Has the time for partial upgrading of heavy oil and bitumen arrived?

Partial or field upgrading of heavy oil produces transportable synthetic crude oil and eliminates the need for diluents for transportation to refiners

JIM COLYAR
Colyar Consultants

Heavy oil and bitumen — from the Athabasca region of Alberta, Canada, for instance — are too heavy and viscous to be transported via pipeline from the field to refining facilities. Options currently practised include dilution with natural gas condensate to produce DilBit, dilution with synthetic crude oil (SCO) to produce SynBit, or upgrading to produce a bottomless SCO. Currently, only full upgrading of Western Canadian heavy oil and bitumen is applied commercially. Full upgrading produces SCO that resembles high-quality light oil and contains very little or no vacuum residue.

Partial or field upgrading of heavy oil and bitumen involves the conversion of only a portion of the vacuum residue and the production of a sour SCO containing 5–25% residue. Partial upgrading facilities can be constructed for less than half the cost of full upgrading. Analytical inspections of partially upgraded SCO will resemble those of a DilBit in terms of gravity and sulphur content. This partially upgraded SCO must meet pipeline specifications and be stable to completely eliminate the need for diluent. Due to a low residue content, the largest potential market for partially upgraded SCO is light oil refineries. However, these refineries may need to increase their hydrogenation capacity to process the sour SCO.

Partial upgrading has not been commercialised due to the lack of technology that can economically produce a specification SCO, issues related to stability and concerns about adequate pricing of the sour SCO. Thanks to improved technology and the current financial situation, lower-cost partial upgrading may now be a viable alternative for exploiting heavy oil and bitumen.

This article provides background information on the current methods for delivering heavy oil and bitumen to the market, with an emphasis on Western Canada, and a summary of the most promising partial upgrading technologies, including preliminary economics and a comparison with DilBit production.

Heavy oil and bitumen resources

Heavy and extra-heavy oils are loosely defined as crude petroleum with API gravities below 20° and 10°, respectively. Bitumen is considered a special classification of heavy oil that is associated with tar sands deposits. It has an API gravity of 7–10° and is very viscous (over 10 000 cPs at reservoir conditions). Worldwide, there are vast quantities of heavy oil and bitumen, which are concentrated in Western Canada, with over 1700 billion barrels in place, and Venezuela, with over 1000 billion barrels in place.[1,2] Current economic proven reserves of heavy oil from these two countries are estimated at 173 billion barrels for Canada and 58.2 billion barrels for Venezuela, with each value representing 10% or less of the oil in place.[3]

Canadian bitumen and SCO production, '000 bpsd

	Production	SCO produced
Mined	813	598*
In-situ	592	61*
Total	1405	659

*Estimated

Table 1

Current Canadian production of heavy oil and bitumen is approximately 1.4 million barrels per day, with a large percentage exported to the US. The discussion below refers to "bitumen", which is a generic term for mined or in-situ bitumen and other heavy oils with an API gravity of less than 20° that require diluent to be transported. Currently, this bitumen is diluted with natural gas condensate (NGC) to produce a DilBit, diluted with SCO to produce a SynBit, or upgraded to produce a bottomless (no vacuum residue) SCO.

A breakdown of Canadian bitumen and SCO production[4,5] for 2007 is shown in Table 1. Of the total 1.4 million barrels per day of bitumen produced, approximately 58% is via mining, with the remaining 42% from in-situ operations. The bulk of the mined bitumen is sent to dedicated upgraders, which produce a high-quality, fully upgraded SCO. A small portion of the in-situ bitumen is upgraded, while most is blended with diluent to produce a transportable DilBit or SynBit. The total SCO produced was 659 million barrels. In-situ production includes steam assisted gravity drainage (SAGD) and other thermal techniques. Given that the estimated Canadian bitumen reserves are just 20% mineable, and that SAGD recovers a much larger portion of the in-place bitumen, in-situ production is expected to be the dominant production technique in the future.

Athabasca bitumen is currently produced via mining and the SAGD in-situ method. When oil sands are

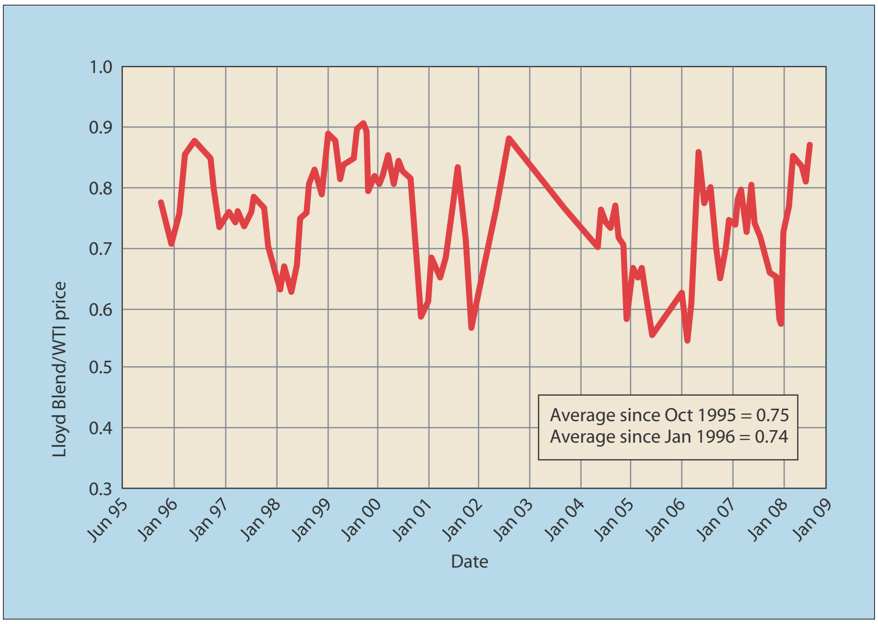

Figure 1 Ratio of LLB and WTI price

mined, the resulting bitumen froth produced from the primary extraction process can be further treated by two broad techniques: using naphtha or using paraffin solvents, including pentane or hexane. With naphtha froth treatment, the bitumen product may contain excess solids (clay fines) and may not meet the Canadian pipeline basic sediment and water (BS&W) specification of less than 0.5 V%. In general, naphtha froth bitumen cannot be diluted and sold as a heavy oil blend and thus is associated with a dedicated upgrader. In the paraffin froth treatment process, the reject streams contain both the clay fines and a portion of the bitumen heavy asphaltenes. The net bitumen product recovery is 5–10% lower than for naphtha froth treatment, but the recovered bitumen is essentially solids free and easier to process, since it contains reduced asphaltene content. With no solids, paraffin froth bitumen can be diluted and sold as a heavy oil blend.

Heavy oils such as Cold Lake and Lloydminster are characterised by API gravities in the 10–14° range and viscosities significantly lower than those of Athabasca bitumen. These heavy oils are obtained using thermal techniques including SAGD and cyclic steam stimulation (CSS) and cold heavy oil production with sands (CHOPS).

Marketing options

Bitumen from mining or in-situ production must be diluted or upgraded to be fluid enough to be transported to refineries for final processing and production of saleable products. In the cases of dilution with light oils or partial upgrading, the blended heavy oil or SCO must meet Canadian and US pipeline specifications to be transported. Canadian specifications are shown in Table 2 and include gravity, viscosity and solids/water values.

Bitumen dilution

Bitumen is typically diluted with either natural gas condensate (DilBit) or a fully upgraded SCO (SynBit) to meet Canadian pipeline specifications. The quantity of required diluent is normally set by the pipeline viscosity specification. DilBits generally use a natural gas condensate with the following inspections: 62 °API, less than 0.1 wt% sulphur and 0.6 cSt viscosity at 40°C. Fully upgraded SCO has an approximate 34 °API, less than 0.1 wt% sulphur and 3 cSt viscosity at 40°C.

Typical blending ratios and blended heavy oil inspections (DilBit) are shown in Table 3. For an Athabasca DilBit, 29 V% condensate is required to meet the pipeline viscosity specification. This results in a 21 °API blend with 3.8 wt% sulphur and 41 wt% vacuum residue. For the less viscous Cold Lake and Lloydminster heavy oils, less diluent is required; however, as is shown in Table 3, the final DilBit inspections are fairly similar.

An Athabasca SynBit will require approximately 50% of fully upgraded SCO in the blend to meet the pipeline viscosity. A SynBit will contain less raw bitumen than a DilBit and will therefore have significantly lower sulphur and vacuum residue contents.

Historical pricing data on the market value of Lloydminster DilBit (LLB) are available from the US Energy Information Administration. Based on this database, the LLB value as a fraction of the West Texas Intermediate (WTI) value is shown in Figure 1. There is a high degree of variability,

Canadian pipeline specifications

Specification	Value
Gravity, °API	19 min
Viscosity @ 7°C, cSt	350 max
BS&W, V%	0.5 max

Table 2

Typical Canadian DilBits

	Cold Lake	Lloydminster	Athabasca bitumen
Crude inspections			
Gravity, °API	11–13	13	8–9
Viscosity @ 40°C, cSt	1100	1000	19 000
Blend inspections			
Diluent, V%	23	20	29
Gravity, °API	19	21	21
Viscosity @ 7°C, cSt	~350	~350	~350
Sulphur, wt%	3.5	3.2	3.8
Vac. residue content, wt%	39	38	41
Approx. blend value, % WTI	NA	75	73

Table 3

with values from 0.55 to 0.90. Recent averages are fairly consistent with LLB at 74–75% of WTI (ie, 25–26% discount). Based on a SCO pricing model that incorporates the quality of the DilBit, the value of other heavy oil blends can be estimated. Using this model, the average value of an Athabasca DilBit, as shown in Table 3, is estimated at 73% of WTI.

The high variability in the value of DilBits indicates the changing light to heavy oil margins. This variability strongly affects the profitability of DilBit production. For example, with WTI at $50/bbl, an Athabasca DilBit would be priced at $36.50/bbl (using a 27% discount). After deducting the costs of the diluent and transportation, the heavy oil producer would receive about $26.84 per barrel of raw bitumen. This would be used to pay for investment and operating costs, royalties and any profits. With a larger 45% heavy oil discount, the DilBit would be valued at $27.50/bbl, with the producer receiving proceeds of just $14.09 per bbl of bitumen. At this level, the costs of producing the bitumen may not be met.

Bitumen upgrading

Upgrading involves the processing of heavy crude or bitumen using refining operations, including distillation, coking, thermal cracking, catalytic cracking, hydrocracking, solvent deasphalting and gasification. To upgrade these heavy oils effectively, it is necessary to convert a portion of the heaviest portion of the oil (vacuum residue) to lighter boiling components.

There are two general classes of residue conversion/upgrading processes: carbon rejection and hydrogen addition. Carbon rejection processes thermally (with no catalyst) crack the residue and produce a high carbon-containing, typically solid product. The reject material (normally coke) is low in hydrogen, and thus the conversion liquid products have a hydrogen content higher than the residue feedstock. Carbon rejection liquid products are generally unstable and can polymerise to form gums and so on. These products require secondary treatment (for instance, addition of hydrogen, removal of sulphur, nitrogen) to be saleable products.

Hydrogen addition processes add hydrogen to the residue. This is carried out at high temperature and pressure, and nearly always uses a catalyst. Relative to carbon rejection, hydrogen addition produces a high yield of higher-quality, stable liquids that require less secondary treatment (hydrotreating). These processes do not produce a solid product, but convert less than 100% of the feed residue. Hydrogen addition processes require a high initial investment (high pressure design) and high operating costs due to hydrogen and catalyst usage. Heavy oil upgrading technologies can also be segregated into full and partial techniques.

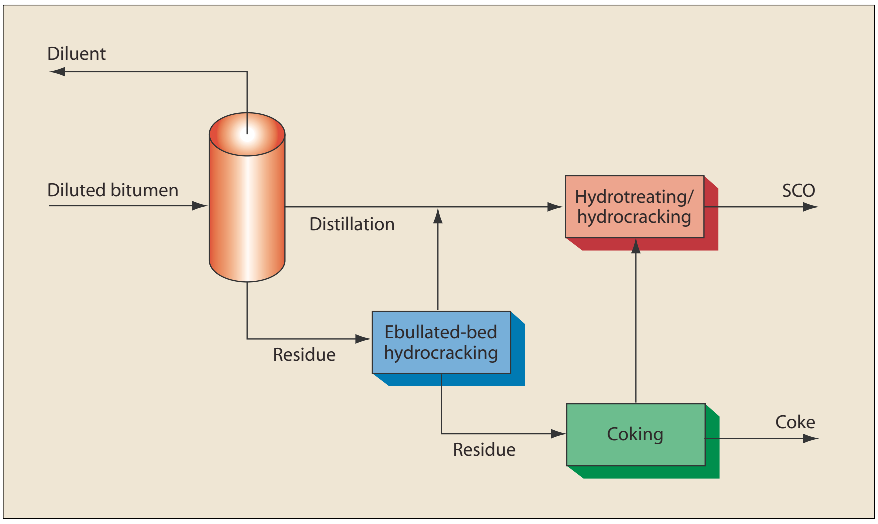

Figure 2 Typical full upgrading block flow diagram

Full upgrading

Full upgrading produces either finished, saleable products, such as gasoline or diesel, or a high-quality SCO that contains no vacuum residue. The SCO distillation products are hydrotreated and of a quality at or near that required for final sales. Much of the worldwide activity in heavy oil upgrading/conversion is in Western Canada, where the SCO is either transported to North American refineries for final refining or blended with heavy oil or bitumen to produce a transportable SynBit.

A simplistic block flow diagram for a typical full upgrading facility is shown in Figure 2. The selected processing configuration includes both hydrogen addition (ebullated bed) and coking. The ebullated-bed unit converts a portion (50–80%) of the vacuum residue and reduces the Conradson carbon residue (CCR) or coking tendency of the bitumen. The unconverted residue from the ebullated-bed unit is sent to a coker that completes the conversion of the residue and produces additional liquids and byproduct coke. All straight-run, ebullated-bed and coker-derived liquids are hydrotreated to produce a high-quality, fully upgraded SCO. The fully upgraded SCO product is valued at approximately the light oil price.

Partial upgrading

Partial upgrading produces a SCO that contains 5–30% vacuum residue and distillation products that require additional refining (hydrotreating). Partial upgraders are located at the heavy oil field so no dilution is required. Many partial upgrading technologies and processing configurations target the production of SCO, just meeting the pipeline specifications for gravity and viscosity (that is, they are pumpable). Nearly all of the new technologies investigated were developed to also produce significant excess energy (steam), which can be utilised for resource acquisition (SAGD).

A block flow diagram for a generic partial upgrading process configuration is shown in Figure 3. In general, these technologies include

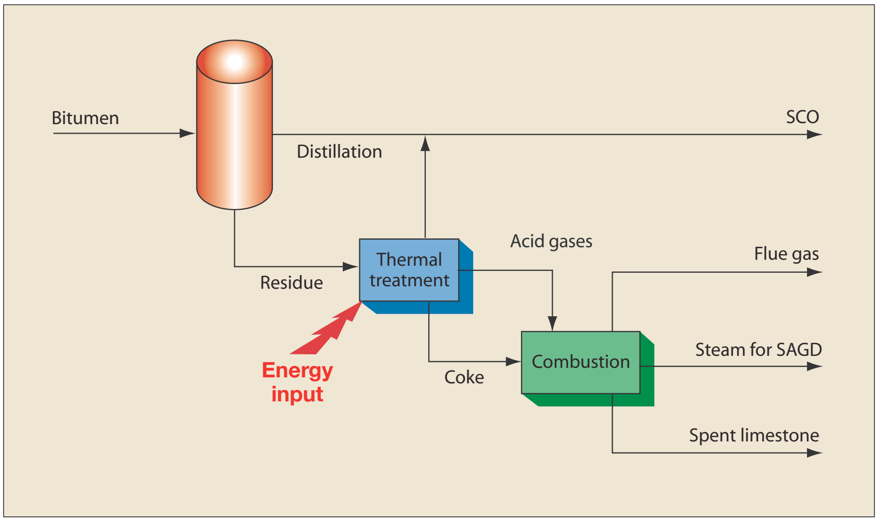

Figure 3 Typical partial upgrading block flow diagram

two steps: a low-investment thermal cracking of the whole bitumen, or bitumen residue followed by combustion of the heavy unconverted product, typically coke. There are many variations of the generic processing configuration and some genuinely novel approaches have been developed. These novel techniques, however, may not be scalable or economically feasible. The thermal cracking of the residue is accomplished by various techniques, including the use of heat, ultrasound energy, kinetic energy and irradiation. The largest challenges of the conversion step are to minimise coke production and to operate at conditions that will produce stable and compatible conversion liquids.

The combustion of the coke or heavy unconverted product (residue, asphaltenes) can produce steam for the process and all or a portion of that required for SAGD. Sulphur removal is required, and a fluidised-bed combustor with lime/limestone sorbent is specified in many of the processes. The investment in the fluidised-bed boiler may be the largest component of the total plant cost.

Besides a lack of commercial experience, the issues that have hindered the implementation of heavy oil partial upgrading the most are:

- **SCO product stability and compatibility** Thermally cracked materials tend to be unstable and can form solids when combined with other pipeline or refinery streams. To address this issue, many of the new partial upgrading processes include technologies that claim to minimise the instability of the product. These include lower operating temperatures, short reactor residence times and removal of the feedstock asphaltenes. Stability and compatibility testing of the final SCO product is required to confirm these claims

- **SCO product value** Typical partially upgraded SCO has a low API gravity (~20°) and a fairly high sulphur content, but a relatively low vacuum residue content. There is no current commercially sold SCO with similar inspections; the most similar products are DilBits based on Cold Lake and Lloydminster heavy oils. These DilBits, however, have higher vacuum residue contents than partially upgraded SCO and sell at an approximate 25% discount to WTI. Developers of the new partial upgrading processes have estimated discounts for their SCO of 0–20%, based in part on the benefit of a lower vacuum residue content. The economic viability of a partial upgrading route is obviously highly dependent on the price received for the SCO product, and estimated discounts of 10–15% (below WTI) are required to result in a profitable project
- **Required upgrader investment** Relative to full upgrading, partial upgrading requires less investment, thanks to the elimination of hydrogen generation, catalyst handling, product distillation and secondary product treatment facilities. The investment will still be in the range of $15 000–30 000 per barrel of installed capacity. There may be industry reluctance to go halfway and invest in a major project which produces a SCO that will require additional treatment and be significantly discounted relative to light oil. To reduce the level of initial investment, developers of partial upgrading technologies have included project elements such as modular construction at sites with attractive labour costs and designs at relatively low feedstock capacities.

Partial upgrading technologies

With the recent high oil price and oil sands development in Western Canada, the development of new techniques and processes for both the full and partial upgrading of heavy oil and bitumen has been active. A 2009 study report available from Colyar Consultants (ColyarConsult.com) has identified and reviewed 14 partial upgrading processes that are at various stages of development. The study report provides a process description, current level of development, merits and deficiencies, plus a hyperlinked reference and intellectual property list.

To highlight the types of technologies being developed and their important characteristics, a subset of these technologies is discussed below.

Specific partial upgrading processes

Table 4 is a summary of eight of the investigated technologies that have a high potential for producing a transportable SCO product from Western Canadian bitumen, eliminating the need for diluent. The table includes information on the licensor, type of process, estimated SCO yields and quality, and the judged level of additional development required to commercialise the technology for Canadian bitumen.

All but one of the listed technologies produce a coke or an asphaltene byproduct that is combusted to produce steam which can be utilised for SAGD. The SCO product yields are in the range of 70–90 V% of the bitumen feed rate and contain less than 25 V% vacuum residue, with many processes estimated to contain less than 15 V%. Many new licensors have constructed, or are planning to build, large-scale demonstration plants that will lengthen the commercialisation schedule but provide considerable confidence in the technology. The level of additional development required is a subjective estimate of the extent of further process definition, R&D, product evaluations and economic valuations required to bring the technology to commercial readiness. It does not necessarily comment on the technical or economic viability of the process.

Four of the most promising and most technically attractive partial upgrading technologies are discussed

Summary of selected partial upgrading technologies

Process	CCU	CPJ	HTL	I^{Y}Q	PetroBeam	TRU	Value Creation	Viscositor
Licensor	UOP	Wesco Energy	Ivanhoe Energy	ETX Systems	PetroBeam	TRU Oiltech	Value Creation	Ellycrack & Wescorp Energy
Processing steps & type	SDA + RFCC of thermal cracking	Thermal cracking	Pyrolysis + coking	Pyrolysis + coking	High energy electrons	Visbreaking + SDA	SDA + coking	Pyrolysis + coking
Reject product	Asphaltenes + coke	Coke + residue	Coke	Coke	None	Asphaltenes	Coke + asphaltenes	Coke
Disposition of reject product	Combustion	Combustion	Combustion	Combustion	–	Combustion	Coke: combustion Asphaltenes: sold	Combustion
Estimated SCO vacuum resid, V%	<25	<20	<15	<15	<25	<25	<5	<15
Estimated SCO yield, V%	70–80	75–85	75–85	8–90	UN	75–85	75–85	75–85
Significant export steam	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Demonstration size plant	No	Yes	Yes	No	UC	No	UN	No
Level of additional development required	Mod	Mod	Low	High	High	Mod/High	None	Mod

Notes UC = Under construction; SU = In startup; UN = Unknown

Table 4

below. The selection among the eight processes in Table 4 is not an endorsement of the four technologies.

HTL process

The Heavy to Light Liquids (HTL) process by Ivanhoe Energy is a thermal pyrolysis/partial coking/coke combustion technology that produces a sour SCO product and a significant amount of excess energy (steam). HTL process performance is accomplished by conversion of a relatively large portion of the vacuum residue, as in a coking process, with accompanying energy export resulting from the combustion of the coke. The process operates at low pressure and is similar in concept to a FCCU. In the HTL reactor (riser-type), the feed oil mixes with a hot, inert carrier. The oil is quickly raised to a high temperature, where pyrolysis and thermal cracking occur. The residence time in the reactor and cyclone separators is very short and the heavy liquid product is quickly quenched. The rapid heating and short residence time are key aspects of the technology and ensure the reactions are stopped prior to full progression to unstable coking type products. The hot carrier, which is captured in cyclones, will contain coke and other heavy material that are deposited on its surface.

This carrier is regenerated to remove the coke and provide a reheated carrier for the HTL reactor. The hydrocarbon light gases produced in the HTL process can also be burned in the regenerator. The flue gas from the regenerator must be treated (with lime/limestone sorbent) before venting to the atmosphere. For a deep reduction in heavy oil viscosity and an improvement in API gravity, it is necessary to recycle the HTL liquid back to the reactor for additional vacuum residue conversion. This mode of operation (high-quality mode) will result in a lower net liquid yield and more excess energy.

I^{Y}Q process

The I^{Y}Q process by ETX Systems is a new, developing carbon rejection process that utilises a technically advanced cross-flow fluidised-bed reactor. The process produces a sour SCO and a coke product that can be oxidised to produce steam and/or power. The heart of the I^{Y}Q process is the cross-flow fluidised bed. A bed of inert solids or coke is vertically fluidised by recycle product gas and moves, via gravity, in a horizontal direction. The feed oil is sprayed on the hot solids as they enter the reactor. The oil converts to form vapour (eventually liquids and non-condensable gas) and coke. Solid fines are removed from the reactor vapour via cyclones, and the condensable vapour is recovered as the product oil. The solids exiting the reactor are now coked and routed to a fluidised-bed boiler to burn off the coke (producing steam) and also for reheating the solids before recycling to the reactor.

The I^{Y}Q cross-flow fluidised bed has a horizontal flow of solids (inert solids or coke) and a vertical flow of gas. This separates the residence times of the solids and gas. The rates of solid and gas can be optimised for maximum liquids production (and minimum gas and coke) and also allow for operation at a lower reactor temperature. This is claimed to be a significant advantage over fluid coking and competing partial upgrading processes. Recycle of the I^{Y}Q unconverted residue increases the level of vacuum residue conversion and the API gravity of the net SCO product.

Base case: DilBit production

Bitumen feed rate, bpsd	30 000
NGC required, bpsd	12 444
Net blend, bpsd	42 444
Blend value, $/bbl	43.81
NGC cost, $/bbl blend	18.65
Transportation cost, $/bbl blend	2.00
Net, $/bbl blend	23.16
$/bbl bitumen	32.77
Revenues to producer, $MM/yr	337.2

Table 5

Partial upgrading: economic assumptions

Investment, $/bpsd	25 000
Annual operating time, days/yr	343
Operating costs, $/bbl feed	5
SCO value (from model), $/bbl	50.87
Credit for steam, $/MM Btu	7.5

Table 6

TRU process

This developing process by TRU Oiltech utilises a combination of visbreaking, solvent deasphalting and fluidised-bed combustion to produce a sour SCO and a significant quantity of steam. The heavy oil plus a proprietary distillable additive are fed to a visbreaker reactor. The thermal reagent may aid in reducing visbreaker severity and olefin production.

The visbreaker liquid product is sent to an atmospheric distillation column, where the additive and a naphtha/diesel stream are recovered. The additive is recycled to the visbreaker and the naphtha/diesel product is routed to SCO blending. The distillation column bottoms are routed to the pentane deasphalting unit. Deasphalted oil (DAO) from the deasphalter, plus the distilled naphtha/diesel oil, is blended to produce the final SCO product. The rejected asphaltenes from the process, plus the light hydrocarbon and acid gases from the visbreaker, are routed to a fluidised-bed combustor to produce steam and optional power.

The TRU process's SCO product contains an unconverted residue. However, as a result of deasphalting, the SCO vacuum residue contains minimal asphaltenes and reduced CCR, sulphur and contaminant metals. This should be an advantage over competing processes.

PetroBeam process

This is a novel and developing process from PetroBeam, in which the heavy oil is cracked with a spray of high-energy electrons. The process operates at a low temperature and pressure, and provides low/moderate conversion and HDS and viscosity improvement. Attaining pipeline specification from heavy oil may be difficult, particularly since there is no low hydrogen-containing reject stream. It is a non-catalytic process that does not add hydrogen. However, the irradiation energy may also be claimed to provide hydrogen via disassociation of water.

In the PetroBeam process, the heavy

Partial upgrading: technical assumptions	
Bitumen feed rate, bpsd	30 000
SCO	
Yield, V%	81
Gravity, API	21
Sulphur, wt%	4
Excess energy, MM Btu/bbl	1.1

Table 7

oil is heated to adequately flow through the PetroBeam reactor. In the reactor, the oil is subject to a high-energy spray of electrons from a linear accelerator (1–5 MV). The energy from the electrons breaks C-C and other bonds. Typically, during this type of treatment, the free radicals formed after bond breakage recombine to form crosslink bonds and even larger molecules than in the feed. In a claim for the PetroBeam process, crosslink bonds are broken or prevented from forming in the first place. The cracked product flows from the reactor and is routed to product separation.

Partial upgrading economics

Preliminary economics for a generic partial upgrading process have been developed to illustrate its feasibility and identify when partial upgrading is preferred over DilBit production. The selected feedstock is a typical Athabasca bitumen feedstock (API = 9°, sulphur = 4.9 wt%) obtained via SAGD at a feed rate of 30 000 bpsd. The economics assume a WTI value of $60/bbl, although the impact of this light oil price is also investigated.

The base case is production of a DilBit utilising NGC (29 bbl NGC/100 bbl of Blend) diluent. The Athabasca DilBit is valued at the average discount discussed above, which is 73% of the light oil (WTI) value. After deducting the cost of the NGC (6% over WTI) and transportation fees ($2/bbl), the netback to the heavy oil producer is $32.77/bbl of raw bitumen. The DilBit economics are summarised in Table 5. The net annual revenues of $337 million are the cash flows to the heavy oil producer, assuming 343 operating days per year. These revenues are utilised for SAGD-related production costs, royalties and profits.

The partial upgrading design produces a sour SCO and eliminates the need for diluent. The major technical and economic assumptions related to partial upgrading are shown in Tables 6 and 7. A 30 000 bpsd partial upgrader is estimated to produce 24 300 bpsd of sour (4 wt% sulphur), transportable SCO and 33 billion Btu/hr of steam, which can be utilised in the SAGD plant. The estimated investment is $25 000/bpsd of feed capacity, with operating costs assumed at $4/bbl of feed. Based on the SCO inspections, a value of $50.87/bbl or approximately 85% of the $60/bbl WTI price was estimated. The assumed credit for the export steam is $7.50/million Btu or 75% of the $10/million Btu oil cost equivalent.

The overall study results are summarised in Table 8. The production of 24 300 bpsd of partially upgraded SCO is estimated to require a $750 million investment and $41.2 million annual operating costs. The net SCO annual revenues, after deducting transportation charges, are $407.3 million. After deducting the operating costs and including the credit for steam to the SAGD facility, the total annual revenues are $448 million. This is an annual $111.1 million in excess of that generated from the DilBit operation (Table 5). Relative to the production of DilBit, the partial upgrading plant will require 6.8 years (750/111.1) to repay the investment for the upgrading facility. This is approximately equivalent to a 14% internal rate of return (IRR).

The economic feasibility of DilBit production and partial upgrading is highly dependent on the price received

Partial upgrading study: results	
Bitumen feed rate, bpsd	30 000
SCO production, bpsd	24 300
Transportation cost, $/bbl SCO	2.00
Cash flows, $MM/yr	
Revenues from SCO	407.3
Operating costs	41.2
Credit for steam	82.2
Net revenues to producer	448.3
Incremental revenue over DilBit, $MM/yr	111.1
Investment for partial upgrading, $MM	750
Simple payout time for partial upgrading investment, yr	6.8

Table 8

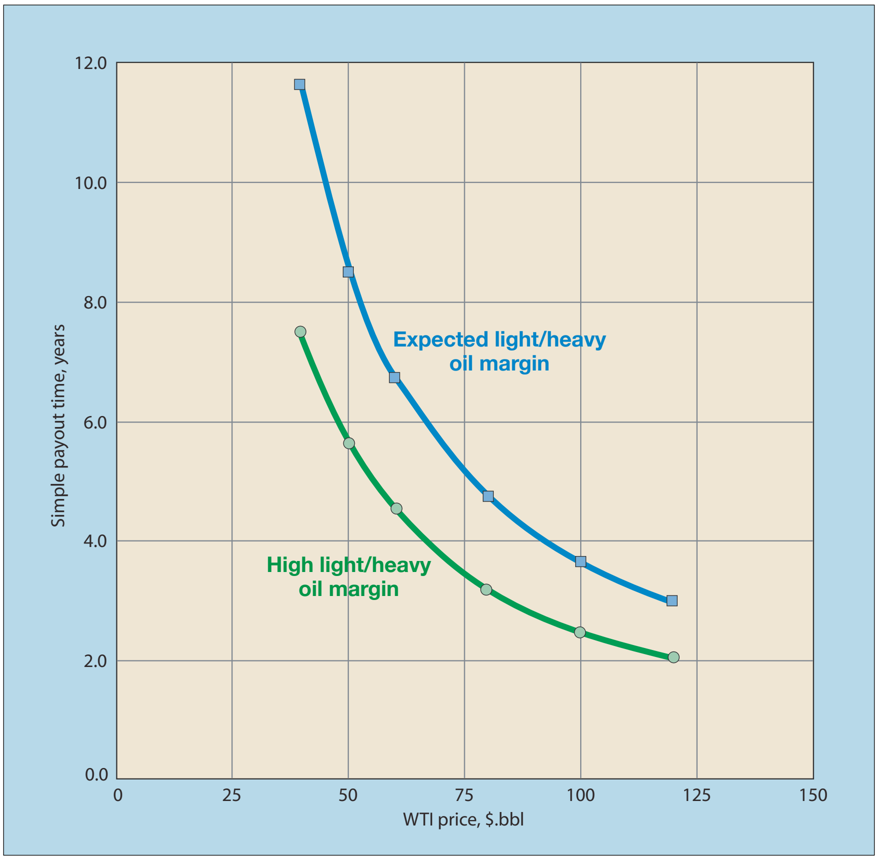

Figure 4 Partial upgrading payout time as a function of WTI price and light-heavy discount

for the blend or sour SCO product. To illustrate the sensitivity of the economics of partial upgrading relative to DilBit production, both the light oil price and the light-to-heavy discount were varied in ranges that have been evident in recent years. The DilBit discount below light oil was found to average 27%, resulting in the discount for the Dilbit case described above. As shown in Figure 1, the light-to-heavy oil discount has been as high as 45%, corresponding to a heavy oil price (DilBit) of 55% of WTI. For each WTI price and heavy oil discount examined, the payout time for the incremental investment of a partial upgrading facility was calculated. The results are shown in Figure 4. The study indicates that partial upgrading profitability is strongly related to the light oil price, with acceptable profitability obtained with WTI greater than approximately $60/bbl.

With higher light-to-heavy oil discounts, Figure 4 indicates a lower payback time or higher partial upgrading profitability. Partial upgrading is preferred over DilBit production for situations where the light-to-heavy oil price differentials are high. This is a key finding and indicates that partial upgrading can remove a large portion of the economic uncertainty of heavy oil production without incurring the large investment required for full upgrading.

Summary and conclusions

Given the low oil price and the situation within the financial markets, lower-cost partial upgrading may be an important future component of the heavy oil upgrading industry, particularly in Western Canada. Many of the planned full upgrading projects have been placed on hold or cancelled.

The concept of partial upgrading is not new. However, there have been significant advances in partial upgrading technology, including novel reactor approaches and synergies with upstream energy demands. The implementation of partial upgrading would effectively distribute the total cost of producing final, saleable products between the heavy oil-producing entity and that taking delivery of the SCO.

Partial upgrading facilities can be constructed for less than half of the cost of full upgrading. Partial upgrading also has significantly lower operating costs, since no hydrogen or catalyst is required. Most technologies produce a substantial quantity of low-value reject product that is burned to produce energy and can be used for in-situ energy requirements, resulting in savings in natural gas costs.

Challenges for the implementation of partial upgrading have included the development of efficient, economic processes, which can produce stable/compatible SCO, relatively low SCO yields and a sufficiently high SCO price. The value of partially upgraded SCO may be subject to a large introductory discount when a market has been established. Many of the technical challenges have been addressed, and a partial upgrading project using one of the new processes can be projected to be profitable.

Besides being an alternative to full upgrading, partial upgrading may eventually displace a portion of the bitumen or heavy oil that is currently diluted with natural gas condensate to produce heavy oil blends. The netback for blend producers is greatly impacted by heavy oil discount and the availability and resultant pricing of the condensate. The implementation of partial upgrading would help to alleviate the large variation that heavy oil producers experience in their margins.

References

1 Bauquis P R, What future for extra heavy oil and bitumen: the Orinoco case, 17th Congress of the World Energy Council, Houston, Sept 1998.

2 Alberta Government Report, Alberta Oil Sands 2006, available at www.energy.gov.ab.ca/OilSands/pdfs/osgenbrf.pdf.

3 Radler M, New estimates boost worldwide oil, gas reserves, *Oil & Gas Journal*, 22 Dec 2008, 20.

4 National Energy Board of Canada, Canadian Energy Overview 2007, 2008.

5 Canadian Association of Petroleum Producers, *Statistical Handbook for Canada's Upstream Petroleum Industry*, January 2009.

Jim Colyar is President of Colyar Consultants, Pennsylvania. He is an independent technical consultant with over 30 years' experience in refining technology, with an emphasis on heavy oil upgrading. *Email: Jim@ColyarConsult.com*