Development of a Static Oil Sands Mine and Extraction Reference Facility

PRESENTED TO
Canada’s Oil Sands Innovation Alliance

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LIMITATIONS OF REPORT
This report and its contents are intended for the sole use of Canada’s Oil Sands Innovation Alliance and their agents. Tetra Tech Canada Inc. (Tetra Tech) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than Canada’s Oil Sands Innovation Alliance, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this report is subject to the terms and conditions stated in Tetra Tech Canada Inc.’s Services Agreement. Tetra Tech’s General Conditions are provided in Appendix B of this report.
1.0 INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech) was contracted by Canada's Oil Sands Innovation Alliance (COSIA) to develop a static block mass and energy flow for a typical oil sands mine (Tetra Tech File No. 704-ENVONG03396-01). The objective of this project was to create Excel spreadsheet block flow diagrams for material and heat / energy for four scenarios. These diagrams will facilitate the evaluation of greenhouse gas (GHG) reduction opportunities by providing a common basis of understanding for prospective technology developers. This allows them to better frame and quantify the GHG reduction benefits of their technologies. The block material and heat / energy diagrams are in a similar format as that used for the production of the COSIA Steam Assisted Gravity Drainage (SAGD) templates.

This report was prepared for COSIA following the development of the flow diagrams to explain the process used to develop them and their intended use. The report provides a summary of the scope of the project, the objectives and the deliverables. A discussion of the methods used and the rationale for their selection is provided. Details regarding the differences associated with Paraffinic Froth Treatment (PFT) and Naphthenic Froth Treatment (NFT) are outlined and the GHG emissions calculation process is explained. The report concludes with a description of the flow diagrams and the assumptions used to prepare them.

2.0 SCOPE

The objective of this project was to create four pairs of Excel spreadsheet block flow diagrams for material and heat / energy for four scenarios considering PFT and NFT. The specific flow diagrams included:

- **PFT:**
  - High grade material and heat/energy flow diagrams in summer condition
  - Low grade material and heat/energy flow diagrams in winter condition

- **NFT:**
  - High grade material and heat/energy flow diagrams
  - Low grade material and heat/energy flow diagrams

The reference oil sands mine and extraction reference facility (hereafter called reference facility) is a fictitious stand-alone mine excluding integration with either an upgrader or adjacent in situ operations. The reference facility is based on a fixed size of 200,000 bbl/d neat bitumen.

All assumptions for the development of the reference oil sands mine were discussed with and agreed by Tetra Tech and COSIA.

The project team to complete the four pairs of Excel spreadsheet block flow diagrams is presented in Table 1.
Table 1: Project Team

<table>
<thead>
<tr>
<th>Team Member</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nelson Lee, M.A.S., P.Eng.</td>
<td>Project Manager</td>
</tr>
<tr>
<td>Ross Huddleston, M.E.Des.</td>
<td>Senior Reviewer</td>
</tr>
<tr>
<td>Doug Cox, P.Eng.</td>
<td>Senior Technical Advisor</td>
</tr>
<tr>
<td>Bruno Dion, P.Eng.</td>
<td>Process Engineer</td>
</tr>
<tr>
<td>Min Si, M.N.R.M., GHG-V</td>
<td>GHG Analyst</td>
</tr>
<tr>
<td>Judy Tai, M.A.S., P.Eng.</td>
<td>GHG Analyst</td>
</tr>
</tbody>
</table>

3.0 APPROACH

Tetra Tech developed the material and energy flow diagrams for both high grade and low grade ore by PFT and NFT processes based on publicly available information, mainly environmental impact assessment (EIA) studies.

Key assumptions for the reference facility are presented in Table 2.

Table 2: Key Assumptions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Reference Facility</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitumen Density</td>
<td>1.007 t/m³</td>
<td>Teck Frontier 2015 Update</td>
</tr>
<tr>
<td>Solvent Density (PFT)</td>
<td>0.624 t/m³</td>
<td>Teck Frontier 2015 Update, isopentane at 20°C</td>
</tr>
<tr>
<td>Diluent Density (NFT)</td>
<td>0.665 t/m³</td>
<td>Engineering Toolbox, Naphtha</td>
</tr>
<tr>
<td>Natural Gas HHV</td>
<td>40 MJ/m³</td>
<td>Fortis BC</td>
</tr>
<tr>
<td>Natural Gas LHV to HHV</td>
<td>1.1</td>
<td>Industrial Practice</td>
</tr>
<tr>
<td>Electric Energy Conversion</td>
<td>3.6</td>
<td>GJ/MWh</td>
</tr>
<tr>
<td>Solvent/Diluent Losses:</td>
<td>Less than 0.4 % vol./vol.</td>
<td>AER Directives</td>
</tr>
<tr>
<td>Bitumen produced</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solvent : Bitumen ratio – PFT</td>
<td>1.65 wt./wt.</td>
<td>Industrial Practice</td>
</tr>
<tr>
<td>Diluent : Bitumen ratio – NFT</td>
<td>0.7 wt./wt.</td>
<td>Industrial Practice</td>
</tr>
</tbody>
</table>

The major equipment for the PFT and NFT processes included two units of Gas Turbine Generation (GTG), two units of Heat Recovery Steam Generators (HRSG) with duct burners, and auxiliary boilers. The natural gas requirement for GTG and HRSG were sourced from the Imperial Oil Kearl Lake EIA and presented in Table 3.
Table 3: Natural Gas Requirement (GJ/h Lower Heating Value – LHV) per Train

<table>
<thead>
<tr>
<th>Scenario</th>
<th>GTG</th>
<th>HRSG</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Grade</td>
<td>865</td>
<td>376</td>
</tr>
<tr>
<td>Low Grade</td>
<td>1,032</td>
<td>471</td>
</tr>
</tbody>
</table>

Note: Kearl EIA, one train is 123,000 bbl/d for high grade and 100,000 bbl/d for low grade.

Approximate size per unit for each equipment configuration was also sourced from the Kearl Lake EIA and presented in Table 4.

Table 4: Major Equipment Size

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Approx. Size per Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>GTG</td>
<td>85 MW</td>
</tr>
<tr>
<td>HRSG</td>
<td>292 MW</td>
</tr>
</tbody>
</table>

3.1 COGENERATION

The GHG credit for cogeneration was calculated as directed by COSIA (Personal Communication, Matt McCulloch, August 12, 2016). The following approach was used:

- Allocation to thermal output based on steam generation (assuming an 80% efficient boiler under Specified Gas Emitters Regulation (SGER) to allocate emissions to the thermal output of cogeneration units.
- Allocation to electrical output based on the difference between the cogeneration unit emissions (Gt as reported under the SGER) and the deemed emissions from heat (Dh).

3.2 STEPS

The following steps were used to develop the flow diagrams.

1. Review of the publicly available information, including EIA studies, Alberta Energy Regulator (AER) reports, SGER reports, etc.
2. Develop material balance sheets and energy consumption.
3. Prepare draft material flow and energy flow diagrams.
4. Review and comment on the draft diagrams by COSIA’s members.
5. Incorporate COSIA member’s comments and revision of the flow diagrams.
6. Final review of the revised diagrams by COSIA members and agreement to issue final flow diagrams.
7. Final review of flow diagrams issued to COSIA.
4.0 PARAFFINIC FROTH TREATMENT

The following EIA studies were reviewed by Tetra Tech to guide the development of the flow diagram for PFT.

- Teck Frontier
- Teck Frontier Project Updates (2015)
- Total Joslyn North Mine
- Total Joslyn North Mine Updates (2010)
- Imperial Kearl Lake

Based on the Scope of Work set out by COSIA, Tetra Tech selected Joslyn North Mine Updates (Joslyn 2010 Update report, 2010) as the basis on which to develop the reference facility. The Joslyn 2010 Update report was selected because it provided detailed fines content in the material balance sheets.

4.1 PARAFFINIC MATERIAL FLOW

The material flow for the reference facility was developed based on the Joslyn 2010 Update report; Figure 5.3-1 for high grade summer condition; and Figure 5.3-3 for the low grade winter condition.

Tetra Tech adjusted the two material sheets by:

- Removing froth storage;
- Removing de-pentanizer and diluent storage;
- Prorating the production rate to 200,000 bbl/d; and
- Updating the bitumen recovery rate to be consistent with other EIA studies.

Tetra Tech considered the specific parameters for the secondary extraction process based on Tetra Tech’s knowledge of industrial practices and publicly available information (Table 5).

Table 5: Key Parameters for PFT Material Flow

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Reference Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphaltene Rejection</td>
<td>Approx. 7% *</td>
</tr>
<tr>
<td>Asphaltene Content in bitumen product</td>
<td>12%</td>
</tr>
<tr>
<td>Solvent Losses: Bitumen Produced</td>
<td>0.3% vol./vol.</td>
</tr>
<tr>
<td>Solvent: Bitumen Ratio</td>
<td>1.65% wt./wt.</td>
</tr>
<tr>
<td>Water + Solids in Diluted Bitumen Products</td>
<td>Less than 0.5%</td>
</tr>
</tbody>
</table>

* expressed as percent of bitumen product
4.2 PARAFFINIC ENERGY FLOW

To be consistent with material balance, Tetra Tech used the Joslyn 2010 Update report as the basis for natural gas and diesel requirements (Table 5.4-3), then prorated these requirements to a static 200,000 bbl/d production volume.

Cooler and exchanger duties (GJ/h) were modeled by Aspen HYSYS based on flow rates and temperature change.

Tetra Tech used the AER ST 39 reports for Kearl, 2014 electricity consumption data to estimate electricity consumption for the reference facility. June to August was considered as the summer period for high grade ore, electricity consumption for summer was estimated to be 3,114 MWh/d. January to March was considered as the winter period for low grade ore, electricity consumption for winter was estimated to be 4,119 MWh/d.

5.0 NAPHTHENIC FROTH TREATMENT

This section provides a description for the development NFT material flow and energy flow diagrams. The following EIA studies were reviewed by Tetra Tech to guide the development of the flow diagram for PFT.

- Syncrude Mildred Lake – 1973
- Alsands Oil Sands Mine – 1978
- Suncor Steepbank Mine – 1996
- Suncor Millennium – 1998
- CNRL Horizon – 2002

5.1 NAPHTHENIC MATERIAL FLOW

The naphthenic material flow was developed based on the paraffinic material flow. Ore preparation and primary extraction were considered to be equivalent for PFT and NFT. Tetra Tech considered the following parameters for the secondary extraction process based on Tetra Tech’s knowledge of industrial practices and publicly available information (Table 6).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Reference Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphaltene Rejection</td>
<td>0%</td>
</tr>
<tr>
<td>Maltene Losses</td>
<td>2%</td>
</tr>
<tr>
<td>Diluent Losses: Bitumen Produced</td>
<td>Less than 0.4% vol./vol.</td>
</tr>
<tr>
<td>Diluent: Bitumen Ratio</td>
<td>0.7% wt./wt.</td>
</tr>
<tr>
<td>Water + Solids in Diluted Bitumen Products</td>
<td>3%</td>
</tr>
</tbody>
</table>

Several adjustments were made to the NFT material flow parameters based on information provided by Mr. Oladipo (Dipo) Omotoso of Suncor (Personal Communication, August 17, 2015).
5.2 NAPHTHENIC ENERGY FLOW

The Suncor Steepbank and Millennium EIA reports provided thermal energy demand for extraction during average conditions. The other EIA reports provided combined energy demand including both extraction and upgrading. As Tetra Tech was not able to separate energy demand between the extraction plant and the upgrader, energy demand for the NFT process was based on information from the Suncor Steepbank and Millennium EIA reports. The supply conditions (temperatures) used for the NFT process are provided in Table 7.

Table 7: Supply Conditions for NFT Material Flow

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Supply Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Sands Feed Temperature</td>
<td>1 °C</td>
</tr>
<tr>
<td>Make-up Water</td>
<td>10 °C</td>
</tr>
<tr>
<td>Diluent Feed</td>
<td>48 °C</td>
</tr>
</tbody>
</table>

6.0 GREENHOUSE GAS EMISSIONS CALCULATIONS

The GHG emissions from stationary combustion (natural gas) and mobile equipment (diesel) were calculated in accordance with the Alberta SGER’s Technical Guidance for Completing Specified Gas Compliance Reports (Version 7.0, January 2014) and Alberta Environment and Parks (AEP)’s Carbon Offset Emission Factor Handbook (Version 1.0, March 2015). Cogeneration GHG emissions were calculated as per COSIA recommendations (described in Section 4.1 of this report).

Fugitive emissions from mine face and tailings ponds were provided by COSIA, and are presented in Tables 8 through 10.

Table 8: Fugitive Emissions from Mine Face

<table>
<thead>
<tr>
<th></th>
<th>CH4 (kg/m²/d)</th>
<th>CO2 (kg/m²/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>High Grade</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Grade</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9: Fugitive Emissions from Tailings Ponds by Paraffinic Froth Treatment Process

<table>
<thead>
<tr>
<th>Paraffinic</th>
<th>CH4 (kg/m²/d)</th>
<th>CO2 (kg/m²/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogenic¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-biogenic</td>
<td>0.00000024</td>
<td>0.000424</td>
</tr>
</tbody>
</table>

¹ All existing PFT ponds are not yet biogenic.
Table 10: Fugitive Emissions from Tailings Ponds by Naphthenic Froth Treatment Process

<table>
<thead>
<tr>
<th></th>
<th>CH4 (kg/m²/d)</th>
<th></th>
<th>CO2 (kg/m²/d)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Naphthenic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biogenic</td>
<td>0.0002933</td>
<td>0.028757</td>
<td>0.003504</td>
<td>0.029262</td>
</tr>
<tr>
<td>Non-biogenic</td>
<td>0.000000105</td>
<td>0.000832</td>
<td>0.001081</td>
<td>0.03645</td>
</tr>
</tbody>
</table>

7.0 FLOW DIAGRAMS

The material and energy flow diagrams are provided in Appendix A. The diagrams are developed using Excel spreadsheets. The detailed material compositions in the material flows are provided in the spreadsheets, including maltene, asphaltene, water, sand, fines, and diluent/solvent. The total energy demand with energy consumption distribution for both NFT and PFT is included in the material and energy diagrams. The key assumptions and variables are highlighted in yellow in the spreadsheet.
8.0 CLOSURE

We thank COSIA for the opportunity to assist in advancing the understanding of this subject and look forward to further development of this valuable process. We trust this report meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech Canada Inc.

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Ross.Huddleston@tetratech.com
REFERENCES

Quantifying land use of oil sands production: a life cycle perspective (Sarah M Jordaan, David W Keith, and Brad Stelfox, Environmental Research Letters 2009 (4), 024004)

Heavy Crude Oils: From Geology to Upgrading: an Overview. Alain-Yves Huc, 6.2.3.3 Upgrading

Pembina Institute Forecasting the impacts of oilsands expansion June 2013, Jennifer Grant, Eli Angen and Simon Dyer
This is a generic and hypothetical mine and extraction facility developed by COSIA. While representative, it is not based on any one facility.

Recovery and solvent loss is based on Alberta Energy Regulator requirements.
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APPENDIX B

TETRA TECH’S GENERAL CONDITIONS
GENERAL CONDITIONS

GEOENVIRONMENTAL REPORT

This report incorporates and is subject to these “General Conditions”.

1.1 USE OF REPORT AND OWNERSHIP

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