Nuclear Energy in Industry: Application to Oil Production

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ABSTRACT

Canada's commitment, via the Kyoto Protocol, to reduce carbon dioxide emissions poses some interesting challenges. New ways of undertaking activities to reduce emissions, while maintaining our standard of living, is the desired end goal.

Canada has vast reserves of oil in its tar sands deposits in northern Alberta. These are world scale deposits relative to known conventional oil reserves and will play an important role in the world's economy in years to come. Substantial energy is required to extract the oil and upgrade it into usable products. This energy is currently derived from fossil fuels and releases of carbon dioxide are a consequence. Additionally, hydrogen may be produced as a material component used to upgrade the oil. This hydrogen is currently produced by reforming of methane to remove the hydrogen component which also produces carbon dioxide which is generally discarded. This paper examines a relatively new extraction and processing concept (Steam Assisted Gravity Drainage) which can use steam and electricity from CANDU reactors and also produces oxygen, and heavy water. These products, in turn, can be used to increase energy production while reducing carbon dioxide emissions. The paper focuses on the magnitude of carbon dioxide emission avoidance which is anticipated based on data from current and projected projects.

The paper reviews the current status of development of the oil sands industry and projects carbon dioxide emissions which would be expected if current extraction and upgrading techniques are continued.

The scope of a project using a CANDU nuclear reactor as an alternate energy source to produce steam and hydrogen for upgrading is outlined.

It is concluded that the carbon dioxide emissions that could be avoided by deployment of nuclear energy powered oil sands projects would be a substantial fraction of Canada's emission reduction goals for Kyoto.

Introduction

A recent article in Scientific American[1] reviews the status of world oil production. It points out that production in the United States and Canada has started to decline. Earth's conventional crude oil is almost half gone. Reserves and future discoveries together will provide little more than has already been recovered. The authors predict (See Figure 1) that annual world oil production will peak in about ten years at around 26 billion barrels. A decline is then predicted to ensue with annual conventional world oil production decreasing to only about 6 billion barrels in 2050.

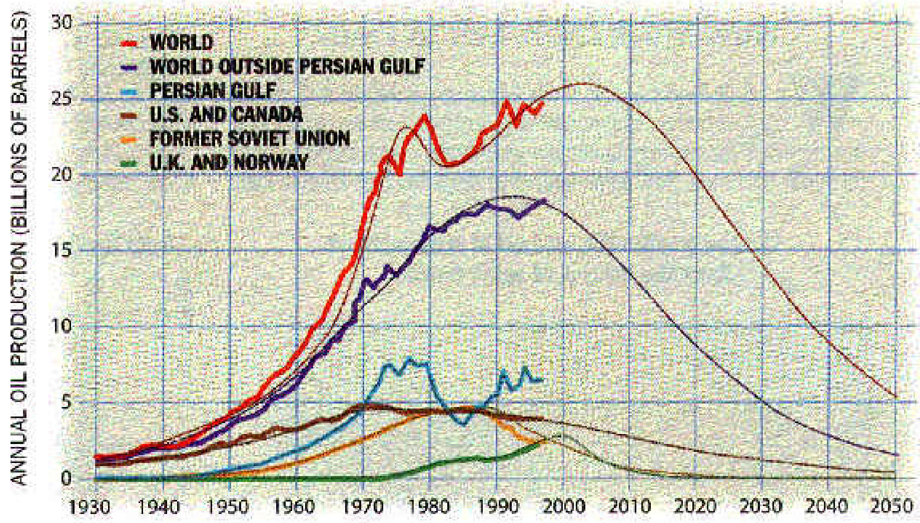

Figure 1. World Oil Production History and Projections

Another article[2] points out that world oil sands and shales could hold several trillion barrels of oil. Alberta's tar sands alone could yield 300 billion barrels of oil using current processing methods - more than the reserves of conventional oil in Saudi Arabia.

It seems likely, in view of continuing requirements for oil as an energy source and raw organic material, that at least some of the decline in conventional production will be replaced by increasing production from oil sands and shales. Thirty years after the first production of oil from Alberta's tar sands deposits, viable and economic production methods have been established. It is difficult to predict the impact on oil use of international concerns with increasing levels of carbon dioxide in the atmosphere. It seems likely this concern will increase the rate of its decline as an energy source. However, it is certain that humanity will benefit from continuing access to oil. It will still be needed as an energy source for specialized applications and as raw material to produce lubricating oil and many other valuable materials.

Canada has agreed, via the Kyoto Protocol, to reduce greenhouse gases by 6% relative to 1990 levels. Fulfillment of this commitment will result in limiting Canada's annual greenhouse gas releases to about 0.5 billion tonnes CO2 equivalent. Current oil sands extraction and upgrading processes, which use natural gas as an energy and raw material source for hydrogen used in the production of synthetic crude oil from bitumen deposits near the surface, release about 0.12 tonnes of CO2 per barrel of oil produced as indicated in Figure 2.

A new Steam Assisted Gravity Drainage (SAGD) process has been developed and demonstrated in Canada during the last decade. It is compatible with the steam conditions from CANDU reactors would release about 0.10 tonnes/barrel for extraction and upgrading of bitumen from much deeper deposits.

We conjecture that world oil use remains constant for the next 50 years while Alberta oil sand production increases to replace the decreasing supply of conventional oil discussed above. Carbon dioxide releases from the increased annual oil sand production of 20 billion barrels would thus be on the order of 2 billion tonnes based on wide adoption of the SAGD process. This is four times Canada's Kyoto commitment with respect to total emissions. It is clear that

Canada's commitment to the Kyoto protocol could potentially constrain the growth of oil sands production, if CO2 intensive processing methods are continued.

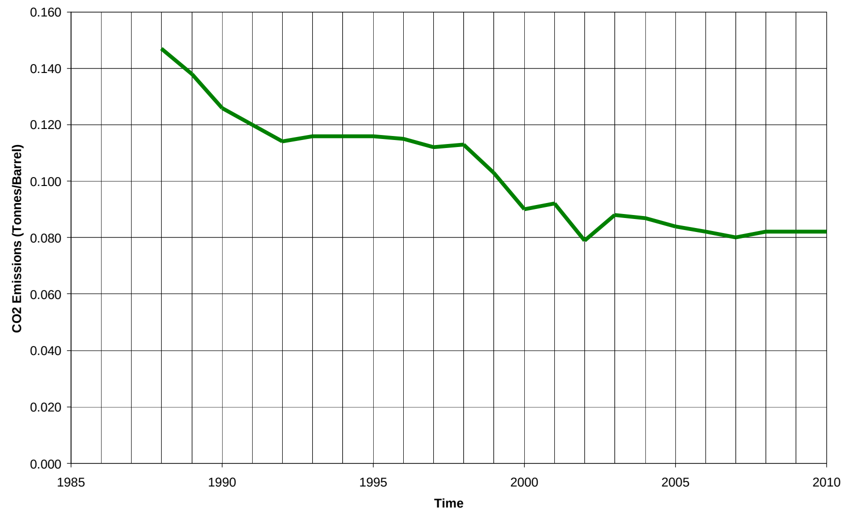

Figure 2. Carbon Dioxide Emissions from Near Surface Bitumen Deposits and Upgrading

We review the technical potential for nuclear energy as a means of recovering oil from Alberta's tar sands while essentially eliminating greenhouse gas emissions relative to production using natural gas.

Carbon Dioxide Emissions from Syncrude Production

Natural gas is currently the fuel of choice in the oil sands industry. It is used to produce steam for bitumen extraction and as a raw material to be reformed to produce hydrogen for bitumen upgrading to syncrude. The oil sands industry also produces other greenhouse gases. (*Natural gas generally co-exists with bitumen deposits. It is possible, although we have not undertaken a quantitative evaluation, that this could be captured and processed to produce liquid fuel as part of a highly integrated energy complex.*) However the volumes are dwarfed by the CO2 emissions and therefore have not been explicitly estimated for this report. We focus on estimating CO2 emissions from the end uses of steam production and reforming as a basis for establishing emissions to be avoided by the deployment of GHG free nuclear energy.

Today the largest volume of production from oil sands is by open pit mining and subsequent extraction by the hot water process. Two major companies[3,4] have reported CO2 emissions from operations and plans for reduction of emissions. Some changes of processes are underway and energy efficiency improvements are being implemented. These are leading to decreased CO2 emissions. This information is summarized in Figure 2. Bock and Donnelley[5] report that upgrading requires 2200 SCF, or 0.00532 tonnes, of hydrogen per barrel of syncrude. To produce this hydrogen using steam methane reforming Donnelly provides[6] information that 0.0526 tonnes of carbon dioxide is emitted per barrel of syncrude produced. It is fair to assume that the mining and extraction would account for most of the remaining carbon dioxide emissions which is between 0.0294 and 0.0344 tonnes of carbon dioxide emissions per barrel of syncrude produced or 0.02 to 0.03 tonnes of carbon dioxide emissions per barrel of bitumen produced from the mining and extraction process.

Another report[7] provides information on carbon dioxide emissions from the in-situ production of bitumen using the cyclic steam stimulation (CSS) process. Emissions varied somewhat with production rates but averaged around 0.085 tonnes of CO2 equivalent for the 1990's.

We do not have access to data for GHG emission from the newer SAGD projects discussed in the next section. However, we have information on steam to oil ratios (SOR) and can estimate emissions from SAGD projects from that information. . Twelve existing and proposed SAGD projects were evaluated[8]. The review establishes an average of slightly over 0.05 tonnes of CO2 equivalent per barrel of bitumen for extraction alone. Adding CO2 emissions from hydrogen produced for upgrading, based on natural gas reforming, increases emissions to about 0.10 tonnes CO2 per barrel. This estimate is taken as a basis to project the emissions for future SAGD extraction and upgrading projects.

Steam Assisted Gravity Drainage (SAGD) Projects

The CSS process has not been successful in the Athabasca Oil Sands where most of the resource is located. The new SAGD process has been developed and demonstrated over the past decade.

This approach to the recovery of heavy oil depends on placing a long horizontal production well near the base of the reservoir and placing a steam injection well parallel to the producer and approximately 6 meters above the production well.

Communication is established between the injector and the producer by circulating steam in both the injector and the producer. The reservoir between the two wells is heated by conduction. Once heated the tar or bitumen flows and communication between the wells is possible.

Once the communication is achieved, because of the low density of gaseous steam it rises in the reservoir from the injection well and heats the formation. The heated oil and water (both condensed steam and heated formation water) in the formation drain down to the horizontal production well from which they are produced to surface. The mechanism by which the process proceeds within the reservoir is illustrated in Figure 3.

As the oil and water is withdrawn from the reservoir, the steam chamber expands both upwards and sideways. The upward growth proceeds in a random but rapid manner until it is limited by the top of the reservoir. In contrast, the steam chamber expands sideways and downwards in a very stable manner.

At a later stage in the process, when the chamber has reached the top of the reservoir, the rate of oil production is controlled by the lateral expansion of the steam chamber. During this phase of the process the production rate will decline and the Steam Oil Ratio (SOR) will eventually increase because of heat losses to the overburden.

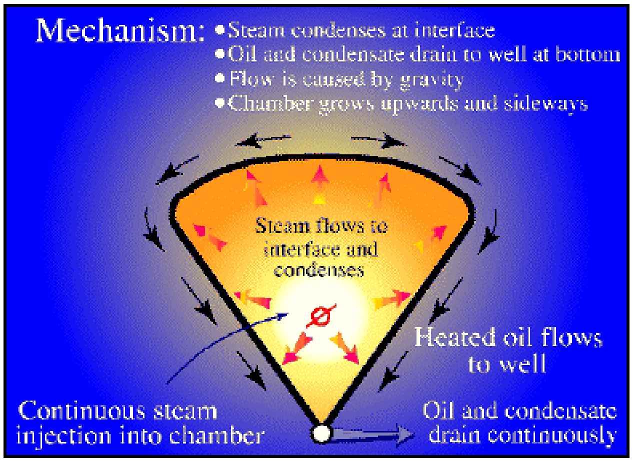

Figure 3: Essential Features of the SAGD Process

Lifting the produced fluids to surface can be achieved in several different ways. Down hole pumps or gas lift can be used. However, if the down hole pressure is sufficient the fluids will flow to surface without artificial lift. The produced water is very near the boiling point at bottom hole conditions. As the water rises in the production well the pressure on the fluid decreases and vapor is formed. This vapor reduces the effective density of the fluid and lifts it to the surface. This phenomenon is called a two-phase thermal siphon. This phenomenon is commonplace, from coffee percolators to geysers.

Demonstration of the SAGD technology was initiated over ten years ago at a site now referred to as the Dover Project. This project was originally funded by a joint government-industry group and operated by the Alberta government. The Dover lease has limited potential. The Dover project will not expand beyond 5,000 barrels per day. However, the technical success of the project has led to several new SAGD pilot and commercial project announcements.

A review[9] indicates twelve projects at seven sites ranging from 5,000 to 100,000 barrels/day have been committed or are being planned. It is deemed likely they will all proceed. However, the timing of these projects will be influenced by market conditions. The current low oil price has already caused some of the projects to be delayed or scaled back. A composite estimate of production from these sites indicates that total production from the SAGD process could well reach 165,000 barrels/day by 2010. Emissions of CO2 from this production, including upgrading, would be on the order of 6 million tonnes/year based on current processes. The role Canada's tar sands will play in supplying oil to the world is something we might ponder. The Scientific American article mentioned in the introduction[10] indicates a major decline in conventional oil supplies beginning about 2010. Concurrently, international commitment to the Kyoto protocol may also reduce dependency on oil thus stretching out supplies. In any case the oil contained within the tar sands is sufficient to produce several billions of barrels of oil per year for a sustained period of many decades.

Reviewing the short history of oil sands production suggests that, based on current production and past rates of growth, production in 2050 would reach about 1.5 billion barrels/year. About half would come from in situ projects. Pessimistically assuming half the historical growth rate results in 2050 production of 750 million barrels/year. Presuming the production rate increases at a higher than historical rate of 5%/year, compounded annually, results in production of 3 billion barrels/year by 2050. Although this is far below the 20 billion barrels/year potential conjecture in the introduction, it still represents very large CO_2 emissions on the order of 75 to 300 million tonnes/year when upgrading of the bitumen to syncrude is included. The upper estimate is approaching half of Canada's current CO_2 emissions. Committment to Kyoto could thus severely curtail Canada's opportunity to supply oil to the world in the future. Beyond Kyoto commitments are expected to require even greater constraints on CO_2 emissions. Adherence to these requirements would require sequestration of CO_2 to avoid emissions or the use of alternate GHG free energy sources for bitumen extraction and upgrading.

We outline the scope of a project which would use alternate GHG free energy from a standard CANDU reactor module.

A Project Concept Proposal

Production of synthetic crude oil from Alberta's tar sands involves two major basic steps. The oil and sand are heated to separate the raw bitumen from the sand. This may be done by mining and processing the sand or, in situ, by applying heat to the sand underground. The bitumen produced from this process is not equivalent to normal crude oil as it is much "heavier" with a preponderance of high carbon content components. The raw bitumen must be "upgraded". The preferred way to accomplish this is to add hydrogen to the bitumen, forming less viscous "lighter" components with a lower carbon content.

Current processes and those under development and demonstration focus on the use of steam to supply heat. Natural gas is used as both fuel to produce steam and as a raw material for the production of hydrogen. Carbon dioxide is a byproduct of it's combustion and of the "reforming" of natural gas to produce hydrogen.

A CANDU nuclear reactor is proposed to be used to provide steam and electricity. The latter would primarily be used to produce hydrogen from water by electrolysis. A useful byproduct of the operation would be the oxygen stream from the electrolysis process. This oxygen could be used to produce liquid fuel[11] from natural gas or in combustion processes to produce carbon dioxide exhaust gas free from nitrogen and so suitable for use in oil recovery combined with sequestration. It is also possible to produce heavy water very economically[12] in synergy with the electrolysis process. Heavy water is an essential material component and significant cost component of the CANDU (CANadian Deuterium Uranium) heavy water reactor. (*Another potential synergy between oil sands production and CANDU reactors has been identified[13]. Oil sands deposits include significant quantities of zircon, which is a source of zirconium metal and an essential material for CANDU reactors.)*

Several studies of the potential for use of nuclear energy for extraction of tar sands oil have been undertaken. The latest Canadian study[14], completed in 1994, considers the application of a CANDU 3 reactor using the new SAGD extraction process. This now proven in situ process does not require the high pressure steam required in the processes reviewed in earlier studies. It is thus suitable for the steam conditions typically output by CANDU reactors. The study notes that the McMurray formation in northern Alberta includes 28 townships (1000 square miles) of high quality resource appropriate to the SAGD process. It estimates that this area could produce 40 billion barrels of oil. The Athabasca region contains an additional 300 billion barrels deemed recoverable by the SAGD process.

A single large dedicated CANDU 9 reactor could supply the steam and electricity to extract and upgrade about 600 million barrels of bitumen over a period of 30 years. The land area from which bitumen would be extracted is about 18 square miles requiring steam distribution and bitumen recovery piping from a centrally located 60,000 barrel/day plant of up to about 3 miles. Smaller reactors would be suitable for smaller production rates with shorter piping distance.

In summary, the project concept is based on a single reactor and electrical generating equipment sized to supply steam and hydrogen for extraction and upgrading of bitumen from 9 to 18 square miles of land area. Production rates range from 30,000 to 60,000 barrels of syncrude per day for standard CANDU 3 and CANDU 9 sized reactor systems. Valuable byproducts include 50 to 100 tonnes year of heavy water and 0.5 to 1 million tonnes per year of oxygen. Carbon dioxide emission avoidance by each such project would amount to about 1 to 2 million tonnes per year. Information needed to derive this quantitative information is summarized in Appendix A.

Observations and Conclusions

Review of the foregoing leads to the following observations and conclusions.

Research and development over the past 50 years has resulted in viable means of extracting and upgrading bitumen from the oil sands which can be sold in competition with conventional oil supplies.

There is great potential for additional exploitation of bitumen as a replacement for dwindling supplies of conventional oil over the coming century.

Substantial quantities of energy and raw materials are required to produce syncrude from the oil sands. Current production methods depend on natural gas as an energy source and as raw material for hydrogen production. Greenhouse gases are emitted which could constrain production because of climate change commitments.

Nuclear energy provides an alternate large scale source of energy which can be used to produce steam for extraction and hydrogen from water by electrolysis for upgrading.

Oxygen is a byproduct of hydrogen production from water which can be sold or used locally in combustion processes to enhance sequestration, or it can be used to produce liquid transport fuels from natural gas. Heavy water can be produced very economically during the electrolysis process reducing the cost of future CANDU reactors. There is thus a unique synergy between these two major Canadian technologies.

Oil sands extraction projects are reaching a size which is commensurate with the large scale energy production inherent to the CANDU reactor concept. Projects up to 100,000 barrels per day are being contemplated. Current CANDU products are suited to the energy requirements of projects extracting and upgrading 30,000 to 60,000 barrels/day. Each system deployed would avoid from 1 to 2 million tonnes of carbon dioxide annually. The potential scope for production of world oil supplies from the oil sands could require the deployment of dozens of projects of this scale avoiding on the order of 100 million or more tonnes of CO_2 annually.

Energy from the CANDU reactor most effectively avoids CO_2 emissions when applied to extraction. The upgrading step requires much more energy per unit of CO_2 avoided.

Additional potential synergies between this project concept and other aspects of CANDU and petroleum production exist. The large quantities of oxygen produced may be useful for liquid fuel production from natural gas or as a means of producing CO_2 rich exhaust from combustion processes. CO_2 can be used to enhance oil recovery while being simultaneously sequestered underground. Zirconium production from the zircon concentrated in the waste stream may be feasible.

These technical facts argue strongly in favor of continued technical, environmental and economic evaluation of the basic concepts presented to establish an optimum system. A major opportunity exists to capitalize on uniquely Canadian technology and world demand for petroleum products while meeting Canada's commitments to the Kyoto protocol.

Appendix A

Supplementary Technical Data

Basic Electricity Needs

A study of a CANDU 3 with a 450MW(e) reactor application to bitumen extraction indicates that, 32 MW(e) are used internally and 0.2 MW(e) electrical power per 1000 BPD is devoted to bitumen production facilities.

Electricity Displaced by Steam production

With all remaining energy dedicated to steam production 123,000 BPD bitumen is produced. Thus 395 MW of potential electrical output results in 123,000 BPD. This may be expressed as 0.0032 Mw(e) - days/barrel.

Electricity Required for Hydrogen Production for Upgrading

Upgrading requires 2200 SCF, or 0.00532 tonnes, of hydrogen per barrel of syncrude[15]. One kilogram of hydrogen may be produced by electrolysis from water with the expenditure of about 50kWh. This may be expressed as 0.0108 MW(e) - days/barrel

Oxygen and Heavy Water Production

For each tonne of hydrogen produced by electrolysis of water , eight tonnes of oxygen are liberated. Application of the symbiotic CECE (Combined Electrolysis and Catalytic Exchange) process to recover deuterium to make heavy water results in about 1 tonne of heavy water per 1000 tonnes of hydrogen[16].

CANDU Reactor Oil Sands and Upgrading Plant Production

From the data above, a CANDU reactor of the size needed to produce 450 MW(e) would be able to extract the bitumen and upgrade it with hydrogen to produce 30,000 barrels of synthetic crude per day or about 10 million barrels per year. The required nominal electrical capacity of the generators would be 360Mw(e). The quantity of hydrogen generated is about 55,000 tonnes per year. In association with this hydrogen about 55 tonnes of heavy water and 440,000 tonnes of oxygen is obtained annually. On the order of 1 million tonnes of CO2 would be avoided annually(see the report body) relative to emissions from a similar plant using natural gas for heat and as a raw material for hydrogen production. For the purpose of this report, the output of CANDU 6 and CANDU 9 reactors of 700 Mw(e) and 950 MW(e) nominal capacity, respectively, can be scaled up linearly.

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