Heavy Oil Upgrading Enhances Profit Streams

In a new price climate where the spread between the value of light and heavy crudes has increased sharply, producers have a great opportunity to increase their profitability by upgrading heavy crude oils into the light oils needed to meet the growing demand for clean transportation fuels

By David K. Lifschultz

CALGARY–Oil markets have witnessed a disconnect between ample supplies of crude oil and rising crude oil and product prices. Hurricanes Katrina and Rita, which knocked out crude oil production and refining capability along the U.S. Gulf Coast, dramatically highlighted a long-simmering problem: the crude oils produced in the world are not well matched with those that refineries need to meet the products consumers and regulators demand. Specifically, there are not enough light, clean crude oils to meet the ever-increasing demand for clean transportation fuels.

There are basically two ways to solve this problem. Refiners can upgrade the heavy fuels they produce, or crude oil producers can upgrade their output. There are three principal methods by which crude producers can upgrade the heavy, dirty crude oils that the earth will increasingly provide to the light crude oils the world demands: use of diluents, carbon rejection, and hydrogen addition.

TABLE 1

World Petroleum Demand By Main Product (thousand bbl/d)

	1971	% Demand	2002	% Demand	% Change 1971-2002
LPG/Naptha	4,367	8.9%	12,131	15.5%	178%
Motor Gasoline	11,542	23.5%	20,336	26.0%	76%
Aviation Fuels	2,326	4.7%	4,500	5.8%	93%
Middle Distillates	12,008	24.4%	22,656	29.0%	89%
Heavy Fuel Oil	14,242	29.0%	10,083	12.9%	-29%
Other	4,697	9.6%	8,473	10.8%	80%
Total Products	49,182	100.0%	78,179	100.0%	59%
Light Products*	30,243	61.5%	59,623	76.3%	97%

*Sum of LPG/naptha, motor gasoline, aviation fuels and middle distillates
Source: International Energy Agency

By way of background, Table 1 compares world demand by main product for 1971 and 2002. Total product demand increased 59 percent over this period. However, the market for light products increased much more rapidly–by 97 percent–while the market for heavy fuel oil actually declined by 29 percent.

More detailed regional analysis of the data suggests this trend will continue for the foreseeable future. This is largely because the United States historically has led the world both in automobile-powered mobilization with its growing gasoline demand and in substituting less polluting natural gas for heavy fuel oil. As the rest of the world catches up, the demand for light transportation fuels will ratchet up while the demand for heavy fuel oils diminishes.

Crude Oil Supply

Table 2 compares the production of different kinds of crude oils in 1994 to 2004 (as calculated by the ENI Group). A decade ago, light and medium crudes (greater than 26 degrees API) accounted for 89 percent of all crude oils, with heavy crudes accounting for only 11 percent. Now, light and medium crudes account for 86 percent and heavy crudes account for 14 percent (this database excludes extra-heavy crude oils of less than 10 degrees API).

Moreover, the refining quality of crude oils has been deteriorating because heavier crude oils tend to have higher sulfur and other acid content corrosive to refinery equipment.

Only 15 percent of today's heavy oil production is sweet (less than 0.5 percent sulfur), compared to 20 percent of medium crude oils and 70 percent of light crudes. Furthermore, 90 percent of the increased heavy crude oil production has been either partially sour (0.5-1.0 percent sulfur) or totally sour (more than 1.0 percent sulfur).

Additionally, the percentage of crude oils with a high (greater than 1.0) total acid number–the standard for measuring the highly corrosive acid in crude oils–has been growing rapidly, increasing from 7.5 percent in 1998 to 10 percent in 2002.

Finally, by all accounts, the share of sour heavy and extra-heavy crudes in world supply will continue to grow. Given that the Middle East produces virtually no sweet oil, it is not surprising that a Simmons & Company study, *A Primer on Crude Oil Quality*, released in January 2005, concludes, "With 80 percent of the world's reserves located in heavy, sour crude oil regions, the trend toward heavy, sour crude production is likely to continue, if not accelerate."

Upgrading Technologies

Given this situation, it behooves crude oil producers to mitigate problems for refiners by upgrading their heavy crude oils since this also will increase the value of these crude oils.

Historically, producers of heavy crude oils have upgraded either by simply blending the heavy crudes with lighter crudes (diluents) for transportation purposes, or by investing in carbon-rejection or hydrogen-addition facilities.

Blending has the advantage of not requiring a significant investment. However, it is a form of upgrading that does not add any value to the heavy crude except insofar as it makes it possible to utilize the heavy crude where it otherwise could not be used. Thus, for example, if a heavy crude is too viscous to transport by pipeline, rather than shut in the production, clearly it is better to upgrade it by blending.

Investing in carbon-rejection or hydrogen-addition upgrading technologies,

TABLE 2

World Crude Oil Production by Quality (thousand bbl/d)

	1994	1994 % of Identified	2004	2004 % of Identified	% Change 1994-2004
World (Identified)	55,227	100.00%	67,064	100.00%	21.4%
Ultralight	1,136	2.06%	1,662	2.48%	46.3%
Light & Sweet	11,732	21.24%	11,981	17.86%	2.1%
Light & Medium Sour	2,394	4.34%	3,052	4.55%	27.5%
Light & Sour	1,907	3.45%	2,466	3.68%	29.3%
Medium & Sweet	5,416	9.81%	8,139	12.14%	50.3%
Medium & Medium Sour	1,640	2.97%	1,637	2.44%	-0.2%
Medium & Sour	25,058	45.37%	28,970	43.20%	15.6%
Heavy & Sweet	1,085	1.96%	1,450	2.16%	33.7%
Heavy & Medium Sour	835	1.51%	2,082	3.10%	149.3%
Heavy & Sour	4,024	7.29%	5,624	8.39%	39.8%
Total Identified	55,227	100.00%	67,064	100.00%	21.4%
Total Light	17,169	31.09%	19,161	28.57%	11.6%
Total Medium	32,114	58.15%	38,746	57.77%	20.7%
Total Heavy	5,944	10.76%	9,156	13.65%	54.1%
Unidentified production	6,286		5,652		-10.1%
World Total (identified and not)	61,513		72,716		18.2%

Source: ENI Group, World Oil and Gas Review: 2005

TABLE 3

Technical Parameters for Upgrading Alberta Bitumens

	Carbon Rejection: Delayed Coking	Hydrogen Addition: Genoil Heavy Oil Upgrader (GHU™)
Bitumen Input		
API	7.80°	8.50°
Sulphur	5.10%	5.14%
Nitrogen	0.45%	0.29%
Output		
API	28.70°	24.80°
Sulfur	3.20%	0.24%
Nitrogen	Not available	0.14%
Crude Barrels as % of Bitumen Input	82.0%	108.0%
Light and Medium Crudes	82.0%	90.5%
Heavy Crudes	0.0%	17.5%
Coke	18.0%	0.0%

Sources:
Delayed Coking: Murray R. Gray, "New technique defines the limits of heavy oils, bitumens," *Oil & Gas Journal*, Jan. 7, 2002)
Genoil Heavy Oil Upgrader: Genoil Web site (www.genoil.net) and Genoil internal estimates

on the other hand, has the advantage of adding value to the crude oil itself.

The defining characteristic of a heavy oil is that its molecules have a relatively high ratio of carbon to hydrogen atoms. To upgrade heavy oils into light ones, one must either subtract carbon atoms or add hydrogen atoms.

While each of these methods has its advantages, the principal economic weakness of carbon rejection is that typically 20-30 percent of the upgraded crude oil will be low-value solid carbon. The principal weakness of hydrogen addition is that large amounts of valuable natural gas typically are required to provide the necessary hydrogen. To see what works best, it is necessary to carefully analyze the outputs from each kind of upgrading along with the investment and operating costs.

This can be illustrated by comparing the economics of two cases of upgrading Alberta bitumen:

- Carbon-rejection methods using a delayed coker; and
- Hydrogen-addition methods using a heavy oil hydro-conversion upgrader.

For the technical aspects of the carbon-rejection example, we are indebted to the work of Murray R. Gray of the University of Alberta ("New technique defines the limits of upgrading heavy oils, bitumens," *Oil & Gas Journal*, Jan. 7, 2002).

Upgrading Economics

Table 3 presents comparable data on Alberta bitumen feedstocks before and after upgrading by both carbon rejection and hydrogen addition. Both methods substantially lighten the bitumen as measured by API degrees: 20 degrees with the delayed coker and 16 degrees with the hydro-conversion upgrader. However, the hydro-conversion upgrader does a far better job of removing impurities, reducing sulfur content by 95 percent compared to only 37 percent for delayed coking.

Furthermore, the light-oil yield with the hydro-conversion upgrader is 100 percent, compared to only 82 percent for the delayed coker. On the other hand, the delayed coker consumes no hydrogen while the hydro-conversion upgrader requires 935 cubic feet of hydrogen per barrel of bitumen input, which if derived through steam reforming natural gas would require 1.170 Mcf of natural gas per barrel of bitumen.

The most profitable technology for a crude oil producer largely will be a function of these variables:

- Investment and operating costs;
- Relative prices of heavy and light crudes;
- Natural gas prices; and
- Value added by removing impurities.

Table 4 shows the estimated profitability, as measured by the internal rate of return (IRR) for an investment in each of the upgrading technologies under two price- and cost-scenario periods: calendar 2003 and January 2005-August 2005 (pre-Katrina).

The year 2003, when West Texas Intermediate averaged $31 a barrel, is taken as representative of the period before the sea change in the oil industry when sharply in-

TABLE 4

Economics of Upgrading
Carbon Rejection Versus Hydrogen Addition (All data per barrel)

	2003 Prices		2005 Prices	
Revenues	Delayed Coker	GHU™	Delayed Coker	GHU™
Light and Medium Oil Prices[1]	$29.35	$29.35	$51.51	$51.51
% Light & Medium Oil Recovery[2]	82.0%	90.5%	82.0%	90.5%
Heavy Oil Prices[1]	$20.15	$20.15	$31.57	$31.57
% Heavy Oil Recovery[2]	0.0%	17.5%	0.0%	17.5%
Gross revenues	$24.06	$30.08	$42.24	$52.14
Bitumen Prices[1]	$20.50	$20.50	$30.73	$30.73
Operating Costs[3]	$4.00	$4.00	$4.00	$4.00
Hydrogen costs[4]	$0.00	$5.00	$0.00	$6.50
Total Current Costs	$24.50	$29.50	$34.73	$41.23
Net Income	-$0.44	$0.58	$7.51	$10.91
Capital Investment	$34.00	$29.00	$34.00	$29.00
IRR (calculated)	0%	0%	18%	28%
Memo Item: WTI Price	$31.08	$31.08	$54.01	$54.01

Sources
1. Crude oils and bitumen prices: Alberta Energy and Utilities Board; Alberta Energy Resource Industries monthly statistics
2. Upgrading conversion factors: See Table 3
3. Operating costs: estimated, based on Genoil and syncrude data
4. Hydrogen costs: Alberta natural gas prices multiplied by 1.25 to calculate hydrogen cost per Mcf of natural gas, multiplied by 0.94 to calcuate hydrogen cost per barrel of bitumen in GHU (Net equal 1.17 times natural gas price per Mcf)

creasing product demand caused crude oil prices to catapult to record highs. The period from January to August 2005, when WTI averaged $54 a barrel, is taken as representative of the new era in oil prices.

To illustrate delayed-coking technology capital costs, we utilize the data for Suncor's planned upgrading expansion in Alberta, which is projected to cost $1.8 billion. This project will expand bitumen upgrading capacity by 150,000 barrels a day at a cost of $11,800 per barrel of daily bitumen upgrading capacity. Assuming 350 operating days a year, the investment cost is $34 for each barrel of bitumen input.

We estimate the capital cost for the hydro-conversion upgrader is no more than $10,000 per barrel of daily capacity for an upgrader of this size, or $29 a barrel of bitumen input.

To compute IRR on investment, in both cases we assume that the capital investment is spread over three years.

Operating costs, exclusive of hydrogen, are estimated at $4 per barrel of bitumen input for both methods (this figure is consistent with Suncor's 2004 syncrude annual report). Per-barrel hydrogen costs in Alberta for the hydro-conversion upgrader are estimated at $5 for 2003 and $6.50 for January-August 2005.

Net revenue for the delayed coking technology is based on average prices in Alberta of light and medium crudes multiplied by 0.82 to reflect the loss of output from virtually no-value coke minus the average price of bitumen.

For the hydro-conversion upgrader, gross revenue is based on the same average prices in Alberta for light and medium crudes multiplied by 0.91 plus Alberta average prices of heavy crudes multiplied by 0.17, which reflects the greater-than-100-percent volumes expected to be produced by hydrogen addition. Net revenue is calculated by deducting the average price of bitumen.

High-Price Value

Based on these assumptions, Table 4 shows that using 2003 prices, when light and medium crude averaged only $29.35 a barrel since bitumen prices averaged $20.15, the spread of only $9 meant that neither technology would be significantly profitable.

For the delayed coker, gross revenues are $24.06 a barrel, which after subtracting bitumen costs of $20.50 and estimated operating costs of $4.00 a barrel, results in a net loss of $0.44 a barrel.

For the hydro-conversion upgrader, while gross revenues are $30.08 a barrel, after deducting bitumen costs of $20.50, operating costs of $4.00 and hydrogen costs of $5.00 a barrel, the net profit is only $0.58 a barrel.

Table 4 also shows that both technologies are quite profitable using 2005 prices, with the hydro-conversion upgrader the far more profitable of the two. With light and medium crudes averaging $51.51 a barrel and a bitumen price of $30.73, the spread between the two more than doubles, from $9 to nearly $21 a barrel.

As a result, for the delayed coker, gross revenues are $42.24 a barrel and net income after operating costs is $7.51, which with an investment base of $34.00 a barrel implies an annual IRR of 18 percent.

For the hydro-conversion upgrader, gross revenues are $52.14 a barrel. Deducting operating costs of $4.00 and hydrogen costs of $6.50 a barrel leaves a net profit of $10.91, which with an investment base of $29.00 implies an annual IRR of 28 percent. We have not attributed any value in these calculations to the ability of the hydro-conversion upgrader to sharply reduce contaminants in the upgraded crude oil.

No claim is made here that these numbers will apply in all situations since profitability depends both on site-specific conditions and future prices and costs. Nevertheless, it is instructive that in its 2004 annual report, Suncor shows a companywide rate of return on total capital employed of 19 percent and a minimum target rate for new projects of 15 percent.

These illustrations demonstrate two things. First, in this new price climate where the spread between the value of light and heavy crudes has increased sharply, the profitability of all upgrading methods has taken a quantum leap upward. Second, upgrading heavy crude oil through hydrogen addition in the form of a hydro-conversion upgrader is far more profitable for heavy crude oil producers than is carbon rejection in the form of delayed coking.

The capital costs for the hydro-conversion upgrader are significantly lower. Even more importantly, the hydro-conversion upgrader has the capacity to upgrade the bitumen input into a greater quantity of valuable crude oils.

Given that 9 million barrels of heavy crude oil are produced every day, and that all sources agree this level will rise faster than will total crude oil production, this represents a great opportunity for heavy crude oil producers.

Furthermore, since the same upgrading technologies are also available to refiners, both to upgrade their heavy products into light products and to set up stand-alone heavy crude oil upgraders adjacent to their facilities, time is of the essence for heavy crude oil producers to seize this opportunity. ❒

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