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SUMMARY
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**1170-MW(t) HTGR-PS/C PLANT
APPLICATION STUDY REPORT:
TAR SANDS OIL-RECOVERY APPLICATION**

by
R. RAO and A. T. McMAIN, JR.

Prepared under
Contract DE-AT03-76SF70046
for the San Francisco Operations Office
Department of Energy

DATE PUBLISHED: MAY 1981

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INTRODUCTION

Tar sands represent a major energy resource that increases in importance as world supplies of crude oil become limited. The oil potential from tar sands in Canada is estimated to equal the world's known reserves of conventional oil; the potential of U.S. tar sands is smaller, but still substantial [4.8 to $5.6 \times 10^9 \text{ m}^3$ (30 to $35 \times 10^9 \text{ bbl}$)]. Current Canadian production is limited to deposits suitable for strip mining; however, the major reserves lie at greater depths. To exploit these deep reserves, large-scale pilot projects are investigating in-situ recovery. These projects inject saturated steam into the tar sands deposits.

This report summarizes a study to apply an 1170-MW(t) high-temperature gas-cooled reactor - process steam/cogeneration (HTGR-PS/C) to tar sands oil recovery and upgrading. The raw product recovered from the sands is a heavy, sour bitumen; upgrading, which involves coking and hydrodesulfurization, produces a synthetic crude (refinable by current technology) and petroleum coke. Steam and electric power are required for the recovery and upgrading process. Proposed commercial plants would purchase electric power from local utilities and obtain steam from boilers fired with coal and with by-product fuels produced by the upgrading. This study shows that an HTGR-PS/C represents a more economical source of steam and electric power.

APPLICATION REQUIREMENTS

This study considered a $7300 \text{ m}^3/\text{day}$ (46,000 bpd) tar sands oil recovery plant using an 1170-MW(t) HTGR-PS/C for economic comparison. Subsequent studies considered a commercial $25,400 \text{ m}^3/\text{day}$ (160,000 bpd) plant using four 1170-MW(t) HTGR-PS/C units. However, no economic analysis has been performed on the commercial plant. The HTGR supplied all plant steam requirements.

Table 1 gives the energy requirements for the single-unit plant. The HTGR supplies 64 MW(e); the remaining 19 MW(e) are purchased from the local utility. In the commercial four-unit plant, which is similar to the proposed Cold Lake recovery project in Canada, the HTGRs supply all electric power and produce an extra 160 MW(e) that can be sold to the local utility. The recovery field is subdivided into 28,300-m² (7-acre) parcels, with a centrally located injection well per parcel. Saturated steam at 3.8 kg/s (30,000 lb/hr) and ~13.8 MPa (~2000 psia) is injected in each well. Approximately 80 m³/day (500 bpd) of bitumen is recovered from the 28,300-m² (7-acre) parcel. Thus, the smaller operation will cover ~2.6 km² (1.0 miles²) of the tar sands field, while the commercial operation will cover ~9.1 km² (3.5 miles²).

The tar sands fields are generally located in sparsely populated areas of Canada. Therefore, the HTGR-PS/C plant can be located at the center of the recovery area, minimizing the required piping and the associated pressure drops and heat losses. When the recovery is complete in one quarter of the operating field, the piping will be shifted to the next quarter until the entire field has been covered. Since it takes ~7 yr to complete each quarter of the field, the HTGR-PS/C will have operated most of its design life (30 yr) by the time the recovery is complete.

The nominal steam conditions desired at the injection well are ~13.8 MPa (2000 psia) and 336°C (636°F). Since this steam is obtained by throttling the main steam from 16.65 MPa (2415 psia), adjusting the pressure to account for variations in the distribution pressure drop has some flexibility. A desuperheater using returned condensate reduces the steam temperature to the saturated condition. The steam required for upgrading, water treatment, and auxiliaries can be further conditioned as required. The balance of the steam, not used by the process, is diverted to a turbine generator, which cogenerates electric power and provides a conventional feedwater heating system for the entire condensate flow. The recovery plant processes makeup and clean condensate. To ensure the specified purity for

TABLE 1
ENERGY REQUIREMENTS FOR A 7300 M³ (46,000 BARREL) PER DAY
BITUMEN RECOVERY PROJECT USING IN-SITU STEAM DRIVE PROCESS

Utility Energy Requirements	MW	Energy Requirements Provided by HTGR-PS/C (MW)	Percent Provided by HTGR-PS/C
Injection steam at 13.79 MPa (2000 psia), 336°C (636°F)	894	894	100
Steam for upgrading at 6.21 MPa (900 psia), 278°C (532°F)	76	76	100
Steam for water treatment at 6.21 MPa (900 psia), 278°C (532°F)	22	22	100
Steam for auxiliaries at 6.21 MPa (900 psia), 278°C (532°F)	98	98	100
Electric power	83	64(a)	77
Total	1173	1154(b)	98.4

(a) 19 MW(e) must be supplied from the local power grid.

(b) The upgrading process produces three forms of fuel which, if used in boilers to produce steam, would reduce the HTGR-PS/C requirements as follows:

<u>Fuel</u>	<u>MW</u>	<u>Percent of Total</u>
Coke	9	0.76
Fuel oil equivalent	293	24.91
Gas	37	3.13

the HTGR-PS/C steam generators, the feedwater train includes a full-flow polishing demineralizer.

Figure 1 shows the cycle for the 7309 m³/day (46,000 bpd) plant. In this case, only enough steam for feedwater heating [147 kg/s (1.16 x 10⁶ lb/hr)] is diverted to the turbine generator; the recovery plant uses the balance [439 kg/s (3.48 x 10⁶ lb/hr)]. The turbine generator is a noncondensing unit similar to the high pressure and intermediate pressure units of a small conventional turbine generator; its gross output is 101 MW(e), while its net output is 64 MW(e). The difference is used to drive the HTGR circulators, the feed pumps, the condensate pumps, and other nonprocess auxiliaries. The 64-MW(e) net output must be complemented by a 19-MW(e) power purchase to meet the recovery plant power requirements.

ECONOMIC ANALYSIS

The revenue requirement method was selected to evaluate alternative projects. This technique is appropriate for evaluating long-lived coal and nuclear cogeneration power plant projects. It determines the revenue needed by the firm as compensation for all fixed and variable expenditures. Hence, the revenue requirements of the firm equal the consumer cost for the process steam cogenerated.

Table 2 compares estimated energy costs for the 1170-MW(t) HTGR-PS/C versus the comparable coal-fired PS/C plant for tar sands oil recovery. It shows a clear advantage (27% less cost to deliver energy) for the HTGR over a coal-fired plant.

This analysis is based on economic assumptions used to evaluate utility cogeneration projects in progress for the Department of Energy (DOE) by GA in coordination with Gas Cooled Reactor Associates (GCRA). Table 3 gives the principal assumptions of the economic analysis, a key one being the 18% fixed charge rate for capital use/recovery. Such a rate may be higher if industrial ownership ground rules are applied. Therefore, the economics

TABLE 2
ECONOMIC ANALYSIS OF HTGR-PS/C PLANT VERSUS
COAL-FIRED PS/C PLANT FOR SHALE OIL RECOVERY APPLICATION

	HTGR-PS/C Plant	Coal-Fired Plant
Heat input to cycle (MW)	1170.0	1230.0
Heat output in process steam (MW)	1090.4	1090.4
Net electrical power output (MW)	63.8	71.2
Capital Costs (\$ x 10 ⁶)		
Base capital cost (1/80 \$)	537	351
Escalation through construction	536	396
Interest during construction	336	149
Total capital cost (1/95 \$)	1409	896
Annual Costs (\$ x 10 ⁶ /year)(a)		
Fixed charges	254	161
Fuel costs	81	299
O&M costs	63	69
Credit for electric power	(67)	(73)
Total annual costs	<u>331</u>	<u>456</u>
Process Steam Cost [mills/kW(t)-hr (\$/MMBtu)]	49.5 (14.50)	68.1 (19.98)
Ratio of Energy Cost to Cost with HTGR-PS/C	--	1.4

(a) 1/95 \$ levelized over a 30-year period.

TABLE 3
ECONOMIC ANALYSIS ASSUMPTIONS

Commercial operation of all plants:	1/1/95
Capacity factor:	70%
Levelizing period:	30 years
Electric power credit:	22 mills/kW-hr (80 \$)
Discount rate:	10%/year
Fixed charge rate:	18%/year
Interest during construction:	10%/year (simple interest)
Coal cost escalation:	8%/year
Fuel oil escalation:	9%/year
All other escalation:	6%/year
Construction period:	6 years for all plants (2 years for No. 6 oil-fired plants)
U ₃ O ₈ (yellowcake) cost:	\$121/kg (\$55/lb) in 1990, rising to \$264/kg (\$120/lb) in 2030
Separative work unit (SWU) cost:	\$100/kg-SWU (80 \$)
Tails assay:	0.2%
Coal cost:	4.64 mills/kW-hr (\$1.36/MMBtu) (80 \$)
No. 2 oil cost:	18.2 mills/kW-hr (\$5.33/MMBtu) (80 \$)
No. 6 oil cost:	13.5 mills/kW-hr (\$3.95/MMBtu) (80 \$)
HTGR-PS/C fuel cycle cost (includes recycle):	11.23 mills/kW-hr (\$3.29/MMBtu) (1/95 \$ levelized over 30 years)

should be determined using the economic ground rules appropriate for the specific application. Industrial user input is being developed regarding possible alternative economic ground rules.

Ultimately, the economic analysis method will be determined by the nuclear cogeneration plant ownership:

1. Industrial ownership with connection to the utility grid for backup electric power and sale of excess power (per recent Federal Energy Regulatory Commission rulings regarding a more favorable arrangement for industry).
2. Utility ownership with both steam and cogenerated electric power sold to nearby industry.
3. Consortia ownership and sale of energy to industry and local utilities.

The analysis compares the cost of process steam produced by the HTGR-PS/C with that produced by a coal-fired cogenerating plant. It includes a credit for the electric power produced by the HTGR and coal-fired cogenerating plants. The analysis indicates a clear advantage for the HTGR over the coal alternative.

If the 1170-MW(t) HTGR-PS/C is used as the reference plant and a 50% recovery factor is assumed, then a potential market for the Canadian tar sands application exists for about 30 units, each having a 30-yr lifetime to complete bitumen recovery. This number is likely to be reduced, because in some cases, the resources are not sufficiently well aggregated to be served by an HTGR. Nevertheless, the market potential is large. However, it is practically confined to Canada, since tar sand resources in the U.S. (and other countries) are comparably modest. Therefore, U.S. dependence on oil imports may not be improved by developing this application, and marketing of

the application should be directed to Canadian companies and the Canadian government. Prospects for the HTGR in Canada could become favorable only if the reactor were to be built under license by suitable Canadian companies which have the explicit endorsement of the Canadian government. Because of indigenous technology, the Canadian government will examine very closely whether the Canadian CANDU reactor (perhaps with fossil superheaters) can perform the required function without importing U.S. reactor technology, but such a scheme would entail both technical/operational problems and economic penalty. On the other hand, the resources from Canadian tar sands would find a ready market in the U.S., and U.S. funding might help development if a Canada-U.S. agreement could guarantee the U.S. an appropriate share of the tar sands crude at an agreed price. Of course, the U.S. government is more likely to fund the development of syncrude from coal and shale, which are indigenous to the U.S. However, since tar sands oil represents such a large resource so close to the U.S. border, it merits large-scale development.

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