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1. Executive Summary

Global demand for crude oil and liquid fuels creates an opportunity for the exploitation of heavy oil resources. Many of these resources exist in the form of stranded assets, which tend to be geographically remote or difficult to access. In these locations, industrial infrastructure has not necessarily matured or the availability of construction resources is extremely constrained. In addition, production techniques continue to become ever more complex. As a result, the development of heavy oil remains economically challenged and deployment of conventional solutions to solve these challenges can be impractical. However, because of the global abundance of heavy oil deposits and depleting conventional oil supplies, heavy oil is becoming an increasingly important global hydrocarbon resource. A viable economic solution is required to address the challenges of heavy oil.

FluidOil’s VHTL® (Viscositor Heavy-To-Light) process provides an economic alternative to traditionally deployed heavy crude oil dilution, heated transport or field-upgrading schemes. Typically, heavy crude is diluted with light oil so that it can be transported to the refinery. This is expensive adding up to $17.00/bbl in cost. VHTL offers a new paradigm where partial upgrading of the heavy oil is accomplished by building a low-cost facility close to the field thus removing the need to dilute the oil for transport. In addition to this, VHTL positions the heavy oil producer to capture the majority of the market value differential between heavy and light oil and eliminates the need for adding diluent to enable transportation.

VHTL converts heavy, viscous crude oil into lighter, more valuable and easily transportable products. The essence of the process is rapid thermal conversion of heavy oil into high value synthetic crude oil (SCO). In the VHTL facility, the bulk of low value carbon is removed and only a much lighter, low viscosity and stable product is transported to the refinery. This rejected carbon, in the form of coke, is converted into significant amounts of energy that is captured and utilized on-site, typically as high-grade steam.

VHTL plants can be economically constructed at smaller scales than conventional upgrading processes and operate at a fraction of the per-barrel cost. Reduced complexity as well as a smaller footprint make it possible for VHTL plants to be built in remote locations not accessible to conventional technologies. VHTL can also be deployed offshore by integrating the plant onto an FPUSO (floating, production, upgrading, storage and offloading) vessel. This provides a unique and economically attractive solution to producing heavy oil from currently stranded offshore oilfields.

Utilizing extensive engineering experience from analogous installations, FluidOil has recently made advancements in VHTL design and modularization which further widens the gap between the cost of VHTL and that of conventional upgrading facilities. The optimized design produces modules which are fabricated off-site and transported via barge, rail or road. Modularization makes it economically feasible to install VHTL plants in remote onshore and offshore locations.

This paper describes the status of the VHTL business with a specific focus on:

- The markets
- Economics
- VHTL development history
- A description of the technology and the competitive landscape
- Readiness for commercialization
- Business models and capital project evaluations
- The business development strategy
2. Overview of Global Oil Supply/Demand Forecast and VHTL Economics

FluidOil Limited has developed a methodology for evaluating the short- and long-term economic feasibility of VHTL projects. Forecasts of project returns depend in part on project costs and in part on projected heavy crude prices verses standard benchmark light crude oil prices (heavy to light spread).

Production and logistics costs, whilst specific to individual cases, are relatively easy to understand at sufficient detail to be able to analyse the impact which VHTL can have on a project. However, given the recent market fluctuations in global pricing of crude oil and in particular the differential pricing between heavy oil and light benchmark oil, this part of the economic proposition is far more difficult to forecast accurately.

As there is some variation in forecasts by various consultants, we collate several views (IHS, CERA, FACT, EIA etc.). This section provides a concise view of price forecasts key to the VHTL economic analysis, along with an explanation of assumptions used in generating these forecasts. In a subsequent section we provide a summary of expected VHTL project economic returns given these pricing forecasts along with a set of specific project parameters such as capital costs and operating expenses.

Oil Production

Accounting for all the forecasted supply from conventional sources globally, as well as tight oil and ultra-deep water offshore, there is an expected shortfall of ~15 MMbpd. This shortfall creates an opportunity to exploit heavy oil resources. Filling the gap provides an opportunity to deploy the various heavy oil exploration/production/monetization business models.

Figure 1 shows a more detailed analysis of the 15 MMbpd heavy crude supply that must be produced to satisfy total global crude oil demand.

![Figure 1 — Analysis of historic and future heavy crude supply](image)

Production from currently producing heavy oil assets will decline to about 8 MM bpd by 2030. To satisfy future demand, about 7 MMbpd of heavy oil production will be required from new developments by 2030.
Roughly 2/3 of this new heavy oil is required to replace production declines and the remaining 1/3 will supply demand growth. Figure 2 shows global sources of heavy crude.

![Figure 2 — Global sources of heavy crude](image)

Total known resources of heavy oil are 3.4 trillion barrels of original oil in place. The total known natural bitumen resource in amounts to 5.5 trillion barrels of oil originally in place. This resource is distributed across 192 basins containing heavy oil and 89 basins with natural bitumen.

Total recoverable heavy oil and bitumen is about 2 trillion barrels but as shown in Figure 3, only about half of this is exploitable due to production technology and cost limitations through 2030. Another 0.4 trillion bbls is not available because it is located in politically or geographically unfavorable locations. About 0.2 trillion bbls fall into a quality range that allows it to be transported through pipelines easily, but production from these assets cannot happen quickly enough to satisfy the heavy crude supply growth rates shown in Figure 2. This leaves 400 billion barrels of heavy oil which is constrained by current supply chain limits (e.g., high viscosity, low gravity etc.), but must be produced in order to satisfy global crude demand as shown in Figure 1. This constrained heavy oil is suited to heavy oil monetization technologies and is the target market for VHTL.
The rest of this section will describe pricing forecasts and heavy/light differentials that are derived from the global oil supply/demand forecasts. The pricing basis is a key component to determine VHTL project returns. The generally accepted market forecast is that growth in the supply of oil will outpace incremental demand for oil products. This will create some downward pressure on future prices, and has pushed our mid-term light oil forecast to a current estimate of $60/bbl. It is very difficult to predict where supply and demand will move over the next decade. Therefore, light oil prices are conservatively assumed to hold at the $60/bbl level through 2030.

Historical price spreads for benchmark heavy oils to light oils have been largely consistent. For Maya (a Mexican heavy blend oil) vs WTI, this has been around $12/bbl. However, given the current price environment, our analysis indicates that the price differential is forecasted at $8-$10/bbl through 2030. Added residual oil upgrading capacity will continue to fall short of new heavy supply. A narrowing of the heavy to light price differential over the last few years has resulted in delays or cancelation of refinery
upgrading projects but supports the ongoing production of additional heavy crude barrels using the dilute and ship transportation approach. In addition, the expansion of heavy crude supplies is significantly outpacing the addition of refinery capacity. The price spread between diesel and fuel oil products will likely remain wide due to increased demand from emerging markets for diesel and decreasing demand for fuel oil as greenhouse gas emissions and sulfur emission reduction programs are implemented.

Table 1—Forecast of Key VHTL Economic Parameters (in 2017 USD, 2018-2030 Averages)

<table>
<thead>
<tr>
<th>Brent $/bbl</th>
<th>WTI $/bbl</th>
<th>Maya $/bbl</th>
<th>WCS $/bbl</th>
<th>Naphtha USGC, $/bbl</th>
</tr>
</thead>
<tbody>
<tr>
<td>$62.00</td>
<td>$60.00</td>
<td>$50.00</td>
<td>$44.50</td>
<td>$61.00</td>
</tr>
</tbody>
</table>

To forecast VHTL SCO prices, FluidOil uses a robust market evaluation taking into account evaluation work completed by Jacobs Consultancy. The forecast assumptions used in the Jacobs study determined that VHTL SCO market value is near par with light benchmark crudes such as Brent or LLS. This is due mainly to the much higher middle distillate content of the SCO vs crudes such as Brent.

We are currently considering three VHTL implementation models that will be discussed in more detail later:

- Upstream integrated at wellhead
- Midstream
- Offshore

Although the heavy oil price discount is not expected to return to the 30 - 35% peaks experienced during years 2003 - 2008, we believe that VHTL projects will generate attractive rates of return with the forecasted price spreads included in this report. Likewise, although global market forecasts are projecting low diluent price premiums and low natural gas prices, VHTL projects are economically feasible even when considering the lower diluent and gas price scenarios. We also believe that there is substantial upside potential depending on specific macro events that could widen the heavy to light spread, increase diluent prices, raise shipping costs or increase gas prices.

In addition to the value uplift created by the price differential between VHTL product SCO and extra heavy oil or bitumen, there are several other value components offered by VHTL. VHTL provides a solution for producing and transporting heavy oil from remote field locations where natural gas and diluent is expensive due to supply constraints. In some cases, natural gas and diluent may be entirely unavailable due to a total lack of infrastructure in the heavy producing region. The capital cost associated with removing the supply constraints, such as the construction of new pipelines, is in many cases higher than the capital cost associated with building the VHTL facility. In these cases, the construction of an VHTL facility which supplies energy to production operations and eliminates diluent from crude transportation, is a better solution than constructing additional infrastructure for bringing natural gas or diluent into the production field. VHTL therefore unlocks the value of remote, stranded assets.

In addition to the project regions of North America and Latin America, comparable project returns can be obtained with VHTL in other regions of the world. These locations, as shown in Figure 5, include Asia/Pacific, Russia, Central Asia, the Middle East, and Africa.
3. VHTL Development History

FluidOil acquired the Viscositor technology from Ellycrack AS in 2012 and the HTL technology from Ivanhoe Energy Inc in 2016. These two technologies have been integrated together and further developed to form the backbone of the VHTL process.

Ellycrack, a Norwegian Company, had been developing the Viscositor oil upgrading technology since around 2003 when it was working with PdVSA to come up with a field upgrading technology to enable extra heavy oil to be transported to market. The technology was developed primarily through the testing of a 50bpd unit with SINTEF Research Institute in Trondheim, Norway.

In 2005, Ivanhoe acquired the rights of a patented process known as Rapid Thermal Processing (RTP) from Ensyn - a Canadian company. Ensyn commercialized RTP technology to produce renewable liquid fuels and chemicals from wood residues and other solid biomass. Ensyn started its original development in the 1990s and has been successfully operating commercial RTP units for over 20 years. The RTP process, as applied to the upgrading of heavy oil, was patented and branded as HTL or “Heavy-to-Light”. The technology was studied extensively during early pilot plant work and then validated by Ivanhoe through the successful operation of a 1,000 bpd Commercial Demonstration Facility (CDF) in Bakersfield, California. Testing of heavy crude oils in the CDF proved the scalability of the HTL process and provided key design information for the first commercial basic engineering design package (BEDP) and front-end engineering design (FEED) of initial projects, including the Tamarack project in Alberta, Canada.
In 2008, the Feedstock Test Facility (FTF) was commissioned at the Southwest Research Institute in San Antonio, Texas, to further improve the process for a range of heavy oil feedstocks. The FTF is designed to model and mimic a full commercial upgrading plant, but at a reduced capacity, making it feasible to rapidly test smaller batches of heavy crude oils. The FTF is equipped with a state-of-the-art process control and measurement system that maximizes quality of data collected, validates technology advancements made to the VHTL process and supplies critical data used for commercial design. It has now been updated to reflect the fully developed VHTL technology. Testing programs in the FTF are used to prove the capability of VHTL to upgrade a variety of global crude oils and to mitigate many of the key process performance risks associated with building a commercial plant. Figure 5 shows photos of the three facilities used in the development of VHTL and its parent technologies.

The data from these three phases have been used to produce commercial designs including a full FEED package for Tamarack in the Alberta oil sands and a BEDP for Dos Bocas in Mexico. Figure 6 is a 3D rendering of the 20,000 bpd Tamarack VHTL plant obtained from the detailed 3D model developed during FEED.
A feasibility study for an offshore facility in the Pemex Ayatsil field in the Gulf of Mexico and Figure 7 is a 3D rendering has been completed:

![3D rendering of the offshore facility in the Pemex Ayatsil field in the Gulf of Mexico](image)

**Figure 7—3D rendering the offshore facility in the Pemex Ayatsil field in the Gulf of Mexico**

Since implementing VHTL in remote locations is a key component of the business strategy, modularization is a critical element and is fully incorporated into the cost estimate and the design plan for all VHTL projects. A 20,000 bpd VHTL plant can be fabricated from 65 modules weighing less than 150 tonnes each. These modules can be transported by truck to remote locations for hook-up and completion. Alternatively, the plant could be constructed in five 2,000 tonne “super-modules” at coastal fabrication yards and carried offshore.
4. VHTL Technology Principals

In VHTL, a circulating flow of hot fluidized sand quickly heats the heavy feedstock in a transport bed reactor and converts the heavy oil to a lighter, more valuable product. The process scheme is depicted in Figure 8.

VHTL converts heavy fractions to high yields of lighter, lower viscosity and more valuable products with minimum production of less desirable coke and gas by-products.

At the heart of the process is a very short residence time reactor featuring an ultra-high efficiency direct contact heat transfer system where hot sand thermally cracks heavy, long chain hydrocarbons. The feedstock oil is dispersed into the reactor using a proprietary steam atomization nozzle and heavy fractions deposited directly onto hot sand particles in a thin film. This is facilitated by using a high sand-to-oil ratio and through efficient mixing created by highly turbulent conditions in the feed injection zone. Light fractions are flashed off straight away, leading to minimal over cracking/cracked gas. The process requires less than two seconds total time from the instant the oil contacts the hot sand to the removal of the cracked products from the contacting device (reactor).

In addition to the fast residence time coking, VHTL also allows the hydrogenation of cracked, highly olefinic hydrocarbons to produce saturated non-olefinic product oil. The lift gas which circulates the sand contains carbon monoxide which combines with the steam from the atomization of the oil to form hydrogen and carbon dioxide. The hydrogen then reacts with the product stream to hydrogenate the oil producing a non-olefinic product.

Mechanically, the VHTL process is similar to fluidized catalytic cracking (FCC), a common conversion process found at the center of most modern refineries. There are over 400 FCCs in operation today, and the process has been commercialized globally since the 1940s. Although configured similarly to an FCC unit, the VHTL process relies on thermal conversion only and is non-catalytic. By comparison, VHTL is more robust in processing heavy feedstock and easier to operate than FCC.
The VHTL process generates enough energy to sustain the upgrading process and provides a substantial amount of excess energy that can be used to support field operations. The energy balance is illustrated in Figure 9.

Energy is generated and recovered within the VHTL process via three routes: the combustion of coke; the combustion of non-condensable product gases; and the recovery of latent and sensible heat from the product streams. The heaviest fractions of the reactor feed are thermally converted to coke, which is directly deposited onto the circulating sand particles. The thin layer of carbon deposited on the sand is removed in the reheater by combusting with air. This provides the energy required to sustain the thermal upgrading reactions. The total amount of energy released from combusting coke is significant and exceeds the amount required to sustain the heavy oil upgrading reactions. Excess heat is recovered by generating high-pressure steam. In addition to producing coke, the upgrading reactions convert a small portion of the reactor feed to non-condensable product gas (C4-). This gas is recovered and used as fuel gas in fired heaters and steam boilers where it supports the unit’s internal energy demand and produces additional high-pressure steam. Lastly, energy is captured from cooling the reactor products thus recovering a significant amount of energy from the latent and sensible heat.

As shown in Table 2, VHTL produces a significant improvement in crude oil quality by upgrading heavy residue to high yields of lighter, less viscous and more valuable products with minimum generation of less desirable coke and gas by-products.
VHTL: A NEW LOOK AT HEAVY OIL

Table 2—VHTL Produces A Significant Improvement in Crude Oil Quality

<table>
<thead>
<tr>
<th>Properties</th>
<th>EHO or Bitumen</th>
<th>VHTL SCO</th>
</tr>
</thead>
<tbody>
<tr>
<td>API</td>
<td>7 - 16</td>
<td>20 to 30 API</td>
</tr>
<tr>
<td>Sulfur, weight %</td>
<td>3.0 – 5.5 %</td>
<td>50% to 90% reduction</td>
</tr>
<tr>
<td>Ni + V, ppm weight</td>
<td>400 – 700 ppmw</td>
<td>90% reduction</td>
</tr>
<tr>
<td>Viscosity, cSt @ 40 C</td>
<td>4,000 – 100,000 cSt</td>
<td>50 – 150 cSt</td>
</tr>
<tr>
<td>TAN, mg KOH/g oil</td>
<td>2.5 – 5.0</td>
<td>30% to 100% reduction</td>
</tr>
<tr>
<td>Crude distillation yields (vol %)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Naphtha</td>
<td>0.5 – 5 %</td>
<td>10 – 20 %</td>
</tr>
<tr>
<td>Kerosene + diesel</td>
<td>5 – 10 %</td>
<td>50 – 65 %</td>
</tr>
<tr>
<td>Vacuum gas oil</td>
<td>25 – 45 %</td>
<td>20 – 30 %</td>
</tr>
<tr>
<td>Vacuum residue</td>
<td>40 – 65 %</td>
<td>2 – 5 %</td>
</tr>
<tr>
<td>Liquid yield, volume %</td>
<td>--</td>
<td>90 – 95 %</td>
</tr>
<tr>
<td>Liquid yield, weight %</td>
<td>--</td>
<td>83 – 87 %</td>
</tr>
<tr>
<td>C4-gas yield, weight %</td>
<td>--</td>
<td>1 – 3%</td>
</tr>
<tr>
<td>Coke yield, weight % (consumed in-situ)</td>
<td>--</td>
<td>8 – 15%</td>
</tr>
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VHTL benefits include:

Upgrades crude oils with characteristics which attract significant market discounts:

- 6 to 16 API gravity
- 35% to 70% by volume residual oil (BP > 538°C)
- High viscosity typically greater than 1,000 cSt at 20°C

Enables economic production of smaller fields:

- production rates as low as 5 to 10 mbpd by providing source of steam at low production volume
- low capital and operating cost
- modular construction for remote, rapid and flexible deployment

Produces synthetic crude oil with improved value:

- low residual oil content, less than 10% by volume
- low viscosity, typically less than 75 cSt at 200°C and easy to pipeline
- reduces contaminants such as sulfur, nitrogen, Ni, V

Utilizes by-product energy from the upgrading process:

- supplies energy to heavy oil production operations (between 125kWh to 175kWh of steam / bbl processed)
- or produce electrical power (between 50kWh to 70kWh / bbl processed)
- life cycle CO2 emissions on par with dilute and ship heavy oil production

VHTL SCO is an excellent feedstock for refiners that wish to increase their production of gasoline and diesel by processing and upgrading middle distillates and vacuum gas oils. Over the years, refiners have tended to expand their middle distillate and vacuum gas oil processing capacities, but also reduce their naphtha and kerosene processing capabilities. This is because crude oils available on the market typically
became heavier and therefore contain less naphtha and kerosene boiling range material. In addition to becoming heavier, they also became more “sour,” meaning they contain higher content of sulfur. Because of changing crude qualities, the refining margins associated with converting vacuum gas oils and distillates to transportation fuels are better than those of refiners which are purely processing light crude. Because of this, refiners have invested in conversion and hydrotreating upgrades to stay economic in an environment where crude oils are heavier and sourer. In addition, refiners have always struggled to keep up with investment in vacuum residue conversion capacity despite the increasing availability of vacuum residue available in the market. This is because very large capital investment is needed in a refinery to process vacuum residue and the economic returns are at risk due to historically volatile heavy oil prices. To note, most heavy oils – those with API less than 20 – contain at least 40% by volume of vacuum residue. Therefore, the demand for heavy oil, as well as its market price, is tied to the vacuum residue conversion capacity in refineries.

Therefore, the average refinery today is best able to process crudes which have large concentrations of middle distillate and vacuum gas oil, high sulfur concentration and lower concentration of naphtha, kerosene and vacuum residue. The resurgence of light oil from tight shale plays challenges today’s modern refinery because they are unable to achieve historical crude volume runs since tight oil contains a high content of naphtha and kerosene boiling range material. The typical refinery cannot process large volumes of light oil because they are unable to process the larger volumes of naphtha and kerosene.

In addition to tight oil, much of the remaining crude supply growth is forecasted to come from heavy oil resources. Future expansion of heavy oil conversion capacity in refineries is not forecasted to outstrip growth in supply of heavy oil.

Therefore, as production from both light and heavy resources increase, refineries will want the types of crudes that they are historically optimized to process. These crudes have larger concentrations of middle distillates and vacuum gas oils. They are also typically sour. The VHTL product is perfectly suited to fill this void since VHTL SCO typically contains ~50% by volume middle distillate plus ~35% by volume vacuum gas oil.

Jacobs Consultancy, using their database of refinery models, has independently confirmed the economics and market capacity and capability for refiners to process HTL SCO. It is assumed that given the improvements provided by VHTL, that the same conclusion can be drawn from VHTL products.

VHTL thermally processes heavy crude oil and therefore key concerns regarding the stability of the products must be addressed. Unstable crude oil can foul transportation system components and form sediments that are left behind as deposits. In order to determine the fouling and sediment forming potential of a crude oil, it is tested with an industry standard method called Shell hot filtration (ASTM D4870). Test data has shown that the SCO is stable and can be transported via pipelines and stored in tanks without sediment formation in the system. Another concern expressed is associated with potential instability of synthetic crude oil caused by mixing with other crude oils. Testing has shown that VHTL has mixing compatibility that is typical of most naturally occurring crude oils. Finally, refinery stability concerns include the fouling propensity of the crude oil distillation unit preheat exchangers, as well as fouling potential of catalyst beds in naphtha, kerosene and diesel hydrotreating units. Analytical testing has shown that VHTL SCO contains minor (and sometimes negligible) amounts of unstable compounds. The analytical data suggests that SCO is thermally stable, as has been demonstrated by use of the Shell hot filtration test.
5. Readiness for Commercialization

FluidOil and predecessor companies, have achieved several significant milestones in the development of the process itself as well as the preparation of a commercial plant design. This includes various pilot scale plants processing 25bpd and 50pbd. Testing of heavy crude oils in a 1,000bpd HTL Commercial Demonstration Facility proved the scalability of the VHTL process and provided key design information for the first commercial design.

The FTF (feedstock testing facility) has been utilized to:

- Make key improvements to the process.
- Test a variety of global crudes oils.
- Mitigate key process performance risks associated with VHTL commercialization.
- Develop a full-plant design that mitigates all risks and utilizes best engineering practices.

The team has completed several in-depth studies and testing programs at the FTF in response to feedback from JV partners and potential customers. These include the following initiatives:

- Stability testing of SCO products produced in the FTF
- Hydrotreating SCO products from FTF to demonstrate refineability / refining value of SCO
- Rigorous market evaluation of SCO pricing by Jacobs
- Life-cycle carbon footprint evaluation
- Long-term commercial plant operability / reliability risk assessment

In addition to internal studies, independent consultant Graham Butler carried out a readiness to commercialization review of HTL. He concluded that HTL had no flaws that would prevent it from being commercialized at this time. This study, additional work completed since and the improvements brought by VHTL leads FluidOil to conclude that VHTL is commercial ready to deploy.

Butler's complete executive summary is available on request for qualified parties.

The last step toward commercialization is the tie-up of partners that will secure all of the necessary project resources. VHTL is economic under current and forecasted market scenarios due to its low cost and high value add. This has allowed FluidOil to secure a variety of Joint Venture partners as well as obtain considerable interest from potential customers and it is expected that the first commercial plants will be operational in 2020.
6. Competitive Landscape

The Kline Group carried out a competitive technology assessment. The universe of technologies selected for comparison was based on a carbon rejection system for improving the quality of the heavy residual oil. The other method for improving quality belongs to the class of hydrogen addition technologies such as H-Oil, LC-Fining and VRDS. For many logistical and economic reasons (e.g., capex, opex, plot space), Kline determined the hydrogen addition category to be only suitable in the context of downstream refining operations.

19 carbon rejection technologies were identified but only four were deemed to be a competitive threat when using the following criteria:

- Commercialization status
- Commercialization potential
- Environmental impact
- Capex
- NPV

Figure 10 shows the qualitative results of how VHTL stacks up against the leading competitors with respect to commercialization potential and NPV-10: KBR Roseflow; Value Creation’s ADC; ETX’s IYQ and MEG Energy’s HI-Q.

Figure 10—Qualitative results of VHTL versus four leading competitors
7. VHTL Commercial Proposition

As described earlier in this paper, there is a clear demand for heavy oil technologies to fill future global crude supply shortfalls. We intend to change a basic paradigm in the processing of heavy crudes. Historically heavy oil is produced at the source and then transported to refineries by midstream operators via pipeline, ship, train or truck. Downstream refiners use complex and capital-intensive facilities to convert the raw crude oil into transportation fuels and other finished products.

Heavy crude oil strains this supply chain and introduces several layers of inefficiency. Low value residual oil with high carbon content is shipped long distances to refineries, which then simply reject the carbon and turn it into coke. Light oil diluent used to reduce the heavy crude’s viscosity consumes a significant portion of already strained pipeline capacity. Diluent is typically blended at a ratio of 0.3 to 0.5 barrel per 1.0 barrel of heavy crude. Upon reaching the refinery, the diluent must be recovered, needlessly using refinery capacity. Most refineries are not geared toward processing the large volume of condensate used as diluents in transporting the heavy crude oil, and therefore condensate -- much like the heavy oil itself -- is not a particularly good refinery feedstock.

These inefficiencies present opportunities for pre-processing heavy crude oil in the production field. Historically, this has meant moving the bulk of the refinery into the field. These projects typically involved upgrading heavy oil by separating the crude into its distillable fractions, processing the residual oil fraction in a conventional heavy oil conversion unit such as coking or hydrocracking and then treating the converted products to remove sulfur and other contaminants. After processing each of the individual crude fractions, the streams are recombined, shipped to a refinery and then separated again only to be reprocessed as typical crude. These upgrading schemes are simply uneconomic. Many companies and industry analysts consider these types of field upgrading projects non-starters.

However, even if classical field upgrading is no longer economic, the supply chain inefficiencies associated with heavy oil remain. Therefore, demand exists for field upgrading solutions that can tackle these inefficiencies in a cost-effective way. FluidOil Limited’s VHTL process offers some inherent benefits that address this challenge. Due to the nature of the partial conversion process, carbon is removed at the production site and therefore not transported long distances to the refinery. Using VHTL, high efficiency heat transfer and short contact time produces a stable product ready for transportation and refining without additional treatment. Viscosity is reduced such that the oil can be transported in standard pipeline operations. The in-situ production of energy in the VHTL process provides a natural synergy with energy intensive heavy oil field production operations.

In the case of a midstream application, where VHTL is located at a crude gathering terminal or even within a refinery, the excess by-product energy can be recovered as electrical power. This power would then be utilized on-site or exported into the local grid. The VHTL process is simple, low cost and constructible in modules thus allowing for deployment into remote production fields.

The economic benefits possible with VHTL can be shown by comparing the value of heavy crude oil in the production field when upgrading with VHTL versus producing and transporting with the alternative currently practiced “dilute and ship” model. As shown in Figure 11, the dilute and ship method requires the heavy oil producer to source light oil and then transport it to the heavy production field.
The VHTL alternative is shown in Figure 12. No diluent is needed, energy is produced for field operations, and a higher value synthetic crude oil is sent to the refinery.

Excess power generated in the VHTL process can be captured in two ways depending on the specific application. Using the example of a 20,000 bpd VHTL plant processing 8 °API Athabasca bitumen, the energy can be captured:

- In the form of steam in an integrated application. The plant generates about 2 bbls steam / bbl heavy oil processed. In the case of a SAGD application this would be sufficient for most if not all of the steam requirement.
- Alternatively, in the form of electricity in a midstream application. In this case, the plant generates excess energy equivalent to about 50 MW or about 60kWh/ bbl heavy oil processed.
The producer's netback is determined by the crude oil sales price realized at the refinery gate minus the costs of producing and transporting the crude oil from the production field to the refinery. VHTL significantly increases the heavy oil producer's netback price by:

- Increasing the refinery gate value of the crude oil
- Decreasing the transportation cost of shipping crude to the refinery through the elimination of diluent transportation
- Decreasing the operating cost by eliminating the need to purchase and blend diluent
- Decreasing the operating cost by supplying a source of energy to the field production operation

The netback possible with VHTL compared with the netback of a dilute and ship scheme is shown in Figure 13.

*Values are shown as $/bbl of extra heavy crude or bitumen produced. Prices assume Brent = $50/bbl and Maya = $42/bbl.

Figure 13—Netbacks Using VHTL Method Versus Dilute-And-Ship Method

This netback analysis shows that a typical VHTL project provides an incremental ~$20 per barrel of monetary incentive over the dilute and ship alternative. For a 30,000 bpd VHTL unit, the additional incentive for VHTL provides a revenue benefit of ~$210 million/year. Considering a capital expenditure of ~$300 million ($10,000 per barrel per day of capacity – worst case assuming deployment in Canada), the economics of VHTL provide very strong investment returns.

Because VHTL addresses the primary challenges of heavy oil resource production, it is envisioned as an upstream or a midstream solution which enables feasible development of heavy oil. There has even been
some interest from refiners to deploy VHTL within a refinery environment, but this is not covered in this paper. Three primary upgrading configurations have been developed for VHTL deployment.

1. Field Integrated: VHTL integrated with field production facilities to upgrade crude oil and supply energy to satisfy demand from field operations. This eliminates the producers’ reliance on externally supplied diluent to reduce crude viscosity for transportation and reduces or eliminates the need for externally supplied energy.

2. Midstream: VHTL is located at a central crude oil gathering terminal, upgrading crude oil and eliminating the need for blending with diluent prior to transporting the crude to a refinery. Excess energy is converted into electrical power that is utilized locally or exported into the power grid.

3. Offshore FPUSO: SBM Offshore and FluidOil Limited have developed a feasibility study for an offshore floating production, upgrading, storage, and offloading facility (FPUSO). The vessel integrates VHTL into the topsides of a conventional FPSO.
8. Intellectual Property

FluidOil Limited has a broad patent portfolio with global coverage. The following is a summary of Issued and pending U.S. Patents

FluidOil Limited Inc. owns eight issued U.S. patents with one pending:

U.S. Patent No. 6,660,158, entitled "Products Viscositor," issued on December 9, 2003 ("the 'Viscositor' Patent");


U.S. Patent Pending entitled "Gravitational Enhanced Cracking," pending ("the 'GEC Patent");


U.S. Patent No. 8,062,503, entitled "Products Produced From Rapid Thermal Processing of Heavy Hydrocarbon Feedstock," issued on November 22, 2011 ("the '503 Patent");


U.S. Patent No. 8,377,287, entitled "Methods and Systems for Producing Reduced Resid and Bottomless Products from Heavy Hydrocarbon Feedstocks," issued on February 19, 2013 ("the '287 Patent");

U.S. Patent No. 7,572,362, entitled "Modified Thermal Processing of Heavy Hydrocarbon Feedstocks," issued on August 11, 2009 ("the '362 Patent"); and,


A summary of each of the issued U.S. patents is provided below:

(1), (2) and (3) The Viscositor, Gasblaster and GEC Patents. The inventions relate to an upgrading process using a circulating bed of hot material as heat carriers. The reactor is designed as an up flow reactor with an inertial separator. The gas is then condensed into a single synthetic crude oil.

(4) and (5) The '743 and the '503 Patents. The inventions of these two patents cover the upgraded products that are uniquely produced from heavy hydrocarbons when processed under RTP™ conditions. The VGO generation process involves, generally, the upgrading of a heavy hydrocarbon feedstock in an upflow reactor wherein the feedstock is introduced to a heat carrier stream in a specified ratio and at a specified temperature to produce a product stream. The product stream is then separated and the VGO is isolated from the liquid product. The vacuum gas oil fraction (VGO) of
the liquid product produced is a suitable feedstock for catalytic cracking purposes, and exhibits a unique hydrocarbon profile, including high levels of reactive compounds.

(6) **The ’482 Patent.** This patent claims a method for producing transportable upgraded heavy petroleum feedstocks. It involves the application of the RTP™ process to upgrade a heavy hydrocarbon feedstock to generate a transportable liquid product, which can then be transferred offsite for further refining or processing. The liquid product generation process involves the use of an upflow reactor wherein the feedstock and a heat carrier are mixed in a specific manner to produce a product stream. The liquid feedstock is then separated from the product stream, and the liquid feedstock can then be transported. The invention provides a rapid upgrading process for heavy oil or bitumen feedstock involving a partial chemical upgrade or mild cracking of the feedstock. The process also reduces the level of contaminants within feedstocks, thereby mitigating contamination of catalytic contact materials with components present in heavy oil or bitumen feedstocks. By creating a transportable product, the present invention reduces costs associated with the processing of feedstocks and reduces processing times.

(7) **The ’287 Patent.** This patent claims a method for producing an upgraded bottomless product by using a modified version of the RTP™ process. The process involves the use of a vacuum tower to obtain the bottomless product from the liquid product mixture. The liquid product mixture is separated into a light fraction and a heavy fraction, and the claimed method further includes recycling a portion of the heavy fraction of the liquid product mixture for further processing. As defined in the patent, a “bottomless product” is a light oil fraction which contains less than 7-8%, more particularly less than 5%, even more particularly less than 1% of a heavy (vacuum) resid component present in a product stream derived from rapid thermal processing. This upgraded product is therefore suitable for transport by pipeline.

(8) and (9) **The ’362 and ’365 Patents.** These two patents are directed to methods of upgrading a hydrocarbon feedstock via the addition of a calcium compound during the RTP™ process. The invention claimed in the ’365 Patent relates to methods for reducing sulfur emissions of heavy hydrocarbons and for reducing the total acid number of the product produced during the processing of heavy hydrocarbons. In addition, the methods of this invention can be used to reduce the total acid number of the feedstock during rapid thermal processing. The invention claimed in the ’362 Patent is focused on methods for the reduction of hydrogen sulfide content of gas components of the product stream derived from rapid thermal processing of a heavy hydrocarbon feedstock. The methods involve the use of a calcium compound during the rapid thermal processing of the feedstock and/or during the regeneration stage.

FluidOil also has 57 patents issued in 49 countries, 20 pending patents in 14 countries and 12 provisional patents covering a wide range of process improvements.