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Bitumen Upgrader Residue Conversion to Incremental Synthetic Fuels Products

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ABSTRACT

During recent years there has been a significant change in market conditions affecting the oil and gas industry in North America. The introduction to the marketplace of natural gas from new sources has decreased the price of gas relative to crude oil and this is expected to continue well into the future. This change in marketplace conditions creates exciting new opportunities to maximize the benefit of "cheap" gas to produce value-enhanced liquid products using gas to liquids technology. One area where this can be of great importance is in bitumen upgrading and refining and, in particular, the effective utilization of the hydrogen-deficient vacuum reside and asphaltenes produced in the upgrading process.

This paper discusses the use of a new process, FTCrude®, to convert the asphaltenes and other residues to synthetic fuel products using existing, commercially proven, technology. The process utilizes a combination of gasification, reforming and Fischer-Tropsch synthesis to produce high value naphtha, diesel and gas oil products. The FTCrude® concept can be applied in a wide range of applications including Partial Upgrading, Full Upgrading and management of Heavy Refinery Bottoms.

Technical and economic results of a case study based on a 50,000 BPD FTCrude® concept bitumen upgrader are presented. The economics of FTCrude® over a range of natural gas and crude oil price scenarios will also be discussed.

In summary the FTCrude® concept exhibits the following advantages:

•The FTCrude® concept is economically very robust for a wide range of natural gas and crude oil prices and favours bitumen upgrader residues conversion to incremental synthetic fuels rather than to hydrogen production.

•The FTCrude® concept provides significant improvements in product quality and yield (>120% vol yield), high operational reliability, and higher carbon conversion efficiency resulting in a sizeable reduction of CO_2 emissions.

INTRODUCTION

Canada has an abundant supply of hydrocarbon resources, primarily located in the province of Alberta and existing in the form of natural gas, natural gas liquids (NGL) and Bitumen or Heavy Oil (API gravity less than 20° API). Current market factors are changing the "Business as Usual" methods used to effectively exploit and market these resources:

- Increased public pressure to improve the "dirty oil" image and produce these valuable resources in an environmentally sustainable manner.
- Bitumen production in next 20 years is expected to grow by over 3,000,000 BPD generating additional 55 BTPY of GHG emissions and 37 MTPY of petcoke using conventional Coking Technology.
- Conventional Coking Technology yield of bitumen feed to synthetic crude oil (SCO) or refinery products is typically 80 to 85%.
- Non-conventional shale gas production has created a long term oversupply of natural gas creating a long term price forecast not expected to exceed \$4 to \$5 /GJ.
- Crude pipeline capacity and rail limitations are restricting access of Alberta Bitumen to USA and offshore markets resulting in significant sales discount pricing of 40% Bitumen to WTI, while WTI and Brent world oil pricing is expected to be stable at greater than \$90/BBL.
- Quality of conventional diesel fuel derived from bitumen feedstock is 30 to 35 cetane, which is below North American standards of minimum 40 cetane and European standards of 50 cetane.
- Access to water sources, especially ground water sources, must be limited and sustainably managed.

- Availability of world light crude oil 30° to 40° API is in decline, requiring the production of heavy oil reserves.

There is a great need for a new economically feasible, commercially proven concept to address all the above concerns for the sustainable production of high quality transport fuels and petroleum products from all heavy hydrocarbon streams.

FTCrude® is a recently patented and patent pending processing technology developed and licensed by Expander Energy Inc. of Calgary, Alberta, Canada, that addresses all these concerns. This paper focuses on the basics of the FTCrude® technology and illustrates its significant capabilities in the processing of bitumen, heavy oil and refinery bottoms.

CURRENT BITUMEN UPGRADER CONCEPTS

As is well known, bitumen is the heaviest, viscous form of petroleum; it is highly deficient in hydrogen and it does not flow at normal pipeline temperatures. In most instances it has to be mixed with lighter hydrocarbons (diluents) before it can be transported by pipeline for upgrading into synthetic crude oil and refined products. Bitumen upgraders can generally be defined in two categories:

1. Carbon rejection types
2. Hydrogen addition types

In both instances the hydrogen deficiency, in addition to sulphur, nitrogen, CCR, TAN and heavy metals removal, is corrected through the upgrading process. Synthetic crude oil , typically consisting of naphtha, diesel and gas oil or finished refinery products, such as low sulphur gasoline, diesel or jetfuel can be produced.

Upgraders can either be located in relatively close proximity to the bitumen source (mine or an insitu reservoir) or be remote from the source and connected by a pipeline supplying diluted bitumen. Diluent is typically removed and returned for upstream production.

Carbon rejection is inherently inefficient (82% vol yield) and wasteful in most cases (significant volumes of petcoke are produced). Petcoke is typically stored at the mine sites and depending on location has limited marketability.

Hydrocracking processes, which requires the addition of significant hydrogen, offers a much higher liquid yield (95 to 100% vol yield), better distillate qualities and quantities, but at a higher capital expense, higher hydrogen demand and higher GHG emissions. Upgraders, located remote from mine sites, generally are selected as the hydrogen addition type, to eliminate the production and storage of petcoke.

The most recent bitumen upgraders in Alberta, Nexen Long Lake (operating) and NorthWest Redwater Upgrader (in construction), use the hydrogen addition process. With this approach, regardless of the ultimate hydro-processing configuration, there is always an unconverted residue. There are two basic options to utilize the unconverted residue:

- Gasification and syngas conversion using partial or full Water-Gas-Shift (WGS) reaction to produce hydrogen to satisfy upgrader requirements, resulting in a low BTU Syngas or pure CO_2 by-product. The CO_2 is further used for enhanced oil recovery (EOR) or the low BTU syngas is combusted and CO_2 is emitted to atmosphere as GHG.
- Gasification and syngas conversion without the use of WGS, and therefore the CO and H_2 are fully converted to synthetic fuels.

The choice between these two options is primarily dependent on the natural gas/crude oil price relationship. During the development stage for the above mentioned upgraders, commodity prices were in the range of $8/GJ for natural gas and <$50/bbl for crude. Under this pricing scenario the hydrogen generation option can be economically justified.

Block diagrams Figure 1 and Figure 2 illustrate the Nexen and Northwest concepts.

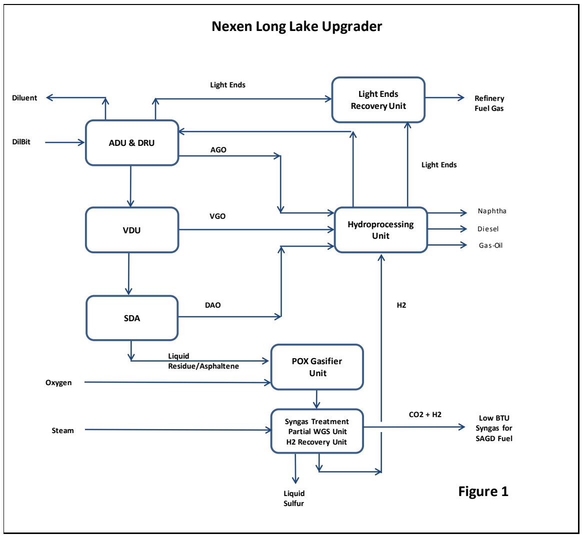

Figure 1

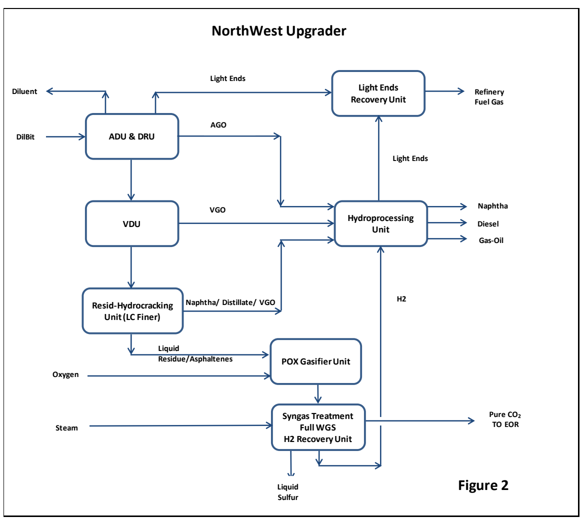

Figure 2

UPGRADER CONFIGURATION REFLECTING CURRENT NATURAL GAS AND CRUDE OIL PRICING

Would the hydrogen addition upgrader configuration change today? Today's commodity price environment is significantly different and long term prices are in the range of $4 to $5/GJ for natural gas and >$90/bbl for WTI crude. Under this pricing scenario, the residue conversion to additional synthetic fuels makes compelling economic sense and should therefore be considered.

In this concept, an unconverted residue can be gasified to syngas and additional synthetic fuels can be produced through Fischer-Tropsch (F-T) syngas synthesis. The F-T process produces primarily paraffinic naphtha and highly valuable sulfur and aromatics free diesel fuel or SynDiesel® with typical cetane numbers in excess of 70. Hydrogen required for the upgrader is produced through standard Steam-Methane Reforming (SMR) using "cheap" natural gas, LPG, RFG or naphtha as feedstock.

Along these lines, Expander Energy, with the assistance of WorleyParsons (formerly Colt Engineering Corporation), developed the FTCrude® concept. This concept is based on incremental synthetic fuels production utilizing gasification of upgrader residue, combined with the reforming of natural gas, to produce optimum syngas formulation for the F-T synthesis. Many significant and valuable synergies result from the integration of the "FTCrude® Island" into the Refinery/Upgrader facility to effectively utilize the bottom of the barrel.

Syngas originating from gasification of a high carbon-content feedstock, e.g. bitumen residue, is by definition hydrogen deficient, and is not directly suited for F-T synthesis as it does not have the required stoichiometric H_2/CO ratio. Therefore, in addition to the standard gasification/syngas/F-T synthesis configuration, FTCrude® also includes hydrogen enrichment of syngas. Hydrogen rich syngas is produced through a standard Steam-Methane-Reforming (SMR) or Auto Thermal Reformer (ATR) process, or combination of both processes using natural gas, LPG, RFG, naphtha etc., as feedstock. The referenced SMR, in addition to enriching the syngas, provides the required amount of hydrogen for the bitumen upgrader as well as for the F-T products upgrade. A common SMR is typically used and provides high reliability syngas and pure hydrogen for the Upgrader needs.

In addition to the economic advantages, there are other inherent benefits to this concept:

- Upgrader operation is critically dependent on a reliable source of hydrogen. In this concept hydrogen is produced from a highly dependable source (SMR) as opposed to a relatively low reliability gasification operation.

- There are major reductions in CO_2 emissions. In this concept, no WGS stage is required, which eliminates the major source of CO_2 emissions and retains the carbon as CO for conversion to synthetic fuels.
- Sufficient energy is produced to satisfy the full refinery steam and electric power needs.
- Surplus high quality process water is produced to fully satisfy the water makeup requirements of the refinery/upgrader. In addition, there will also be excess high quality water available to meet the requirements of makeup water needed for the upstream SAGD facility.
- The FTCrude® syngas generator can be configured in addition to consuming natural gas, to consume excess LPG, RFG, naphtha and CO_2 from other refinery sources (such as furnaces, boilers) to significantly reduce overall upgrader/refinery GHG emissions and increase yield of high value SynDiesel®.

The FTCrude® concept is patented and patent pending worldwide and the intellectual property is exclusively owned by Expander Energy. The FTCrude® employs proven and commercially available technologies for all the processing steps. As a result, there is very limited technical risk. A simplified block diagram illustrating the FTCrude® concept is presented in Figure 3.

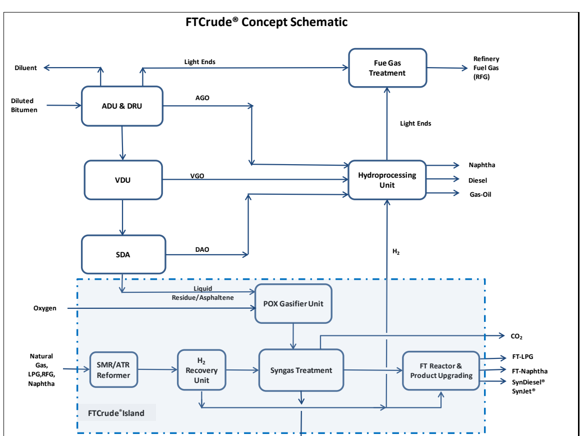

Figure 3

FTCrude® CASE STUDY

In concert with WorleyParsons, Expander Energy has developed a process design for an integrated bitumen upgrader/FTCrude® system with an upgrader capacity of 50,000 bpd of neat bitumen feed. In one, preferred configuration, the upgrader process is based on hydrocracking of deasphalted oil and vacuum gas oil and hydrotreating of straight run and hydrocracked naphtha, diesel and gas oil. The FTCrude® section receives asphaltenes from the Solvent De-asphalting (SDA) or Vacuum Distillation Unit (VDU) as feed. This heavy residue liquid (10° to -12° API) is gasified in a Partial Oxidization Reactor (POX) unit with pure oxygen (>98wt% O_2) to generate a sour hydrogen lean syngas. After gasification, the heavy metals as slag, sulfur (H_2S,COS, etc.) and NH_3 compounds are removed from the raw syngas to form the clean hydrogen lean syngas (H_2:CO = 0.8 to 1.0). Separately, a SMR syngas generator (or Auto-thermal Reformer (ATR) or combinations of SMR/ATR) provides additional hydrogen rich syngas to combine with the hydrogen lean syngas for the F-T synthesis. The SMR is a combined service to provide sufficient hydrogen for both the bitumen upgrader and F-T product upgrading. Based on 50,000 bpd of neat 8° API bitumen feed to the upgrader, and with minimum SDA residual bottoms production, then 47,300 bpd of 30 API SCO, 542 bpd F-T LPG, 1,715 bpd F-T naphtha and 11,412 bpd F-T diesel is produced. To achieve this production, 98 MMSCFD of natural gas is used for the common SMR. Refinery fuel gas (RFG) is used for all furnaces in the upgrader or refinery.

About 60,500 bpd of 35° API SCO is produced when the F-T products are included. This represents approximately 121% volumetric yield on bitumen. The table below summarizes the overall material balance for the study case.

Feed Streams			kg/hr
Bitumen			
(excl. Diluent)	*50,000*	bpd	334,560
Natural Gas	98	MMSCFD	78,090
Steam (SMR)			179,722
Oxygen (POX)			45,526
Steam (POX)			25,292
Total Feed Streams			**663,190**
Product Streams & Effluents			
Upgrader			
Naphtha	2,625	bpd	13,234
Diesel	22,014	bpd	125,421
Gas Oil	22,653	bpd	136,301
FTCrude®			
Offgas	41.1	MMSCFD	52,033
LPG	542	bpd	2,392
Naphtha	1,715	bpd	7,798
Diesel	11,412	bpd	57,899
Process Water	13,023	bpd	87,519
SMR Water	17,310	bpd	116,352
CO_2	11.1	MMSCFD	24,306
Other Effluents by Difference			39,935
Total Products Streams & Effluents			**663,190**

PreFeed capital costs (+/- 30%) for this integrated case installed in Northern Alberta was estimated to be in the range of $4.0 to $5.0 billion (CDN) or about $65,000/bpd to $85,000/bpd of total SCO blend, subject to the level of contingency, escalation, actual location and extraneous infrastructure requirements.

It should be noted that the capital costs include the Upgrader and FTCrude® process areas as well as Utilities & Offsites as a full green field Total Installed Cost (TIC). Oxygen supply for the gasifier is considered to be over the fence and as such the Oxygen Plant capital costs are not included.

FTCrude® ECONOMICS

WorleyParsons used its EcoNomics® Comparative Assessment tool to assess the economic robustness of the FTCrude® concept. The first chart, Figure 4, presented below indicates project unlevered IRRs for the Base Case for three natural gas prices, namely $3, $6 and $12 GJ as a function of WTI crude oil prices. It can be seen that negative NPVs can only be observed at very low crude oil prices. The probability for these very low crude oil prices, based on numerous long term forecasts, is equally very low. Consequently, assuming longer term crude oil prices being in the range of $90 to $110/bbl, the FTCrude® concept can be considered economically robust and be able to tolerate significant increases in natural gas prices beyond the $3 to $12/GJ range.

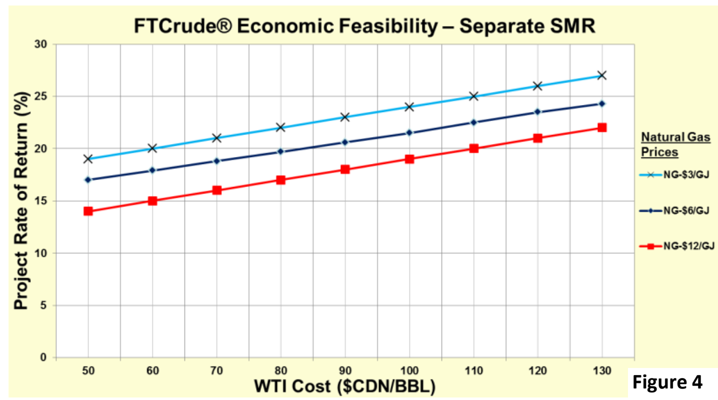

Figure 4

Using the same tool, an analysis was made to identify a balancing "sweet spot" between the upgrader hydro-processing and FTCrude® section conversion capacities. As the economics are very sensitive to diesel prices, a range of diesel price assumptions are evaluated along with a range of natural gas and SCO prices.

The interface between the bitumen upgrader and the FTCrude® unit is downstream of the SDA unit. The SDA produces de-asphalted oil (DAO) and asphaltenes and the asphaltenes are sent (via intermediate storage) to a POX unit (gasifier). The operation of the SDA controls the volume, API gravity and other properties (viscosity, CCR, sulfur and metals content) of the feed to the gasifier and subsequently controls the balance point between the bitumen upgrader and the FTCrude® unit. Two main cases were compared:

Case 1, FTCrude®(min) case: The SDA Unit produces the lowest volume and lowest API density (-10° API) asphaltenes being fed to the gasifier, thereby maximizing the volume of DAO feed to the hydrocracker/hydro-treaters. For Case 1, the amount of heavy metals and CCR in the DAO may have impact on the conventional hydrocracker catalyst.

Case 2, FTCrude®(max) case: The SDA Unit produces the highest volume and highest API density (0 to 10° API) asphaltenes being fed to the gasifier, minimizing the volume DAO feed to the hydrocracker, thereby representing the minimum throughput and highest DAO quality feed for the hydrocracker. For Case 2, the amount of heavy metals and CCR in the DAO are below maximum allowed for typical hydrocracker catalyst, allowing for the use of less expensive conventional single fixed bed reactors.

The following are the basic parameters for the two cases, based on vacuum residue feed to SDA unit:

	Case 1	**Case 2**
DAO yield % (Lift)	73	58
DAO flow to HCU (bpd)	20,126	16,296
Asphaltenes to POX (bpd)	6,286	10,116
Natural Gas (MMSCFD)	98	143
Total SCO (bpd)	60,500	68,525
Product Yield (vol%)	121%	137%
CAPEX ($ M CDN)	$4,000	$4,600

Both cases are compared for the same project return as a function of natural gas and crude prices. The results are presented in the Figure 5. At current crude oil price range of $80 to $100/bbl and natural gas prices below $14/GJ, the CASE 2 FTCrude® (max) economics is strongly favoured.

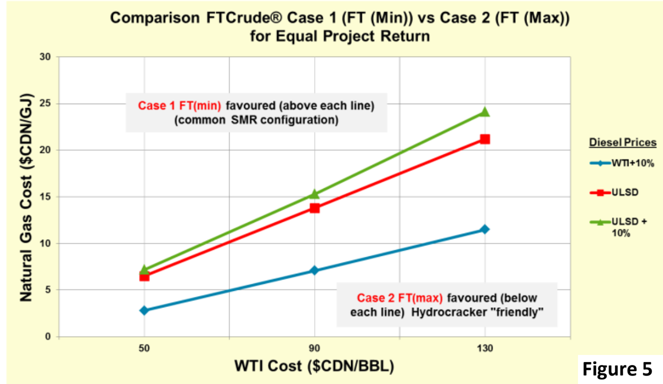

Figure 5

FTCrude® Opportunities

The FTCrude® concept can be applied in a wide variety of facilities, such as existing upgraders that produce asphalt and asphaltenes, or unconverted hydrocracked residue or petcoke. Similarly, the FTCrude® concept can also be applied in any heavy or deep conversion refineries producing asphalt or heavy fuel oil as unconverted residue. In the North American context of low natural gas and high crude oil prices the opportunities are numerous. Because of the demonstrated tolerance of the FTCrude® to relatively high natural gas prices, this concept can also be applied in many facilities in Europe and Asia.

Immediate opportunities in Alberta include retrofitting the existing operating Nexen Long Lake Upgrader or the NorthWest Redwater Upgrader that is currently in construction. The design of both upgraders includes gasification of residues to generate hydrogen and therefore require the retrofit of the F-T Synthesis unit and the Syngas Generator. Other immediate opportunities in North America and Europe include conversion of low and medium conversion refineries to process heavy crudes and focus on high yields of high quality synthetic diesel.

Because of the high carbon retention inherent to the FTCrude® concept, there is minimum 50% and as great as 80% reduction in carbon dioxide emissions compared to other upgrading and refining technologies. This reduction in greenhouse gas emissions is an additional driver for retrofitting existing facilities.

Last, but not necessarily least, the FTCrude® concept will increase the reliability of operation for hydrogen addition upgraders since hydrogen production is shifted from a less reliable operation (gasification) in the plant to highly reliable and industry proven SMR technology.

The FT Crude® Technology can be configured in three main process arrangements:

1. **FTCrude® Partial Upgrader** process is used to convert bitumen to unique bottomless 20° to 24° API gravity Partially Upgraded Bitumen (PUB) with significant reduction in sulfur, heavy metals, naphthenic acid (TAN) and Conradson Carbon (CCR). PUB has preferred chemical and physical properties exceeding requirements for pipelining (without diluent) and is also preferential for refining. These properties exceed current WCS quality specifications and the PUB is expected to receive $5.00 to $10.00 premium to WCS.
2. **FTCrude® Full Upgrader** process is used to convert bitumen to Sweet Synthetic Crude Oil (SCO) with 35° to 40° API gravity and 50+ cetane diesel fraction, exceeding current Alberta SCO specifications.
3. **FTCrude® Refinery** process is used to convert bitumen to full specification refined products such as gasoline (ULSG), high cetane diesel (ULSD) and jet fuel (ULSJ).

Figure 6 illustrates the typical range of FTCrude® products available from 8.0° API Bitumen feed and compares these products to common North American crudes.

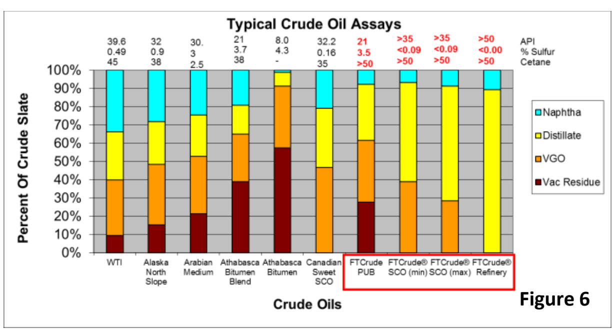

Figure 6

In summary the FTCrude® concept offers the following advantages when employed in a hydrogen addition upgrader and compared to the residue gasification for hydrogen production:

- Major economic advantage at current and future forecasted natural gas and crude oil price relation,
- Increased operational reliability,
- High feedstock carbon retention and conversion to product , thus lower CO_2 emissions,
- Improved flexibility and marketability of FT products.

SUMMARY AND CONCLUSIONS

- Under current and medium term forecasts for natural gas and crude pricing, residue conversion to incremental synthetic fuels rather than to hydrogen production is economically, technically and environmentally attractive.
- The FTCrude® concept is economically very robust for a wide range of natural gas and crude oil prices.
- The FTCrude® concept can be used for partial and full bitumen upgrading as well as for complex bitumen refineries producing high quality transportation fuels (gasoline, jet fuel and diesel).
- The FTCrude® concept employs, for all processing steps, proven and commercially available technologies. As a result there is very limited technical risk.
- The FTCrude® concept provides significant improvements in SCO yields, operational reliability, and carbon conversion efficiency (> 90% conversion), resulting in sizeable reduction of CO_2 emissions.

LIST OF FIGURES

REFERENCES

1. **Crude Oil Forecast, Markets & Transportation, (CAPP) Canadian Association of Petroleum Producers, June 2013**
2. **Air Emissions in Canada's Oilsands, (CAPP) Canadian Association of Petroleum Producers, July 2011**

NOMENCLATURE

CDN - Canadian
FTCrude® - Fischer-Tropsch Crude- Registered Trademark of Expander Energy Inc.
SynDiesel®- FT synthetic Diesel - Registered Trademark of Expander Energy Inc.
SynJet® - FT synthetic Jet Fuel - Registered Trademark of Expander Energy Inc.
PUB – Partially Upgraded Bitumen
CO_2 – Carbon Dioxide
CO – Carbon Monoxide
H_2 – Hydrogen
O_2 – Oxygen
COS – Carbonyl Sulfide
H_2S – Hydrogen Sulfide
GHG – Greenhouse Gases
API Gravity – American Petroleum Institute Gravity Index
NGL – Natural Gas Liquids
LPG – Propane & Butane Liquid
RFG – Refinery Fuel Gas
BTPY – Billion Tonnes per Year
MTPY – Million Tonnes per Year
MMSCFD – Million Standard Cubic Feet per Day
SCO – Synthetic Crude Oil
GJ – Metric Thermal Unit
BTU – British Thermal Unit
WTI – West Texas Intermediate – North American Crude Index
Brent – World Crude Index
WCS – Western Canadian Select DilBit
DilBit – Bitumen with Diluent added
ULSD – Ultra Low Sulfur Diesel
ULSJ – Ultra Low Sulfur Jet Fuel
ULSG – Ultra Low Sulfur Gasoline
CCR – Conradson Carbon Number – measure of coking material
TAN – Measure of naphthenic acid content
Vol Yield % - volume product yield from bitumen
WGS – Water Gas Shift Reaction
EOR – Enhanced Oil Recovery
Bbl – Barrel = 42 US gallon
Bpd – Barrels per day
F-T – Fischer Tropsch Process
GTL – Gas to Liquids
SMR – Steam Methane Reformer
ATR – Auto Thermal Reformer
SAGD – Steam Assisted Gravity Drain Process
SDA – Solvent De-Asphalting Unit
DAO – De-asphalted Oil
ADU – Atmospheric Distillation Unit
VDU – Vacuum Distillation Unit
POX – Partial Oxidization Unit
HCU – Hydro-cracking/Hydro-processing Unit
TIC – Total Installed Cost
IRR – Unlevered Project Rate of Return
NPV – Net Present Value
CAPEX – Project Capital Cost