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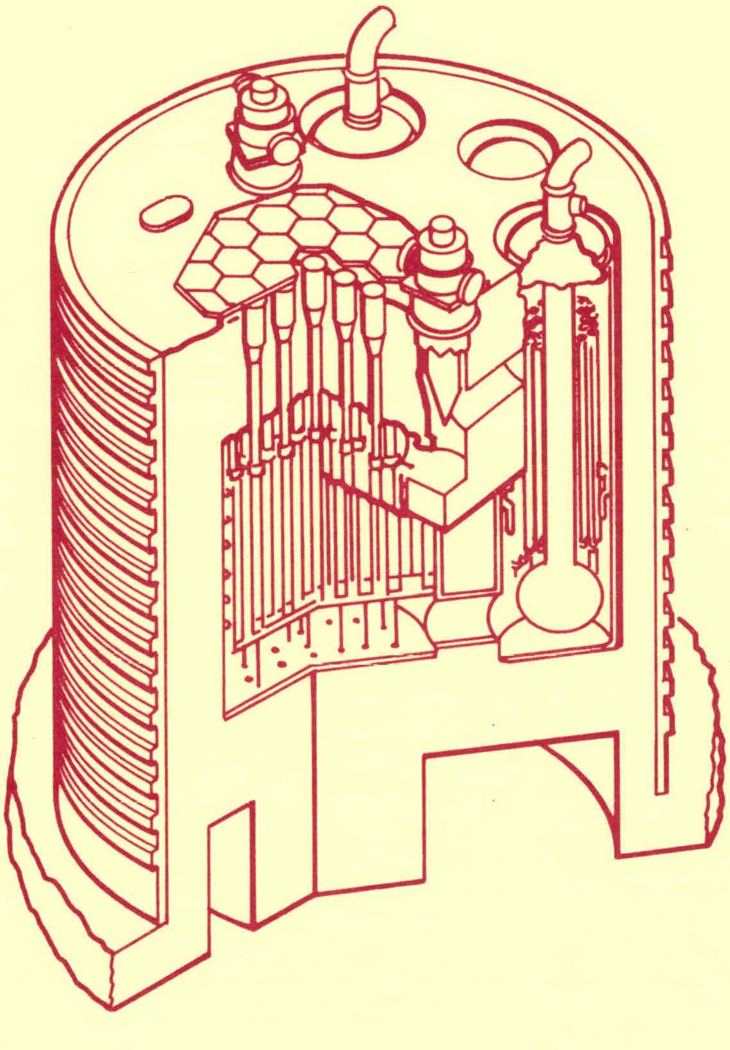
High-Temperature Gas Reactor (HTGR) Market Assessment, Synthetic Fuels Analysis



August 1980
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Prepared for
Gas-Cooled Reactor Associates
Under Contract No. GCRA/TRW/80-111

TRW ENERGY SYSTEMS PLANNING DIVISION
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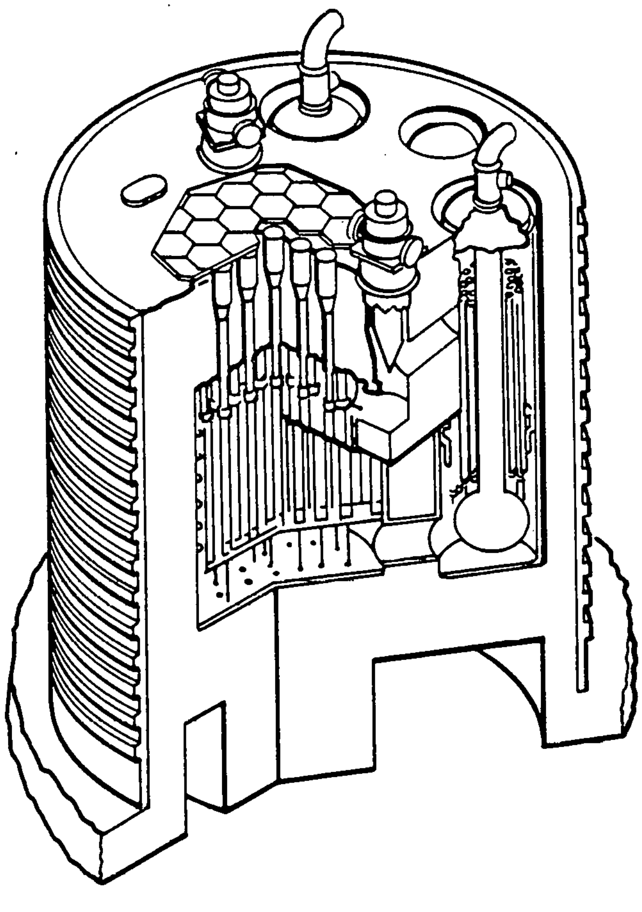
DISCLAIMER

AC03-78SF02034

High-Temperature Gas Reactor (HTGR) Market Assessment, Synthetic Fuels Analysis



MASTER

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SUMMARY

This study is an update of assessments made in TRW's October 1979 broad-based assessment of overall high-temperature gas-cooled reactor (HTGR) markets in the future synfuels industry (1985-2020) (Reference 1-1). The following activities and considerations were involved in the updating process:

- Three additional synfuels processes were assessed.
- Revised synfuel production forecasts were used.
- General environmental impacts were assessed.
- Additional market barriers, such as labor and materials, were researched.
- Market share estimates were used to consider the percent of markets applicable to the reference HTGR size plant.

Based on this assessment, 11 HTGR plants under nominal conditions and two under pessimistic assumptions are estimated for selection by 2020. No new HTGR markets were identified in the three additional synfuels processes studied. This reduction in TRW's earlier estimate is a result of later availability of HTGR's (commercial operation in 2008) and delayed build up in the total synfuels estimated markets. Also, a latest date for HTGR capture of a synfuels market could not be established because total markets continue to grow through 2020. If the nominal HTGR synfuels market is realized, just under one million tons of sulfur dioxide effluents and just over one million tons of nitrous oxide effluents will be avoided by 2020.

Major barriers to a large synfuels industry discussed in this study include labor, materials, financing, siting, and licensing. Use of the HTGR intensifies these barriers. Therefore, the penetration of the synfuels market presents a challenge to the HTGR industry to reduce these barriers in an appropriate time frame.

ACKNOWLEDGEMENTS

This report was prepared under the direction of the Project Manager, Dr. Frank P. Mertes. The principal investigators were J. D. Forster and H. Spiro. Technical coordination was provided by Mr. G. R. Pause of the Gas-Cooled Reactor Associates. The authors are grateful for the assistance provided by the following TRW staff members:

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1.0 INTRODUCTION

The United States is entering a period of decision and construction in the use of synthetic fuels to reduce oil imports. To give these ventures the best chance for success, careful planning, including systematic analysis of all alternatives, must be undertaken. This study is one step in such a process leading to the evaluating of using high-temperature gas-cooled reactors in synfuel plants.

1.1 BACKGROUND

In October 1979, TRW Energy Systems Planning Division completed a major study of the projected market for high-temperature gas-cooled reactors (HTGR) (Reference 1-1). This study examined markets in the synthetic fuels industry, electric utilities, and the industrial sector for the time period 1985-2020. The synthetic fuels applications using HTGR's relied principally on including nuclear-heated reformers within the processes to match the capabilities of the HTGR to the needs of the system. Although significant markets were identified, technical and institutional barriers to HTGR use must still be overcome.

Since publication of the TRW market assessment of the HTGR, significant changes have occurred in Government projections of anticipated synthetic fuel use, including major changes in the alcohol fuels area. Recent detailed data concerning potential development plans for reformer applications driven by gas-cooled reactors has also been projected by the Gas-Cooled Reactor Associates (GCRA) (Reference 1-2). Accordingly, GCRA requested TRW to update its gas-cooled reactor market projections in the synthetic fuels area to reflect these new data. This report incorporates those revisions.

Specifically, the following categories of synthetic fuels are addressed:

- Methanol from coal
- Ethanol from biomass
- Synthetic liquids from oil shale
- Synthetic liquids from direct liquefaction of coal

- Synthetic liquids (other than methanol) from indirect liquefaction of coal
- High-Btu synthetic natural gas
- Medium- and low-Btu synthetic gas

The time horizon remained 1985 to 2020 in the study update; more attention, however was devoted to covering environmental impacts, institutional barriers, development timing, and other risks to HTGR penetration of the synthetic fuels market.

1.2 APPROACH

TRW began this study by reexamining the four synfuels applications of HTGR's in the early TRW market assessment (Reference 1-1). Revisions to the data on these four processes were not required. Research was then conducted into the methanol from coal, ethanol from biomass, and medium- and low-Btu gas synfuels processes. These processes were briefly compared to processes replacing boiler heat with the original study reference 3000 MW_t HTGR and the 1170 MW_t HTGR (Reference 1-2) for process heat. General environmental effluent data were assembled for each process, and data were gathered regarding barriers to construction of a synfuels industry, including the impact of integrating HTGR's into that industry. The mid- and long-range synfuels production forecasts of the Energy Information Agency were used because they are the most consistent and reliable source of synthetic fuels market projections for the desired time frame.

After evaluating the economic data, the extent of barriers and risks, the processes' environmental changes, and the initial HTGR availability provided by GCRA in Reference 1-2, the percentage of each synfuels market that will be captured by HTGR's was assessed. This estimate was translated into the number of reference HTGR's to be built, and the total environmental changes that would result from selecting HTGR's.

Inasmuch as this study draws data from a number of independent sources and did not involve performing detailed economic analyses, results should be judged accordingly.

2.0 HTGR SYNFUELS MARKET ASSESSMENT

This section presents a summary of the study research to assess the potential of HTGR's in synfuels application. The total market for synfuels is described as expected by the Energy Information Agency from 1985-2020 in the seven synfuels categories. The timing of HTGR introduction is addressed, and a nominal and pessimistic market share is assigned in the form of a percentage of each total market that will choose to use the HTGR. This HTGR market is displayed in terms of the number of plants required and the overall environmental impact.

2.1 THE MARKET FOR SYNFUELS

Since publication of TRW's previous HTGR market assessment (Reference 1-1), a number of new synfuel market forecasts have been made. These include predictions in The National Academy of Science report Energy in Transition: 1985-2010, DOE's budget preparation assumptions in its Policy and Fiscal Guidance memorandum of February 1980, and the Energy Information Agency's mid- and long-term forecasts for the Annual Report to Congress. TRW reviewed each of these predictions.

Major delays in synfuels market predictions have occurred in the last year as a result of peer review, analysis of constraints, changes in regulatory groundrules, and the failure of Congress to create the Energy Mobilization Board. TRW selected the forecasts of the Energy Information Agency as the best current synfuels market predictions. These forecasts have the following advantages. They are:

- Integrated with the complete energy supply and national demand through an experienced systematic process
- Have used an internally consistent set of assumptions
- Are sufficiently detailed so that potential conflicts in definitions and categorizations can be resolved by examination
- Cover the complete time frame of interest
- May be traced to past predictions and projected when future forecasts become available because they are required annually by Congress

These forecasts have only three disadvantages:

- They are based on different methodologies from mid- to long-term forecasts (breaking between 1995 and 2000)
- The mid-term forecast does not cover ethanol or methanol
- They do not breakdown synthetic liquids between direct and indirect processes

Table 2-1 lists these predictions as they appear in the middle world oil price cases of the mid- and long-term EIA service reports of 1980 (References 2-1, 2-2, 2-3, and 2-4). This table illustrates a growth in synthetic fuels consumption of more than two orders of magnitude in 35 years. Only ethanol from biomass decreases during this time frame due to lower-priced alternatives.

To complete the required market analysis, TRW considered the technical and economic status, the relative demand for products output, other barriers of direct and indirect liquefaction, and the percent of total capacity that is added in each interval. The synthetic liquids from coal market forecast by EIA was divided by TRW as follows:

Coal Synthetic Liquids (except Methanol) Market Distribution

Year	Percent Indirect	Percent Direct
2000	90	10
2005	85	15
2010	80	20
2015	70	30
2020	60	40

(These percentages are used in identifying the direct and indirect liquefaction applications of HTGR's as discussed in Section 2.3.)

2.2 TIMING OF HTGR COMMERCIALIZATION

Reference 1-2 provides a tentative schedule of HTGR availability, calling for an operational demonstration plant in 1995, an operational lead commercial plant in 2002, and first commercial operational availability in 2008. Table 2-1 shows that this availability date leaves one-half of the synthetic fuels market through 2020 within the period of HTGR availability. This timing is also convenient because this later stage will be more amenable to the construction of larger-scale synfuels plants. Larger plants will be more appropriate to the larger power capabilities of HTGR's.

Table 2-1. EIA Synfuels Market Projections

TECHNOLOGY	QUADS PER YEAR							
	MID-RANGE			LONG-RANGE				
	1985	1990	1995	2000	2005	2010	2015	2020
Methanol from Coal		Not Forecast		0.300	0.700	1.500	3.000	5.000
Ethanol from Biomass		Not Forecast		0.800	1.200	1.602	1.426	1.239
Synthetic Liquids from Oil Shale	0.019	0.531	0.850	2.092	3.009	4.009	5.167	5.609
Synthetic Liquids[1] from Coal	0.084	0.099	0.606	1.114	2.355	4.432	7.375	10.482
High Btu Gas	0.091	0.110	0.121	0.135	0.266	0.477	0.788	1.196
Med/Low Btu Gas	0.000	0.221	0.606	0.628	0.766	0.923	1.057	1.124
TOTAL	0.194	0.961	2.183	5.869	8.296	12.943	18.813	24.650

[1]Excluding Methanol. Including Direct and Indirect Liquefaction.

Delay in the commercialization of the HTGR will, of course, lose that portion of the synfuels market before actual HTGR availability. This market will continue strongly through 2020, but in the oil shale, high Btu gas, and medium-to-low Btu gas markets, growth rates will decline in 2020. Therefore, delay beyond 2020 will risk restricting HTGR use to liquids from coal. This restriction will occur because the declining growth is more likely to be met with conventional sizes and technology plants. The decline of the liquids from coal market may be near 2020 if breeder, fusion, and solar technology make sufficient progress. Because predictions of this nature are speculative and highly uncertain, latest availability cannot be established. The potential market negated by delay would be the total HTGR synfuels market predicted in the following section.

2.3 HTGR SYNTHETIC FUELS MARKET SHARES

For each synfuels process TRW has estimated the percent of the market applicable to large plants and the percent of that market captured by HTGR's, and divided by the 3000 MW_t HTGR plant size to estimate the cumulative number of plants for each time interval after 2008. Between 2005 and 2010, 50 percent of the incremental additions were considered available (in 40 percent of the time) to account for increasing market growth rates. This method is inflexible with respect to HTGR size. Three HTGR's of the size in Reference 1-2 would be required to produce the same thermal power. Smaller HTGR's may prove less economic than larger HTGR's due to economies of scale but may provide greater availability and size flexibility. Pessimistic estimates assume that generally unfavorable conditions relative to HTGR's occur throughout the time period involved. Table 2-2 summarizes the number of 3000 MW_t synfuel HTGR plants ordered under nominal and pessimistic assumptions.

Table 2-2. Cumulative Number of HTGR's in Synfuel Applications*

TECHNOLOGY	2010		2015		2020	
	NOMINAL	PESSIMISTIC	NOMINAL	PESSIMISTIC	NOMINAL	PESSIMISTIC
Methanol from Coal	0	0	0	0	0	0
Ethanol from Biomass	0	0	0	0	0	0
Oil Shale	0	0	1	0	2	0
Direct Liquefaction	0	0	1	0	4	1
Indirect Liquefaction	0	0	2	0	3	1
High Btu Gas	0	0	1	0	2	0
Med/Low Btu Gas	0	0	0	0	0	0
TOTAL	0	0	5	0	11	2

2.3.1 Methanol from Coal

As a result of the low heat requirements of the methanol from coal process, TRW anticipates that the HTGR will not penetrate the market in this technology. This situation is discussed further in Section 6.1.

2.3.2 Ethanol from Biomass

The HTGR is also not expected to capture a share of the ethanol from biomass market. This situation is caused by increased costs without compensating feedstock improvement, the need to handle huge quantities of feedstocks in the HTGR case, and few compensating environmental improvements.

*Each of these 3000 MW_t HTGR's could be replaced thermally by three 1170 MW_t HTGR's. Smaller plants may be less economic but more available and flexible.

2.3.3 Synthetic Liquids from Oil Shale

Because of the location of oil shale deposits in remote areas, and the favorable economics of oil shale refining in comparison to other synfuels processes, HTGR's can expect reasonable penetration of the oil shale market. TRW estimates that 90 percent of the capacity added to supply the market (as presented in Table 2-1) will be large enough to consider the HTGR process. And, because economics are approximately comparable, 50 percent of these large plants will select HTGR's. Therefore, 45 percent of new capacity will use the HTGR process. This market share implies initiation of two 3000 MW_t oil shale HTGR's, one each in approximately 2015 and 2020. Under pessimistic assumptions, however, even these plants may not be ordered because incremental plant capacity additions only closely approach the increment provided by the HTGR process. Smaller HTGR's may capture shale oil markets even in pessimistic scenarios depending on their economic characteristics.

2.3.4 Direct Liquefaction

This process will enter the market later, and consequently larger plants will be needed sooner in its relative life. The simpler nature (one rather than two steps) will also make larger plants possible. TRW estimates that 80 percent of the direct liquefaction synfuels market will be in consideration for very large plant size. Sixty percent of the applicable market will be captured by this alternative because HTGR economics for this process are fully favorable.

The late introduction of direct liquefaction will limit the 2010 market, but sufficient quantity of product will be required by 2015 to support building one 3000 MW_t plant. The strong market gains to 2020 will require three additional HTGR's. In the pessimistic case, only one plant may use this technology by 2020.

2.3.5 Indirect Liquefaction

The complexity of this process indicates a number of small plants will always be used in this market. Seventy percent, however, are judged to be available for very large plants. Since HTGR process economics are only favorable in the processes that maximize gasoline output (see Section 6.5), only 40 percent of the remaining market will be captured by indirect liquefaction HTGR's.

The market captured remains at the level of approximately one-half plant capacity in 2010, with two 3000 MW_t HTGR's required to fulfill this market in 2015, and a third in 2020. In the pessimistic case, only one plant may be ordered.

2.3.6 High Btu Gas

Since high Btu gas markets do not increase as greatly as liquid markets, only 70 percent of the estimated market will be applicable to very large plant sizes. Favorable HTGR economics, however, will capture 60 percent of the remaining market. Being the smallest sized HTGR synfuels process in output Quads per year, this technology will still capture one 3000 MW_t plant in 2015 and another in 2020 even though projected total markets will remain low.

2.3.7 Medium/Low Btu Gas

For the technical and economic reasons described in Section 6.7, TRW assumes that there will not be any low-to-medium-Btu gas process that is attractive to HTGR's.

2.4 HTGR MARKET PENETRATION ENVIRONMENTAL EFFECTS

Table 2-3 summarizes the changes in environmental effects that will result if the nominal or pessimistic plant schedules of Section 2.3 are implemented. These projections use the annual plant emissions described in Section 3.0. All plants begin operation in the year in which they are first shown in Table 2-2. These effluent savings are conservative because any earlier plant openings would increase environmental effects.

2.5 HTGR MARKET PENETRATION INVESTMENT REQUIREMENTS

If the nominal market penetration of Table 2-2 occurs, the additional cumulative investment that would be required by 2015 is $4.1B (1979) and by 2020 $8.4B (1979). If the pessimistic market penetration occurs an additional investment of $1.5B (1979) will be required. These values are based on the total investment estimates made in Reference 1-1 and displayed in Section 6.0, Process Economics.

Table 2-3. Cumulative HTGR Environmental Impacts*

	TONS OF EMISSION AVOIDED			
	2015		2020	
	NOMINAL	PESSIMISTIC	NOMINAL	PESSIMISTIC
OIL SHALE				
SO_2	757	0	6,056	0
NO_x	3,953	0	31,624	0
Solid Waste	4.164×10^6	0	33.312×10^6	0
CO	803	0	6,424	0
HC	284	0	2,272	0
DIRECT LIQUEFACTION				
SO_2	29,857	0	298,570	29,857
NO_x	11,200	0	112,000	11,200
Solid Waste	0.277×10^6	0	2.27×10^6	0.227×10^6
CO	NA	0	NA	NA
HC	NA	0	NA	NA
INDIRECT LIQUEFACTION				
SO_2	30	0	450	15
NO_x	NA	NA	NA	NA
Solid Waste	0.309×10^6	0	2.321×10^6	0.155×10^6
CO	2,490	0	18,675	1,245
HC	228	0	1,710	114
HIGH BTU GAS				
SO_2	83,000	0	664,000	0
NO_x	139,300	0	1,114,400	0
Solid Waste	(7.4×10^6)	0	59.2×10^6	0
CO	NA	NA	NA	NA
HC	NA	NA	NA	NA
TOTAL				
SO_2	113,644	0	969,076	29,872
NO_x	154,453	0	1,258,024	11,200
Solid Waste	12.1×10^6	0	97.103×10^6	0.382×10^6
CO	3293	0	25,101	1,245
HC	512	0	3,982	114

*Assumes all plants operational only in latest year of period shown.

3.0 ENVIRONMENTAL EFFECTS

In order to assess the general environmental effects from using HTGR's in synfuel processes, the differences in effluents from alternative plants with and without HTGR's has been derived from recent literature. Four of these processes, assessed in Reference 1-1, are restated here as differences. In methanol from coal, and ethanol from biomass processes, TRW has assumed that HTGR's replace the conventional boilers described in the conventional process literature and assessed the resulting environmental changes. No data was found for low- to medium-Btu gasification, but effects are expected to be small because coal burning is not avoided.

The effluents addressed included sulfur dioxide, nitrous oxide, solid waste, carbon monoxide, and hydrocarbons. Solid waste effluents include spent rock, ash, and nuclear waste, each with different disposal requirements. Other effluents and environmental effects which should be considered, include trace elements, land and water requirements, radiation releases, and socio-economic effects.

Table 3-1 presents these relative environmental changes as effluent reductions on a single plant basis. For reference, the output of a 500 MW_t conventional coal boiler (both uncontrolled and with EPA's revised new source pollution standards (NSPS) applied) is shown on both tables as derived from DOE's Environmental Office (Reference 3-3). Table 3-2 presents the same information based on effluents per 10^{12} Btu produced for comparison on an energy output basis. Figure 3-1 displays the sulfur and nitrous oxide values graphically. The conventional methanol from coal process comparison assumes the plant meets EPA's new source pollution standards (NSPS) as shown in Reference 3-1.

These effluents are aggregated for the number of plants estimated in this report's market assessment and displayed in Section 2.0.

Table 3-1. HTGR Reduction in Effluents over Non-Nuclear Powered Synfuels Plant -Single Plant Basis

PROCESS	DIRECT BASIS: PRODUCT OUTPUT	NET REDUCTION IN EFFLUENTS (TONS/YR)				
		SO_2	NO_x	SOLID WASTE (ASH)	CO	HC
Methanol from Coal	58,300 tons/day (Reference 3-1)	30.500	12,500	136,750	N/A	N/A
Ethanol from Biomass	50 x 10^6 gallons/yr (Reference 6-2)	612.5	340.4	9189.2	54.1	16.1
Oil from Shale	254,000 Bbl/day (Reference 1-1)	757	3953	4,164,000	803	284
Direct Liquefaction	186,000 Bbl/day (Reference 1-1)	29,857	11,200	227,000	N/A	N/A
Indirect Coal Liquefaction (Mobil M)	177,800 Bbl/day gasoline +30,800 Bbl/day LPG (References 1-1, 3-2)	15	N/A	154,750	1245	114
High-Btu Gasification	540 x 10^6 scf/day (Reference 1-1)	83,000	139,300	7.4 x 10^6	N/A	N/A
Reference emissions from a 500 MWe	8.2 x 10^{12} Btu/yr energy production	45,649	9,405	89,191	525	156
Conventional Eastern Coal Boiler (Reference 3-3)	Same boiler meeting revised NSPS	5,945	3,305	89,191	525	156

Table 3-2. HTGR Reduction in Effluents Over Non-Nuclear Powered Synfuels Plant - Energy Output Basis -

PROCESS	DESIGN BASIS: PRODUCT OUTPUT	Net Reduction in Effluent (Tons/10^{12} Btu Product)				
		SO_2	NO_x	SOLID WASTE (ASH)	CO	HC
Methanol from Coal	58,300 tons/day MOH	855	350	3830	NA	NA
Ethanol from Biomass	50 X 10^6 gallons/yr	153	85.1	2300	13.5	4.0
Oil from Shale	254,000 bbl/day	1.78	9.28	9784	1.88	0.67
Direct Liquefaction	186,000 bbl/day	83.4	31.3	634	NA	NA
Indirect Coal Liquefaction	177,800 bbl/day gasoline +30,800 bbl/day LPG	.04	NA	455	3.7	0.3
High Btu Gasification	540 x 10^6 SCF/day	428	718	38,150	NA	NA
Reference Emissions from a 500 MW_e Conventional Eastern Coal Boiler (Reference 3-3)	8.2 x 10^{12} Btu/Yr Energy Production	5567	1147	10877	64	19
	Same Boiler Meeting Revised NSPS	725	403	10877	64	19

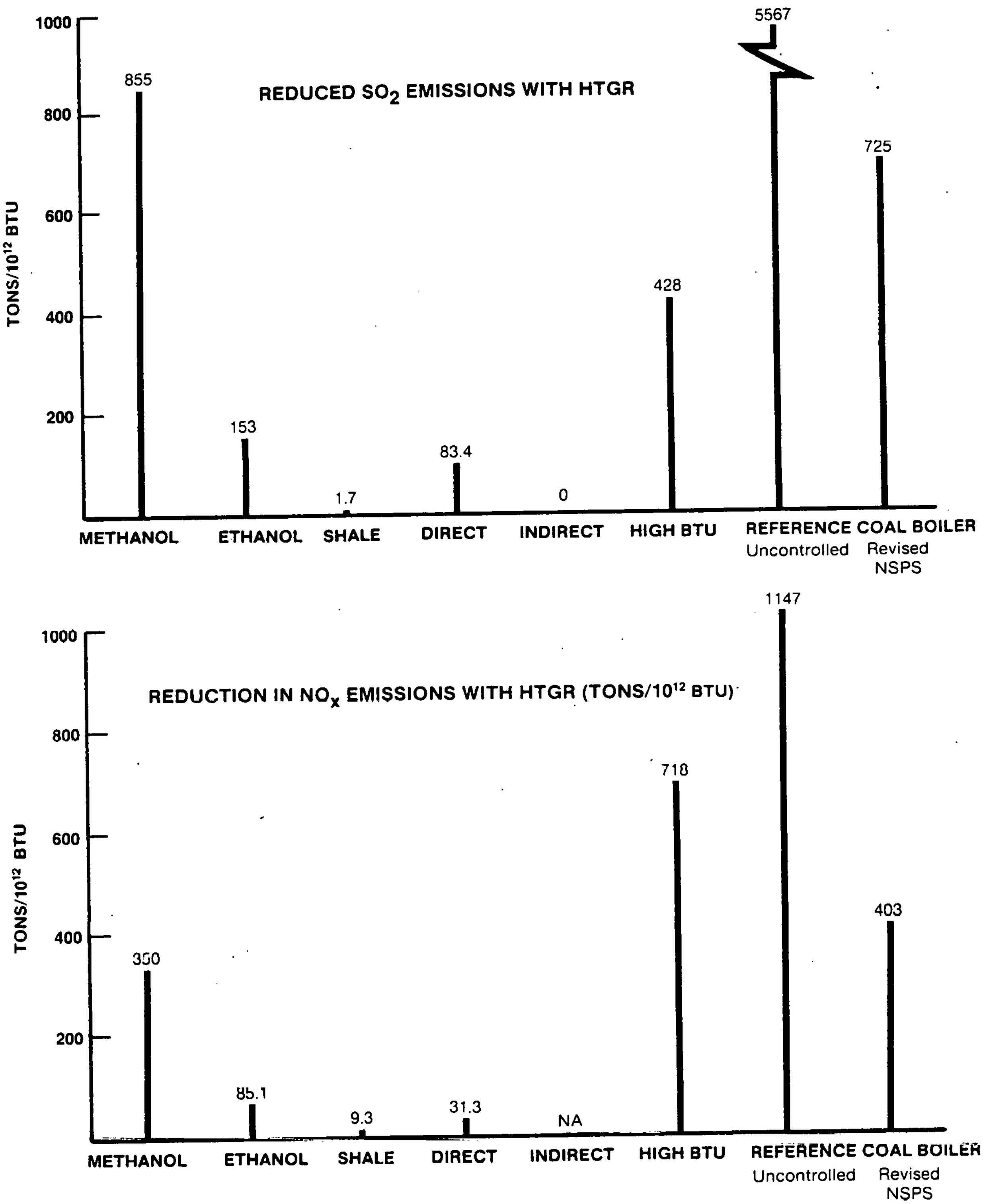

Figure 3-1. HTGR Effluent Reductions

4.0 INSTITUTIONAL ISSUES

The use of HTGR's in the synfuels program combines two technology areas that are virtually uncommercialized in the United States. There is only one operating commercial-scale HTGR in the United States (although Western Europe has several), while the synfuel program has a goal of growth to 2.5 million B/D in 10 years.

Three issues can be identified as critical to the successful integration of synthetic fuels and HTGR's.

4.1 RELIABILITY AND AVAILABILITY

Reliability of supply is a critical factor in the decision concerning selection of process fuels. Another critical element influencing the profitability of a multibillion dollar synthetic fuel facility is the attainment of assumed values for a stream factor. If the synthetic fuel industry were to apply the same criteria applied in the chemical industry, the reliability of the HTGR must be thoroughly demonstrated before it would be selected for use in a coal conversion plant. The typically assumed stream factor value for a synthetic fuel plant is 330 days per year or 0.90.

The HTGR may have to demonstrate superiority over current LWR technology (existing data are difficult to evaluate due to inclusion of turbine- and generator-caused downtime) by attaining an availability factor which equals or approaches the theoretical 0.90 stream factor assumed for the synfuels plant. Clearly, capital cost considerations would dictate using only one 3000 MW_t HTGR, although smaller multiple-unit HTGR's may provide the required availability.

4.2 SAFETY

The safety characteristics and licensing requirements for a synthetic fuels plant using an HTGR may be placed in two categories: (1) the characteristics of the HTGR itself, and (2) the degree to which the intermediate heat exchanger (IHX) isolates the HTGR, the chemical process plant, and the process products. The superior safety characteristics of the HTGR include the following:

- The high thermal capacity neutron moderating graphite core provides operators much more time during transients to assess operating characteristics because the core temperature rises very slowly.
- The ceramic fuel particle design provides significant improvements in fuel integrity and fission product retention capability as a function of time and temperature relative to cores incorporating metallic cladding.
- Under maximum design basis accident conditions (a Type 9 accident) in which the plant loses all primary coolant and fission products are released to the atmosphere, exposure levels are well within the allowed limits of 10 CFR 100.
- Helium as a coolant is a single-phase gas; there are no occurrences of steam/water flashes or chemical reactions between coolant and fuel.
- The HTGR has a much lower power density than LWR's which also slows transients.
- The prestressed concrete reactor vessel holds concrete or cast steel blocks in compression by steel tendons so that the vessel cannot fail in a manner that results in missile fragments which may damage the structural integrity of the secondary containment, as in LWR's.

Therefore, any evaluation of the use of the HTGR must make a distinction between the safety characteristics of the HTGR and existing LWR technology. Furthermore, the degree of acceptance of the HTGR for use within both the chemical process and synthetic fuel industries will be influenced by recognition of the superior safety characteristics of the HTGR relative to the LWR.

The design of the HTGR/reformer unit must provide a high degree of isolation of the process plant and products from the radioactive contaminants produced by the HTGR. Failure to provide such isolation may lead to difficulties in licensing the HTGR for such an application or lack of acceptance by decision-makers within a synthetic fuels industry. Specific problems which must be minimized are product or helium coolant contamination as a result of reformer tube failure, and hydrogen and tritium passage through the reformer tube wall, which would cause contamination of the product stream. As proposed in Reference 1-1 and 1-2, the use of an intermediate heat exchanger between the primary helium loop and the hydrocarbon reformer solves this problem by significantly reducing the level of contamination experienced during reformer tube failure.

4.3 EXTENSION OF THE SCOPE OF NUCLEAR ENERGY

The accident at Three Mile Island has focused attention on the entire nuclear option. With the ever-present option of another moratorium on further licensing of new LWR's, the public will look carefully at any attempt to expand the scope of nuclear power. The link of the HTGR with the synfuels program will bring the designs under careful scrutiny of environmental as well as anti-nuclear orgnizations.

To anticipate these problems and create an atmosphere in which they can be solved, long-range education and liaison programs with all levels of regulators and public representatives should be initiated as early as possible. To achieve continuity, these programs should grow from existing efforts whenever possible.

4.4 SITING & LICENSING

The major advantage of using HTGR's in fossil-fuel based synfuels programs seems to be the increased efficiency in the utilization of the feedstock. By eliminating the fossil-fuel fired boiler which generates process steam, there is a resultant reduction in emissions associated with fossil-fuel combustion, i.e., SO_2, NO_x (for ethanol from biomass schemes, the same efficiency of feedstock use is obtained, but a coal boiler is replaced by the HTGR).

By using the HTGR the coal-generated effluents are replaced by other substances such as nuclear wastes. The HTGR waste problem is not substantially different from that of LWR's, but the public will view the HTGR as environmentally different from fossil-fueled steam generators.

Prior to the licensing of a reactor for construction, applicants must submit a preliminary safety analysis report (PSAR) and an environmental report (ER). These reports must prove the feasibility of the proposed nuclear system to operate within legal and regulatory constraints at the proposed site. Prior to the granting of an operating license, a final safety analysis report (FSAR) and a final environmental impact statement (FES) are issued and approved. The nuclear process system will have to go through this regulatory procedure. Emphasis in the PSAR and the FSAR will be on the nuclear reactor, but it will be necessary to show that the process does not reduce nuclear safety factors. The ER and the FES will have to deal with all impacts of the nuclear process system, demonstrate a demand for the products of the system that can best be supplied by the proposed facility, and show that the benefits of the system exceed the costs (Reference 5-7).

5.0 OTHER BARRIERS

5.1 LABOR

Several studies (References 5-1 through 5-4) have addressed impediments to meeting the production goals set up by DOE for synfuels: 1 million B/D of coal liquids by 1990, and 3 million B/D by 2000. The potential labor shortage problems can be separated into two groups: engineering manpower and manual labor.

5.1.1 Engineering Manpower

Estimates of the requirements of the synfuels program for manpower range from 6 to 18 million man-hours/year, or from 20-60 percent of the available supply (Reference 5-4). The Bechtel study (Reference 5-1) which looked at manpower needs, distinguished between processes used, and contrasted them with the needs of refineries (Table 5-1).

The estimated engineering design man-hour requirements for the direct and indirect liquefaction processes are respectively 1.5 and 3 times greater than refinery requirements. Contributing to the greatly increased engineering effort are process complexity, handling of solid, mixed and liquid phases, high temperatures and pressure, and ash and waste disposal.

Greater engineering manpower is required for the indirect process because it is, in effect, two processes in series--gasification and synthesis--requiring considerably more equipment, piping, and instrumentation engineering.

The 3 million B/D production scenario could require up to 1300 additional chemical engineers for coal liquefaction process work by 1984. This amount represents a 65 percent increase in the major engineering force in 6 years, and it appears that the supply of other engineering disciplines should be adequate.

The scenario for 3 million B/D by 2000 will tax the supply of chemical engineers for process and project work and will be further constrained by the projected growth in the chemical, and petrochemical industries.

Table 5-1. Labor Requirements (1000 Man-hours)*

LABOR CATEGORY	REFINERY	COAL DIRECT LIQUEFACTION	COAL INDIRECT LIQUEFACTION
	200,000 BPD	60,000 BPD	60,000 BPD
Engineers	1,430	2,280	4,770
Designers & Draftsmen	1,000	1,270	2,650
TOTAL	2,430	3,550	7,420

5.1.2 Manual Labor

The same problem of shortages in key engineering skill areas occur with craftsmen, further complicated by regional differences. Peak employment of craftsmen occurs during the period 1980 to 1990 for the coal liquids construction period. As a consequence of the current shortage of skilled construction workers, especially pipefitters, pipefitter-welders, boilermakers, boilermaker-welders, and electricians, a shortage of manpower for a coal liquids construction program could develop rapidly in the areas with the greatest possible concentration of plants. The regions most affected will be the East North Central/East South Central (Ohio River Valley), the West North Central, and the Northern Mountain Regions (Table 5-2, Reference 5-1).

During the past 10 years, a sharp decline in the willingness of craftsmen to follow the work has drastically altered the historical manpower-mobility pattern in the construction industry. Major factors influencing decisions on where to work include higher hourly wages, better benefit packages, the proximity of the job to home, or to a favorite recreational area, and the housing and recreational facilities that are available at the project.

Nevertheless, shortages in any particular craft should not be a problem. Contractors have been able to upgrade laborers in less than 6 months of intensive training in many crafts. Given wage incentives, and in the absence of institutional barriers, people should be willing to retrain (Reference 5-2).

*Reference 5-1.

Table 5-2. Regional Manual Labor for Construction and Maintenance for Coal Liquids Plants and Associated Mines

CRAFT	CURRENT CRAFTSMAN	COAL LIQUIDS PROGRAM "PEAK" REQUIREMENTS	
		3MMBPD Scenario	1MMBPD Scenario
PIPEFITTERS (Incl. Welders)			
East North Central and East South Central Regions	37,672	10,300	6,300
West North Central and Northern Mountain Regions	14,498	11,800	6,900
BOILERMAKERS (Incl. Welders)			
East North Central and East South Central Regions	5,260	900	500
West North Central and Northern Mountain Regions	2,075	1,100	600
ELECTRICIANS			
East North Central and East South Central Regions	36,861	3,300	2,000
West North Central and Northern Mountain Regions	6,905	2,000	1,200
CARPENTERS			
East North Central and East South Central Regions	107,634	3,400	1,500
West North Central and Northern Mountain Regions	29,244	3,100	1,900

5.1.3 Integration of the HTGR with Synfuels Manpower Needs

The combination of requirements for a major synfuels program with the development of an HTGR industry linked to that program results in aggravation of the above-mentioned labor shortages. Introduction of HTGR's will require still more specialized laborers and engineers, especially chemical and nuclear engineers. In an era where the future role of nuclear power in the United States is highly uncertain, HTGR developers will have to encourage enrollments in nuclear sciences and engineering by providing enticing starting salaries.

Some of the other manpower shortages can be mitigated through the following strategies:

- Management could make better use of the labor force through a stabilization agreement that eliminates wasteful labor practices.
- Training programs could help upgrade existing craftsmen through use of onsite training programs and expansion of current apprenticeship programs.

- "Nonjourneymen" or "helpers" could be used to perform the less skilled work now done by fully qualified journeymen.
- A comprehensive recruitment program could be initiated to attract minorities and females to the construction industry.
- A program of constant coordination with vocational and trade schools, as well as Government training programs, could ensure additional use of existing training facilities.
- Utilization of engineering capabilities outside the United States could fill some of the gaps in the need for design engineers. Furthermore, if LWR construction does not increase nuclear resources, manpower may be available from the normal industry sources.

5.2 MATERIALS AND EQUIPMENT

Because of the sizes of the synfuels plants which have been proposed, and the scope of the program, some of the equipment needs would represent a substantial fraction of U.S. capacity. For some of the equipment, both in the synfuels plants and in the HTGR's, there will be no established record of service life. Thus a relatively high replacement or failure rate should be anticipated. (There are only two licensed HTGR's in the United States: Peach Bottom and Fort St. Vrain). Many items will be the biggest of their kind to be built. Table 5-3 exhibits some potentially critical items.

Oxygen

Several sources (References 5-2 through 5-5) cite the supply of oxygen as being a potentially limiting factor to synfuels development. All current coal conversion processes need supplies of oxygen, some at ratios of 0.5 ton of oxygen per ton of coal. Current domestic oxygen supply capability is about 70,000 tons/day, while projected demand could reach an additional 100,000 tons/day to meet a 500,000 bbl/day synfuels production target.

Draglines

Draglines are large-size excavators capable of stripping or excavating overburden and ores of various types including coal. Draglines are basically manufactured from iron and steel castings, forgings, and fabricated mill shapes. Draglines for the coal liquids program in 1987 could be accommodated with a lead time for ordering of 2 to 2-1/2 years. The synfuels requirement calls for 88 percent of the present manufacturing capacity.

Table 5-3. Potentially Critical Materials and Equipment Requirements for Coal Liquids Plants and Associated Mines (3 MMBPD Scenario)

CATEGORY	UNITS	PEAK ANNUAL REQUIREMENTS	U.S. PRODUCTION CAPACITY	REQUIREMENTS PERCENT OF PRODUCTION
Chromium	tons	10,400	400,000[1]	3
Valves, Alloy, & Stainless Steel	tons	5,900	70,000	8
Draglines	yd^3	2,200	2,500	88
Pumps and Drivers (less than 1000 hp)	hp	830,00	20,000,000	4
Centrifugal Compressor (less than 10,000 hp)	hp	1,990,000	11,000,000	18
Heat Exchangers	ft^2	36,800,000	50,000,000[2]	74
Pressure Vessels (1.5-5" walls)	tons	82,500	671,000	12
Pressure Vessels (greater than 4" wall)	tons	30,800	240,000	12

[1]Current consumption.
[2]Total for surface condensers, shell and tube, and fin-type.
SOURCE: Bechtel

Chromium

Chromium is used to form alloys with iron, nickel, or cobalt. The United States imports over 92 percent of its chromium, as domestic costs currently make it economically infeasible to use U.S. resources. Availability of chromium is dependent on the world market, and 90 percent of the world's resources are in Zimbabwe (Rhodesia) and the Republic of South Africa (Azania).

Alloy and Stainless Steel Valves

These are made of cast, forged, or fabricated materials. Restraints that valve manufacturers must overcome to meet the demand for a specialized valve are:

- Availability of quality castings and forgings
- Availability of chrome, molybdenum, and cobalt
- Availability of qualified machinists or time to train new ones
- Sufficient time to plan physical expansion, if required

Heat Exchangers

Heat exchangers are devices used to transfer heat from one medium to another. The heat exchanger industry has recently experienced significant declines in production. Two major constraints are: (1) manpower to operate the machines and weld, and (2) availability of heat-treated plates for the heat exchangers. Requirements for a 3 million B/D coal liquids program could strain domestic capacity. Some mitigating factors are:

- Foreign manufacturing capacity is high.
- The industry can rapidly expand production as demand develops.
- The potential exists for reducing heat exchanger requirements through use of alternative processes.

6.0 PROCESS ECONOMICS

This section presents a review of the economics of applying GCR's to seven categories of synthetic fuels processes at the single plant level. Four of these processes are discussed in the original TRW HTGR study and are summarized in this report. These processes use the design and capital costs of the 3000 MW_t HTGR of Reference 6-1, inflated to 1979 dollars using the Chemical Engineering Plant Cost Index. Nuclear fuel costs are based on using the methodology defined in Reference 6-2, adjusted to $50 per lb. U_3O_8, $80 per SWU (both in 1979 dollars), and 90 percent plant capacity factor. Economic methodology employed the TRW INVEST computer model to calculate complete net present value and internal rate of return results. INVEST is fully documented in Reference 6-3. If the economics of these processes were recalculated using the Reference 1-2 HTGR, they would probably be less favorable. The processes are presented in the order given in the introduction.

6.1 METHANOL FROM COAL

Although the production of methanol from coal was not addressed in Reference 1-1, it is one of the most economically attractive synthetic fuels processes when viewed in terms of price per barrel of oil displaced. Recent Government actions have created incentives for alcohol fuels processes thereby enhancing the potential for expansion. The long-range market for methanol from coal is specifically projected in the Energy Information Agency's recent long-range energy projections (References 2-3 and 2-4) to reach 5 Quads by 2020. This is the third largest synthetic fuels market estimated in these references.

The methanol-from-coal alternative does not require large heat input as a result of the basically exothermic nature of the methane to methanol reaction. Mobil (Reference 6-4) has designed a process, for example, which could produce 7080 tons/day (methanol) from just 6.55 MW_t (net) power input by burning gasifier byproducts. If this ratio held, a 100,000 crude barrel equivalent per day plant would require only 14 MW_t to drive the process. Furthermore, current methanol from coal processes do not include reforming which could favor HTGR capabilities. These technical considerations are expected to prevent HTGR use in methanol from coal production.

6.2 ETHANOL FROM BIOMASS

The ethanol-from-biomass process, like methanol-from-coal, was not considered in Reference 1-1. It has the advantage of being quickly available on a moderate scale and has been recently supported by Government actions.

TRW has considered the application of 3000 MW_t and 1170 MW_t HTGR's to the 100 million gallon (ethanol) per year (0.008 Quads/yr) plant design described in a recent conceptual design study by Raphael Katzen Associates (Reference 6-5). This plant design is the largest plant capacity studied in the reference report. TRW assumes that the boilers providing steam at 600^{o}F and 600 psig for the 100 million gal/yr plant will produce twice the thermal power of the 50 million gallon per year, 95 MW_t design-basis plant or 190 MW_t. This steam would be replaced with steam from the HTGR. At a capacity factor of 95 percent, the 3000 MW_t HTGR power level is sufficient to supply 15 such plants producing 0.12 Quads of energy output per year. The 1170 MW_t HTGR in Reference 1-2, however, would supply only 6 plants. The investment in boilers and accessories which are replaced is estimated from costs in Reference 6-5 to be $15 M (1979 dollars) per plant replaced. The reference HTGR's however, represent a substantial investment increase over the conventional technology with separate boilers. This investment avoids burning coal and returns some environmental improvements. No biomass feedstock improvement rate (as with coal processes) occurs however, and opportunities are lost to burn waste. Consequently, no market is anticipated for the HTGR in ethanol from biomass.

Among other problems that might be encountered in this application of the HTGR are: 1) transportation from farm sources and handling equipment for the large quantity of feedstock required to operate this size plant, and 2) plant redesign to use HTGR waste heat instead of flue gases in byproduct drying. Furthermore, because the limit of economies of scale has been approached in the 100 million gallon per year plant size (based on Reference 6-5), little will be gained from further increases in plant capacity.

6.3 SYNTHETIC LIQUIDS FROM OIL SHALE

A detailed review of this technology is contained in Reference 1-1. Table 6-1 lists the economic findings of that study which have been re-examined and found to be still valid. Table 6-1 indicates that this process

Table 6-1. Comparison of Shale Oil Recovery Processes

	CONVENTIONAL	NUCLEAR
CAPACITY		
Products: Hydrotreated Syncrude — *Thousands of Barrels per day*	200	254
10^{12} Btu/yr equivalent	374	426
SHALE REQUIRED (Millions of tons/year)	51.8	51.8
CONSTRUCTION PERIOD (years)	4	8
OPERATING PERIOD (years)	20	20
INVESTMENT COST (Millions of 1979 $)		
Process Plant, Mining & Prep. Equip.	4094	4237
Reactor (3000 MW_t—Reference 6-1)	N/A	926
Start-up	147	147
Working Capital	101	101
TOTAL INVESTMENT	4342	5411
ANNUAL OPERATING COSTS (Millions of 1979 $)		
Coal	N/A	N/A
Water	N/A	N/A
Electric Power	N/A	N/A
Supplies, Chemicals, & Materials	113.6	113.3
Nuclear Fuel (Reference 6-2)	N/A	41.3
Direct Operating		
Process Plant and Mine*	206.5	191.1
Reactor	N/A	12.0
Other		
Gross Operating (excl. depletion allowance)	320.1	357.7
Byproduct Credit	51.6	104.7
Net Operating (excl. depletion allowance)	268.5	253.0
INVESTMENT PERFORMANCE		
Return at $4/million Btu Syncrude	15.92%	15.41%
Producer's Price at 8% ROI ($/Million Btu Supply)	2.12	2.01
Maximum Exposure (Millions of 1979 $)	4502	5590

*Includes royalty payment

produced mixed results. An analysis of the HTGR process at the plant capacities analyzed results in syncrude from oil shale priced roughly 5 percent below conventional processes at 8 percent return on investment (ROI). However, the HTGR process return at $4/million Btu is 3 percent less. Thus a market in producing syncrude from oil shale should be expected for HTGR's.

6.4 SYNTHETIC LIQUIDS FROM DIRECT LIQUEFACTION OF COAL

This process, described in detail in Reference 1-1, remains acceptable for this review. Table 6-2 reproduces these findings, which show both a 3 percent advantage to the HTGR in producer's price at 8 percent ROI and a 10% advantage to the HTGR in return at $4/million Btu. Therefore a significant market should be expected for HTGR's in synthetic fuels from direct liquefaction of coal.

6.5 SYNTHETIC LIQUIDS FROM INDIRECT LIQUEFACTION OF COAL

TRW performed preliminary design modification to the Mobil M-Gasoline process to incorporate HTGR heated steam hydrocarbon reformers (Reference 1-1). The resulting economics displayed in Table 6-3 are believed representative of most modern indirect (other than methanol) liquefaction processes. Although return and price performance measures favor the conventional non-reformer process, more than half of the Btu's per year produced in this case are in synthetic natural gas. If maximum gasoline output is desirable, the nuclear reformer is again preferable by a small margin.

Because indirect liquefaction is currently commercially available in South Africa, using the Lurgi Fischer-Tropsch process, and because the products can be used directly without further refining, indirect liquefaction methods are expected to be the earliest liquefaction technologies commercialized.

6.6 HIGH BTU SYNTHETIC NATURAL GAS

This technology was the first to be supported under the newly passed synthetic fuels legislation (P.L. 96-126) and had the lowest total investment costs of all synthetic fuels processes studied in Reference 1-1. It is, however, the second smallest EIA projected total market in 2020 (Section 2.1 and Reference 2-2).

Table 6-2. Comparison of H-Coal Liquefaction Processes

	CONVENTIONAL	NUCLEAR
CAPACITY		
Major Product: Synthetic Crude Liquids, Thousand BBLS/Day	165	186
10^{12} Btu/yr. equivalent	305	358
COAL REQUIRED (Millions of tons/year)	19.8 (eastern)	19.8 (eastern)
CONSTRUCTION PERIOD (Years)	4	8
OPERATING PERIOD (Years)	20	20
INVESTMENT COST (Millions of 1979 $)		
Process Plant	3703	3309
Reactor (3000 MW_t—Reference 6-1)	N/A	926
Start-up	156	166
Working Capital	127	143
TOTAL INVESTMENT	3986	4544
ANNUAL OPERATING COSTS (Millions of 1979 $)		
Coal	673	673
Water	5	5
Electric Power	—	—
Supplies, Chemicals, & Materials	35	35
Nuclear Fuel (Reference 6-2)	N/A	41.3
Direct Operating		
Process Plant	68	64
Reactor	N/A	12
Other		
Gross Operating	781	830
Byproduct Credit	29	29
Net Operating	752	801
INVESTMENT PERFORMANCE		
Return at $4/Million Btu Synfuels	7.18%	7.89%
Producer's Price at 8% ROI ($/Million Btu Synfuels)	4.17	4.03
Maximum Exposure (Millions of 1979 $)	4377	4959

Table 6-3. Comparison of Indirect Liquefaction Processes

	CONVENTIONAL	REFORMER	GCR/REFORMER
CAPACITY			
Products: Gasoline, Thousand BBLS/Day	88.2	149.7	177.8
SNG, Millions Standard Cubic Feet/day,	594.0	0	0
LPG (Mixed Butanes) Thousands BBLS/Day	8.8	15.2	18.1
LPG (Propane) Thousands BBL/Day	6.2	10.7	12.7
10^{12} Btu/Yr. Equivalent (1)	360	287	340
COAL REQUIRED (Millions of tons/year)	36.1	36.1	36.1
CONSTRUCTION PERIOD (Years)	4	4	8
OPERATING PERIOD (Years)	20	20	20
INVESTMENT COST (Millions of 1979 $)			
Process Plant	6842	7839	7808
Reactor (3000 MW_t—Reference 6-1)	N/A	N/A	926
Start-up	154	164	191
Working Capital	152	156	177
TOTAL INVESTMENT	7148	8159	9088
ANNUAL OPERATING COSTS (Millions of 1979 $)			
Coal	397	397	397
Water	Incl. in Supplies	Incl. in Supplies	Incl. in Supplies
Electric Power	N/A	N/A	N/A
Supplies, Chemicals, & Materials	22.7	27.1	27.1
Nuclear Fuel (Reference 6-2)	N/A	N/A	41.3
Direct Operating			
Process Plant	347.8	394.4	475.6
Reactor	N/A	N/A	12.0
Other			
Gross Operating	767.5	818.5	953.0
Byproduct Credit	845.3	106.8	120.0
Net Operating	(77.8)	711.7	833.0
INVESTMENT PERFORMANCE			
Return at $6.00/MMBtu	8.32%	5.95%	6.25%
Producer's Price at 8% ROI, $/MMBtu	5.74	7.03	6.89
Maximum Exposure (Millions of 1979 $)	7532	8568	9565

(1) Gasoline: 5.105×10^6 Btu/BBL
SNG: 980 Btu/SCF
LPG (mixed butane): 4.191×10^6 Btu/BBL
LPG (propane): 3.816×10^6 Btu/BBL

In the TRW design modification of Reference 1-1, the HTGR provides the process electrical power for operation of the plant, and process heat and steam for hydrogen manufacture. The economic comparison of this process to the conventional hydrogasification process is shown in Table 6-4. The nuclear process return at $4/million Btu is 30 percent higher than the conventional process while the producer's price at 8 percent ROI remains 4 percent lower. Furthermore, the plant capacity of the high-Btu HTGR is closer in size to currently conceived commercial size synfuels plants than are other processes.

6.7 MEDIUM AND LOW-BTU SYNTHETIC GAS

When coal is gasified with air as an oxidizing agent instead of oxygen, the product is a low-Btu (per standard cubic foot) gas suitable for industrial process heat, cogeneration of electricity, or combined-cycle generation of electricity. This process has the advantage of not needing an air separation (oxygen) plant which has been identified as a critically short component of synthetic fuel plants. Since the product gas is difficult to transport (large volumes are required) it must be generated at the site it is consumed.

The principal use of low- and medium-Btu gases is electricity generation. For example, the EIA long-range forecasts predict low-Btu gas from coal markets in Quads per year as follows.

Low Btu Gas Technology	2000	Year 2010	2020
Industrial Use	0.294	0.387	0.437
Industrial Cogeneration	0.334	0.536	0.687
Combined-Cycle Coal	1.311	2.406	3.624

Since the HTGR is an efficient baseload electricity generation method itself, it is unlikely to be used with an intermediate step which consumes another resource.

Nevertheless TRW assessed the use of an HTGR to replace high-pressure boiler power in an air-blown moving-bed Lurgi coal gasification process designed by Fluor Engineers and Constructors Inc. in Reference 6-6. The characteristics of this process are:

Input: 10,000 short tons/day of 12,235 Btu/lb. coal
Output: 134,000 Million Btu/day of 179 Btu/SCF fuel gas (net of internal use)
Power Required: 537 MW_t derived from 58,600 Million Btu/day of internally consumed product gas.

Table 6-4. Comparison of Processes for the Hydrogasification of Coal

	CONVENTIONAL	WITH GCR
CAPACITY		
Major Product: Synthetic pipeline gas, millions of standard cubic feet per day	685	540
10^{12} Btu's/yr equivalent	185	194
COAL REQUIRED (Millions of tons/year)	11.7 (eastern)	10.8 (eastern)
CONSTRUCTION PERIOD (years)	4	8
OPERATING PERIOD (years)	20	20
INVESTMENT COST (Millions of 1979 $)		
Process Plant	2370	2099
Reactor (3000 MW_t—Reference 6-1)	N/A	926
Start-up	129	93
Working Capital	76	79
TOTAL INVESTMENT	2575	3197
ANNUAL OPERATING COSTS (Millions of 1979 $)		
Coal	398	368
Water (included in plant operations)		
Electric Power	plant operation	Sup. Chem. & Mat.
Supplies, Chemicals, & Materials	plant operation	19.5
Nuclear Fuel (Reference 6-2)	N/A	41.3
Direct Operating		
Process Plant	187	26
Reactor	N/A	12
Other		
Gross Operating	585	467
By product Credit	64	69
Net Operating	521	398
INVESTMENT PERFORMANCE		
Return at $4/Million BTU pipeline gas	4.99%	6.56%
Producer's Price at 8% ROI ($/Million Btu pipeline gas)	4.62	4.45
Maximum Exposure (Millions of 1979 $)	2867	3430

If this power were provided by 3000 MW_t or 1170 MW_t HTGR's, 5 plants or 2 plants could be supplied respectively. Assuming these boilers and their accessories will cost the same in dollars per MW_t as those of reference 6-5, (the coal feed accessories compensate for the larger burner volume required to burn low-Btu gas), \$82 M (1979) of investment is avoided in the 1170 MW_t HTGR case. However the HTGR investment of \$1166 M (1979) results in an increase of 80% in total plant investment. Furthermore the annual operating cost increases by 26% for the purchase of nuclear fuel.

When these percentage increases are applied to the capital and operating charges for the process shown in reference 6-6, and the 44% increase in product is divided into these costs, a 3% increase in product cost per million Btu is estimated. These results are preliminary, but TRW believes these unfavorable economics, the large plant sizes required and the small non-electric generating market will result in no selections of HTGR's for low- or medium-Btu applications.

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