Background

Within the global petroleum industry and in the halls of many governments, there is an ongoing debate on whether or not conventional oil resources have peaked or soon will. Regardless of which side is correct, it can be generally agreed that because conventional oils are lighter and easier to produce and refine, they have been preferentially targeted for exploitation before all others. Conventional oils account for a declining share of the world’s remaining oil endowment, and non-conventional oils will account for an ever-increasing share.

This report focuses on unconventional heavy oils, which are the heaviest of the non-conventional hydrocarbons and constitute the world’s largest known and relatively untapped source of petroleum. It addresses the potential opportunity for these enormous resources to mitigate the decline of conventional oils through man’s ingenuity and technology.

Most countries generally describe extra heavy oil and bitumen as having an API gravity of less than 10° API. A more rigorous technical definition will also include reference to viscosity, which is a measure of the crude oil’s resistance to flow within the formation.

- Extra heavy oil has a viscosity that ranges between 1,000 - 10,000 centipoises
- Bitumen is generally defined as having a viscosity above 10,000 centipoises

Although extra heavy oil and bitumen are worldwide in occurrence, a single extraordinary deposit in each category is dominant.

- Alberta Oil Sands - Canada: This deposit comprises 85 percent of the world’s total natural bitumen in place.
- Orinoco Belt - Venezuela: This extra-heavy crude oil deposit represents nearly 90 percent of the world’s known extra-heavy oil in place.

The efforts to more precisely quantify unconventional heavy oil reserves have mostly been concentrated in Venezuela and Canada, yielding the following results:
• Orinoco Belt technically recoverable extra heavy oil reserves = 270 billion barrels
• Alberta oil sands technically recoverable bitumen reserves = 300 billion barrels

Canada and Venezuela are now producing around 1.7 million barrels of unconventional heavy oils per day, which is still only 2 percent of the total worldwide oil production of some 80 billion barrels per day in the year 2004. But unlike conventional sources of oil, these enormous deposits have almost zero exploration risk and their production rate is more a function of refining capacity than anything else.

Canada’s bitumen deposits are located in the Western Canadian Sedimentary Basin, almost entirely within the province of Alberta where they are trapped within sandstone and carbonate “oil sands” in three separate geographic regions: Athabasca, Cold Lake and Peace River.

According to the country’s National Energy Board (NEB), these regions cover a surface area of 23,000 square miles that is equivalent to the size of Scotland. The Athabasca area is by far the largest region, covering 70 percent of the total surface area.

The oil sands are unconsolidated and the composition is 75-80 percent sand, 3-5 percent water, and 10-12 percent bitumen.

The remaining established or proven reserves of bitumen were estimated to be approximately 175 billion barrels, as of December 31, 2003, of which approximately 11 billion barrels are within the areas of active development.

Approximately 20 percent of the proven bitumen reserves can be surfaced mined, while the remaining 80 percent of the oil sands that are deeper than 75 meters are considered too deep to be economically surfaced mined and require some form of in-situ recovery method. Total bitumen production exceeded 500,000 barrels per day in 1997 and 1 million barrels per day in 2004.

Most of Venezuela’s extra heavy oil deposits are located in the Eastern Venezuela Sedimentary Basin, where they are trapped in sandstone formations in a region immediately North of the Orinoco River called the Orinoco Belt.

Petróleos de Venezuela, S.A. has booked some 35 billion barrels of extra heavy oil in the Orinoco Belt as proven reserves. This volume is equivalent to only 3 percent of the total in-place resource; however, at current rates of oil demand, even these reserves are sufficient to meet Venezuela’s domestic oil requirements for some 350 years.

The Orinoco Belt projects are producing around 600,000 barrels per day and already make up about one-fifth of all the oil produced in Venezuela.

Technology
The development of unconventional heavy oils is technology intensive and production scenarios forecasts of these crude oils typically assume various levels of sustained improvement in technologies to discover additional deposits, increase recoverable reserves from known fields, improve the efficiency of production and upgrading and refining yields, and reduce production and transportation costs.

Oil Recovery

Bitumen is exploited by employing mining and in-situ recovery technologies, while extra heavy oil is exploited only through the application of in-situ recovery technologies.

Before oil sands can be mined, the surface vegetation and overburden must be removed. Once removed, the oil sands 40 – 60 meters thick are exposed for mining. In the Athabasca bitumen deposits, mechanical shovel mining techniques can recover over 90 percent of the oil sands that can be physically accessed through surface mining equipment; however, they present other problems such as the inability to economically mine deep oil sand strata and unfavorable environmental impacts. Research is thus focused on lowering mining costs and protecting the environment.

Extra heavy oil and bitumen that is not accessible through surface mining are recovered through in-situ techniques that leave the formation in place and recover only the bitumen or extra heavy oil. In-situ techniques employ primary recovery and/or enhanced recovery mechanisms, which are the primary areas of technological focus.

Primary recovery mechanisms in both conventional and non-conventional oil reservoirs use the natural energy within the reservoir and formations to recover the crude oil. Whereas the primary recovery factors for conventional oil reservoirs range from 10 percent to 30 percent of the oil initially in place, primary recovery factors for bitumen and extra heavy oil typically range from 3 percent to 10 percent.

While the enhanced recovery factors for conventional oil reservoirs typically range from 30 percent to 50 percent of the oil initially in place, enhanced recovery of bitumen and extra heavy oil typically range from 10 percent to 30 percent.

The technologies that are employed to enhance the in-situ recovery of bitumen and extra heavy oil include the following:

- Cyclic steam stimulation
- Steam flood
- Steam-assisted gravity drainage (SAGD)
- In-situ combustion
- Toe to heel air injection (THAI)
- CAPRI technology (THAI plus in-situ catalytic upgrading)
- Vapor extraction (VAPEX)

Production

Bitumen is separated from the mined oil shale after the ore is conditioned by steam, hot water and caustic soda and discharged onto vibrating screens where rocks and lumps of clay are removed. Bitumen rises to the surface as froth and is skimmed off, while the remaining sand settles to the bottom. Naphtha is added to the bitumen, and the mixture enters high-speed centrifuges to complete the cleaning process before being moved to the upgrading facility.

The extraction of bitumen from the mined oil sands typically produces 90 percent of the bitumen that is mined, which is highly productive. Therefore, technological improvements are focused on making the extraction process more cost effective through synergies with other processes.

Extra heavy oil can be produced using conventional technology such as vertical wells and standard rod pumps; however, the production rates are low with high per barrel cost of production. Thus, the focus of new technologies has been on increasing production rates and reducing unit production costs. The new in-situ technologies that are being employed to produce unconventional heavy oils include:

- Multilateral Horizontal Drilling
- Sand management
- High Capacity Pumps

Transportation

Pipelines are the least expensive and most efficient way to move crude oils over land. However, moving bitumen and extra heavy oil by pipeline is difficult because these oils are so viscous that they do not readily flow at ambient temperatures.

To overcome this intrinsic condition, producers and pipeline companies employ technologies that either reduce the density and viscosity of the unconventional heavy oils or reduce the friction between the pipeline and the unconventional heavy oils.

The midstream technologies that are being employed to produce unconventional heavy oils include:

- Dilution with lighter hydrocarbons
- Emulsions created with water and surfactants
- Heating the fluids to be transported
- Core annular flow with a water ring
Upgrading

Bitumen and extra heavy oil consist of large hydrocarbon molecules, which contain proportionately more carbon atoms than hydrogen atoms. In their natural state, unconventional heavy oils cannot be economically refined in large quantities. They must therefore be upgraded to add hydrogen atoms and/or remove carbon atoms, which convert the bitumen into a product similar to conventional light crude oil. Technology is focused on achieving this upgrade in the most cost effective way possible.

The bitumen mined from the Alberta oil sands deposits and the extra heavy oil produced from the Orinoco Belt have an API gravity of around 8° API, which is upgraded or partially upgraded into synthetic oil qualities ranging from 16° API to 33° API in a two-step process.

There are two principal technologies used for primary upgrading, both of which are capable of handling the high metals and asphaltenes contained in bitumen and extra heavy oils.

- Coking, the predominant technology employed, converts residues to synthetic oil by rejecting coke, metals, and some of the sulfur and nitrogen. It is basically a carbon removal process that cracks the bitumen or extra heavy oil by using heat and catalytic processes to form lighter products. This process typically removes 15 percent of the original volume as coke, which must be disposed or sold.

- Ebullated bed hydro-conversion process employs hydrogen addition and a solid catalyst in a semi-fluidized reactor. The process uses lower temperatures to crack the residue into lighter oils, with a volume that is slightly higher than the original volume because hydrogen is added.

A variety of hydro-processing technologies are used for the secondary upgrading step. Through hydrogen addition, this process removes sulfur and nitrogen from the products of the primary upgrading step to levels required by refineries. Secondary upgrading typically splits the total product stream into two or three individual product streams with specifications to satisfy the markets (e.g. naphtha, kerosene and gas oil).

Economics

The economic attractiveness of unconventional heavy oil projects depends on many factors that are common to all petroleum projects, not least of which are the market price of oil, ambient conditions, and fiscal regimes. However, because of the unique characteristics of unconventional heavy oils, the impact of the following parameters on project economics is especially significant:

- Thickness of the overburden for bitumen mining projects
- Thickness of the formations for bitumen and extra heavy oil projects
• Depth of the reservoirs for bitumen and extra heavy oil projects
• Energy costs for bitumen and extra heavy oil projects

Because the development of unconventional heavy oil deposits has been concentrated in the sweet spots so as to reduce the impact of the above-mentioned parameters, extrapolating their project economics to other less favorable areas might be optimistic. On the other hand, improved technology will likely allow the exploitation of areas that are less favorable at lower or comparable cost than some of the original developments.

A grassroots and integrated mining project in the Alberta Oil Sands, with a production capacity of 100,000 barrels per day of bitumen and syncrude oil quality of 36º API would have the following development cost:

• US$20.93/barrel over a 20-year project life
• US$17.17/barrel over a 40-year project life

Based on the investment and operating costs of the existing Orinoco Belt projects, the unit development cost for Orinoco Belt extra heavy oil projects has the following range for syncrude oil quality of at 32º API:

• US$9.90/barrel over a 20-year project life
• US$8.22/barrel over a 35-year project life

Taxes and royalty would be additional costs in all cases.

**Impact on Global Markets**

Obviously, there will be worldwide geopolitical events and macro-economic issues that are beyond the influence of technology and which will play a fundamental role in international markets and influence the viability of future unconventional heavy oil projects. However, it is equally evident that more and expanded unconventional heavy oil developments would have the following impact on the global oil market:

• Diversification of oil supply sources
• Reduction of North American import dependency
• Replacement of falling non-OPEC conventional oil production
• Contribution to global market price stability
• Incorporation of new refining capacity

The following oil production scenario was developed by the IEA and is based on substantial production coming from high risk unexplored sources as well as the sustainability of conventional oil production with enhanced recovery. (Figure 1)
As emphasized in this report, in addition to markets and crude oil prices, technology will continue to drive the viability and profitability of unconventional heavy oil developments. The following technological trends are expected to be in the forefront:

- Improved tools to assess the impact of new concepts such as integrated processing and management of hydrogen content

- Integration of energy consumption between process segments. For example, using waste heat to drive cycles for hydrogen production or optimizing use of bitumen by-products, coal, and natural gas for steam and power production and turbine fuel

- On-line sensors for monitoring and correcting process operations. New techniques based on nanotechnology are expected to emerge with applications in this area.

- Catalysis and bio-catalysis for low temperature conversion of bitumen and extra heavy oil

- Better understanding of the molecular structure and properties of bitumen and extra heavy oil components, particularly asphaltenes, to support technology development in separations, conversion and value-added processing
• Production of value-added products through integration with petrochemicals

Even in the most optimistic scenario, future production from the Alberta Oil Sands and Orinoco Belt will not compensate for declining production from existing conventional oil reserves and cannot prevent a global peak oil scenario. However, bitumen and extra heavy oil production can definitely slow the rate of decline of liquid hydrocarbon production if conventional oils do indeed peak.