

14.2 Appendix 2: **HEAVY OIL POTENTIAL: THE NEXT 50 YEARS**

Emerging Technology for Economic Heavy Oil Development

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Abstract

Technology development and field implementation of new production concepts in the last 15 years has revolutionized the heavy oil industry in Canada (Alberta and Saskatchewan). By the mid-1990's, production costs per barrel dropped to half the values of a decade previously. Recovery efficiency is increasing through the implementation of technologies such as pressure pulse flow enhancement and cold heavy oil production. Refining costs for heavy crude have not risen for a decade, and new-generation upgrading facilities to be constructed in the first half of this decade may be more economic than the previous facilities. The concept of partial upgrading locally through carbon rejection may lead to further reductions in the cost of bringing heavy oil to market. Better sand disposal technologies such as slurry fracture injection are displacing costly methods such as washing, or environmentally questionable practices such as land or road spreading.

Heavy oil became highly profitable in the year 2000, and it seems likely that profitability will be sustained into the future, although excessively high differential process between conventional and heavy crude has decreases profits substantially for the producers in Canada. Much of the success in heavy oil development has taken place in small and intermediate-size companies with highly flexible management structures, cost-reduction philosophies, and possessing willingness to try out new ideas. Intermediate and large companies are also seriously reconsidering the role of heavy oil in their corporate long-term strategy; if they do not, an excellent long-term and stable profit source might be lost to them. Many large corporations that do not possess the new heavy oil experience in-house will have to acquire the experience through the acquisition of smaller companies, and this has largely happened in the period 1997-1999, where companies such as UPR (now Anadarko) and Canadian Occidental (CanOxy) bought companies such as Norcen and Wascana. More recently, Husky bought Renaissance, Conoco bought Gulf Canada, and other small heavy oil companies have been absorbed into larger entities as the interest

level grows. Large companies will have to develop different engineering and financial approaches for heavy oil development, as the basic parameters and the time and capital deployment and commitment are quite different than for conventional oil. The Canadian expertise is being accessed through the advice of experienced experts, and through special alliances with Canadian companies. The Canadian-developed technologies are now being considered or actually implemented in places such as Venezuela, China, California and Oman.

Resources

A basic economic issue to be considered in adopting a corporate heavy oil strategy is the vastness of the on-shore volume of accessible resources in stable political climates relatively near to large markets. A number of important attributes of the Canadian heavy oil deposits are listed to demonstrate their potential value:

- Perhaps 2,500,000,000,000 BBL ($\sim 350 \times 10^9 \text{ m}^3$) of heavy oil (8.5-20°API gravity) has been identified in Alberta and Saskatchewan, 85% in unconsolidated sandstones, 15% in fractured carbonates. This is several times the World's conventional crude reserves. In fact, based on the new technologies, Alberta now claims recoverable reserves of oil that are about the same size as Saudi Arabia's, about 40 billion barrels.
- The resource in Canada is extremely well defined; there are essentially no exploration costs, the resource richness is understood, the depth, location, and type of reservoirs are clearly delineated. (Exploration costs for conventional oil in mature basins such as the Western Canadian Sedimentary Basin are CAN\$8.00-12.00/bbl and rising.)
- Even if only 30% of the Canadian heavy oil and oil sands deposits is accessed, it will meet the entire current needs of the USA and Canada for over 100 years, based on an assumption of steady consumption at 20,000,000 BBL/day ($\sim 1.2 \times 10^9 \text{ m}^3/\text{yr}$).
- Canada, a net oil exporter (mainly to the USA), already meets close to 50% of its production from heavy oils (2000), and this figure will likely continue to slowly grow, even with the advent of East Coast production (Hibernia, Terra Nova, White Rose, Hebron-Ben Nevis...).

- The probability of major on-shore and off-shore conventional oil discoveries in mature North American basins is relatively slim, and could only temporarily and in a minor way affect the production-consumption short-fall that exists in the USA.

Other large heavy oil resource bases exist elsewhere in the World. Most of these are also heavy oil deposits in unconsolidated to poorly consolidated, high porosity sandstones. However, no single heavy oil resource base is both of the same magnitude and so easily accessible as the Canadian oil sands and heavy oils, which have an excellent infrastructure, including pipelines, a well-trained workforce, and easy access through existing roads. Venezuela is developing its oil sands, currently using long horizontal wells with many multi-laterals, and the size of the Venezuelan resource is similar to the Canadian deposits (about 65% of the size).

Several countries have total heavy oil resources of a magnitude between 30 and $100 \times 10^9 \text{ m}^3$, roughly the same order as those in Canada. Examples are China, Russia, Indonesia, and the Middle East. For example, in China, the oil field areas of Daqing, Liaohe, Shengli, Nanyang and Jilin all have substantial heavy oil strata, often associated with deeper conventional deposits. Other fields in Xinjiang (e.g. Karamay) have large heavy oil resources, and deposits of substantial size are known in the provinces of Inner Mongolia and Xizang. Many other countries have substantial heavy oil resources, but approximately an order of magnitude less in size (Argentina, Brazil, USA, etc.). Finally, it is important to realize that the large oil companies that have tended to concentrate mainly on conventional oil development, where production development is relatively rapid after discovery and where profits arrive earlier, have until recently largely ignored major heavy oil resources. In the last five years, this has changed dramatically, and the major world producers are now all involved in large heavy oil projects (BP, Exxon-Mobil, TotalFinaElf and Chevron-Texaco in Venezuela, Conoco in Canada and Venezuela, Shell in Oman...).

Politics and Economics

The world seems to be moving toward greater political and economic stability, although a few recent exceptions are notable, and social upheaval in non-democracies may be a serious reality over the next generation. However, there are also a number of important political and economic realities which exist or which have evolved over the last twenty years in Canada:

- Canada is a politically stable, highly developed country with a long history of development in heavy oil.
- The political climate in Canada is currently “development friendly” with respect to natural resources such as oil.
- The creation of NAFTA (North American Free Trade Association) means that massive development of such a resource has become politically and economically feasible, as the economies of the US and Canada are becoming more and more integrated. This also means that expertise developed in Canadian heavy oil will be useful when the Mexican oil industry becomes open to foreign investment, which is likely to happen in the next decade.
- Distance to American and Canadian markets are already well developed by the world’s most extensive pipeline network, which can easily be expanded to accommodate larger volumes. In the 24 months of 2000-2001 Canada has been either the largest or the second largest oil exporter to the USA, providing about 16-17% of US oil imports. Saudi Arabia is second with 15-16% of US imports, and Venezuela is third with about 13-14%). Canada also provides on the order of one-third of the natural gas consumed in the USA, and this proportion will rise to 40% by the year 2010.
- The oil industry is highly mature in North America; for example, the United States is on a slow continuous depletion curve since 1970, with little chance of reversing or stabilizing the trend. This means that a large customer is locally available, as the USA currently imports over 50% of its petroleum, most from outside North America, most from countries that are neither democratic nor politically stable.
- The full cost to place a barrel of reserves on the company ledger (exploration costs plus development costs plus transportation costs plus refining costs) varies from a small number in the Persian Gulf to perhaps \$8.00-12.00 in the North Sea, and more in the US. The full cost for heavy oil property acquisition is at most only a few dollars per barrel of reserves.
- With the new technologies that have been developed and are just emerging, development and operating costs per barrel remain stable at low values (CAN\$5.00-7.00, up to CAN\$15.00 for thermal projects). In fact, heavy oil is now reasonably profitable in Canada, and the prospects for accelerated development of heavy oil production are good, if only the upgrading capabilities existed.

Technology

The major new technologies that have positively affected the heavy oil industry in Canada in the last 10 years are:

- Horizontal well technology for shallow applications (<1000 m), often combined with gravity drainage approaches;
- Gravity-driven processes, particularly SAGD (Steam-Assisted Gravity Drainage) using horizontal wells to establish a stable gravity-assisted thermal EOR (enhanced oil recovery) process.
- CHOPS technology, where sand production is encouraged and managed as a means of enhancing well productivity.
- Pressure pulse flow enhancement technology, both as a reservoir-wide method and as a workover method.
- Improvements in upgrading viscous, sulfur-rich heavy crude oil feedstocks.

The oil industry in Canada has developed means of drilling shallow (250-1000 m deep) **horizontal wells** at cost-per-metre values about 1.2 times the cost of vertical wells (approximately 4 to 5 times the total costs). These wells, in the shallowest cases (300-400 m depth), are often drilled using masts inclined at 25°-45° to reduce curvature build rates required to “turn the corner” from vertical to horizontal. Also, coiled tubing drilling was introduced in the last decade, further reducing costs of horizontal well drilling. Good seismic control (3-D seismics) and cuttings analysis allows precise steering in thin zones (<20') to place the well in the optimum position in the reservoir. In the production phase, the long drainage length of the well, as much as 1300 m in many cases, allows much more effective production, giving higher production percentages of OOIP (original oil in place). Recently, implementation of inert gas drainage technology, where nitrogen or carbon dioxide is injected through vertical wells at the top of the reservoirs, has increased the potential total productivity of horizontal wells through gravity-driven processes.

SAGD (steam-assisted gravity drainage), developed for reservoirs where the heavy oil is essentially immobile, involves drilling one or two horizontal wells at the bottom of a thick unconsolidated sandstone reservoir, then injecting steam slowly and developing a “steam chamber”. The heat and steam rise, whereas condensed water and mobilized oil flow downward through the porous medium by counter-

current, gravity-driven flow. Injection pressures are much lower than the fracture gradient, which means that the chances of breaking into a thief zone are essentially zero (something which plagues massive cyclic steam injection). This process is extremely stable because the steam chamber grows only by upward and lateral gravity segregation and there are no pressure-driven instabilities (channeling, coning, fracturing). SAGD seems also to be insensitive to shale streaks and horizontal barriers to flow that otherwise would seem to be serious impediments to the success of the technology. In fact, it appears that SAGD does not even “see” these permeability barriers. As the rock is heated, differential thermal expansion causes the shales to be placed under a tensile stress, and vertical fractures are created, which serve as conduits for steam (up) and liquids (down). Furthermore, as high steam temperatures hit the shale, instead of expanding thermally, dehydration (loss of water) and dehydroxylation ($-OH + HO- \Rightarrow H_2O + -O-$ bonds) lead to volumetric shrinkage of the shale barriers, opening the induced vertical fractures even more. Thus, the combined processes of gravity segregation and shale thermal fracturing make SAGD so efficient that recovery ratios of 50-75% are probably achievable in appropriate cases (thicker horizontal sandstone reservoirs, porous-flow dominated except for the shales).

CHOPS (Cold Heavy Oil Production with Sand) is now widely used as a “quasi-primary” production approach in unconsolidated sandstones, and many thousands of wells in Canada are now stably producing oil through CHOPS. Instead of blocking sand ingress by screens or gravel packs, sand is encouraged to enter the wellbore by aggressive perforation and swabbing strategies. Wells (vertical to 45°) are operated with rotary progressive cavity pumps, rather than reciprocating pumps, and old fields are converting to higher-capacity progressive cavity pumps, giving production boosts to old wells. Note that if a screen is installed to keep out sand, oil production will drop to uneconomic levels. Productivity increases over conventional primary production as high as $\times 10$ and $\times 20$ have been achieved regularly (100 b/d rather than 5-10 b/d). Also, from 12-20% of OOIP can be developed, rather than the 0-2% typical of primary production in such cases. Finally, because massive sand production creates a large disturbed zone, the reservoir may be positively affected for later implementation of thermal processes. CHOPS increases productivity for four reasons:

- If sand can move, the basic permeability to fluids is enhanced.
- As more sand is produced, a growing zone of greater permeability is generated, similar to a large-radius well which gives better production.

- Gas exsolution in heavy oil does not generate a continuous gas phase; rather, bubbles flow with the fluid (and sand) and do not coalesce, but expand down-gradient, generating an “internal” gas drive, referred to as “foamy flow”.
- Continuous sand production means that asphaltene or fines plugging of the near-wellbore environment cannot occur (no possibility of a “skin” effect which impairs productivity), which would inhibit the free flow of liquids.

Typically, a well placed on CHOPS production will initially produce a high percentage of sand, greater than 10% by volume of liquids; however, this generally decays to 0.5-3% sand by volume (more for lower API gravity oils which are more viscous) after some weeks or months. The huge volumes of sand are disposed of by a new technology, Slurry Fracture Injection (SFI), recently developed in Canada, and this has proven to be critical to the economics of cold production. SFI involves injection the waste sand as an aqueous slurry back into the deep formations from where it came. Operating costs for cold production have been driven down from CAN\$12.00-13.00/BBL in 1987-91 to CAN\$5.00-7.00/BBL in 1999-2000, raising the profitability of small heavy oil projects. These massive cost reductions have been implemented mainly in small companies, although now large companies have instituted and carried out similar cost reduction programs.

CHOPS production is not trivial. Approximately **16-17% of TOTAL CANADIAN PRODUCTION** in the years 2000 and 2001 was from CHOPS applied to reservoirs from 11° to 18°API.

A radically new aspect of porous media mechanics was discovered and developed into a production enhancement method in the period 1997-2002, based on theoretical developments in carried out at the University of Alberta in the period 1985-1995. **Pressure pulse flow enhancement technology (PPT)** is based on the discovery that large amplitude pressure pulses that are dominated by low-frequency wave energy generate enhanced flow rates in porous media. For example, in heavy oil reservoirs in Alberta, PPT has reduced the rate of depletion, increased the oil recovery ratio, and prolonged the life of wells. Also, it has been found that very large amplitude pressure pulses applied for 5-30 hours to a blocked producing well can re-establish economic production for many months, and even years. The mechanism by which PPT works is to generate local liquid movement into and out of pores, through the propagation of a porosity dilation wave. As the porosity dilation wave moves through the porous medium at a velocity of about 40-80 m/s, the small expansion and contraction of the pores with the passage of each packet of wave energy helps unblock pore throats, increase the velocity of liquid flow, overcome part of the effects of capillary blockage, and reduce some of the negative effects of advective instabilities such as

viscous fingering, coning, and permeability streak channeling. Although very new (dating only since 1999 in applications), PPT promises to be a major adjunct to a number of oil production processes.

Hybrid approaches that involve the simultaneous use of several of these technologies are evolving and will see great applications in the future. For example, a period of primary exploitation using CHOPS can be substantially extended (producing more OOIP) using pressure pulsing. Then, after the primary phase is essentially complete, a period of gravity drainage, aided by inert gas injection and steam injection, could be used once the initial reservoir pressure is re-established. Different exploitation phases and the use of hybrid approaches may well allow the production of as much as 30-50% of the heavy oil in good quality reservoirs. Furthermore, the technologies developed for heavy oil will also be useful for conventional oil.

On the environmental side, slurry fracture injection has been developed to help address environmental issues that arise because of the production of large quantities of sand along with the heavy oil (330,000 m³ of sand in 1997). Slurry injection involves taking the oily sand, slurring the sand with waste water and other waste fluids (slops or sludge), and injecting the slurry under fracture pressures into suitable porous and permeable strata at depths that are well below even the deepest potable water flow. This method is turning out to be cheaper than many other methods, and carries no environmental penalties whatsoever. In fact, placing the oil sand at depth merely returns the materials whence they came, thus closing the loop on environmental concerns in heavy oil development.

Finally, recent pilot-plant scale **developments in upgrading of heavy oil** indicate that the near future could see a reduction of the differential cost of upgrading heavy oil from CAN\$6.00/BBL to perhaps as low as CAN\$4.00/BBL, which is the same as a permanent ~9% price increase (or a direct, substantial profit increase). These processes are based on a better understanding of the issues of asphaltene solubility effects at high temperatures, incorporation of a catalyst that is chemically precipitated internally during the upgrading, improving hydrogen addition or carbon rejection, and so on.

Corporate Philosophy

The corporate philosophies involved in conventional oil and heavy oil development are substantially different, and many large companies have experienced difficulty in attempting to integrate heavy oil activities into a corporate structure geared to exploration and development of conventional oil. Interestingly, the most rapid advances in new technology have been initiated and implemented by the

small to intermediate size Canadian corporations, rather than the large multi-nationals. Now, the larger companies are playing “catch-up” in these vital new technologies, and applying them in areas such as Oman and Venezuela.

Conventional oil is exploration-intensive and capital-driven. Substantial effort is necessary to discover and delineate reservoirs, requiring massive expenditures in geophysics, geological modeling, and exploratory drilling, often in difficult areas offshore or in remote basins that are poorly serviced. Once a discovery is made that warrants development, the process becomes capital-driven: large offshore facilities, transportation networks, and autonomous support environments for the personnel are often necessary. This expenditure must be made as fast as possible in order to reduce capital costs and in recognition of the typical declining production behavior of conventional oil properties. On a world average, the cost of adding a new barrel of reserves of conventional oil to a company’s portfolio is about CAN\$5.00 to CAN\$6.50 worldwide, but is higher in Western Canada (CAN\$8.00+), which is considered a “mature” oil province.

The vast, on-shore, heavy oil resources in Canada are currently being developed with a radically different philosophy. Exploration costs are essentially zero, and a reasonable infrastructure already exists. In early stages of heavy oil development, the “large-scale” mentality was applied, leading to projects such as the Suncor mine, the Syncrude mine, and the Esso Cold Lake Project (Imperial Oil Resources). However, the last 15 years have seen the new technologies mentioned above applied in a cost-driven, small-scale regime. The philosophy is to keep initial developments small, keep operating costs as low as possible, allow operational autonomy for the local field groups, and grow only as fast as the profits from the operations permit. This has resulted in massive risk reduction and lower capitalization, meaning that small and intermediate companies have done well, usually better than large companies. Finally, instead of a standard decline curve, heavy oil is characterized by a continuing development approach which builds up and maintains production levels commensurate with economic factors, leading to a different, cost-driven philosophy of oil production, characterized by careful engineering. Total production potential in Canada is far greater than the current levels of production, which now exceed two million barrels per day.

One problem that plagues heavy oil development at present is cyclic price drops to uneconomic levels when production exceeds upgrading capacity. This is likely to change permanently in about 5-10 years, when the world production rate of conventional oil will peak at about 27 billion barrels per year. Then, a persistent demand will create a more permanent and economically stable period of heavy oil development in Alberta and Saskatchewan. (Currently, world oil production is about 28 billion barrels per year, but

8.8% of this, about 2.5 billion barrels per year, already comes from heavy oil, and this proportion will grow rapidly in the next 20 years.)

Summary

New technologies and a proven track record of their implementation in Canada suggest that any corporation that is interested in growing, maintaining production levels, or meeting more of the intercontinental petroleum demands must seriously consider making heavy oil production an increasing part of their strategy. The technologies being developed and perfected in Canada will have worldwide applications. The best supporting evidence for this economic opportunity is given by the success in Canada in continuously reducing production costs over the last decade, leading to a new modest oil “boom” in Alberta in 1994-97, and another in 2000 (after the price collapse of late 1997 and 1998). Canada now obtains almost 50% of its oil production from heavy oil and oil sands, and these projects were more and more profitable for their owners during the 1990’s (excepting the period from late 1997 to the middle of 1999). Considering the vastness of the resource in Canada, the favorable economical-political climate, the continuing depletion of conventional oil and natural gas, and the longer-term stability of oil prices that is now expected, aggressive investment in these new methods warrants consideration at the highest corporate levels. Also, considering that these technologies have great potential in other areas, a process of evaluation and pilot testing could increase the value of assets in other sedimentary basins.

There are new projects in Alberta and Saskatchewan involving mining, CHOPS and SAGD technologies that should add close to one million barrels per day to current Canadian heavy oil and bitumen production. The in situ technologies that will be used are those that have been developed in Canada in the last 20 years.