Economic Analysis of the Application of Nuclear Thermal Sources to SAGD Extraction Technologies to Eliminate GHG Emissions

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Background

The attached table demonstrates the use of patented methods, on a pro forma basis, of the economic and financial value of using a nuclear thermal source in order to eliminate the Greenhouse Gas Emissions (GHG) from oil sands production when using the *in-situ* method known as Steam Assisted Gravity Drainage (SAGD).[1] The SAGD method of oil sands production is used because 80% of the oil sands reserves in Canada are at a depth which is not compatible with surface mining methods. As a result, it is clear that the SAGD method will be increasingly used as time and oil sands production progresses and increases.

The use of natural gas combustion as a source of thermal energy in SAGD oil production results in substantial emissions of GHGs. Currently, the use of natural gas in oil sands production in Canada utilizes 30% of the entire volume of natural gas consumed in Canada. The amount of natural gas use for oil sands production is projected by the Alberta Energy Regulator to increase by 62% by the mid-2020s.[2] In 2015, oil sands producers emitted over 70 million MT of GHG's and that will increase to over 100 million MT annually during the next decade according to Canadian government sources.[3] These GHG emissions arise almost exclusively from the use of natural gas as a source of thermal energy for production of bitumen and the upgrading of bitumen to Synthetic Crude Oil (SCO) which is a marketable product. Substitution of nuclear thermal sources for natural gas combustion in SAGD oil production and upgrading processes eliminates this source of GHG emissions and natural gas purchases.

This analysis uses the GE – Hitachi PRISM Mod A Reactor as a proxy reactor for a thermal source. This reactor has a thermal rating of 471 MW_{th}. Because the steam output of the reactor is used only for powering a SAGD *in-situ* oil extraction system, the operation of this

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[1] SYSTEM FOR EXTRACTION OF HYDROCARBONS FROM OIL SANDS, Granted US Patent No. 7,931,080, issued 4/26/2011
METHOD AND SYSTEM FOR EXTRACTION OF HYDROCARBONS FROM OIL SANDS, Granted US 8,186,430, issued 5/29/2012
METHOD AND SYSTEM FOR EXTRACTION OF HYDROCARBONS FROM OIL SANDS, Granted Canadian Patent 2,643,214, issued 4/12/2016

[2] http://www.naturalgasintel.com/articles/110182-natgas-demand-from-oilsands-producers-projected-to-balloon (accessed June 7, 2017)

[3] *Canadian Oil Sands Supply Costs and Development Projects (2016-2036)*, Canadian Energy Research Institute, 2017, p.xvii

reactor involves no electric generation. Therefore, all capital costs and operational costs associated with the electric generation block are omitted from this analysis. This also means that the steam output of the reactor need not be of the strict quality standards that would be used for input to a steam turbine electric generation unit.

The data that are used in this analysis are taken from Canadian government and industry sources in order to illustrate the potential value of the patents noted above. The patents have been issued in both the United States and Canada and cover the use of any type of nuclear thermal sources in any type of oil sands production.

The Analysis

The number of kilograms of GHG produced from SAGD production (principally carbon dioxide) are 116 kg per CO_2e per barrel of bitumen. The bitumen which is produced then is upgraded and converted into SCO which is the marketable product from oil sands production. That adds approximately 50 kg of CO_2e emissions per barrel. In all, using SAGD the production of a barrel of oil produces approximately 166 kg of CO_2e.

The PRISM Mod A Unit is capable of producing approximately 60,000 barrels of oil per day (BPD) in a SAGD operation. On an annual basis, the emissions produced by the SAGD operation using natural gas combustion as a thermal source will be 3,635,400 MT. The federal government in Ottawa has directed that, at a minimum, a carbon tax of $50 per MT will be levied on all GHG emissions by the year 2022.[4] While other methods of GHG emission reduction in oil sands production such as solvent extraction and Carbon Capture and Sequestration (CCS) have been proposed, none has been proven to be economic.[5] Because the lead time for licensing, planning, construction, and startup of a nuclear reactor takes several years, it is likely that by the time the reactor begins operating it will be 2022 or at least approaching that time. If a nuclear thermal source were used instead of natural gas, the avoided carbon tax in Canadian dollars would be $181,770,000 per year. ($134,644,444 per year USD).

In addition, the operation using nuclear thermal sources would not have to purchase natural gas. An avoided cost of $3.00 per MMBtu is used in this analysis to reflect the likely cost of avoided natural gas purchases in 2022 and after.[6] At this price, the avoided

[4] https://www.technologyreview.com/s/602857/canada-moves-ahead-on-carbon-taxes-leaving-the-us-behind/ (accessed June 7, 2017)

[5] It should be noted that the cost of carbon capture and storage has been conservatively estimated to be more than $57 CDN per MT by the Canadian Federal Government, *Canada's Greenhouse Gas Emissions: Developments, Prospects and Reductions*, Office of the Parliamentary Budget Officer, April 21, 2016

[6] There are number of factors which may influence this price including the likely exportation of liquefied natural gas (LNG) which is currently a product that is growing in international commerce at a very fast pace. This price could very well be much higher in the future.

natural gas purchases would be $42,245,704 per year.

The use of the 165 MWe MOD A GE – Hitachi reactor was chosen in order to have a reasonable proxy for any reactor which would be used in oil sands service. It is also one of the only Small Modular Reactors (SMR) that has received initial approval from the USNRC. As such, it is reasonable to anticipate that future reactors would be at least as effective and efficient as the proxy reactor used because the development of SMRs has been progressing rapidly and is expected to continue doing so.

The sum of the avoided gas cost and the avoided carbon tax produces a total avoided cost of $224,015,704 per year using a nuclear thermal source. The inclusive operating cost for the reactor without any generation block is estimated using government sources to be $8.80 per megawatt thermal produced for a total operating cost of $99,475 per day. The total annual operating cost of the reactor is calculated to be $36,308,448 per year.

The installed capital cost per megawatt hour thermal has been calculated to be $2,669,938. For the full 471 MW thermal installed the capital cost of the reactor is estimated to be $1,257,540,798. At a debt/equity level of 60/40, the annual debt payments through an amortization calculation over 15 years at 6% annual interest compounded annually is $77,687,926. Therefore, the total annual operating cost plus annual debt payments is $113,996,374 annually. This leaves a residual value for the project substituting nuclear thermal sources for natural gas combustion of $110,019,331 for a conservative rate of return on the invested equity of $503,016,319 or 22%.[7]

Conclusion

The patents and substitution of nuclear thermal sources for natural gas combustion clearly have value with regard to the future of oil sands production. Canada's GDP depends heavily on oil sands production as it currently constitutes almost 3% of Canada's GDP.[8] If this production increases by 62% by the mid-2000's, as has been projected by CERI, revenues from oil sands production will exceed $7 billion and become an even more important contribution to Canada's economy. As a result, it is very unlikely that this production will be curtailed. At the same time, the threat of climate change accelerating as GHG's accumulate in the atmosphere may very well force Canada into raising its proposed $50 per MT tax to amounts above that. If that happens, the value of the patents and the use of nuclear thermal sources rather than natural gas combustion will increase dramatically.

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[7] This return is indifferent to the market price of oil since it is only the result of substituting nuclear thermal sources for natural gas combustion.

[8] Canada's GDP in 2015 was $1.55 trillion. At $50 per barrel CDN the production of oil sands in Canada of 912,500,000 barrels equals approximately $4.562 billion.

PRISM MOD A Oil Sands Economic Analysis--Confidential

SAGD Productoin Emissions	Assumptions		
	1MT = 1,000 KG		
	KG GHG per barrel SCO		
	In situ extraction		116
	Upgrading & Conversion		50
	Total per barrel (KG)		166
	Total per barrel (MT)		0.166
Emission Savingss Analysis	Annual		
Single PRISM MOD A Unit (bpd)	60,000		
Emissions per day (MT)	9,960		
Emissions per year (MT)	3,635,400		
GHG Tax per MT	$ 50.00		
Total GHG Tax $50 CAD		$	181,770,000
In $USD		$	134,644,444

Avoided Gas Costs $CAD	MW Thermal Capacity		471
	MMBTU per Hour		1,608
	MMBTU per day		38,581
	MMBTU per year		14,081,901
	Gas Cost $CAD	$	3.00
	Total Avoided Gas Cost	$	42,245,704

165 Mwe MOD A PRISM per year		
Total Avoided Gas Cost	$	42,245,704
GHG Tax $CAD	$	181,770,000
Total Revenue (Avoided Cost)	$	224,015,704
Operating Cost per MWTh $CAD	$	8.80
MWTh per day		11,304
Op cost per day $CAD	$	99,475
Annual Op Cost	$	36,308,448
Capital Cost $CDN		
Capital Cost per MWTh Installed	$	2,669,938
Total Capital Cost	$	1,257,540,798
Equity (40%)	$	503,016,319
Debt $CAD (60%)	$	754,524,479
Annual Debt Payments	$	77,687,926
Debt Interest Rate		6%
Total Annual Op and CAPEX Cost	$	113,996,374
Profits per reactor-year	$	110,019,331
Return on Equity		22%

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