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Material and Energy Balance for an Oil Sands Surface Mining and Bitumen Extraction Reference Facility

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Executive Summary

This report provides a description of an oil sands surface mining (known as "Open Pit mining") and bitumen extraction process, and a methodology used to create material and heat balances and calculate GHG emissions for the process. This work is based on Paraffinic Froth Treatment (PFT) and Naphthenic Froth Treatment (NFT) reference facilities producing 200,000 barrels per day (bbl/d) of bitumen for the four scenarios listed below.

- PFT – High Grade Ore in summer condition
- PFT – Low Grade Ore in winter condition
- NFT – High Grade Ore in summer condition
- NFT – Low Grade Ore in winter condition

The resulting Material and Energy balances are intended to facilitate the evaluation of GHG reduction opportunities and water and heat recovery possibilities by providing a common basis of process information needed for prospective technology developers to better quantify the benefits and complete the analysis of their technologies.

Stantec's approach is to create Aspen HYSYS models and Excel spreadsheet calculators for the utility plant, for power, steam and hot water, of the reference facility to determine the natural gas consumption and the boiler feed water flow rate required by the ore preparation and extraction process, which are provided by CanmetEnergy. Stantec has collaborated with CanmetENERGY for their insight and knowledge of the mining extraction process. Their feedback on the following parameters were required to complete the Aspen HYSYS models and excel spreadsheet calculators of the utility plant.

- Steam flow rate
- Hot/warm process water flow rate
- Reclaimed water flow rate
- Heat requirement for ore preparation and extraction process

The iterative process between Stantec and CanmetENERGY was initiated to check and balance these process parameters until all the simulations and calculations matched. The key inputs and assumptions were extracted from COSIA's internal database and industrial practices in oil sand industry, which are publicly available.

The GHG emissions (tonnes CO_2e) for all four scenarios were calculated for three emission categories as listed below following the completion of the analysis of the material and energy balance.

- Stationary Combustion Emissions (CO_2) from the combustion of natural gas used for gas turbine generator, heaters and auxiliary boilers.

- Fugitive Emission (CO_2 and CH_4) from mine face and tailing ponds

The calculations were based on the Aspen HYSYS's results, COSIA recommendations, and emission factors as per the Alberta Specified Gas Emitters Regulation (SGER)'s Technical Guidance for Completing Specified Gas Compliance Reports (Version 7.0, January 2014) and the 2019 National Inventory Report 1990 – 2017: Greenhouse Gas Sources and Sinks in Canada Part 2.

Abbreviations

bbl/d	Barrels per day
BFW	Boiler Feed Water
CH_4	Methane
CO_2	Carbon Dioxide
CO_2e	CO_2 equivalent
COSIA	Canada's Oil Sands Innovation Alliance
CW	Cooling Water
FSU	Froth Settling Unit
GHGs	Greenhouse gases
GTG	Gas Turbine Generators
GWP	Global Warming Potential
HFCs	Hydrofluorocarbons
HHV	High Heating Value
HRSG	Heat Recovery Steam Generators
IPS	Inclined Plate Separator
LHV	Low Heating Value
LPS	Low Pressure Steam
MPS	Medium Pressure Steam
N_2O	Nitrous oxide
NFT	Naphthenic Froth Treatment
PFCs	Perfluorocarbons
PFT	Paraffinic Froth Treatment
PSC	Primary Separation Cell
PW	Process Water
SF_6	Sulphur Hexafluoride
SGER	Specified Gas Emitters Regulation
SRU	Solvent Recovery Unit
TSRU	Tailing Solvent Recovery Unit

1.0 INTRODUCTION

[redacted] COSIA retained Stantec Consulting Ltd. ("Stantec") to create Excel spreadsheet block flow diagrams with combined material and energy balance of the oil sands surface mining and bitumen extraction for Paraffinic Froth Treatment (PFT) and Naphthenic Froth Treatment (NFT) reference facilities producing 200,000 barrels per day (bbl/d) of bitumen for the four scenarios listed below.

- PFT – High Grade Ore in summer condition
- PFT – Low Grade Ore in winter condition
- NFT – High Grade Ore in summer condition
- NFT – Low Grade Ore in winter condition

The objective of these diagrams is to facilitate the evaluation of GHG reduction opportunities and water and heat recovery possibilities by providing a common basis of process information needed for prospective technology developers to better quantify the benefits and complete the analysis of their technologies.

Since the reference facility consists of two major areas – ore preparation and extraction process and utility plant, Stantec has collaborated with CanmetENERGY for their insight and knowledge on the mining extraction process. Their feedback on the required amount of steam and process water as well as the heat requirement for the ore preparation and extraction process are needed to complete Stantec's Aspen HYSYS models and Excel spreadsheet calculators for the utility plant. This creates an iterative process required to converge both Stantec's models and CanmetENERGY's calculations for a complete material and heat balance.

This report is prepared for COSIA to provide a description of surface mining and extraction process, and to explain a methodology used to create material and heat balances and calculate GHG emissions. The report concludes with the complete Material and Energy balances for all four scenarios. Details regarding the development of the reference facility and the differences associated with PFT and NFT processes are not part of this work.

2.0 MATERIAL AND ENERGY BALANCE

The Material and Energy balances for each scenario of the reference facility has two major areas, each represented by five sections. Sections 1 – 4 represent the ore preparation and extraction process and Section 5 highlights the utility plant. The following is a brief discussion of each section.

Section 1: Ore Preparation: Conditioning, Crushing and Conveying

Once the mined oil sand is hauled to the processing plant, it will be first processed in an Ore Preparation Plant, where clumps of oil sands are broken up into loosely crushed oil sands by the Crusher and dumped onto a conveyor. Then, hot and warm water are added and vigorously mixed to this crushed oil sand, producing a wet, aerated slurry in the Rotary Breaker. Caustic soda is also added to help improve the bitumen recovery as the slurry pH is raised. Any oversized material (such as petrified wood, rocks or large chucks of ice) that could not be re-crushed will be separated by screening and then rejected as the Breaker Reject. The Hydrotransport Pump will pump this wet slurry through hydrotransport pipelines to the Extraction Process. These pipelines are designed to provide additional residence time for extra mixing and aeration, and mechanical shear to further break down the oil sand lumps, releasing bitumen from the sand.

Section 2: Primary Extraction Process

The bitumen in the oil sand slurry is recovered in the Primary Separation Cell (PSC), while the solids such as sand will be rejected to the tailings plant. This PSC is a large cone-bottomed vessel that employs a simple water-based gravity separation process to produce three streams – overflow, middlings and underflow. The bitumen released from the sand tends to attach to free air bubbles and rises to the top of the vessel, forming a clean bitumen froth overflow stream. This overflow stream then flows to the Deaerator to reduce the air content. Steam is also added to the Deaerator to help reduce the bitumen froth viscosity and destabilize the air bubbles. This deaerated intermediate bitumen froth product will be pumped by the Deaerated Froth Pump to the Froth Treatment Stage for further bitumen recovery. The middlings stream from the middle of the PSC, which is comprised of water and a still higher bitumen content than the underflow, is sent to the Flotation & Cyclone for secondary bitumen recovery. The underflow containing mostly solids and residual bitumen will be rejected at the bottom of the PSC and sent to the tailings pond.

Section 3: Secondary Extraction Process – Froth Treatment

Due to a high content of solids and water, the intermediate bitumen froth product from the Primary Extraction Process needs to be cleaned using the Froth Treatment Process where a hydrocarbon-based gravity separation technique is used to remove fine solids and water from the bitumen. Paraffinic and Naphthenic solvents are the two main types of hydrocarbons used to add and mix with the bitumen froth to reduce the viscosity of the mixture in the Froth Treatment process. In the solvent extraction process, bitumen is soluble in the solvents; but water is not. Oil phase and water phase are formed. Sands tend to stay in the water phase. This improves the gravity separation between fine solids/water and the bitumen/hydrocarbon. Hydrocarbon is then recovered from the bitumen/hydrocarbon mixture and recycled back for reuse, leaving relatively clean diluted bitumen product ready for use in either an upgrader or a refinery depending on the product quality.

Paraffinic Froth Treatment (PFT)

In PFT, the paraffinic solvent containing primarily paraffin hydrocarbons is added to the bitumen froth in the Froth Settling Unit (FSU). The overflow of the very rich bitumen/solvent mixture from the FSU is sent to the Solvent Recovery Unit (SRU) to recover a majority of the solvent and produce a final clean bitumen product ready for an upgrader. The underflow containing mostly water and solids with a small amount of solvent is sent to the Tailing Solvent Recovery Unit (TSRU) to recover any residual solvent prior to disposal in the tailings pond. Steam is injected to both the SRU and TSRU for solvent recovery. The recovered solvent, together with the fresh solvent, will be sent to the FSU.

Naphthenic Froth Treatment (NFT)

In NFT, the naphthenic solvent containing primarily naphthene hydrocarbons is added to the bitumen froth in the Inclined Plate Separator (IPS) to produce a good quality overflow ready for an upgrader. The underflow from the ISP still needs to be processed through the Centrifuge Unit to improve bitumen recovery. Any residual solvent remaining in the bottom discharge of the Centrifuge Unit will be recovered in the Naphtha Recovery Unit (NRU), prior to disposal in the tailings pond. Steam is injected in the NRU for solvent recovery. The recovered solvent, together with the fresh solvent, will be sent to the IPS.

Section 4: Tailings Unit

The tailings pond receives the tailings from the Extraction Process. It will allow any fine solids and coarse sand to settle down to the bottom, while the reclaimed water is sent to the Recycled Water Pond for reuse.

Section 5: Utility (Steam Generation)

The main objective of this unit is to produce steam for use as a heating and stripping medium in the process. Steam is produced using a combination of auxiliary boilers and a cogeneration facility, which has two trains each containing gas turbine generators (GTG), duct burners and heat recovery steam generators (HRSG). Natural gas is used to fuel for the GTGs, duct burners and auxiliary boilers.

Medium Pressure Steam (MPS) is used partially as stripping steam and to a larger extent for process heating in the extraction process, while Low Pressure Steam (LPS) is only used for process heating to produce hot water in the water distribution system. The condensed steam is returned as process condensate and recycled as boiler feed water (BFW). Steam conditions are listed below:

• MPS conditions are at 225°C and 2100 kPag

• LPS conditions are 210°C and 1390 kPag

Water Distribution System

Makeup water drawn from natural resources such as the nearby river is sent to the Raw Water Pond Water Treatment Plant prior to being split into two main streams. One is mixed with the return process condensate and then fed to the auxiliary boilers and the HRSGs as BFW. The other stream is combined with the reclaimed water from the Tailings Unit, which is Process Water (PW). This PW is heated, either by a series of heat exchangers, or by mixing with hot water as explained below prior to distribution to the Ore Preparation and Extraction process as Hot PW and Warm PW.

The PW from the Recycled Water Pond must flow through the following heat exchangers to achieve the final temperature of Hot and Warm PWs:

• PW/CW Exchanger recovering heat from Cooling Water (CW) by cooling it down from 60°C to 30°C. The cold CW is sent to the three coolers and for process use in the mining process. The warm CW return then rejects its heat in the PW/CW Exchanger to complete the cycle.

• PW/Condensate Exchanger exchanging heat with LPS condensate; and

• PW/LPS Exchanger exchanging heat with LPS to reach approximate 80°C Hot PW.

A certain quantity of Hot PW is stored in the Hot Water Tank, the rest is partially mixed with the PW to obtain 45°C Warm PW, which is stored in the Warm Water Tank. Any remaining PW will be sent out for cooling requirements.

3.0 METHODOLOGY

To successfully deliver a complete material and energy balance for the 200,000 bbl/d oil sands surface mining and extraction Paraffinic Froth Treatment (PFT) and Naphthenic (NFT) reference facilities, Stantec developed an Aspen HYSYS model for the utility plant, while CanmetEnergy separately developed their own internal calculations and simulation models for the ore preparation and extraction process. The connections between these two processes are listed below.

- The required steam from the HRSGs and the auxiliary boilers used for stripping steam for solvent recovery in the Froth Treatment process and deaerating steam in the Deaerator as well as process heating steam for heating the solvents prior to injecting to the Froth Treatment process, and to the FSU overflow stream in the PFT facility. Only the condensate of the process heating steam will return to the utility plant as the BFW
- The hot/warm process waters generated from a series of heat exchangers in the water distribution system using LPS steam and its condensate
- The reclaimed water from the Tailing Pond

As a result, the iterative process between Stantec and CanmetENERGY was initiated to check and balance these process parameters until all the simulations and calculations matched. The real operation parameters (as well as given from open literature) are always in a range. The tolerance of some of the numbers in this report are approximately ±7%. Stantec varied the natural gas consumption and the BFW flow rate to the HRSGs and Auxiliary Boilers based on the inputs and assumptions summarized in Section 3.1 to meet the steam and hot/warm process water requirements for the ore preparation and extraction process.

3.1 INPUTS AND ASSUMPTIONS

Inputs and assumptions as used in the models and calculation are listed in Table 3.1 for the ore preparation and extraction process and Table 3.2 for the utility plant are extracted from COSIA's internal database and industrial practices in oil sand industry, which are publicly available.

Table 3-1 Key Inputs and Assumptions for the Ore Preparation and Extraction Process

Parameter	Unit	Reference Facility		Source
		PFT	NFT	
Oil Sands Feed Temperature	°C	5 (PFT-High Grade), -3 (PFT-Low Grade)	4 (NFT-High Grade) 1 (NFT-Low Grade)	COSIA internal database
Bitumen Density	tonne/m³	1.007		Tech Frontier 2015 Update
$C_{p,\ sand}$	J/gK	Composition-averaging method from quartz silica sand and clay		Engineering Toolbox and Oilsands Magazine
$C_{p,\ bitumen}$	J/gK	1.45		M. R. Cervenan, F. E. Vermeulen, and , F. S. Chute, *Thermal conductivity and specific heat of oil sand samples*, Canadian Journal of Earth Sciences, 1981, 18(5): 926-931
Solvent Composition	mol fr.	**PFT**	**NFT**	**NFT** – Jiawei Du and William R. Cluett, *Modelling of a Naphtha Recovery Unit (NRU) with Implications for Process Optimization*, Processes, 2018, 6, 74
- i-Pentane	mol fr.	0.33	N/A	
- n-Pentane	mol fr.	0.33	N/A	
- n-Hexane	mol fr.	0.33	0.12	
- Toluene	mol fr.	N/A	0.03	
- Methylcyclopentane	mol fr.	N/A	0.07	
- Methylcyclohexane	mol fr.	N/A	0.11	
- n-Heptane	mol fr.	N/A	0.11	
- 2-Methylhexane	mol fr.	N/A	0.10	
- o-Xylene	mol fr.	N/A	0.00	
- m-Xylene	mol fr.	N/A	0.03	
- n-Octane	mol fr.	N/A	0.06	
- 1-Methyl-1-ethylcyclopentane	mol fr.	N/A	0.06	
- 2-Methylheptane	mol fr.	N/A	0.09	
- 2,2,5-Trimethylhexane	mol fr.	N/A	0.11	
- n-Nonane	mol fr.	N/A	0.04	
- n-Decane	mol fr.	N/A	0.03	
- 1-Methyl-3-ethylbenzene	mol fr.	N/A	0.04	
Total	**mol fr.**	1.00	1.00	

Parameter	Unit	Reference Facility		Source
		PFT	NFT	
Solvent Density	tonne/m^3	0.624	0.665	**PFT** – Tech Frontier 2015 Update, isopentane at 20°C, **NFT** – Engineering Toolbox, Naphtha
$C_{p,\ solvent}$	J/gK	2.30	2.10	**PFT, NFT** – Aspen HYSYS properties
Solvent Temperature	°C	20 (High Grade), 2 (Low Grade)	48	COSIA internal database
Solvent : Bitumen ratio	wt/wt	1.65	0.7	**PFT, NFT** - Industrial Practice
Solvent Losses : Bitumen Produced	vol/vol	0.3	Less than 0.4	**PFT** – COSIA internal database, **NFT** - AER Directives
Asphaltene Rejection	%	Approx. 7	0	**PFT, NFT** – COSIA internal database
Asphaltene Content in Bitumen Product	%	12	N/A	**PFT** – COSIA internal database
Water and Solids in Diluted Bitumen Products	%	Less than 0.5	3	**PFT, NFT** – COSIA internal database

Table 3-2 Key Inputs and Assumptions for the Utility Plant

Parameter	Unit	Reference Facility				Source
		High Grade		Low Grade		
Natural Gas Requirement per Plant						COSIA's internal database
- GTG	GJ/h HHV	774		1045		
- HRSG and Duct Burner	GJ/h HHV	336		537		
Electricity	MW	127		175		
		PFT	NFT	PFT	NFT	
Natural Gas Temperature	°C	25	10	2	10	COSIA's internal database and CanmetENERGY's calculation
Air Temperature	°C	25	10	2	10	
Make-up Water Temperature	°C	25	10	2	10	
Hot Water Flow Rate	T/h	5,918	5,045	8,195	8,271	
Warm Water Flow Rate	T/h	4,396	3,533	1,716	6,464	
Cooling Water Flow Rate	T/h	6,217	5,599	7,604	6,849	
Hot Water Temperature	°C	80	80	80	80	
Warm Water Temperature	°C	45	45	45	45	
Cooling Water Temperature	°C	25	10	2	10	
MPS Stripping Steam	T/h	144	105	148	105	
Boiler Blowdown Flow Rate	T/h	21	20	50	28	

3.2 GHG EMISSIONS CALCULATION

The reference facility is a fictitious stand-alone mine excluding integration with either an upgrader or adjacent in-situ operations with a fixed size of 200,000 bbl/d bitumen. It also has an on-site cogeneration unit using natural gas as a fuel to produce steam and electricity. The facility has natural gas fired equipment including boilers and building heaters, which are the main sources of GHG emissions onsite. In addition, the emissions calculation includes the emissions from mobile equipment for ore trucking using diesel as fuel and the fugitive emissions from mine face and tailing ponds.

GHGs emitted at the reference facility are mainly carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). There are no activities identified resulting in emissions of sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs).

Categories of GHG emissions sources include:

- Stationary Combustion Emissions (CO_2) from the combustion of natural gas used for gas turbine generator, heaters and auxiliary boilers.
- Fugitive Emission (CO_2 and CH_4) from mine face and tailing ponds

The total quantity of each GHG species subject to each category in units of tonnes of the gas species is calculated as detailed below. Since the total GHG emissions for each source must be reported in tonnes of CO_2 equivalent (tonnes CO_2e), the global warming potential is used to multiply with each GHG emission using (Eq.1).

$$ES_y = \sum_p E_{y-p} \times GWP_p \qquad \text{(Eq.1)}$$

Where:

ES_y = the total emissions for category y (tonnes of CO_2e)

E_{y-p} = the total emissions of a particular prescribed GHG species p from category y (tonnes of the particular prescribed GHG species p)

GWP_p = the global warming potential for the particular prescribed GHG species p, CO_2 = 1, CH_4 = 25 and N_2O = 298 as per Alberta Specified Gas Emitters Regulation (SGER)'s Technical Guidance for Completing Specified Gas Compliance Reports (Version 7.0, January 2014)

y = a regulated source category

p = a prescribed GHG

3.2.1 Stationary Combustion Emissions

The GHG emission from the stationary combustion is extracted from the Aspen HYSYS's results. For GHG emissions credit from the cogeneration unit, it is calculated as per COSIA recommendations listed below:

- Deemed emissions from heat (D_H) - Allocation to thermal output based on steam generation (assuming an 80% efficient boiler under SGER) to allocate emissions to the thermal output
- Deemed emissions from electricity (D_E) - Allocation to electrical output based on the difference between the total emission from cogeneration unit and the D_H.

3.2.2 Fugitive Emissions

The emission factors in tonne CO_2e provided in Tables 3.4 – 3.5 are used as a guideline to calculate the fugitive emissions from mine face and tailings ponds in this study. The finalized emission factors are still under evaluation.

Table 3-3 Fugitive Emission Factors from Mine Face

Condition	CH_4 (kg/m²/d)		CO_2 (kg/m²/d)	
	Low	High	Low	High
High Grade	0	0.000294	0.0001333	0.007648
Low Grade	0	0.000904	0.000007085	0.0129

Table 3-4 Fugitive Emission Factors from Tailing Ponds

Reference Facility		CH_4 (kg/m²/d)		CO_2 (kg/m²/d)	
		Low	High	Low	High
Paraffinic	Biogenic*	non-zero	non-zero	non-zero	non-zero
	Non-biogenic	0.00000024	0.000424	0.000743	0.009501
Naphthenic	Biogenic	0.0002933	0.028757	0.003504	0.029262
	Non-biogenic	0.000000105	0.000832	0.001081	0.03645

*Early stage microcosm studies conducted in 2019 (K.Budwill, Innotech) reflect paraffinic tailings ponds can generate biogenic emissions. Further work needs to be done to confirm this observation is broadly applicable for inclusion in a reference facility.

4.0 FLOW DIAGRAM

The material and energy flow diagrams are provided in Appendix A. Table 4.1 summarizes key results obtained from the flow diagrams for all scenarios.

Table 4-1 Output Summary

Parameter		Unit	PFT		NFT	
			High Grade	Low Grade	High Grade	Low Grade
Bitumen Recovery Summary						
Ore Preparation		%	99.0	98.2	98.9	98.9
Primary Extraction		%	94.6	92.3	98.0	98.0
Froth Treatment (without rejected asphaltenes)		%	98.4	98.4	98.2	98.2
Total Bitumen Recovery		%	92.2	89.1	95.2	95.2
Asphaltenes Rejection		%	7.6	7.7	0.0	0.0
Total Bitumen Recovery (with rejected asphaltenes)		%	85.1	82.3	95.2	95.2
Water Summary						
Process Water – Cooling Water		T/h	6,217	7,604	5,599	6,849
Process Water – Heated Water		T/h	10,314	9,911	8,578	14,735
Reclaimed Water		T/h	14,051	15,206	12,304	20,292
Raw Water		T/h	2,480	2,309	1,873	1,292
BFW		T/h	165	198	125	133
Boiler Blowdown		T/h	21	50	20	28
Make-Up Water		T/h	2,645	2,507	1,998	1,425
Condensate Return		T/h	843	1,139	632	792
Fresh Water : Bitumen		vol. /vol.	2.04	2.25	1.80	2.70
Cogen Energy Summary						
Input -	GTG	GJ/h	1,547	2,090	1,547	2,090
	HRSG	GJ/h	672	1,074	672	1,074
	Compressor	GJ/h	12	16	12	16
	Total	***GJ/h***	***2,231***	***3,180***	***2,231***	***3,180***
Output -	Electricity	GJ/h	457	630	457	630
	Steam	GJ/h	1,321	2,044	1,383	1,993
	Cogen Losses	GJ/h	453	506	391	557
	Total	***GJ/h***	***2,231***	***3,180***	***2,231***	***3,180***

Flow Diagram

Parameter		Unit	PFT		NFT	
			High Grade	Low Grade	High Grade	Low Grade
Boiler Energy Summary						
Input		GJ/h	1,407	1,473	583	388
	Total	***GJ/h***	***1,407***	***1,473***	***583***	***388***
Output -	Steam	GJ/h	1,222	1,372	530	353
	Boiler Losses	GJ/h	185	101	53	36
	Total	***GJ/h***	***1,407***	***1,473***	***583***	***388***
Flue Gas from Combustion						
Cogen Flue Gas		e^3m^3/h	2,163	3,343	2,278	3,247
Boiler Flue Gas		e^3m^3/h	554	629	242	161
Exchanger & Cooler Duty						
Process Water / Cooling Water		GJ/h	755	1,365	1,224	2,190
Process Water / Condensate		GJ/h	208	357	160	244
Process Water / LPS		GJ/h	768	1,280	613	937
SRU Feed / MPS		GJ/h	800	811	754	754
Solvent Feed / MPS, Heater		GJ/h	321	415	41	43
Cooler x 3		GJ/h	1,356	1,366	372	396
Heat Rejection		GJ/h	601	0	0	0
Other Process Use		GJ/h	0	0	852	1,794
Energy Consumption Summary						
Natural Gas -	GTG	GJ/h	1,547	2,090	1,547	2,090
	HRSG	GJ/h	672	1,074	672	1,074
	Space Heating	GJ/h	604	949	366	414
	Boilers	GJ/h	1,407	1,473	583	388
	Total	***GJ/h***	***4,231***	***5,586***	***3,169***	***3,966***
Energy Intensity		GJ/bbl	0.51	0.67	0.38	0.48
Electricity Generated		MWh/d	3,044	4,198	3,044	4,198
GHG Emissions Summary						
Stationary Combustion		tCO_2e/d	4,974	7,364	4,057	5,079
Fugitive Mine		$kg\ CO_2e/m^2/d$	0.0001 – 0.0150	0.000007 – 0.0355	0.0001 – 0.0150	0.000007 – 0.0355
Fugitive Pond		$kg\ CO_2e/m^2/d$	0.0007 – 0.0201	0.0007 – 0.0201	0.0119 – 0.8054	0.0119 – 0.8054
Total Cogen Emissions (Gt)		tCO_2e/d	2,698	4,171	2,842	4,051
D_H		tCO_2e/d	2,158	3,337	2,273	3,241
D_E		tCO_2e/d	540	834	568	810
CO_2 : Bitumen		tCO_2e/bbl	0.029	0.043	0.024	0.031

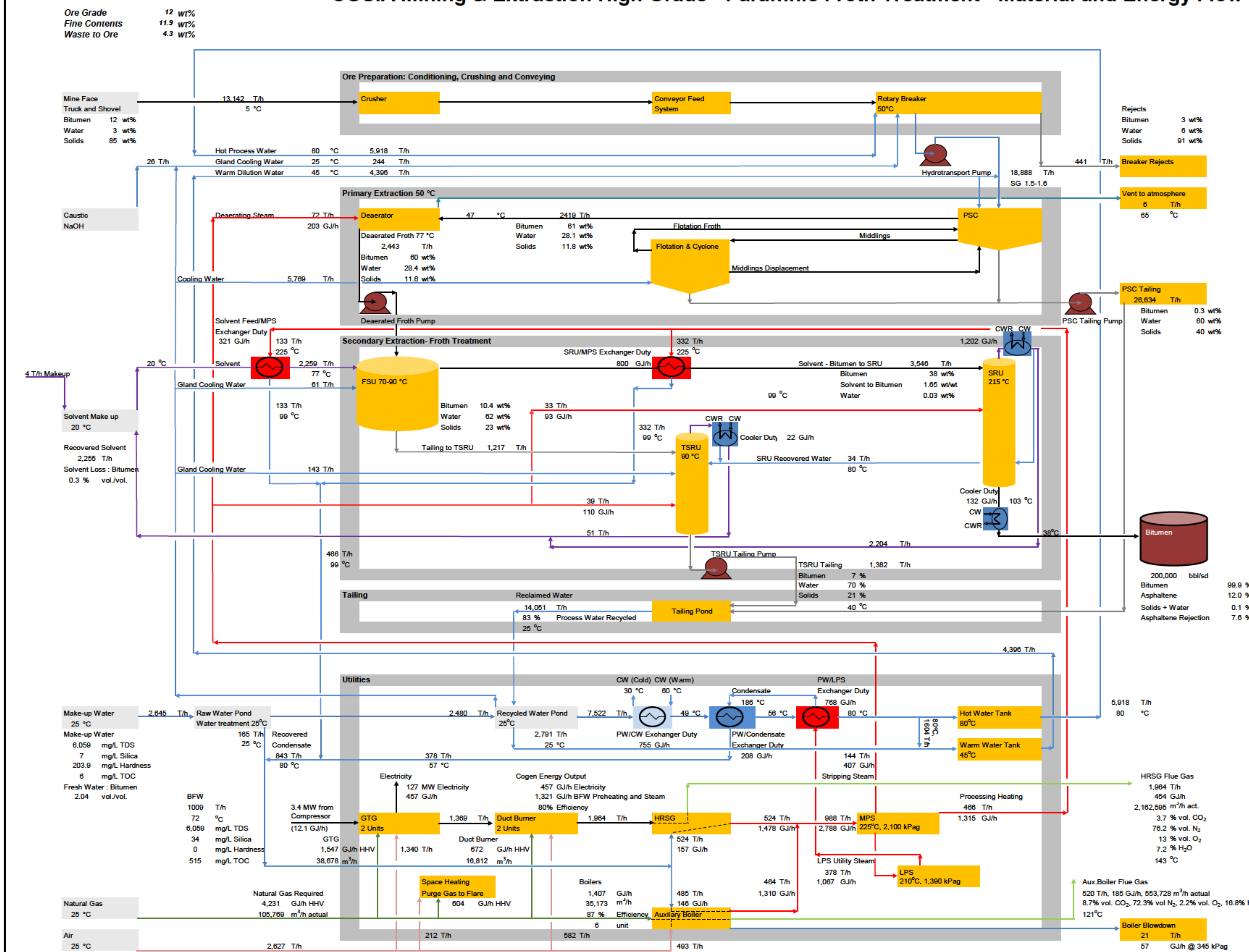
5.0 CONCLUSION

Stantec completed four material and energy flow diagrams for oil sands surface mining and extraction PFT and NFT reference facilities for both high and low grade conditions with a production of 200,000 bbl/d of bitumen. These diagrams provide a basis of process information intended to help prospective technology developers evaluate any GHG reduction opportunities and water and heat recovery possibilities. Process simulation models and Excel spreadsheet calculators were used as a key tool to achieve the natural gas consumption and the quantity of the boiler feed water required to produce sufficient energy and steam for the ore preparation and extraction processes, which was provided by CanmetENERGY. The GHG emissions from the reference facility were also calculated for each of the processes.

APPENDIX

Appendix A MATERIAL AND ENERGY BALANCE DIAGRAMS

COSIA Mining & Extraction High Grade - Paraffinic Froth Treatment - Material and Energy Flow



Legend			
Bitumen	Steam	Flue gas	Tailing
Water	Natural Gas	Solvent	Air

Abbreviations			
BFW	Boiler Feed Water	PSC	Primary Separation Cell
CW	Cooling Water	PW	Process Water
CWR	Cooling Water Return	SG	Specific Gravity
FSU	Froth Settling Unit	SRU	Solvent Recovery Unit
GTG	Gas Turbine Generator	TDS	Total Dissolved Solids
HHV	Higher Heating Value	TOC	Total organic carbon
HRSG	Heat Recovery Steam Generator	TSRU	Tailing Solvent
LPS	Low Pressure Steam		Recovery Unit
MPS	Medium Pressure Steam		

Bitumen Recovery Summary	
Ore Preparation	99.0%
Primary Extraction	94.6%
Froth Treatment (without rejected asphaltenes)	98.4%
Total Bitumen Recovery	92.2%
Asphaltenes Rejection	7.6%
Total Bitumen Recovery (with rejected asphaltenes)	85.1%

Water Summary (T/H)		
Process Water	Cooling Water	6,217
	Heated Water	10,314
Reclaimed Water		14,051
Raw Water		2,480
BFW		165
Boiler Blowdown		21
Make-Up Water		2,645
Condensate Return		843

Energy Output Summary		Input (GJ/h)		Output (GJ/h)
Cogen	GTG	1,547	Electricity	457
	HRSG	672	Steam	1,321
	Compressor	12	Cogen Losses	453
Subtotal - Cogen		**2,231**		**2,231**
Boilers		1,407	Steam	1,222
			Boiler Losses	185
Subtotal - Boilers		**1,407**		**1,407**
Total		**3,638**		**3,638**

Flue Gas - Based on Stochiometric Combustion		
Natural Gas HHV	40	MJ/m^3
Excess air @ 13% O_2 (from Cogen Facility)	179	%
Excess O_2 (from Cogen Facility)	13	%
Cogen Flue Gas	2,163	e^3m^3/h
CO_2 in Flue Gas from Cogen	4%	vol.%
H_2O in Flue Gas from Cogen	7%	vol.%
Boiler Flue Gas	554	e^3m^3/h
CO_2 in Flue Gas from Boilers	9%	vol.%
H_2O in Flue Gas from Boilers	17%	vol.%
Flue Gas Temperature - Acid Dew Point Limit	121	°C
Flue Gas - Max. without Economizer	274	°C

Exchanger & Cooler	Duty (GJ/h)
Process Water / Cooling Water	755
Process Water / Condensate	208
Process Water / LPS	768
SRU Feed / MPS	800
Solvent Feed / MPS	321
Cooler x 3	1,356
Heat Rejection	601

Energy Consumption Summary		GJ/h	e^3m^3/d
Natural Gas	GTG	1,547	928
	HRSG	672	403
	Building Heating and Flare	604	363
	Boilers	1,407	844
Energy Intensity (GJ per bbl of bitumen produced)		0.51	GJ/bbl
Electricity Generated		3,044	MWH/d

GHG Emissions Summary				
Stationary Combustion & Flaring			4,974	t CO_2e/d
Fugitive Mine	0.0001	-	0.0150	kg CO_2e/m²/d
Fugitive Pond	0.0007	-	0.0201	kg CO_2e/m²/d
Total Cogen Emissions (Gt)			2,698	t CO_2e/d
Deemed emissions from Heat by Cogen (D_H)			2,158	t CO_2e/d
Deemed emissions from Electricity by Cogen (D_E)			540	t CO_2e/d

Project:	Material and Energy Balance for an Oil Sands Surface Mining and Bitumen Extraction Reference Facility		
Case:	Paraffinic - High Grade	Revision:	NA
Owner:	COSIA	Date:	25-Feb-20

Material & Energy Balance
High Temperature Extraction, High Grade, Summer Condition
By B. Thitakamol (Stantec)
Q. Zhuang (CanmetENERGY/NRCAN)

This is based on assummed open-pit mine that produces 200,000 barrels per day. 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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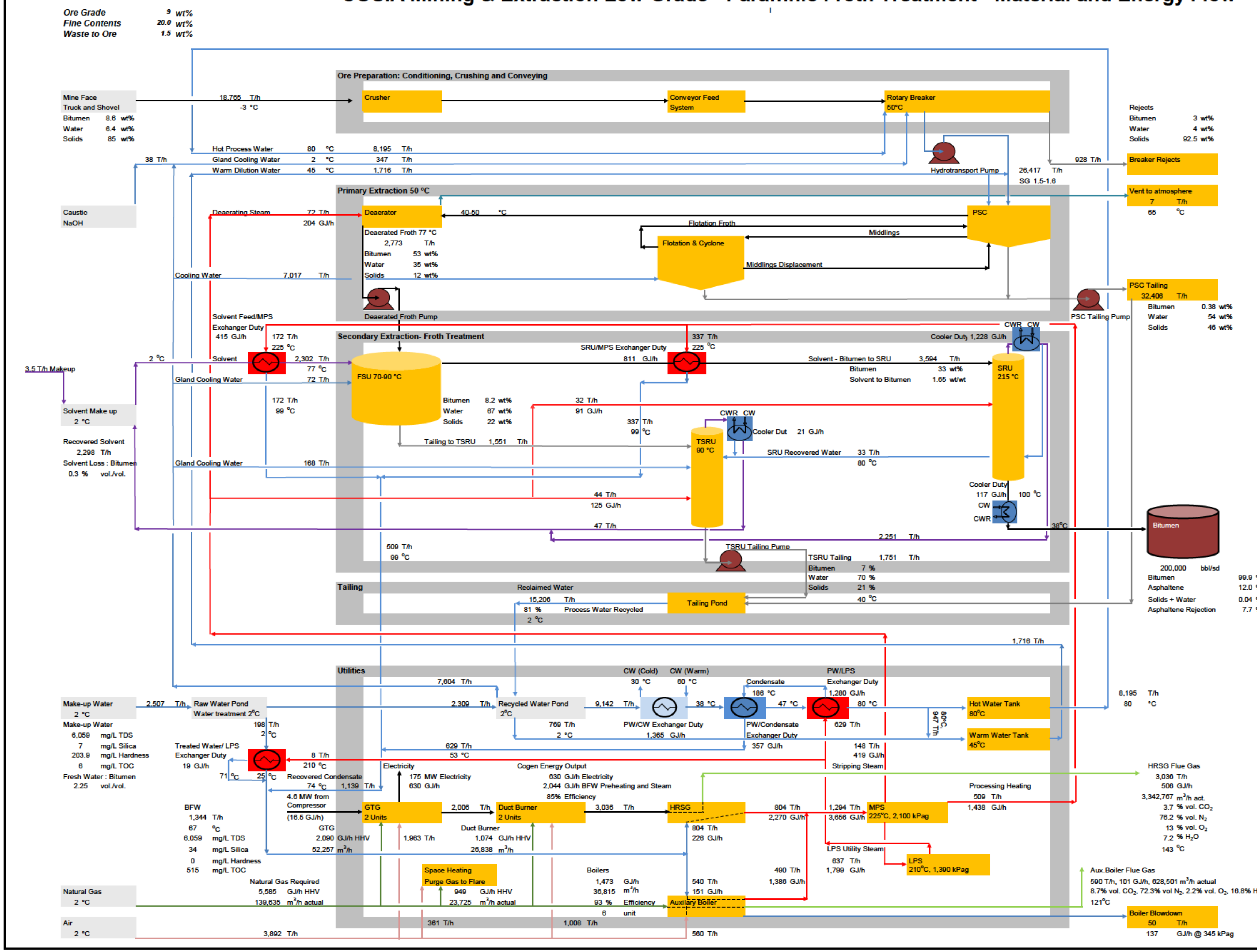
COSIA Mining & Extraction Low Grade - Paraffinic Froth Treatment - Material and Energy Flow



Legend			
Bitumen	Steam	Flue gas	Tailing
Water	Natural Gas	Solvent	Air

Abbreviations			
BFW	Boiler Feed Water	PSC	Primary Separation Cel
CW	Cooling Water	PW	Process Water
CWR	Cooling Water Return	SG	Specific Gravity
FSU	Froth Settling Unit	SRU	Solvent Recovery Unit
GTG	Gas Turbine Generator	TDS	Total Dissolved Solids
HHV	Higher Heating Value	TOC	Total organic carbon
HRSG	Heat Recovery Steam Generator	TSRU	Tailing Solvent Recovery Unit
LPS	Low Pressure Steam		
MPS	Medium Pressure Steam		

Bitumen Recovery Summary	
Ore Preparation	98.2%
Primary Extraction	92.3%
Froth Treatment (without rejected asphaltenes)	98.4%
Total Bitumen Recovery	89.1%
Asphaltenes Rejection	7.7%
Total Bitumen Recovery (with rejected asphaltenes)	82.3%

Water Summary (T/H)		
Process Water	Cooling Water	7,604
	Heated Water	9,911
Reclaimed Water		15,206
Raw Water		2,309
BFW		198
Boiler Blowdown		50
Make-Up Water		2,507
Condensate Return		1,139

Energy Output Summary		Input (GJ/h)	Output (GJ/h)	
Cogen	GTG	2,090	Electricity	630
	HRSG	1,074	Steam	2,044
	Compressor	16	Cogen Losses	506
Subtotal - Cogen		**3,180**		**3,180**
Boilers		1,473	Steam	1,372
			Boiler Losses	101
Subtotal - Boilers		**1,473**		**1,473**
Total		**4,653**		**4,653**

Flue Gas - Based on Stochiometric Combustion		
Natural Gas HHV	40	MJ/m^3
Excess air @ 13% O_2 (from Cogen Facility)	180	%
Excess O_2 (from Cogen Facility)	13	%
Cogen Flue Gas	3,343	e^3m^3/h
CO_2 in Flue Gas from Cogen	4%	vol.%
H_2O in Flue Gas from Cogen	7%	vol.%
Boiler Flue Gas	629	e^3m^3/h
CO_2 in Flue Gas from Boilers	9%	vol.%
H_2O in Flue Gas from Boilers	17%	vol.%
Flue Gas Temperature - Acid Dew Point Limit	121	°C
Flue Gas - Max. without Economizer	274	°C

Exchanger & Cooler	Duty (GJ/h)
Process Water / Cooling Water	1,365
Process Water / Condensate	357
Process Water / LPS	1,280
SRU Feed / MPS	811
Solvent Feed / MPS	415
Cooler x 3	1,366

Energy Consumption Summary		GJ/h	e^3m^3/d
Natural Gas	GTG	2,090	1,254
	HRSG	1,074	644
	Building Heating and Flare	949	525
	Boilers	1,473	884
Energy Intensity (GJ per bbl of bitumen produced)		0.67	GJ/bbl
Electricity Generated		4,198	MWH/d

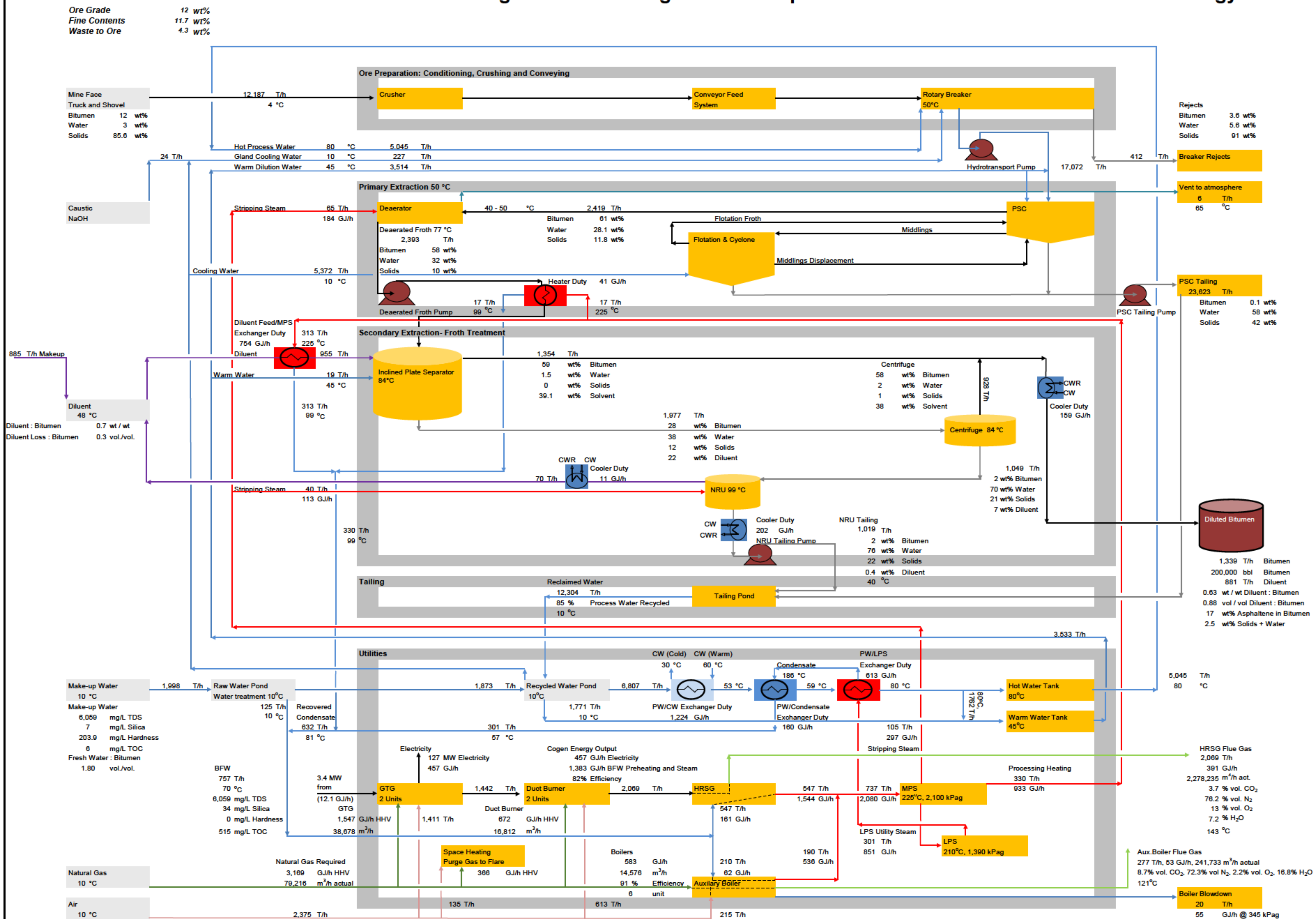
GHG Emissions Summary				
Stationary Combustion & Flaring			7,364	t CO_2e/d
Fugitive Mine	0.000007	-	0.0355	kg $CO_2e/m^2/d$
Fugitive Pond	0.0007	-	0.0201	kg $CO_2e/m^2/d$
Total Cogen Emissions (Gt)			4,171	t CO_2e/d
Deemed emissions from Heat by Cogen (D_H)			3,337	t CO_2e/d
Deemed emissions from Electricity by Cogen (D_E)			834	t CO_2e/d

Project:	Material and Energy Balance for an Oil Sands Surface Mining and Bitumen Extraction Reference Facility		
Case:	Paraffinic - Low Grade	Revision:	NA
Owner:	COSIA	Date:	25-Feb-20

Material & Energy Balance
High Temperature Extraction, Low Grade, Winter Condition
By B. Thitakamol (Stantec)
Q. Zhuang (CanmetENERGY/NRCAN)

This is based on assummed open-pit mine that produces 200,000 barrels per day. While representative, it is not based on any one facility.
Recovery and solvent loss is based on Alberta Energy Regulator requirements.

COSIA Mining & Extraction High Grade - Naphthenic Froth Treatment - Material and Energy Flow



Legend				
Bitumen	Steam	Flue gas	Tailing	Vent
Water	Natural Gas	Solvent	Air	

Abbreviations			
BFW	Boiler Feed Water	MPS	Medium Pressure Steam
CW	Cooling Water	PSC	Primary Separation Cell
CWR	Cooling Water Return	PW	Process Water
GTG	Gas Turbine Generator	NRU	Naphtha Recovery Unit
HHV	Higher Heating Value	TDS	Total Dissolved Solids
HRSG	Heat Recovery Steam Generator	TOC	Total organic carbon
LPS	Low Pressure Steam		

Bitumen Recovery Summary	
Ore Preparation	98.9%
Primary Extraction	98.0%
Froth Treatment (without rejected asphaltenes)	98.2%
Total Bitumen Recovery	95.2%
Asphaltenes Rejection	0.0%
Total Bitumen Recovery (with rejected asphaltenes)	95.2%

Water Summary (T/H)		
Process Water	Cooling Water	5,599
	Heated Water	8,578
Reclaimed Water		12,304
Raw Water		1,873
BFW		125
Boiler Blowdown		20
Make-Up Water		1,998
Condensate Return		632

Energy Output Summary		Input (GJ/h)	Output (GJ/h)	
Cogen	GTG	1,547	Electricity	457
	HRSG	672	Steam	1,383
	Compressor	12	Cogen Losses	391
Subtotal - Cogen		**2,231**		**2,231**
Boilers		583	Steam	530
			Boiler Losses	53
Subtotal - Boilers		**583**		**583**
Total		**2,814**		**2,814**

Flue Gas - Based on Stochiometric Combustion		
Natural Gas HHV	40	MJ/m^3
Excess air @ 13% O_2 (from Cogen Facility)	179	%
Excess O_2 (from Cogen Facility)	13	%
Cogen Flue Gas	2,278	e^3m^3/h
CO_2 in Flue Gas from Cogen	4%	vol.%
H_2O in Flue Gas from Cogen	7%	vol.%
Boiler Flue Gas	242	e^3m^3/h
CO_2 in Flue Gas from Boilers	9%	vol.%
H_2O in Flue Gas from Boilers	17%	vol.%
Flue Gas Temperature - Acid Dew Point Limit	121	°C
Flue Gas - Max. without Economizer	274	°C

Exchanger & Cooler	Duty (GJ/h)
Process Water / Cooling Water	1,224
Process Water / Condensate	160
Process Water / LPS	613
Diluent Feed / MPS	754
Heater	41
Cooler x 3	372
Other Process Use	852

Energy Consumption Summary		GJ/h	e^3m^3/d
Natural Gas	GTG	1,547	928
	HRSG	672	403
	Building Heating and Flare	366	220
	Boilers	583	350
Energy Intensity (GJ per bbl of bitumen produced)		0.38	GJ/bbl
Electricity Generated		3,044	MWH/d

GHG Emissions Summary				
Stationary Combustion & Flaring			4,057	t CO_2e/d
Fugitive Mine	0.0001	-	0.0150	kg $CO_2e/m^2/d$
Fugitive Pond	0.0119	-	0.8054	kg $CO_2e/m^2/d$
Total Cogen Emissions (Gt)			2,842	t CO_2e/d
Deemed emissions from Heat by Cogen (D_H)			2,273	t CO_2e/d
Deemed emissions from Electricity by Cogen (D_E)			568	t CO_2e/d

Project:	Material and Energy Balance for an Oil Sands Surface Mining and Bitumen Extraction Reference Facility		
Case:	Naphthenic - High Grade	Revision:	NA
Owner:	COSIA	Date:	25-Feb-20

Material & Energy Balance
High Temperature Extraction, High Grade, Summer Condition
By B. Thitakamol (Stantec)
Q. Zhuang (CanmetENERGY/NRCAN)

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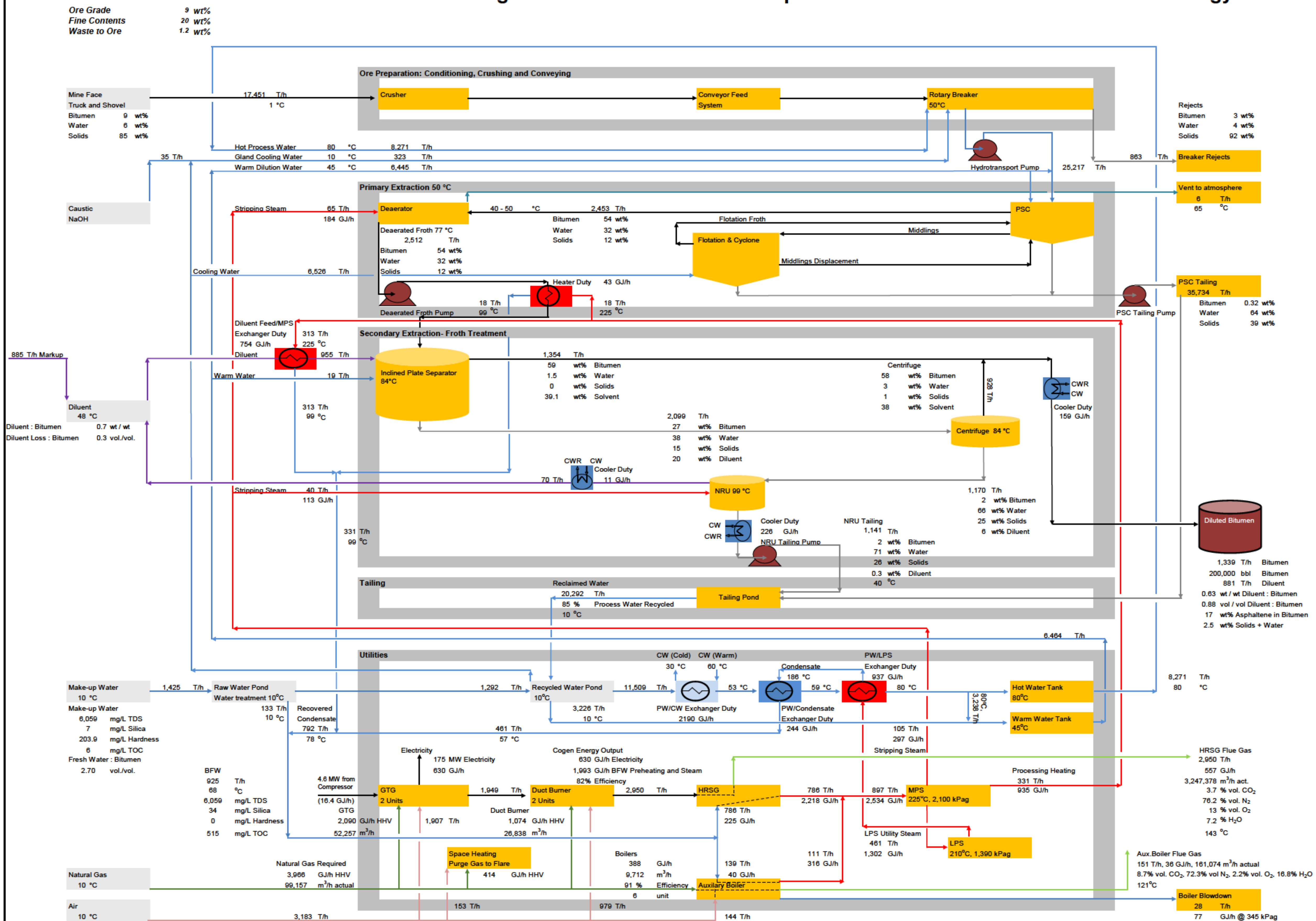
COSIA Mining & Extraction Low Grade - Naphthenic Froth Treatment - Material and Energy Flow



Legend				
Bitumen	Steam	Flue gas	Tailing	Vent
Water	Natural Gas	Solvent	Air	

Abbreviations			
BFW	Boiler Feed Water	MSC	Medium Pressure Steam
CW	Cooling Water	PSC	Primary Separation Cell
CWR	Cooling Water Return	PW	Process Water
GTG	Gas Turbine Generator	NRU	Naphtha Recovery Unit
HHV	Higher Heating Value	TDS	Total Dissolved Solids
HRSG	Heat Recovery Steam Generator	TOC	Total organic carbon
LPS	Low Pressure Steam		

Bitumen Recovery Summary	
Ore Preparation	98.9%
Primary Extraction	98.0%
Froth Treatment (without rejected asphaltenes)	98.2%
Total Bitumen Recovery	95.2%
Asphaltenes Rejection	0.0%
Total Bitumen Recovery (with rejected asphaltenes)	95.2%

Water Summary (T/H)		
Process Water	Cooling Water	6,849
	Heated Water	14,735
Reclaimed Water		20,292
Raw Water		1,292
BFW		133
Boiler Blowdown		28
Make-Up Water		1,425
Condensate Return		792

Energy Output Summary		Input (GJ/h)		Output (GJ/h)
Cogen	GTG	2,090	Electricity	630
	HRSG	1,074	Steam	1,993
	Compressor	16	Cogen Losses	557
Subtotal - Cogen		**3,180**		**3,180**
Boilers		388	Steam	353
			Boiler Losses	36
Subtotal - Boilers		**388**		**388**
Total		**3,569**		**3,569**

Flue Gas - Based on Stochiometric Combustion		
Natural Gas HHV	40	MJ/m^3
Excess air @ 13% O_2 (from Cogen Facility)	179	%
Excess O_2 (from Cogen Facility)	13	%
Cogen Flue Gas	3,247	e^3m^3/h
CO_2 in Flue Gas from Cogen	4%	vol.%
H_2O in Flue Gas from Cogen	7%	vol.%
Boiler Flue Gas	161	e^3m^3/h
CO_2 in Flue Gas from Boilers	9%	vol.%
H_2O in Flue Gas from Boilers	17%	vol.%
Flue Gas Temperature - Acid Dew Point Limit	121	°C
Flue Gas - Max. without Economizer	274	°C

Exchanger & Cooler	Duty (GJ/h)
Process Water / Cooling Water	2,190
Process Water / Condensate	244
Process Water / LPS	937
Diluent Feed / MPS	754
Heater	43
Cooler x 3	396
Other Process Use	1,794

Energy Consumption Summary		GJ/h	e^3m^3/d
Natural Gas	GTG	2,090	1,254
	HRSG	1,074	644
	Building Heating and Flare	414	363
	Boilers	388	233
Energy Intensity (GJ per bbl of bitumen produced)		0.48	GJ/bbl
Electricity Generated		4,198	MWH/d

GHG Emissions Summary				
Stationary Combustion & Flaring			5,079	t CO_2e/d
Fugitive Mine	0.000007	-	0.0355	kg $CO_2e/m^2/d$
Fugitive Pond	0.0119	-	0.8054	kg $CO_2e/m^2/d$
Total Cogen Emissions (Gt)			4,051	t CO_2e/d
Deemed emissions from Heat by Cogen (D_H)			3,241	t CO_2e/d
Deemed emissions from Electricity by Cogen (D_E)			810	t CO_2e/d

Project:	Material and Energy Balance for an Oil Sands Surface Mining and Bitumen Extraction Reference Facility		
Case:	Naphthenic - Low Grade	Revision:	NA
Owner:	COSIA	Date:	25-Feb-19

Material & Energy Balance
High Temperature Extraction, Low Grade, Winter Condition
By B. Thitakamol (Stantec)
Q. Zhuang (CanmetENERGY/NRCAN)

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