PAPER 2003-096

PETROLEUM SOCIETY
CANADIAN INSTITUTE OF MINING, METALLURGY & PETROLEUM

CANADIAN INTERNATIONAL
PETROLEUM CONFERENCE

Does Nuclear Energy Have a Role in the Development of Canada's Oil Sands?

R.B. Dunbar, T.W. Sloan
Canadian Energy Research Institute

This paper is to be presented at the Petroleum Society's Canadian International Petroleum Conference 2003, Calgary, Alberta, Canada, June 10 – 12, 2003. Discussion of this paper is invited and may be presented at the meeting if filed in writing with the technical program chairman prior to the conclusion of the meeting. This paper and any discussion filed will be considered for publication in Petroleum Society journals. Publication rights are reserved. This is a pre-print and subject to correction.

ABSTRACT

The Canadian Energy Research Institute (CERI) recently completed a study for Atomic Energy of Canada Limited (AECL) that compares the economics of a modified ACR-700™ Advanced CANDU Reactor with the economics of a natural gas-fired facility to supply steam to a hypothetical Steam Assisted Gravity Drainage (SAGD) project located in north-eastern Alberta. This paper presents the results of CERI's evaluation.

The comparison was made by using discounted cash-flow methodology to estimate the levelized unit cost of steam that could be supplied to the SAGD project from either a nuclear or a gas-fired facility. The unit cost of steam was determined by treating the steam supply facility as a standalone business; it would ensure that all costs are recovered including capital costs, operating costs, fuel costs, and a return on investment.

The study indicated that steam supply from an ACR-700 nuclear facility is economically competitive with steam supply from a gas-fired facility. An examination of key variables indicated that the cost of steam from the nuclear facility is very sensitive to capital cost of the facility, while the cost of steam from the gas-fired facility is very sensitive to natural gas price and possible Kyoto compliance costs.

INTRODUCTION

The Alberta Energy and Utilities Board (EUB) estimated that Alberta's oil sands deposits contain 259.2 $10^9 m^3$ of initial crude bitumen in-place and that over 10% of the initial crude bitumen in-place (28.33 $10^9 m^3$) is recoverable using either surface mining (5.59 $10^9 m^3$) or in situ recovery (22.74 $10^9 m^3$) techniques.[1] At year-end 2001, only 2.0% (0.56 $10^9 m^3$) of the initial established reserves had been produced.

The EUB reported that, in 2001, Alberta produced 116.6 $10^3 m^3/d$ of crude bitumen, with surface mining accounting for 58% and in situ recovery 42%. In the same year, non-upgraded bitumen and synthetic crude oil accounted for 43% of Alberta's total crude oil and equivalent production. The EUB reported that it expected total mined bitumen production to increase from 67.4 $10^3 m^3/d$ in 2001 to 223 $10^3 m^3/d$ in 2011 and in situ crude bitumen production to increase from 49.2 $10^3 m^3/d$ in 2001 to 126 $10^3 m^3/d$ in 2011. Total bitumen production in 2011, 349 $10^3 m^3/d$, would represent a three-fold increase from 2001. Based on the configuration of currently operating projects, it is estimated that achieving this production level could require approximately 60 $10^6 m^3/d$ of natural gas in 2011, a significant quantity relative to Alberta's remaining established reserves of 1,184 $10^9 m^3$ at year-end 2001 and total production of 143 $10^9 m^3$ that year (Reserve Production Ratio of 8.3 years). Using nuclear energy to generate steam would reduce the oil sands industry's reliance on limited natural gas resources, reduce its exposure to volatile natural gas prices, and reduce its greenhouse gas (GHG) emissions.

This study updates work carried out over the last two decades regarding the possible application of nuclear technology for oil sands development.[2,3] The study focuses on the relative economics of the nuclear and gas-fired steam generation options. It does not address non-economic issues that might be associated with either option.

THE ACR-700 NUCLEAR REACTOR

The ACR-700 Advanced CANDU Reactor, designed by AECL, is the genesis of a new generation of technologically advanced nuclear reactors founded on the proven CANDU reactor concept. In the ACR-700 configuration, the CANDU power plant uses a heavy-water moderated and a light-water cooled reactor system. It continues CANDU's on-power fueling capability, which eliminates the need for scheduled outages built around refueling requirements.

The ACR-700 is a 731 MW_e (1,983 MW_t) design. It has evolved from technological changes made to previous reactor systems that make it more economical to operate and less expensive to build. Some of the advances include: substituting light-water coolant for the heavy-water coolant used in earlier reactors designed by AECL; using slightly enriched uranium fuel; increasing the thermal operating capability of the fuel bundles; reducing the size of the reactor core; reducing and simplifying the heat transport system; increasing thermal efficiency by operating with higher reactor coolant temperature and pressure; and adapting advanced construction techniques that have been proven at recent CANDU 6 construction projects in China and Korea. The typical configuration for the generation of electricity using an ACR-700 is shown in Figure 1.

EVALUATION APPROACH

The economics of the nuclear and gas-fired options were compared by using discounted cash-flow methodology to estimate the levelized unit cost of steam that would be supplied to the SAGD project from either the nuclear or the gas-fired facility. The unit cost of steam was determined by treating the steam supply facility as a standalone business; it would ensure that all costs are recovered including capital costs, operating costs, fuel costs, and a return on investment.

For the purpose of this evaluation, the steam generation facility was "ring-fenced" as illustrated in Figure 2. It was assumed that water treating facilities would be outside the plant boundaries; i.e., identical external water treating facilities would supply treated boiler feedwater (BFW) to either the nuclear or the gas-fired steam generation facility. It was assumed that the BFW would meet quality specifications typical for oilfield Once Through Steam Generators (OTSGs) as specified in Table 1. The BFW would be provided to the steam generation facility at 170^0C.

STEAM GENERATION USING THE ACR-700

A nuclear plant can be built with any steam/electricity ratio that a customer may want provided that there is enough electricity available to operate the plant. For the purposes of this study, AECL provided a configuration where most of the thermal energy produced by the ACR-700 would be used for steam production rather than the generation of electricity. Steam from the ACR-700 unit's steam generators would be directed to "saline water boilers" where it would exchange heat with treated BFW for generation of SAGD steam (80% quality, 3.0 MPa). A steam quality of 80% was selected to match the quality of steam typically produced in by oilfield gas-fired steam generators. Higher steam quality would likely be possible for the nuclear configuration since steam is produced by heat exchange rather than by gas firing, which has more serious scaling problems. While the 3.0 MPa steam pressure is adequate for subsurface injection at most SAGD operations, it would be possible to reconfigure the nuclear facility to produce higher pressure steam if desired. Figure 3 is a schematic diagram for the ACR-700 nuclear facility in the steam generation configuration.

AECL calculated stream day outputs for the nuclear facility to be 78,020 m^3/d of 80% quality steam and 100 MW (net) of electricity (unless otherwise stated, all capacity figures are given on a stream day basis). The selection of this configuration was somewhat arbitrary; it would be possible to design the facility to produce less steam and more electricity if desired. No attempt was made to optimize the balance between steam and electricity output.

AECL estimated the capital cost of the nuclear facility to be $1,400 million (unless otherwise stated, all costs are given in constant 2002 Canadian dollars) and the annual operating cost to be $91 million, including fueling costs and spent fuel management costs. AECL included an allowance for higher Northern Alberta construction costs when preparing its capital cost estimate, and expects it could mitigate the capital cost overrun risk through a high level of modularization in the design.

GAS-FIRED STEAM GENERATION

The SAGD process traditionally uses gas-fired generators to produce steam for subsurface injection and in situ bitumen recovery. Steam can be produced using either standalone OTSGs or Heat Recovery Steam Generators (HRSGs) in a cogeneration configuration. For the purpose of this study, a gas-fired configuration was selected that would match the steam and electricity output of the nuclear option (i.e., 78,020 m^3/d of 80% quality steam and 100 MW of electricity).

Equipment requirements for this configuration consist of one Alstom 11N2 gas turbine/electrical generator set (116.5 MW ISO rating), one HRSG producing 13,700 m^3/d of steam, and 21 conventional OTSGs producing the remaining 64,320 m^3/d of steam. Capital cost for this facility was estimated to be $230 million. Annual operating and maintenance cost was estimated to be $8.5 million excluding fuel costs. Natural gas fuel requirements were estimated to be 164,800 GJ/d.

SAGD PROJECT

The nuclear and gas-fired facilities were both configured to produce 78,020 m^3/d of 80% quality steam. Following separation, 62,400 m^3/d of 100% quality steam would be available for injection into the oil sands reservoir. Operation at a 93% capacity factor and a 2.5:1 steam oil ratio would result in a calendar day bitumen production rate of 23,200 m^3/d (146,000 b/d).

A project of this size is large relative to existing commercial SAGD projects. However, several companies have announced plans and filed applications for projects in the 12,700 m^3/d (80,000 b/d) to 15,900 m^3/d (100,000 b/d) range. Given the limitations of transporting steam over long distances, adequate bitumen reserves to support a project of this scale (23,200 m^3/d) would need to be located within reasonable proximity of the central steam generation site.

STEAM SUPPLY COSTS

Discounted cash flow techniques were used to calculate the constant dollar price that the steam generation facility would need to charge for steam to recover all costs and earn a return on investment. The steam generation facility was treated as a standalone business selling steam to the SAGD operator and selling electricity into the Alberta Interconnected Electrical System. Steam supply costs were calculated before tax for comparative purposes (as a crown corporation, AECL is not taxable). Cash flows were discounted at 10%/a (real) to provide a 10%/a (real) return on investment. Base case economics were calculated using flat real natural gas and electricity prices of $4.25/GJ and $50/MWh at the plant gate. The assumed gas price is equivalent to a NYMEX price of US$3.50/MMBtu. Both facilities were assumed to operate with a 93% capacity factor, and to commence operations in 2011. No Kyoto compliance costs were assumed.

Using the assumptions described above, steam supply costs were calculated to be $8.61/t for the nuclear facility and \$8.71/t for the gas-fired facility, roughly the same. Additional details are provided in Table 2.

A sensitivity analysis was conducted to identify key variables and determine their influence on steam supply cost. Results are summarized in Figure 4.

Not surprisingly, the cost of steam supply from the nuclear facility is very sensitive to capital cost of the facility. A 25% increase in the capital cost of the nuclear facility would increase the steam supply cost from \$8.61/t to \$10.31/t.

The cost of steam supply from the gas-fired facility is very sensitive to the cost of natural gas and any Kyoto compliance costs. A 25% increase in the cost of natural gas for the gas-fired facility, from \$4.25/GJ to \$5.21/GJ, would increase the steam supply cost from \$8.71/t to \$10.96/t. A Kyoto compliance cost of \$15 per tonne of CO_2 emitted would increase the steam supply cost from \$8.71/t to \$10.29/t.

OTHER OPPORTUNITIES

The subject study did not attempt to optimize the configuration of the nuclear facility with respect to the balance between steam and electricity output. It would be possible to configure the nuclear facility differently to balance the SAGD operator's steam requirements with opportunities for greater electricity sales.

It may also be possible to use electricity produced at the nuclear facility for generation of hydrogen through hydrolysis of water. A considerable amount of hydrogen is consumed by the oil sands industry to convert crude bitumen into a more desirable synthetic crude oil product. Hydrogen is produced today using steam methane reforming, resulting in increasing demands on limited natural gas resources and significant GHG emissions.

CONCLUSIONS

In conclusion:

1. Steam supply from an ACR-700 nuclear facility would be economically competitive with steam supply from a gas-fired facility;
2. Based on the configuration studied, the ACR-700 nuclear facility would support a very large SAGD project (23,200 m^3/d) - adequate bitumen reserves to support this scale of operations would need to be located within reasonable proximity of the central steam generation site;
3. Steam supply cost from a nuclear facility is very sensitive to capital cost; and
4. Steam supply cost from a gas-fired facility is very sensitive to natural gas price and possible Kyoto compliance cost.

ACKNOWLEDGEMENTS

The authors thank the Canadian Energy Research Institute and Atomic Energy of Canada Limited for permission to publish the results of this study. Technical assistance provided by Outtrim Szabo Associates Limited (Dr. John Donnelly) and Jacobs Canada Inc. is also greatly appreciated.

ABBREVIATIONS

ACR	Advanced CANDU Reactor
AECL	Atomic Energy of Canada Limited
CERI	Canadian Energy Research Institute
CAPEX	Capital Expenditures
EUB	Alberta Energy and Utilities Board
GHG	Greenhouse Gas
HRSG	Heat Recovery Steam Generator
NYMEX	New York Mercantile Exchange
OTSG	Once Through Steam Generator
OPEX	Operating Expenditures
SAGD	Steam Assisted Gravity Drainage

REFERENCES

1. Alberta Energy and Utilities Board; Alberta's Reserves 2001 and Supply/Demand Outlook 2002-2011; Statistical Series 2002-98.

2. Bock, D. and Donnelly, J.K.; Fuel Alternatives for Oil Sands Development – The Nuclear Option; Proceedings of the Canadian Nuclear Society Annual Meeting, Saskatoon, Saskatchewan; May 1995.

3. Bancroft, A.R.; Nuclear Energy for Oil Sands - A Technical and Economic Feasibility Study undertaken jointly by Atomic Energy of Canada Limited, Alberta Power Limited, Petro-Canada and NOVA; Chalk River Nuclear Laboratories; February 1982.

Factor or Component	*Level Required*
Hardness ($CaCO_3$)	1 ppm or less
Total Dissolved Solids ($CaCO_3$ Equivalent)	12,000 ppm or less
pH	7.5 to 9.0
Free Oxygen	Negligible
Free Chlorine	Negligible
Iron	0.25 ppm or less
Sulphur	Negligible
Manganese	Negligible
Silica Oxides (dissolved)	100 ppm or less
Oil	0.5 ppm or less

TABLE 1: Boiler Feedwater Quality Specifications

	Nuclear	Gas-Fired
Costs ($/t)		
Fixed Capital	6.71	0.96
Working Capital	0.09	0.01
Fuel	included	8.98
Spent Fuel Management	0.28	0.00
Other O&M Costs	3.07	0.30
Subtotal	**10.15**	**10.25**
Credit for Electricity Sales ($/t)	**1.54**	**1.54**
Total Supply Cost ($/t)	**8.61**	**8.71**

TABLE 2: Steam Supply Costs

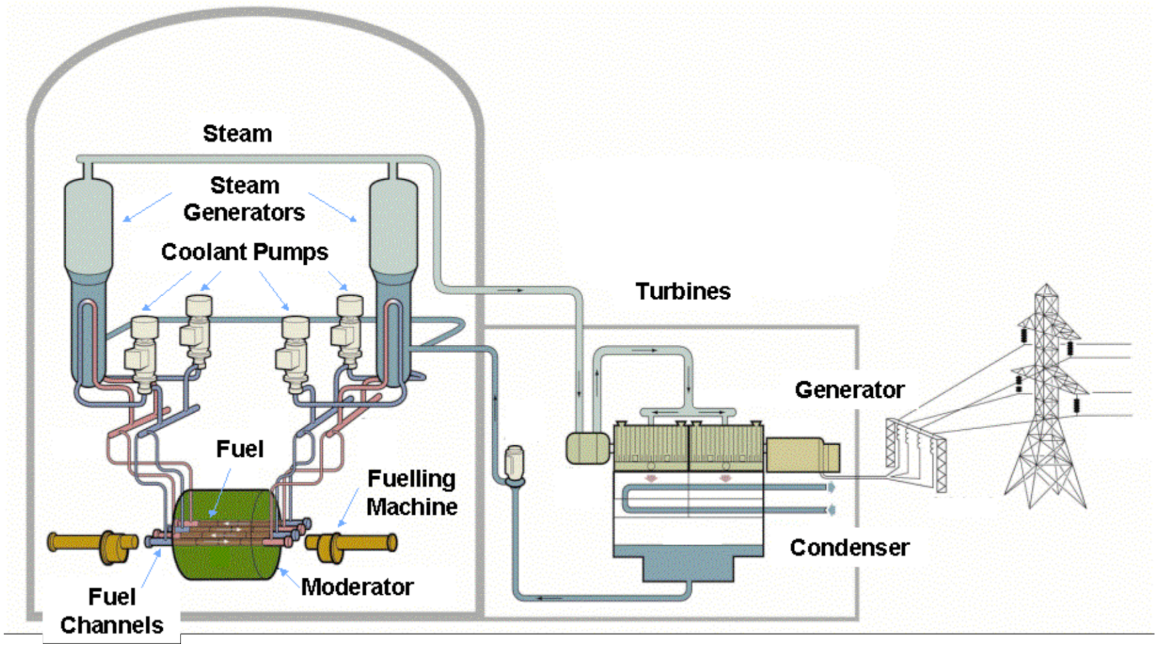

FIGURE 1: ACR-700 Reactor: Typical Configuration

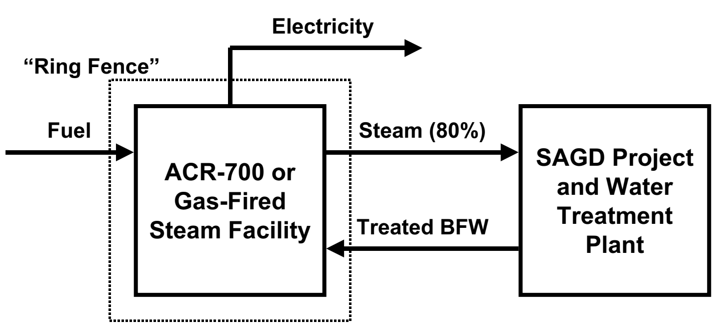

FIGURE 2: "Ring Fence" for Steam Facility

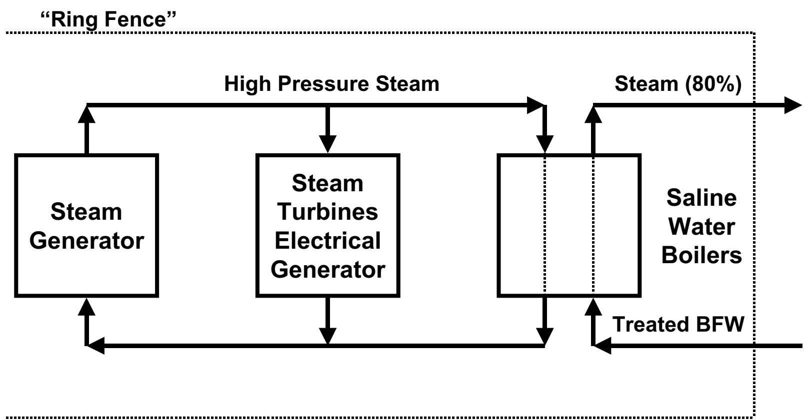

FIGURE 3: ACR-700 Reactor Configured for Steam Generation

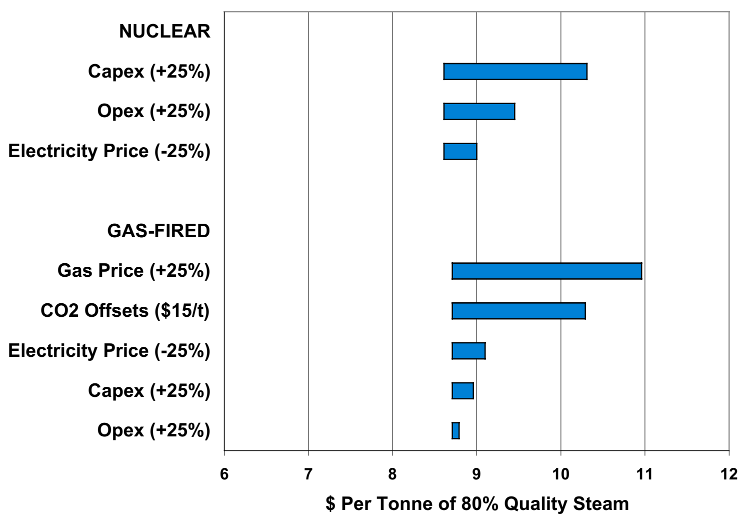

FIGURE 4: Steam Supply Cost Sensitivities