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The Bituminous Sands: a Canadian Mirage?

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Abstract

Canada ranks second after Saudi Arabia, and ahead of Iran, in the amount of proven oil reserves. Canada's oil reserves are mostly in the form of bituminous sands, 10% of which can be recovered under existing political and economic contexts as well as existing technology, and constitute the country's current proven reserves. The bitumen reserves are located in the north-eastern part of the western Canadian province of Alberta. It involves a large territory nearly twice as vast as the UAE and slightly larger than England. That is the surface area involved is 140,000 km^2 (the UAE are 83 600 km^2). Alberta is the home to the largest deposits of crude bitumen in the world.

The paper questions the actual controversy about the potential role of a major increase in Canadian oil snads production so as to bridge the upcoming gap between the world's ever increasing demand and the total recoverable oil supply. The actual potential of crash scenarios is presented, the prediction cost forecasts is considered, and the environmental impact is briefly overviewed. Then, it is shown that although the actual energy return on energy investment (EROEI) may not be alarming, the coming capital investments needed and the costs related to pollution will jeopardize the sustainability of the actual forecasted increase in production. Hence, enhanced recovery techniques are clearly a need for future sustainable exploitation of these tar sands.

Keywords: : *Petroleum, bituminous sands, enhanced oil recovery.*

1. Introduction

The concept of "Peak oil'' is a term that refers to the idea that the production of a finite resource in a market economy – initially defined with respect to crude oil only – grows, reaches a peak, and then declines. This concept was expressed for the first time by Marion King Hubbert in 1956 [1]. Hubbert had proposed that the production curve follows a Verhulst or logistic curve. The logistic equation is given by :

$$\frac{dQ}{dt} = bQ\left(1 - \frac{Q}{Q_\infty}\right) \tag{1}$$

Where Q_∞ is the ultimately recoverable reserve; Q is the cumulative production, b is the initial rate of growth of reserve production, and the left-hand side of the equation is the rate of extraction. This provides a yearly oil production curve which is symmetric with respect to the peak. In this model, the peak occurs when half of a non-renewable resource is extracted.

Following this model, initially, the (exponential) extraction of an abundant and cheap resource leads to economic growth and to increasing investments in further extraction. Gradually, however, the cheap resources are depleted and extraction costs become higher because of the need of extracting lower quality deposits with ever increasing technology requirements. In time, investments cannot keep pace with these rising costs; the growth slows down and, eventually, production starts declining [2].

This theory may fall short in describing the actual curve of extraction: it is nowadays challenged by numerous authors such as Rea [3] based on the original projections of Hubbert who predicted in the mid 1950s that US oil production would peak between 1965 and 1970 (he was right indeed as his predictions were carried out with respect to continental US oil only). On the other hand, papers such as that of Bardi [2], Goodwin [4], Devezas *et al.* [5] claim that refinements of Hubbert's model combined with more sophisticated ones such as those of Marchetti in the 70's or Fisher-Pry [5] confirm, in some sense, that the original idea is quite applicable as we know it today.

In recent years, the debate about the correctness of such oil peaking calculations has become fairly heated.

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Books have appeared covering both sides of the debate such as those by Clarke [6] and Strahan [7], as well as journal articles such as by Watkins [8] and Bentley et al. [9].

Whoever is right or wrong is not the subject matter of this paper. Nevertheless, in February 2005 the report “Peaking of World Oil Production: Impacts, Mitigation and Risk Management” [10] was released. The report gave an overview of the subject of peaking of world oil production and possible mitigation measures in order to dampen the effects of increased scarcity of oil. The report explained that the peaking of world oil production is such a serious problem that without preventive actions, ‘‘the economic, social, and political costs will be unprecedented’’.

In this context, it is often claimed that non-conventional oil production, such as Canadian oil sands production, may play an important role for bridging the coming gap between the world’s soaring oil demand and global oil supply.

For the reader who may not be familiar with the subject, Canada’s tar sands are concentrated in the Athabasca watershed, in Northern Alberta (fig.1).

Fig. 1. Tar sands sites (light gray) in Alberta, Canada [19]

They are exploited in two main methods; open-pit mining, or in-situ through Steam Assisted Energy Drainage (SAGD).

In open-pit mining, soils are excavated and the tar sands are recovered with heavy machinery and then sent through plants in which processing is centralized. In those plants, the bitumen is separated from the other components of the tar sands in steam pressure vessels. This technique cannot be effectively used for about 80% of the Canadian tar sand deposits, which are too deep for open-pit mining techniques. Those deposits are recovered in-situ, through SAGD, a technique in which two horizontal wells, spaced about 5 m apart, are drilled horizontally into the underground tar sands deposit. The wells tend to be about 40 m deep, and extend from 500 m to 1,000 m horizontally [11]. They are slotted to allow the passage of steam that is blasted into the injection well and rises up to form a steam chamber in which the heat conducts to colder bitumen at the interface and lowers its viscosity, thus causing it to separate from the attached sand. An emulsion of bitumen, water and steam then condensates and drains to the bottom production well by gravity, and can then be pumped up to the surface to a processing facility.

This paper will demonstrate that even in a very optimistic scenario, Canada’s oil sands accelerated production will have a negligible effect on the aforementioned gap, have a considerable impact on environment that has yet to be accounted for, and does not seem to present a favourable Energy Return on Investment.

Fig. 2. Shallow oil sands deposits in open-pit mining [19]

The next section presents a concise analysis of how, although stressed by the pace of economic changes, an overnight decision making by the government and/or industry should not rely on a scenario based on the Canadian tar sands industry.

The third section will present a simple model to predict supply costs over the next 55 years. This section demonstrates that the business will be highly profitable, based solely on extraction costs, despite the technology requirements.

The fourth section will then point out the environmental treat that tar sands exploitation may represent. Impact on water, atmospheric emission and land degradation as well the treat for human health will be briefly examined.

The fifth section will examine the aspect of payback or return on investment. Life-cycle assessment will be considered as well as an overall payback ratio definition as applied to the sands.

Then, several general remarks will conclude this paper.

2. Market share analysis

Alberta’s tar sands have received a great deal of attention as a large new resource for petroleum extraction and liquid-fuel production. As of 2003, 175 Gb of reserves were suddenly added to Canada’s officially reported totals, all from tar sands [12]. Eighteen percent of Alberta’s Tar Sands reserves are close enough to the surface (less than 200 feet) to be mined. The remaining 82 percent are extracted through *in situ* recovery methods that use drilling technology to deploy steam or solvents into the reservoir in order to mobilize the bitumen so it can be pumped to the surface.

Estimated resources in place are roughly 10 times this amount. If verified, this would potentially make

Canada the biggest future source of petroleum products in the world, second only to those of Saudi Arabia. In a recent paper, Söderbergh *et al.* [13] analyze projections for production from tar sands over the next 45 years. While acknowledging the presence of large reserves and an even larger resource base, the authors [13] conclude that "a short-term crash program from the Canadian Tar Sands industry achieves about 3.6Mb/d by 2018. A long-term crash program results in a production of approximately 5Mb/d by 2030." The Canadian Association of Petroleum Producers [14] has issued a recent report with a slightly updated estimate for production in 2020 of 4.5 Mb/d, a broadly similar conclusion to that of Söderbergh *et al.*

Current tar sand oil production is approximately 2,7 Mb/d [14], as compared to a world total liquid-fuel production of slightly less than 84Mb/d (2005). According to the EIA International Energy Outlook 2008 [15] reference case, world liquid-fuel consumption is projected to be 113Mb/d in 2030. Thus, as a percentage of world production, tar sands will certainly contribute a growing share, rising from 1% currently to 4% in 25 years. However, as pointed out by Söderbergh *et al.* [13], a comparison between these estimates and projections for the future continuing decline in production of North Sea oil shows that the two taken together essentially balance one another, leaving no net gain in liquid fuel for world consumption. In fact, given the relatively poor net energy gain for synthetic crude oil derived from tar sands, there will certainly be less net energy with respect to today's production. In other words, the impeding decline of global crude oil production, which is for many coming into view, has led to a substantial rush to raise the production from tar sands. But this race will not make a significant difference in global oil production in 2030.

3. Production costs forecasts

In this section, a simple probabilistic model for projecting the cost of supply bitumen is presented. The model is that proposed by Mejean and Hope [16] for any fuel including bio-fuels and carbon-intensive fuels. As the crude oil prices have increased dramatically to more than 140$/b in July 2008, some argued that this was due to cyclical changes while others stated that high prices are a direct consequence of structural transformations of oil market, and still others argued that the end of cheap oil was the first sign of oil supply constraints. At the moment of writing this paper, the cost was back to about 60$/b.

In any cases, the recent variations in crude oil prices dictate the need for modelling the learning curves for bitumen so as to identify technologies that could become competitive with adequate investment [17]. These curves represent a powerful tool for energy policy making as they allow to "assess the prospects for future improvements in the performance of a technology" [18]. Here, the model used can be written as:

$$C_t = C_{\min} + \left[C_0 - C_{\min}\right] \left(\frac{X_t}{X_0}\right)^{-b} + C_{\max}\left(\frac{X_t}{X_u}\right)^{\gamma} \qquad (2)$$

where C_t is the unit cost at time t; $C_{\min}$ is minimum unit costs, C_0 the initial costs; X_t the cumulative production at time t, X_0 the initial cumulative production at time t, $C_{\max}$ is maximum unit costs of the depletion, and X_0 the ultimately recoverable resources [16].

The results show large uncertainties on future supply costs, with costs falling in the range $7-$12/b in 2030 and $6-$15/b in 2060 (2005 USD). The slight raise after 2030 is mainly due to the influence of the depletion curve exponent which increases.

But this scenario could be challenged as this model does not take into account the necessary logistics of production. In the current context of confusion about the extent of proven reserves, investors in Canadian tar sands production appear to disregard the fact that the energy-intensive extraction and refining processes depends heavily on low cost stranded natural gas. Although Canada is a net exporter of natural gas, it lacks large reserves, and will have to find other sources of energy to be able to refine the extracted ore. This is leading producers to a "conceptual leap", relying on nuclear technology to promote hydrocarbon production rather than replacing their consumption. This would harm the extraction cost.

But as of today, even when alarmist reports claim that the cost increase would make about a 10% return on its investment if oil were to remain at 50$/b [19], it will not be the extraction costs that will constrain production of synthetic crude from the tar sands.

4. Environmental impacts

The impact of open-pit mining excavation technique is obvious, because of the high visibility of the excavation

Indeed, both techniques have a measurable impact on the surface. In the case of SAGD, because of the porosity of the sand and the shallowness of the wells, the residues that remain can easily seep out of the well chambers and affect the soils and waters in ways that maybe less obvious to the naked eye than open-pit mining.

In order to evaluate the impact of either technique, it is best to consider the "natural boundaries" of the Athabasca basin's shared ecosystem, in which water acts as a transport mechanism of the main pollutants. This is done by considering the impact of extraction activities on the qualities of Land, Water, Air and Ecosystem [20]. In order to quantify this environmental impact, it is also necessary to compute the energy required to remedy any environmental damage incurred within the Watershed.

In practice, however, such a task can not be carried out because of the paucity of the available data. Hence, this section will focus on highlighting the specific areas that require data collection.

4.1. Land Degradation

In evaluating land degradation in general, the amount of deforestation and land erosion could be a good indicator of land degradation. This applies to most extraction techniques whereby extraction is carried out as "open pit" mining operations.

These operations involve extensive amounts of soil, since even "rich" tar sand deposits contain as little as 20% of oil by weight. Since those deposits tend to have about half as much as the same amount of energy as Coal, it is often necessary to mine about three tons of tar sands to obtain the energy equivalent of one ton of coal [21].

In such operations, not only is the surface vegetation at the mine site destroyed, but the topsoil is so disturbed that it becomes very difficult to rehabilitate the site and restart the native growth pattern. This is especially harder as the weathering of mine waste residues accelerates over time, with oxidation producing sulphuric acid and releasing toxic materials such as arsenic, selenium, and beryllium that can eradicate all life near the mine, or at least strongly alter the region's fauna and flora [21].

There is little reliable published data as to the extent of such pollution, but early evidence suggests that such damages may take hundreds of years to mitigate or correct themselves.

4.2. Water Contamination

In general, for every metric ton of tar sands recovered, more than four Tons of mine tailings are left. While their toxicity may be less than that of coal residues in some cases, their larger volumes mean that their environmental hazards remain similar [21].

Because the volume of the loosely compacted residue is much larger than that of the original material in its compacted form, it overfills the cavity produced by the mining, and is used to create tailing dams that are used to store the polluted water used up in the process. The extraction process generally consumes 12 barrels of water (2 m^3) per barrel of bitumen produced [21]. As a result, tar sand industries use up more than 76% of the water of the Athabasca river basin, representing more than 8% of all the water licensed in the province of Alberta [21]. Contrary to the water consumed by most other human activity, this toxic suspension cannot be recycled back into the system without extensive treatment. Such waste is a luxury Alberta can ill afford considering its high risk of "total economic loss" in case of drought [21].

The McKenzie basin also faces an additional risk due to the potential failure of tailing dams for which construction is poorly documented. Such failures can have far reaching effects, since "*in most of the cases such an analysis will end with the result that risk will be coupled with any effect of water*" that require data collection and assessment to understand the fundamentals of any possible problem and to determine its extent [22]. In other countries where failures of similar structures have occurred, much of the highly contaminated sediment still contained a large proportion of potentially reactive tailings-related minerals long after the catastrophes [23].

In spite of Environment Canada's mounting concerns about the "*lack of proper assessment of the cumulative effects associated with these projects*" [24], there appears to be no analyses of the actual contents of those ponds. However, it has been noted that the water in the ponds may stay liquid in the freezing winter, down to temperatures as low as -30 ^{o}C. This is a strong indication of high content of heavy metal solutes. In addition, there are no cumulative impact study of the effect of these ponds, and no evaluation of the remediation costs.

However, based on the data available, a rough estimation of the order of magnitude of the cost can de developed. The Tar ponds have been constructed to be, in general, about 90 m deep. Their total surface appear to cover about a 60 km^2 area in total, which would representing about 5.4 km^3 (or 5,400 Million m^3) of toxic sludge. This sludge may prove much harder to clean those other industrial wastes, not least because of the high variety of toluene-insoluble organic contaminants [25].

From experience with urban wastewater treatment, the cost of treating the comparatively less polluted sludge may amount to as much as 1 CAN$/$m^3$. This suggests that the cost of treating the amount of toxic waste resulting from mining the tar sands may well exceed l5.4 Billion CAN$ and this would be more than actual royalty payments recovered by the province of Alberta.

4.3. Ecosystem Damage and Air Pollution

Because of the paucity of cumulative studies on the impact of tar sands, the impact on ecosystem and air pollution is hard to assess. However, there is anecdotal evidence on health and air pollution that may serve as indirect indicators.

The McKenzie river basin drains northwards, towards the sparsely populated Northern regions of Alberta and the Northwest Territories. In those regions, however, there is anecdotal evidence of rare cancers in the small populations of the regions, but the small population sizes limit the usage of traditional statistical techniques. Since 2006, a controversy erupted between the Alberta Cancer Board and the small community of Fort Chipewyan [26], raising larger concerns about protection for medical whistle-blowers [27].

In addition, the lack of direct measures of air pollution makes the direct impact of the tar sands difficult to evaluate. This impact is not limited to the actual energy used during extraction, but may linger over time, as evidenced by the strong smells that are reported to constantly emanate from the many tar ponds. Those indicate the existence of evaporates such as sulfur dioxides and nitrogen oxides, which would then contribute to creating acid rain in those remote regions, an effect further compounded by the presence of toxic metals in the disturbed soils.

4.4. Nuclear energy as a solution?

In addition to the steam needed for the extraction processes, any deployed nuclear reactors would be able to produce electricity for the facilities, and even the necessary hydrogen necessary for upgrading the bitumen from the tar sands to "Syncrude" [11]. Implementing this "nuclear option" would allow Alberta to avoid the release of 100 MTons of CO_2 and numerous other greenhouse gases" for every 100,000 Barrel. However, this idea illustrates the needs for large investments in complex technologies to maintain production.

5. Energy ratios

5.1. Energy return on energy investment

Nowadays, in spite of suggestions that oil production may be peaking, there remains large quantities of recoverable proven reserves of conventional oil and gas available. From a financial standpoint, the problem lies not in the amount of oil that may be available, but in the economics, determined by the ratio of the price to the cost often called Energy return on Energy Investment (EROEI) [28].

$$EROEI_f = \frac{\text{Value of energy produced [\$]}}{\text{Cost of energy used [\$]}} \qquad (3)$$

Here, we refer to a financial definition of the EROEI. That is the ''costs'' are to be understood as the cost of energy expenditure required to extract the oil. Such costs start growing as the resource is being depleted, when an increasing amount of energy is spent to extract a resource of decreasing quality. Hence, in the case of oil, the $EROEI_f$ depends on market prices and on several physical factors such as the progressive the fall in reservoir pressure, for instance. The $EROEI_f$ varies tremendously among different types of available crude oils. The most cost-effective is Middle East oil, for which $EROEI_f \cong 30$. In general, this is more likely to be about 15. Based on recent market prices, tar sands have an $EROEI_f \cong 3\text{-}4$.

However, there are already indications that estimates of EROEI have habitually been "overly optimistic" for new technological alternatives. For example, records show that "*we have overestimated actual capital costs of new energy plants by 100%*" [29]. This would definitely increase the denominator in eq.3., especially when the aforementioned nuclear solution is considered for the future Another increase could be attributable to the "quality" parameter which accounts for the relative productivity of the energy source used to define the EROEI. In this case, the extracted crude contains extremely abrasive minerals that render pumping extremely difficult. In addition, because of its high content of Sulfur (at least 5%), and various heavy metals [25], the crude requires specially equipped refineries, and is therefore more energy intensive and expensive. Indeed, in North America, the trend for EROEI is a declining one, and "*the increase in drilling effort since 1973 has not reversed*" it [29].

Hence, to propose a proper definition of the $EROEI_f$, one should take into account the cost of decontamination (ecosystems, air, water, land) and that of capital needed in addition to the extraction costs discussed in section 3.

5.2. Energy available on energy used

But there is another important concept to take into account: the Energy Return on Energy Investment ($EROEI_e$) in terms of amounts of energy. This concept is almost never though of when it comes to feed our current political debates on new energy sources.

In short, it may be casted in the following simple statement:

$$EROEI_e = \frac{\text{Energy produced [J]}}{\text{Energy used [J]}} \qquad (4)$$

This definition of the EROEI leads to values that are not necessarily related that that in eq. 3. $EROEI_e$ has no impact on the market but a major one on the planet as it provides a mean to rate the amount of actual usable energy obtained to that used to extract, transport, process, or convert a crude resource. Of course, when this ratio falls below 1, it takes more energy to produce a given fuel that this fuel can provide. In any case, it should be at least 5.

Whether open-pit mining or SAGD techniques are considered, on an average basis, tar sands may have an $EROEI_e \cong 1{,}5$ which is very low. But, to the best knowledge of the authors, there is no viable data published by the authorities or exploiting companies on the subject. The few large environmental studies commissioned – whose optimistic conclusions were found to be "not warranted" – could be challenged if not considered inadequate because their "main monitoring programs significantly [lacked] strategic directions and scientific process" [30].

5.3. Energy payback

As an interesting parameter in life-cycle assessment, the external energy ratio or energy payback ratio [31], is, nevertheless, a preponderant one. Gagnon [32] mentions that the energy payback is the ratio of the total energy produced during a given system's normal life span to the energy required to build, maintain, and fuel it. "For a thermal power plant, this calculation does not include the embedded energy in the fule burned at the plant" [32]. In Gagnon's review, the life-cycle energy payback ratio of a thermal power plant operating a conventional boiler with 35% efficiency is 0,7.

Hence, whether EROEI or life-cycle assessment is examined, the production of oil from tar sands does not seem to be viable despite the immense challenges ahead of us for liquid fuels.

6. Conclusion

In this paper, Canadian tar sands have been examined under the aspects of their capacity to prevent shortages based on crash scenarios, their extraction cost projections over the next decades, their environmental impacts, and on their real return on investments.

It is first shown that even an increase from about 1% to about 4% of the total production of world's oil due to specific crash programmes over the next 25 years, Canadian tar sands production increase would not have a major impact upon an eventual sharp decline in conventional oil production.

Then, the production costs are examined to show that actual optimistic forecasts are based upon simple models accounting for extraction costs, but often neglecting other aspects that contribute to the real total exploitation costs.

The environmental aspect is considered next to state that although highly visible or predictable, the quantitative aspects of pollution as yet to be determined with precision.

Finally, the energy return on energy investment ratio or EROEI is examined. A financial acknowledged definition is first given, stressing the fact that the denominator, in eq.(3), should also account for future capital costs and environmental treat. An efficiency definition of the EROEI with respect to energy itself is also provided showing that the process is not efficient. A payback definition is also presented to strengthen this assertion.

Hence, the major uncertainty factors that could help stating on the appropriateness of an immediate major production increase from this source are that the extent of pollution appears to be poorly documented, the effect on health as well in such a sparsely populated region, and its real costs remain poorly assessed. These key issues should then be investigated more thoroughly before any further increase in production is decided.

Only then can Canadians will determine whether the development of heavy crudes can be sustainable on the long run, or whether it is just another economic mirage.

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