste from projects that produce solid waste do not require fluid holding dykes. The difference is illustrated by Figure B.22 in Report B. The cost of building the in-pit dykes was determined because of this difference.

4. Some projects release more heated process water in their tailings discharge stream than others do. The heat discharged in tailings water by each project was derived from mass balances.

Figure A.2 shows how the mine develops over time. As each area is mined out, in-pit dykes are constructed to separate plant waste from the ongoing mining activities. The figure shows the location of the dykes vs. time.

Some other differences that are monitored as the projects progress include:

1. Waste transport is managed in different ways so the cost associated with each was determined. That means pumps and pipelines for some and conveyors or trucks for others.

2. There as a possibility that MFT deposits will have to be reprocessed and solidified before they can be reclaimed. The work and cost associated with that activity was determined.

3. Some projects are able to reclaim disturbed areas sooner than others. Discount analysis discourages early reclamation. That trend is reversed by recognizing environmental obligations as they are created. The vehicle to recognize reclamation obligations as they occur assumes that funds of equivalent value are deposited in a Qualifying Environmental Trust. The funds can be recovered when reclamation is undertaken.

Differences in equipment, work effort, performance and associated capital and operating costs were determined so the projects could be compared. Key factors are noted in Table A.4.
Part A - Study Cases
Screening Study of Tailings Reclamation Options.

Figure A.2 Mine plan year 12

Table A.4 Factors documented vs. time for each tailings technology

**Capital** – investment in capital associated with the particular tailings option.

**Plant operation** – looks at the work involved in processing ore, the tonnages involved, and the cost of processing - typical chemicals added etc.

**Earthwork** involves the quantity and cost of constructing dykes to contain waste products. The lowest cost involves solid waste that does not require dykes capable of holding fluid materials. Next comes containment made of sand. It is relatively easy to place and compact. In addition fines capture in tailings sand may reduce MFT production by 30% or more. The most expensive earthwork involves projects that save sand for other uses, and build the fluid retaining structures using overburden or other waste from mining operations.

**Tailings management** involves the work and cost of transporting and disposing of the plant waste products. It also includes the cost of recycling water from the waste disposal facility.

**Heat loss** is the indicator of energy efficiency. It involves identifying the quantity of heated process water that is discarded to tailings facilities. Some projects claim to have an abundance of free heat available, so this item is not of interest to them. The input spread sheet allows those who are blessed with free heat to place a lower value on this item if they wish.

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Table A.4 (continued)

Finally a price is put on four environmental factors that involve future reclamation obligations. The model assumes that funds equal to the value of the reclamation obligation are deposited in an environmental trust account when the obligation is created. The four environmental factors are:

- **Land disturbance** which, for the geometry of the generic ore body, occurs at the rate of 2 hectares per million cubic metres of ore processed;
- **Creation of fluid tailings** – which, at Syncrude, has averaged 0.266 cubic metres of MFT per cubic metre of average ore processed;
- **Establishing a fund to treat water so it can be released to the surrounding area.** This cost is arbitrarily set at $0.10 per cubic metre of ore processed;
- **Establishing a fund to pay for closure operations after operations cease.** This cost is also arbitrarily set at $0.10 per cubic metre of ore processed;

Tables A.5 and A.6 show capital and operating cost input values used in this study.

Electronic spreadsheets from the study of each technology show material balances, work and activity, associated capital and operating costs vs. time for the life of the project. The spreadsheets are provided in Appendix B.1 and are user friendly. Users can input their own values for capital and operating costs.

Entry of reasonable capital and operating costs is not likely to change the trend of the current appraisal and conclusions.
Part A - Study Cases
Screening Study of Tailings Reclamation Options.

Table A.5 Capital costs input values.

| Capital cost of facilities processing 100,000 bpd of Synthetic Crude |
| Does not include costs common to all cases |

**Base Extraction plant**
- MFT dredge with pumps: $25.00 million
- Tailings pipeline and pumps: $4.00 million per km
- MFT pipeline & pumps: $2.00 million per km
- Water recycle barge and pump: $10.00 million
- 36 inch pipeline: $0.80 million per km
- 20 inch pipeline: $0.50 million per km

**Thickener facility**
- Thickener facility: $100 million
- Cyclone facility: $100 million
- TT pipeline and pumps: $2.00 million per km

**CT facility**
- CT plant (cyclones, thickener)
- (blender, chem facility): $200.00 million
- CT pipeline & pumps: $4.00 million per km

**Centrifuge facility**
- Thickener: $100 million
- Centrifuge plant large: $200 million
- Centrifuge plant (small): $100 million
- Cake loading facility: $35 million
- Conveyor and stacker/spreader: $175 million
- Clearwater mine & crusher: $35 million

**Reclamation costs**
- Reclaim disturbed ground: $30,000.00 $ per hectare
- Reclaim MFT $ per m^3: $5.00 $/m^3
- Water treatment $/m^3 ore: $0.10
- Closure cost $/m^3 ore: $0.10

**Power use**
- Natural gas per gigajoule: $5.00
- Electrical power $/MW-h: $60.00
- Value of heat $/gigajoule: $5.00

Note – Unit costs for reclamation and power are also included in the above list of capital costs.
Table A.6 Operating cost input parameters.

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<thead>
<tr>
<th>Material Transport</th>
<th>General</th>
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<tr>
<td>Shovel/Truck</td>
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<tr>
<td>Classify ($/t)</td>
<td>$0.15</td>
<td></td>
</tr>
<tr>
<td>Excavate ($/t)</td>
<td>$0.25</td>
<td>$0.50</td>
</tr>
<tr>
<td>Transport ($/t-km)</td>
<td>$0.10</td>
<td>$0.10</td>
</tr>
<tr>
<td>Place ($/t)</td>
<td>$0.10</td>
<td>$0.20</td>
</tr>
<tr>
<td>Earthwork premium ($/t)</td>
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<tr>
<td>Premium if filter required</td>
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Hydrotransport (cost includes pipe and pump replacement)

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<th>General</th>
<th>Construction</th>
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<tbody>
<tr>
<td>Thin tails or water ($/m³-km)</td>
<td>$0.01</td>
<td></td>
</tr>
<tr>
<td>Coarse tailings and CT ($/t-km)</td>
<td>$0.03</td>
<td></td>
</tr>
<tr>
<td>Transfer MFT to CT plant ($/m³)</td>
<td>$0.15</td>
<td></td>
</tr>
<tr>
<td>TT slurry to pond ($/m³)</td>
<td>$0.15</td>
<td></td>
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</tbody>
</table>

Conveyor (cost includes replacement)

<table>
<thead>
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<th>General</th>
<th>Construction</th>
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</thead>
<tbody>
<tr>
<td>Bulk conveying ($/t-km)</td>
<td>$0.02</td>
<td></td>
</tr>
<tr>
<td>Bulk conveying with stacker</td>
<td>$0.06</td>
<td></td>
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</table>

Relocate MFT barge to another pond $5.00 (million per move)

Relocate water recycle barge $3.00 (million per move)

CT facility

<table>
<thead>
<tr>
<th>Material</th>
<th>General</th>
<th>Construction</th>
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</thead>
<tbody>
<tr>
<td>Operate plant ($/m³ of slurry)</td>
<td>$0.10</td>
<td></td>
</tr>
<tr>
<td>Chem facility ($/m³ of slurry)</td>
<td>$0.02</td>
<td></td>
</tr>
<tr>
<td>Gypsum ($/m³ of slurry)</td>
<td>$0.05</td>
<td></td>
</tr>
</tbody>
</table>

Thickener

<table>
<thead>
<tr>
<th>Material</th>
<th>General</th>
<th>Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operate plant ($/t solid)</td>
<td>$0.20</td>
<td></td>
</tr>
<tr>
<td>Floc ($/t solid)</td>
<td>$0.40</td>
<td></td>
</tr>
<tr>
<td>Operate cyclones ($/t solid)</td>
<td>$0.10</td>
<td></td>
</tr>
</tbody>
</table>

Centrifuge

<table>
<thead>
<tr>
<th>Material</th>
<th>General</th>
<th>Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant operation ($/t solid)</td>
<td>$0.25</td>
<td></td>
</tr>
<tr>
<td>Floc ($/t solid)</td>
<td>$0.35</td>
<td></td>
</tr>
<tr>
<td>Load cake on truck ($/t solid)</td>
<td>$0.10</td>
<td></td>
</tr>
</tbody>
</table>

Earthwork

<table>
<thead>
<tr>
<th>Material</th>
<th>General</th>
<th>Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compact overburden fill ($/t)</td>
<td>$0.50</td>
<td></td>
</tr>
<tr>
<td>Compact tail cell sand ($/t)</td>
<td>$0.25</td>
<td></td>
</tr>
</tbody>
</table>

Tailings Ponds and Dykes monitor and maintain

<table>
<thead>
<tr>
<th>Material</th>
<th>General</th>
<th>Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual cost ($/m³ stored)</td>
<td>$0.02</td>
<td></td>
</tr>
</tbody>
</table>
A.4 Description of the individual technologies.

A.4.1 Introduction

This section provides an overview of the technologies evaluated.

Performance is summarised and compared in Section A.5.

Economic evaluations are compared in Section A.6

Material Balances for each technology are provided in the electronic spread sheets - Appendix B.1 of Report B.

A.4.2 The Base Case

The Base case is a clone of early Syncrude. It produces solid sand waste and fluid tailings that require containment. Operators would like to permanently store the fluid tailings under a water cap in the end-pit lake. This study assigns a cost to solidify the inventory of MFT as it is created over the life of the project.

Figure A.3 is the site plan of the Base Case.
Figure A.4 is a simplified process flow sheet for this case. The focus is on what goes in and what comes out of extraction. Fine adjustments for internal process steps are not needed as long as the main flows are reasonable.

A.4.3 Thickener Cases

Two versions of the Thickener Case were appraised.

The first option uses a thickener to densify the fines stream. The second option uses a thickener to densify the fines, and hydrocyclones to densify the sand stream.

Figure A.5 is a site plan for this case. It is very similar to the base case. Figure A.6 shows the process flow sheet.

In thickener operations the fine grained stream is diluted and then flocculants are added. With flocculation the fines stream is gradually densified, aided by stirring rods and by the weight of overlying material. Sometimes sand is added to speed up the thickener process. The sand will add to the volume and density. It will not change the strength unless it changes the clay/water ratio of the component that controls the strength of mixes with high fines ratios.
Material released at the thickener overflow is mostly fluid. Densified fines exit at the underflow. It would not be practical to add so much dilution water if the thickener could also not remove it. The density of the underflow is probably similar to the density achieved in the tailings pond – about 30
Part A - Study Cases

Screening Study of Tailings Reclamation Options.

weight % solid. Industry is optimistic that a super flocculating agent will be found, that is compatible with extraction, and yields higher densities.

Hydrocyclones provide a swirling water vortex that exerts forces on the contents. Hydrocyclones are used to sort solid materials such as sand on the basis of particle size and density. Overflow from the hydrocyclones is a dilute suspension of fine grained material. The underflow yields sand with a solids content of up to 72%.

Together these treatments extract water from the waste material in the plant. That allows in-plant recycle of the process water, and its contained heat.

In the current assessment, the densified streams were combined and sent to the sand disposal and then to the tailings pond.

The equipment in this case is also capable of making CT. It is used in that fashion in the next section.

A.4.4 CT Cases

Three CT Cases were evaluated.

1. A CT facility processing MFT from external sources.

2. A CT facility processing thickened tailings produced by the plant (i.e. from internal sources).

3. Adding a CT facility to an existing Base Case type facility.

The claim of CT processing is that it consumes fluid tailings by mixing it with gypsum and sand. The resulting slurry is pumped to storage where the deposit consolidates. Eventually the deposit consolidates to a solid material suitable for reclamation. Limitations of the CT technology are discussed elsewhere in Report B.

If all the fines are transformed to MFT containing 30 weight percentage solids, each cubic metre of average ore should yield 0.91 cubic metres of MFT. In contrast, the historical yield at Syncrude is only 0.266 cubic metres of MFT per cubic metre of ore. That indicates that only 30% of fines are active in making MFT. The rest of the fines are either inert silt, or are captured in sand voids. Implications:

- Processing fines from within the plant processes all fines, of which only 30% create MFT. In one year, in-plant treatment of the fines stream avoids 8.5 million cubic metres of MFT.

- Processing fines from an external source such as a tailings pond deals with the active component of fines so can treat 23.5 million cubic metres of MFT.
A.4.4.1 CT Case 1

CT Case 1 processes MFT from an external source. Figure A.7 shows the site layout. MFT is dredged from a tailings pond and pumped to the CT processing facility. Figure A.8 shows the process flow sheet for making CT.
Part A - Study Cases
Screening Study of Tailings Reclamation Options.

At the CT facility a coagulant is added to MFT to overcome repulsive forces between clay particles that resist densification. Next, sand is added to create a sand:fines mix of about 4.5:1. The resulting CT slurry is pumped to storage. Each cubic metre of fluid tailings processed becomes 2.27 cubic metres of CT slurry. In place the slurry consolidates. The weight of overlying material and a surcharge of clean sand at surface aid consolidation to a solid product. Eventually, about one cubic metre of water is released so the final volume of the consolidated CT deposit is about 1.27 cubic metres. The associated density is 80% solids.

For our generic project, producing 100,000 barrels of synthetic crude per day, the sand stream is theoretically capable of treating 23.5 million cubic metres of MFT per year.

The extraction process that yields the sand stream used in CT processing also produces fines. In the study case the extraction fines are pumped to a tailings pond where it creates fresh MFT. On the basis of historical MFT make at Syncrude, it is expected to create about 8.5 million cubic metres of new MFT per year. Thus the net amount of MFT removed by this option is 15 million cubic metres per year.

Field trials to verify CT performance are still underway. However, if the deposits densify as forecast, this process converts fluid tailings to a solid material that can then be reclaimed.

A.4.4.2 CT Case II

In the second CT Case, fines for CT are obtained from thickened tailings produced by the plant.

The “average” ore assumed in our study has a sand to fines ratio of 4.25 so all waste can be used to make CT. Material fed to the CT mixer includes sand densified to 72% solids by hydrocyclones, fines, densified to 30% fines solids by a thickener, and gypsum. The resulting CT slurry is pumped to storage where it is expected to consolidate to a dense CT deposit.

If successful, this option prevents the formation of 8.5 million cubic metres of MFT per year. It also creates a solid landscape that will allow progressive reclamation.

This case is based on processing with a continuous stream of “average” ore. In the real world the extraction process must deal with variable ore. That means there will be times when there is too much sand, and times when there is not enough sand. Too much sand can be accommodated by making a CT with a higher sand to fines ratio – provided the sand content does not exceed the no segregation boundary. Insufficient sand, will result in a high fines mix that will not be acceptable. During such periods, surplus fines will have to be diverted to temporary holding facilities. That means times when there will be less CT processing than predicted.

A.4.4.3. CT Case III
Part A - Study Cases
Screening Study of Tailings Reclamation Options.

CT Case III involved a mini study to appraise the potential of a CT add-on to process the inventory of MFT that accumulated in the early years of operations.

CT Case II dealt with CT treatment of fines from within. It prevented the formation of 8.5 million cubic metres of MFT per year and had no spare capacity to process fines beyond day-to-day needs. In reality, the plant will fall behind on days when high fines ore is encountered. That suggests that an in-plant CT facility is unlikely to be able to deal with an inventory of MFT that accumulated before CT treatment was introduced.

CT Case I treated 23.5 million cubic metres of MFT per year from external sources while producing 8.5 million cubic metres of fresh MFT. The 23.5 million cubic metre capacity was derived by matching sand in the cyclone underflow with MFT solids at a ratio of 4.5:1. The 8.5 million cubic metres of fresh MFT was forecast from the Syncrude historic average.

Figure A.9 is a plot of cumulative MFT production in a plant that produces 100,000 barrels of synthetic crude per day for 30 years. The plant produces 8.5 million cubic metres of MFT per year throughout its 30 year life. CT treatment facilities are added at different times after start-up: 4, 8, 12, or 16 years. They are capable of treating 23.5 million cubic metres of MFT per year. MFT is processed at a rate that will consume the MFT inventory by the end of operations.

Figure A.9 shows how the inventory of MFT declines after the CT facility is added. The legend also shows the CT processing efficiency required to consume the MFT by the end of operations. Figure A.10 shows the required efficiency vs. the time that CT facilities are introduced.

CT processing efficiency is the product of the percentage of time that the plant is making CT, and when it is, the percentage of time that it is able to produce and place CT as specified. Actually, the problem is more complex than indicated because non-specification CT may have to be reprocessed.

Public data on CT processing efficiency is not available. However, in view of reported shortfalls in CT production, (Houlihan et al., 2008) it is assumed to be low. Syncrude’s capacity for treating MFT is not known, but in the past decade they only treated about 20 million cubic metres of MFT (Fair, 2008), about 10% of the MFT that they produced.

Figure A.10 suggests that if CT production efficiency cannot be sustained above 50%, the projects will not be able to process the existing MFT inventory.
A.4.5 Centrifuge Technology
Part A - Study Cases
Screening Study of Tailings Reclamation Options.

This case uses a centrifuge to dewater the fines stream. Figure A.11 shows the layout for the centrifuge case. The centrifuge can process fines from internal or external sources.

Figure A.11 Centrifuge Case – Site Plan

Figure A.12 shows the process components.
Part A - Study Cases
Screening Study of Tailings Reclamation Options.

Centrifuges are brute force devices. They apply thousands of times the force of gravity to accelerate drainage from fine grained soil. A thickener precedes the centrifuge – to prepare the feed. Centrifuges are not high capacity units so many units are required to process large tonnages. Fortunately, the fines stream that they process is relatively small.

In centrifuge processing, 5% of the solids remain in the centrifuge overflow. They are circulated back to the primary separation vessel at the start of extraction. The target solids content of the centrifuge cake is 60% by weight fine solids. At that density the cake must be transported as a solid. Truck transport was selected to transport the centrifuge cake to the disposal site. Although trucking is probably four times as expensive as conveying, the costs are better understood and are more predictable. The transport cost used in the study was $0.10 per tonne-km. In addition an allowance of $0.20 per tonne was assumed to spread material at the waste disposal site.

The study assumes that sand waste is pumped to the waste disposal site. There it is passed through hydrocyclones to yield sand that is 72% by weight solid. Cyclone overflow water is returned to the extraction plant. The densified sand is discharged onto a conical pile to facilitate additional drainage.

The sand volume is 4.5 times the volume of the centrifuge cake. The two are kept as separate materials. The sand will be placed so it surrounds the cake. In that manner it can provide support, surcharge the cake to induce consolidation, and provide drainage. Figure A.13 illustrates how deep burial can surcharge and consolidate the cake. Figure A.14 shows different options for placing the sand and cake at depth.

Characteristics of proposed centrifuge cake disposal:

1. The entire sand component is available to support placement of the centrifuge cake if it is weaker than the target strength of 10 kPa.

2. The cake only represents 11% of the total pit backfill. (plant waste + overburden). That means that the potential surcharge above the cake could be 70+ metres thick.

3. The weak cake will be placed below the depth of possible exposure by long term gully erosion. The safety zone for such placement is discussed in Report B and is illustrated by Figure B.25.
Part A - Study Cases
Screening Study of Tailings Reclamation Options.

Figure A.13 Option for deep placement of centrifuge cake

Cross section of backfilled pit

Figure A.14 Options for sand – cake inter-layering in-pit

Layered

Dumped

Windrows

Polders

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A.4.6 Dry Tails Case

This case was added to the studies to meet the requirement of offering at least one option with a high probability of meeting the strength goals for reclamation. The case involves centrifuging fines to produce cake. Then “dry” swelling clay is added to extract the last bit of water required to achieve the target density associated with the target strength. Figure A.15 shows the layout for the dry tails case.

Figure A.16 shows the process flow sheet.
Table A.7 lists detailed steps involved in the Dry Tails Case.

Table A.7 Steps in the Dry Tails Case:

1. Build a robust dredge to reclaim MFT from an existing deposit.
2. Decant the water off the top of the pond and transport it to another pond.
3. Dredge the MFT and pump it to the processing facility on land.
4. On land, MFT is placed in one of two thickeners. The thickeners can be used to densify any MFT diluted in transit. They also act as a surge facility ahead of the centrifuges.
5. Centrifuge the MFT using the largest centrifuges available. Densities of about 60% can probably be achieved on a sustainable basis. 70% is probably needed to achieve the strength target of 10 kPa.
6. Blend “dry swelling clay” with the centrifuge cake in accordance with Figure A.17 to remove the targeted amount of water from the cake. When “dry swelling clay” is added to the cake, water transfer will occur until an equilibrium state is reached between the two materials. The “dry swelling clay” is obtained from an adjacent pit and conveyed to the centrifuge facility.
7. Convey the blended cake and clay to a disposal site. There it will be spread over a large area using stacking conveyors.
8. The study included 6 kilometres of conveyor to transport ‘dry swelling clay’ to the centrifuge processing site and 4 kilometres of conveyors to transport the blended product to the disposal site.

Figure A.17 shows the blending requirements to remove water from centrifuge cake.

The Dry Tails Case requires access to the Clearwater formation. Figure B.8 in Report B shows that the Clearwater Formation is nearby for most mineable oil sand projects. Appendix B.2 provides a more complete description of the Dry Tails Case.
A.5 Performance evaluation

A.5.1 Physical performance

Physical performance data is summarised below.

Hot Water Loss

Hot water loss is the amount of hot water that is discharged to tailings. Water loss is always less than hot water loss because surplus water that reaches the pond can be recycled.

The Base Case lacks equipment to remove water in-plant. In addition, it uses the tailings pond to clarify water and to mature the fines component to MFT. As a result it has a high hot water loss. Today the hot water loss at Syncrude is less than it was because Syncrude limit the amount of water used in extraction.

The Thickener 1 Case shows the benefit of adding a thickener to reduce hot water discharged to tailings. The thickener reduces the heat loss of the Base Case by 10%. The impact is relatively small because fines only represent 20% of the solid material processed.

The Thickener 2 Case shows the added benefit of having hydrocyclones to dewater the biggest waste stream – the sand. In this case the thickener and the cyclones reduced the heat loss of the Base Case by 30%.

The hot water loss associated with CT processing is equivalent to Thickener II which also used a thickener and hydrocyclones.

The centrifuge case has the lowest hot water loss because it removes the most water from its products before releasing them.

The potential value of the hot water lost is about $0.83 per cubic metre. That assumes a temperature loss of 40 degrees centigrade and that a gigajoule of heat is worth $5.00.

Water loss

Water loss is the amount of water permanently removed from circulation. Most of it resides in the pore space of sand. The remainder resides in fluid tailings in the tailings pond. Material balances give a breakdown of the relative volumes.
Table A.8 Comparison of water use and waste volume for the different technology cases. (Data represents cubic metres of water or waste per cubic metre of ore processed)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Base Case</th>
<th>Thickener 1 without cyclones</th>
<th>Thickener 2 with cyclones</th>
<th>CT-2 Processing internal TT</th>
<th>Centrifuge Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water loss</td>
<td>1.764</td>
<td>1.598</td>
<td>1.214</td>
<td>1.207</td>
<td>0.704</td>
</tr>
<tr>
<td>Water loss*</td>
<td>0.633</td>
<td>0.628</td>
<td>0.613</td>
<td>0.437</td>
<td>0.704</td>
</tr>
<tr>
<td>Waste Volume</td>
<td>1.320</td>
<td>1.301</td>
<td>1.286</td>
<td>1.108</td>
<td>1.318</td>
</tr>
</tbody>
</table>

*Water loss assumes that MFT is the final product for the Base Case and Thickener options.

** CT Case 1 and the Dry Tails Case process MFT so are not presented in this table which relates to production per cubic metre of ore processed.

The Base Case and the thickener cases have similar water losses. The lost water is mostly trapped in sand voids so is more a function of the sand deposit than of the tailings technology.

Water loss reported for the centrifuge case represents the water content of the cake and the initial sand slurry. The mass balance suggests that subsequent drainage from sand waste could reduce the long term water loss to 0.517 cubic metres of water per unit of ore processed.

**Waste volumes.

Waste volume is the total volume of the sand and fluid tailings. It does not include the water cap on the tailings pond because it is temporary. MFT is considered to be the end product for fines in the Base Case and Thickener Cases. The volume of waste created was about 1.3 cubic metres per cubic metre of ore for all cases. Seventy five percent of the waste volume is sand. The tailings pond gets attention but it only represents 25% of the total waste volume.

The smallest volume of waste occurs with CT Case 2 because it maximizes the storage of fines in the void space of the sand.

The volume of the waste from the centrifuge case is relatively high because the fine waste is not stored in the void space of the sand.

**A.5.2 Cost performance

Electronic spread sheets in Appendix A.1 detail the life of project activity and associated costs for each tailings option. Cost data is summarised in Table A.9.
Table A.9  Summary of cost differences between tailings technologies.

<table>
<thead>
<tr>
<th>Cost Centre Summary (Undiscounted cost per m³ of ore processed)</th>
<th>Base Case w/o cycl</th>
<th>T1 w/cycl External MFT</th>
<th>T2 w/cycl Internal MFT</th>
<th>CT I</th>
<th>CT II Centrifuge</th>
<th>Dry Tails</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPV0 Capex</td>
<td>$ 0.06</td>
<td>$ 0.16</td>
<td>$ 0.30</td>
<td>$ 0.27</td>
<td>$ 0.40</td>
<td>$ 0.50</td>
</tr>
<tr>
<td>NPV0 Opex</td>
<td>$ -</td>
<td>$ 0.22</td>
<td>$ 0.40</td>
<td>$ 0.40</td>
<td>$ 0.54</td>
<td>$ 0.57</td>
</tr>
<tr>
<td>NPV0 Earth</td>
<td>$ 0.06</td>
<td>$ 0.06</td>
<td>$ 0.06</td>
<td>$ 0.70</td>
<td>$ 0.62</td>
<td>$ 0.03</td>
</tr>
<tr>
<td>NPV0 Tailings O</td>
<td>$ 0.22</td>
<td>$ 0.28</td>
<td>$ 0.27</td>
<td>$ 0.43</td>
<td>$ 0.20</td>
<td>$ 0.41</td>
</tr>
<tr>
<td>NPV0 Heat loss</td>
<td>$ 1.47</td>
<td>$ 1.33</td>
<td>$ 1.01</td>
<td>$ 1.47</td>
<td>$ 1.01</td>
<td>$ 0.59</td>
</tr>
<tr>
<td>NPV0 Land</td>
<td>$ 0.12</td>
<td>$ 0.12</td>
<td>$ 0.12</td>
<td>$ 0.14</td>
<td>$ 0.12</td>
<td>$ 0.15</td>
</tr>
<tr>
<td>NPV0 MFT</td>
<td>$ 1.33</td>
<td>$ 1.33</td>
<td>$ 1.33</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>NPV0 Water</td>
<td>$ 0.10</td>
<td>$ 0.10</td>
<td>$ 0.10</td>
<td>$ 0.10</td>
<td>$ 0.10</td>
<td>$ 0.10</td>
</tr>
<tr>
<td>NPV0 Closure</td>
<td>$ 0.10</td>
<td>$ 0.10</td>
<td>$ 0.10</td>
<td>$ 0.10</td>
<td>$ 0.10</td>
<td>$ 0.10</td>
</tr>
<tr>
<td>Unit cost</td>
<td>$ 3.46</td>
<td>$ 3.71</td>
<td>$ 3.66</td>
<td>$ 3.64</td>
<td>$ 2.96</td>
<td>$ 2.35</td>
</tr>
</tbody>
</table>

Note 1  The CT I and Dry T cases are designed to process external MFT. Consequently they are misfits for this comparison that is based on unit cost per cubic metre of ore.

Note 2  % Reclaimed

<table>
<thead>
<tr>
<th>Land</th>
<th>35%</th>
<th>35%</th>
<th>35%</th>
<th>100%</th>
<th>100%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFT</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>274%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

The table shows the components included in unit costs. Unit costs are averaged from costs incurred over the full life of the project. Amounts indicated for environmental costs include deposits to an environmental trust as the reclamation obligation occurred.

The bottom line of Table A.9 shows how much of the work required for closure has been accomplished during operations. Projects on the left, that show minimal progress, are not leading to closure. Projects on the right show considerable progress toward closure.

The cost trends of Table A.9 are illustrated by Figures A.18 to A.20. Costs for Cases CT 1 and Dry Tails are not included in the figures because they process external MFT. The base unit of cost per cubic metre of ore processed does not apply to those cases.

Figure A.18 shows basic capital and operating costs that are often used to screen options.

Figure A.19 is the same as A.18 but includes operating costs arising from extra earth work, tailings operations and heat loss specific to each technology.
Figure A.20 is the same as A.19 but includes environmental costs as the liabilities associated with land reclamation, MFT solidification, and establishing funds for water treatment and other closure activities at the end of the project.
A.5.3 Economic performance

The preceding section examined the technologies on the basis of cost. The next step is to test the economics of the different technologies in the real financial environment that the integrated project faces. Project economics are complicated by capital cost allowances, royalty before and after pay-out, and income taxes. An economic test is needed to confirm that the winning technology retains its rank by showing a superior rate of return for the project.

A financial model was developed to represent the full life cycle of the integrated oil sand project. Input includes key factors required to calculate the rate of return for the life of the integrated project. That includes the following vs. time: production and income from product sales, all project capital and operating costs, royalty, capital cost allowances, federal and provincial income tax. The rate of return for the integrated project is then compared with specific capital and operating costs entered for each tailings technology. An electronic copy of the full project financial model is provided in Appendix B.1 of Report B. Table A.10 compares the Developer’s rate of return for each technology.

Table A.10 – Developer’s rate of return for different tailings technologies.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Return to the Developer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case</td>
<td>10.73%</td>
</tr>
<tr>
<td>Thickener I Technology</td>
<td>10.58%</td>
</tr>
<tr>
<td>Thickener II Technology</td>
<td>10.49%</td>
</tr>
<tr>
<td>CT II Technology</td>
<td>10.55%</td>
</tr>
<tr>
<td>Centrifuge Technology</td>
<td>10.57%</td>
</tr>
</tbody>
</table>
Table A.10 shows the developer’s return for the different technologies. The centrifuge case is the best of the technologies that are leading the project to closure. Table A.10 also shows that the cost of tailings is a relatively small part of the overall project economics.

A.5.4 Discussion

Base Case and Thickener Options

The Base Case and Thickener options are not preparing the projects for closure. They stockpile fluid tailings that prevent access for land reclamation. Other technologies will be required to treat the fluid tailings.

CT Processing

Oil sand operators are still evaluating the CT option despite the fact that it has been in commercial use for over 10 years. They are optimistic that CT, manufactured with a sand to fines ratio of 4 or more, will yield a solid surface suitable for reclamation.

The cost data for CT Case 1 is misleading when judged on the basis of cost is per cubic metre of ore processed. CT Case 1 is processing MFT that was created by others. In that sense CT Case 1 is acting like a contractor, processing MFT and collecting from the environmental fund for doing so.

The CT process offers a solution to treat MFT. However it has limitations:

- There is not enough sand to support CT processing of all MFT.
- CT production has a history of low operating efficiency.
- The CT slurry is a fluid that requires containment. It costs more to build facilities to hold fluids.
- Assigning all sand to CT production causes operators to substitute other materials to build dykes and containment structures. There is a cost associated with those substitutions.
- Eliminating sand dykes, and the fines captured in them, will increase the fines available to make MFT (estimated increase 30%).
- If the CT process efficiency is below 50% it will not be able to process prior inventories of MFT.

Centrifuge Case

The centrifuge case has higher capital and operating costs than the other technologies. However, it also appears to have the lowest unit cost for tailings when all costs are taken into account. Offsetting factors include:

- A significantly lower cost for earth structures because extensive water retaining structures are not needed.
Part A - Study Cases
Screening Study of Tailings Reclamation Options.

- Less heat loss.
- A significantly lower cost for MFT because the process creates solid waste. There is no MFT.

Higher costs associated with the centrifuge option include:
- Capital – the plant includes the most process equipment so is the most expensive.
- Operating costs – it costs more to operate all that equipment.
- Higher tailings costs – it costs more to transport and to place solid waste. Fortunately the volume is small.

Waste disposal for the centrifuge case has not been optimized. It is possible that optimization studies will make this option even more attractive.

The Dry Tails Case

Like CT Case 1 the Dry Tails Case is different from the other technologies studied. It processes cold MFT and converts it into a solid reclaimable material. That allows other reclamation tasks to proceed.

The Dry Tails technology involves high capital and operating costs:

Low costs result from:
- No heat loss,
- No need for costly water retaining structures,
- No MFT cost,
- No significant delay in land reclamation.

The Dry Tails Option processed cold MFT. That may be the preferred feed source for centrifuges because:

- It is not tied to a production facility.
- Centrifuges may not like sand in the material that they process. Feed from a pond may be the ideal feed for a centrifuge because the pond acts as a huge sorting vessel. In the plant environment, upset conditions that will put sand in the feed are to be expected.
- The natural density of MFT reduces the need for thickener treatment to densify the feed.

Discussion of economic performance

The unit costs indicated are cost differences between the cases.

Table A.9 shows unit cost trends. Projects on the left have low capital and operating costs. Projects on the right have higher capital and operating costs.
Part A - Study Cases
Screening Study of Tailings Reclamation Options.

Figure A.18 shows differences in capital and operating costs. That is often the basis for comparing technologies. It suggests that the preferred technologies are those on the left.

Figure A.19 adds project specific costs to Figure A.18. It adds the cost of extra earthwork, tailings operating costs, and heat loss. The outcome still favours the technologies on the left.

Figure A.20 includes the cost of environmental liabilities as they are created. Now the lowest unit costs, and hence the preferred options are those on the right. Although the preferred cases have high capital and operating costs, they also have the lowest overall unit costs when environmental liabilities are taken into account.

Traditional economic analysis that overlooks environmental obligations from the time that they are incurred is misleading and favours the technologies that are not leading the project to satisfactory closure.

If the economic evaluations are based on discounted full life cycle unit costs they will still favour technologies on the right if reclamation liabilities are booked as they occur. Booking liabilities as they are created avoids the distortion caused by discounting over long periods of time.

A.6 Screening study summary, conclusions and recommendations

A.6.1 Summary

The study reviewed extraction and tailings practices and then developed generic cases to evaluate the relative merits of different tailings technologies.

Technologies appraised:

- Conventional processing – equivalent to the technology used at the start of Syncrude.
- Thickener technology – that has the potential to produce thickened tailings and paste.
- CT technology – that creates a pumpable slurry that consolidates to a reclaimable material.
- Centrifuge technology – that creates solid waste.
- A Dry Tails option involving centrifuge treatment followed by blending with swelling clay to further reduce the water content.

A generic project platform was developed so projects based on the different technologies could be tested in the same environment. First a process flow sheet and material balance was prepared for each technology. Project development and reclamation plans followed. Finally, a spreadsheet was developed for the life of each project – showing work and costs involved in operating, reclaiming, and meeting requirements for closure after a thirty year life. That data provided a screening level basis for comparing the different technologies.
Part A - Study Cases
Screening Study of Tailings Reclamation Options.

Normal cost categories included capital and operating costs, the cost of differences between technologies such as heat loss, constructing waste containment, tailings transport and placement.

The current appraisal also linked reclamation obligations to production so they were captured as they occurred. The model assumed that funds were placed in a Qualifying Environmental Trust at the time that future obligations were incurred. Funds were recovered from the Trust as reclamation took place.

The technologies were compared on the basis of:

- Physical attributes such as hot water loss, water loss, and the volume of waste.
- How well they prepare the project for closure.
- Cost differences between technologies.

Life cycle costs were appraised on the basis of the average unit cost to process one cubic metre of average ore. Discounted unit costs are also indicated and yield similar results.

Economic analysis indicates that centrifuge technology is the preferred technology.

Economic evaluation, based on the rate of the return to the developer, confirm that the centrifuge technology is the preferred technology.

The study did challenge some myths that often interfere with the screening of tailings technologies:

- The study looked at conditions in extraction – a subject normally excluded from tailings studies.
- The study was not required to be compatible with an approved project business plan.
- The study did not have to accept pumped transport.
- All processing does not have to take place in the central processing facility.
- Economic evaluations were not conducted by corporate financial staff, who follow traditional economics based on discounted cash flows.
- The economic evaluation considered the cost of reclamation liabilities as they were created.

A.6.2 Conclusions

The study methodology provided a credible appraisal of tailings technologies.

The simple Base Case technology is stockpiling fluid tailings that prevent reclamation and preparation for closure. Other technology must be introduced to prepare the project for closure.

Thickener based technology is similar to the Base Case technology. The waste product is still fluid tailings that accumulates and prevents reclamation.
Most developers are relying on CT or a related technology to solidify fluid tailings allowing reclamation and closure. CT treatment creates a slurry that can be pumped to the waste disposal site. There the slurry consolidates to a solid reclaimable material. However, CT technology has limitations that should be recognized. CT limitations are discussed in Report B.

The appraisal concludes that centrifuge treatment looks promising. It creates a fine grained cake that is approaching a solid consistency. It also produces a separate sand stream that should be able to contain the cake.

The centrifuge option involves more equipment, and has higher capital and operating costs than the other technologies. However, due to savings in key areas it also offers the lowest full cycle unit cost of the tailings technologies studied. Savings come from the fact that:

- The technology solidifies fluid tailings and prepares the project for closure.
- Costly water retaining structures are unnecessary.
- Heat loss is minimized.

The Dry Tailings option also looks promising. It was designed as an independent operation to convert MFT to cake strong enough for reclamation. If the water content of the centrifuge cake is not low enough it can be lowered further by adding “dry swelling clay”.

Centrifuge based technology has not been demonstrated at a large scale on MFT materials. Large scale tests, using the largest centrifuges available are needed because scale-up from smaller machines is problematic.

An unexpected finding was that CT processing of MFT is different from CT processing of in-plant fines. Only one third of in-plant fines create MFT but, when treated in-plant, all fines must be treated. The remaining fines are inert silt particles or are captured in sand voids. When MFT from an external source is processed all the treated material has been active in making MFT.

Full life cycle evaluations need to include environmental obligations in the analysis. This study recognized environmental obligations as they were created by assuming that funds of equivalent value were deposited in an environmental trust. That offsets the trend of traditional approaches that defer reclamation for decades and then seriously discount the value of obligations. Evaluations that recognize environmental liabilities as they occur also identify technologies that facilitate reclamation.

**A.6.3 Recommendations**

1. Undertake an independent review to verify the procedures and conclusions of this report:
   a. Confirm that the approach followed was reasonable and effective.
b. Confirm that the closure plans and indicated costs are directionally correct.
c. Confirm the potential of the centrifuge option.

2. Undertake research to build confidence in the centrifuge/solid waste option. Recommendations for research are provided in Appendix B.5 of Report B.

3. Encourage adoption of the procedure used in this study to conduct economic evaluations when environmental liabilities are involved. The study assumed funding a Qualifying Environmental Trust at the time a liability is created. That overcomes the unnatural effect that discounting over long periods of time has on future obligations.

This study shows that it is feasible to solidify fluid tailings. The study sets a benchmark for solidification. The author encourages discovery of a lower cost approach to achieve the same results.

A.7 Closure

Considerable effort was expended to provide a background and context on how to screen technology for use in oil sands. Readers are encouraged to read Report B which provides a background on tailings and suggestions of how technology options should be screened.

Many people contributed to the author’s background and to this study. Their contributions are greatly appreciated. In particular I thank Brian Raymond for preparing cost estimates for the Dry Tails Centrifuge Case.

The approach to screening options was novel. It is believed to be thorough and appropriate for a screening study. The conclusions are supportable and warrant follow-up.

Hopefully, this document will help readers understand the issues in tailings and of the need to find an appropriate path to closure.

Thanks to AERI and for sponsoring the work, and to Richard Nelson for effective management on behalf of AERI.

I would be pleased to answer any questions about the study

Respectfully submitted

David Devenny PhD., P. Eng., P. Geol. (Alberta)
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