Presented at: BNES Internat'l Conf. on (The HT
Process A
London, England.
Nov 26, 28, 1974

71057

MASTER

Industry consumes a major portion of the total energy used in the United States. Presently natural gas and petroleum are the dominant industrial fuels, but in the future coal and nuclear are expected to become increasingly important. The High-Temperature Gas-Cooled Reactor (HTGR) shows promise as a source of industrial energy for certain applications especially in petroleum refining and petrochemical plants. One limitation to the use of large HTGR's for industrial energy stems from the mismatch in size between nuclear plants and most industrial plants. Even very large refineries could use the output of only one HTGR. The size mismatch, coupled with the need for multiple nuclear units to provide reliability, will limit applications to joint uses of a nuclear power station. One desirable arrangement is for an electric utility to generate both electricity for the grid and thermal energy for local industries. In those places where this arrangement can be implemented, the HTGR would have significant economic advantages over alternative fossil energy systems.

## INTRODUCTION

1. The industrial sector is the largest energy user in the United States, accounting for over 40% of the total primary energy consumed (Fig. 1). The term "industry" includes many diverse activities ranging from small food processors to giant petrochemical complexes, and their needs are met in a variety of energy forms (Fig. 2) such as steam, direct furnace heat (process heat), and fossil fuels for feedstock. The largest amount of industrial energy is consumed in the form of steam. In fact, the primary energy consumption related to industrial steam production is nearly 17% of the total national energy use. Process heat is also a significant fuel user and, taken together, the production of industrial process heat and steam requires more fuel than the entire electric utility industry.

2. Natural gas and petroleum are the primary fuels currently used by industry. [illegible] the direct fuel uses, 51% is natural gas and 27% is oil. Both natural gas and oil are becoming scarce and the prices are escalating rapidly. Perhaps of even greater concern to industry is that no longer can a long-term supply of gas or oil be assured regardless of price. As a consequence, U.S. industry will, in the future, reply more and more on the plentiful domestic fuel resources; these are coal and nuclear. Although coal can be expected to be the major alternative fuel, nuclear's role may become significant [illegible] industries because of its potential for supplying process heat.

### Limitations to industrial applications

3. Commercial nuclear energy systems are large, require a sizable capital investment, involve a long period of planning and construction, and generally have design characteristics intended to match the requirements for central station power generation. The HTGR nuclear steam supply system, offered commercially in the United States by General Atomic Company, is available in two standard sizes with nominal ratings of 2000 and 3000 MW(t). Steam conditions are approximately 510°C and 16,548 k Pa abs. (950°F and 2400 psia). If the HTGR follows the pattern of LWR's, the time required to construct a reactor and put it into operation will range from seven to ten years. After a reasonable shakedown period, a plant availability factor of 80 to 90% might be expected. There are several limitations on the use of large nuclear plants in industry, but two of the most important are related to unit size and construction period.

4. Although industrial energy consumption is large, the size of individual blocks of industrial energy is small in relation to the size of nuclear units. As an example, a 500,000 barrels per day petroleum refinery would require approximately 4000 MW(t) of energy input and 2000–3000 MW(t) of this would be based on purchased fuels; the remainder would be supplied by internally

responsibility for the accuracy, com- usefulness of any information, apparatus, process disclosed, or represents that its use infringe privately owned rights.

2: BNES Internatl Conf. on (The HTR Process Application)
London, England
Nov 26, 28, 1974

71057

MASTER

ajor portion of the total energy used in the United States. Presently natural the dominant industrial fuels, but in the future coal and nuclear are ex- easingly important. The High-Temperature Gas-Cooled Reactor (HTGR) shows f industrial energy for certain applications especially in petroleum refining nts. One limitation to the use of large HTGR's for industrial energy stems size between nuclear plants and most industrial plants. Even very large re- output of only one HTGR. The size mismatch, coupled with the need for to provide reliability, will limit applications to joint uses of a nuclear sirable arrangement is for an electric utility to generate both electricity al energy for local industries. In those places where this arrangement can TGR would have significant economic advantages over alternative fossil energy

ctor is the largest energy tates, accounting for over ary energy consumed (Fig. 1). includes many diverse activ- all food processors to complexes, and their needs of energy forms (Fig. 2) t furnace heat (process els for feedstock. The dustrial energy is consumed . In fact, the primary related to industrial steam 17% of the total national heat is also a significant together, the production s heat and steam requires ntire electric utility

petroleum are the primary by industry. Of the direct tural gas and 27% is oil. oil are becoming scarce and ating rapidly. Perhaps of to industry is that no rm supply of gas or oil be f price. As a consequence, in the future, reply more tiful domestic fuel re- oal and nuclear. Although to be the major alternative may become significant.

industries because of its potential for supplying process heat.

Limitations to industrial applications

3. Commercial nuclear energy systems are large, require a sizable capital investment, involve a long period of planning and construction, and generally have design characteristics intended to match the requirements for central station power generation. The HTGR nuclear steam supply system, offered commercially in the United States by General Atomic Company, is available in two standard sizes with nominal ratings of 2000 and 3000 MW(t). Steam conditions are approximately 510°C and 16,548 k Pa abs. (950°F and 2400 psia). If the HTGR follows the pattern of LWR's, the time required to construct a reactor and put it into operation will range from seven to ten years. After a reasonable shakedown period, a plant availability factor of 80 to 90% might be expected. There are several limitations on the use of large nuclear plants in industry, but two of the most important are related to unit size and construction period.

4. Although industrial energy consumption is large, the size of individual blocks of industrial energy is small in relation to the size of nuclear units. As an example, a 500,000 barrels per day petroleum refinery would require approximately 4000 MW(t) of energy input and 2000-3000 MW(t) of this would be based on purchased fuels; the remainder would be supplied by internally-

2

MASTER

Industry consumes a major portion of the total energy used in the United States. Presently natural gas and petroleum are the dominant industrial fuels, but in the future coal and nuclear are expected to become increasingly important. The High-Temperature Gas-Cooled Reactor (HTGR) shows promise as a source of industrial energy for certain applications especially in petroleum refining and petrochemical plants. One limitation to the use of large HTGR's for industrial energy stems from the mismatch in size between nuclear plants and most industrial plants. Even very large refineries could use the output of only one HTGR. The size mismatch, coupled with the need for multiple nuclear units to provide reliability, will limit applications to joint uses of a nuclear power station. One desirable arrangement is for an electric utility to generate both electricity for the grid and thermal energy for local industries. In those places where this arrangement can be implemented, the HTGR would have significant economic advantages over alternative fossil energy systems.

## INTRODUCTION

1. The industrial sector is the largest energy user in the United States, accounting for over 40% of the total primary energy consumed (Fig. 1). The term "industry" includes many diverse activities ranging from small food processors to giant petrochemical complexes, and their needs are met in a variety of energy forms (Fig. 2) such as steam, direct furnace heat (process heat), and fossil fuels for feedstock. The largest amount of industrial energy is consumed in the form of steam. In fact, the primary energy consumption related to industrial steam production is nearly 17% of the total national energy use. Process heat is also a significant fuel user and, taken together, the production of industrial process heat and steam requires more fuel than the entire electric utility industry.

2. Natural gas and petroleum are the primary fuels currently used by industry. Of the direct fuel uses, 51% is natural gas and 27% is oil. Both natural gas and oil are becoming scarce and the prices are escalating rapidly. Perhaps of even greater concern to industry is that no longer can a long-term supply of gas or oil be assured regardless of price. As a consequence, U.S. industry will, in the future, reply more and more on the plentiful domestic fuel resources; these are coal and nuclear. Although coal can be expected to be the major alternative fuel, nuclear's role may become significant. Eventually, special-purpose industrial reactors may be developed, but in the intermediate-term, nuclear energy for industry is likely to be supplied by adaptations of existing power reactors. Either light water reactors (LWR's) or high temperature gas-cooled reactors (HTGR's) could supply most industrial steam requirements, but the HTGR is more adaptable than LWR's to some industries because of its potential for supplying process heat.

### Limitations to industrial applications

3. Commercial nuclear energy systems are large, require a sizable capital investment, involve a long period of planning and construction, and generally have design characteristics intended to match the requirements for central station power generation. The HTGR nuclear steam supply system, offered commercially in the United States by General Atomic Company, is available in two standard sizes with nominal ratings of 2000 and 3000 MW(t). Steam conditions are approximately 510°C and 16,548 k Pa abs. (950°F and 2400 psia). If the HTGR follows the pattern of LWR's, the time required to construct a reactor and put it into operation will range from seven to ten years. After a reasonable shakedown period, a plant availability factor of 80 to 90% might be expected. There are several limitations on the use of large nuclear plants in industry, but two of the most important are related to unit size and construction period.

4. Although industrial energy consumption is large, the size of individual blocks of industrial energy is small in relation to the size of nuclear units. As an example, a 500,000 barrels per day petroleum refinery would require approximately 4000 MW(t) of energy input and 2000-3000 MW(t) of this would be based on purchased fuels; the remainder would be supplied by internally-generated low-value fuels. Thus a refinery slightly larger than any presently operating in the United States could take the output of one commercial HTGR. But a single unit would not provide the reliability required and at least two, and probably three, units would be needed. This, then, leads to one important conclusion concerning the use of large nuclear power plants

Legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

MASTER

tion of the total energy used in the United States. Presently natural inant industrial fuels, but in the future coal and nuclear are ex- important. The High-Temperature Gas-Cooled Reactor (HTGR) shows rial energy for certain applications especially in petroleum refining limitation to the use of large HTGR's for industrial energy stems een nuclear plants and most industrial plants. Even very large re- of only one HTGR. The size mismatch, coupled with the need for ide reliability, will limit applications to joint uses of a nuclear arrangement is for an electric utility to generate both electricity y for local industries. In those places where this arrangement can have significant economic advantages over alternative fossil energy

the largest energy counting for over gy consumed (Fig. 1). many diverse activ- processors to , and their needs y forms (Fig. 2) heat (process feedstock. The energy is consumed ct, the primary industrial steam the total national also a significant r, the production nd steam requires ectric utility

are the primary stry. Of the direct s and 27% is oil. becoming scarce and pidly. Perhaps of stry is that no y of gas or oil be As a consequence, uture, reply more estic fuel re- nuclear. Although he major alternative ome significant. industrial reactors intermediate-term, is likely to be sup- ting power reactors. (LWR's) or high ors (HTGR's) could requirements, but han LWR's to some

industries because of its potential for supplying process heat.

Limitations to industrial applications

3. Commercial nuclear energy systems are large, require a sizable capital investment, involve a long period of planning and construction, and generally have design characteristics intended to match the requirements for central station power generation. The HTGR nuclear steam supply system, offered commercially in the United States by General Atomic Company, is available in two standard sizes with nominal ratings of 2000 and 3000 MW(t). Steam conditions are approximately 510°C and 16,548 k Pa abs. (950°F and 2400 psia). If the HTGR follows the pattern of LWR's, the time required to construct a reactor and put it into operation will range from seven to ten years. After a reasonable shakedown period, a plant availability factor of 80 to 90% might be expected. There are several limitations on the use of large nuclear plants in industry, but two of the most important are related to unit size and construction period.

4. Although industrial energy consumption is large, the size of individual blocks of industrial energy is small in relation to the size of nuclear units. As an example, a 500,000 barrels per day petroleum refinery would require approximately 4000 MW(t) of energy input and 2000–3000 MW(t) of this would be based on purchased fuels; the remainder would be supplied by internally-generated low-value fuels. Thus a refinery slightly larger than any presently operating in the United States could take the output of one commercial HTGR. But a single unit would not provide the reliability required and at least two, and probably three, units would be needed. This, then, leads to one important conclusion concerning the use of large nuclear power plants

MASTER

TRUMAN D. ANDERSON and IRVING SPIEWAK, Oak Ridge National Laboratory, Oak Ridge, Tennessee, U.S.A., Operated by Union Carbide Corporation for the U.S. Atomic Energy Commission.

for industrial energy: a multi-unit station will be needed and the output will be shared by a group of industrial plants or by one or more industrial plants and an electric utility. The latter situation is illustrated by the arrangement between Dow and Consumers Power at Midland, Michigan; about 500 kg/sec (4 million pounds/hr) of steam will be provided to the Dow Chemical Complex from the Consumers Power nuclear (PWR) station.

5. The second major limitation on the use of large nuclear plants for industry is that it takes three to seven years longer to build a nuclear plant than to build a new industrial plant. Thus, industry's planning horizon will need to be extended or the construction period for nuclear plants reduced (or both) if nuclear is to be an acceptable energy source for new industrial plants. The long construction period may not be as serious if nuclear is used to retrofit existing industrial plants since existing plants already have energy systems that might be used until the nuclear station becomes available.

6. Another present-day limitation, although not necessarily one for the future, is that, since HTGR's were developed for the electric utility industry, they are steam producers. The higher temperature needs, presently satisfied by gas- or oil-fired process heaters, cannot be met with existing HTGR's. But with design modifications, the HTGR could provide many industrial process heat needs. Studies by the General Atomic Company (ref. 1) indicate that a core outlet temperature of ~900°C (1620°F) may be achieved with minor modifications to the present core design. This outlet temperature would be adequate to heat process streams to 650-750°C (1200-1400°F).

Application to petroleum refining

7. One promising application of the HTGR is to petroleum refining. The petroleum refining industry is a very large consumer of energy-- the third largest in the industrial sector as illustrated in Fig. 3. Refineries start with raw materials, primarily crude oil, and convert them into automotive and aircraft fuels, fuel oils, lubricants, coke, and chemical feedstocks. The kind and quantities of individual products vary among refineries, and, consequently, the characterization of energy consumption for a typical refinery is difficult. The industry average is an input in the form of thermal and electrical energy of about 700,000 Btu/barrel of crude processed; this is equivalent to 12% of the energy content of the crude. Refineries vary in size leum coke. It is the marketable fossil fuels that could potentially be displaced by nuclear fuel.

9. Thermal energy is required both in the form of steam and process heat with process heat generally being the larger fuel user. The fraction of total fuel consumption that goes to producing process heat varies from refinery to refinery (depending on products, age, and size of the refinery) but typically is on the order of 60%. Almost all of the thermal energy needs could be obtained from a modified HTGR since process temperatures generally range from 400 to 750°C (700 to 1400°F).

Economics

10. As may be inferred from the previous discussion, the implementation of large nuclear power plants to provide industrial energy is not as simple as using fossil fuels. What then are the incentives for considering nuclear energy? A desirable industrial energy source is one that is reasonably economical, meets environmental constraints, and has a favorable long-term supply outlook. On these three points, nuclear is promising. But, in the United States, a similar case can be made for coal assuming environmentally acceptable methods of using it can be developed. The major environmental contaminant is sulfur.

11. The relative costs of supplying industrial steam using the HTGR and various "clean" coal systems are shown in Fig. 4. These data are specifically applicable to U.S. Gulf Coast locations, and for that reason, the transportation cost for coal is high. For many other industrial areas the coal-based systems would look somewhat better relative to nuclear, but the Gulf Coast area is the region in which new industrial energy alternatives are most important since the present industrial fuel in that area is natural gas, a resource which is expected to be in increasingly short supply.

12. Shown in Fig. 4 are data for two different HTGR stations. One is a three-unit station based on units of 3000 MW(t) each and owned by an electric utility. The other is a two-unit station based on units of 2000 MW(t) each and owned by industry. As noted earlier, two units would appear to be a minimum because of reliability considerations; in most cases the station would be shared by more than one industry. The difference in cost between the two nuclear cases arises because of differences

steam will be provided to the Dow Chemical plex from the Consumers Power nuclear (PWR) tion.

The second major limitation on the use of rge nuclear plants for industry is that it es three to seven years longer to build a clear plant than to build a new industrial ant. Thus, industry's planning horizon will d to be extended or the construction period r nuclear plants reduced (or both) if nuclear to be an acceptable energy source for new in- trial plants. The long construction period y not be as serious if nuclear is used to retro- t existing industrial plants since existing ants already have energy systems that might be d until the nuclear station becomes available.

Another present-day limitation, although not cessarily one for the future, is that, since GR's were developed for the electric utility dustry, they are steam producers. The higher mperature needs, presently satisfied by gas- or il-fired process heaters, cannot be met with ex- sting HTGR's. But with design modifications, he HTGR could provide many industrial process eat needs. Studies by the General Atomic Com- any (ref. 1) indicate that a core outlet temper- ture of ~900°C (1620°F) may be achieved with inor modifications to the present core design. his outlet temperature would be adequate to heat process streams to 650-750°C (1200-1400°F).

Application to petroleum refining

7. One promising application of the HTGR is to petroleum refining. The petroleum refining industry is a very large consumer of energy-- the third largest in the industrial sector as illustrated in Fig. 3. Refineries start with raw materials, primarily crude oil, and convert them into automotive and aircraft fuels, fuel oils, lubricants, coke, and chemical feedstocks. The kind and quantities of individual products vary among refineries, and, consequently, the characterization of energy consumption for a typical refinery is difficult. The industry average is an input in the form of thermal and electrical energy of about 700,000 Btu/barrel of crude processed; this is equivalent to 12% of the energy content of the crude. Refineries vary in size from 300 barrels/day to 434,000 barrels/day. In January 1972 there were 247 refineries with a total capacity of 13 million barrels/day, for an average size of 53,000 barrels/day. Thus, based on industry-wide energy data, one might expect the "average" refinery to have an energy use rate of about 450 MW(t) and the largest refinery would require about 3700 MW(t).

8. Refineries produce waste-product hydrocarbon mixtures which are normally used as fuel; these fulfill 30 to 40% of the energy needs. The remaining energy is provided by fuels with market value such as natural gas, fuel oil, and petro- of total fuel consumption [illegible] process heat varies from refinery to refinery (depending on products, age, and size of the refinery) but typically is on the order of 60%. Almost all of the thermal energy needs could be obtained from a modified HTGR since process temperatures generally range from 400 to 750°C (700 to 1400°F).

Economics

10. As may be inferred from the previous discussion, the implementation of large nuclear power plants to provide industrial energy is not as simple as using fossil fuels. What then are the incentives for considering nuclear energy? A desirable industrial energy source is one that is reasonably economical, meets environmental constraints, and has a favorable long-term supply outlook. On these three points, nuclear is promising. But, in the United States, a similar case can be made for coal assuming environmentally acceptable methods of using it can be developed. The major environmental contaminant is sulfur.

11. The relative costs of supplying industrial steam using the HTGR and various "clean" coal systems are shown in Fig. 4. These data are specifically applicable to U.S. Gulf Coast locations, and for that reason, the transportation cost for coal is high. For many other industrial areas the coal-based systems would look somewhat better relative to nuclear, but the Gulf Coast area is the region in which new industrial energy alternatives are most important since the present industrial fuel in that area is natural gas, a resource which is expected to be in increasingly short supply.

12. Shown in Fig. 4 are data for two different HTGR stations. One is a three-unit station based on units of 3000 MW(t) each and owned by an electric utility. The other is a two-unit station based on units of 2000 MW(t) each and owned by industry. As noted earlier, two units would appear to be a minimum because of reliability considerations; in most cases the station would be shared by more than one industry. The difference in cost between the two nuclear cases arises because of differences between utility and industrial financing, unit size, and station size. The range represented by the two nuclear cases should be fairly indicative of steam prices from the HTGR. The cost estimates include all aspects of making prime steam and also include the cost of a reboiler which would probably be required to provide isolation between the nuclear and industrial plants.

13. The coal-based systems shown in Fig. 4 are those which our studies show to be the most economical and these include (1) conventional boilers using either low- or high-sulfur coal with stack-gas scrubbing, (2) fluidized bed boilers

burning high sulfur coal, and (3) solvent refined coal. Other coal-derived fuels, including liquid boiler fuel and low-Btu gas, are more expensive than those shown. As with the nuclear cases, all costs necessary to produce steam are included.

14. It seems evident that large HTGR's will be competitive with the lowest-cost coal-based systems for making industrial steam--at least in the Gulf Coast region. A particularly attractive arrangement for industry would be to buy steam from a nuclear power station owned by an electric utility. Concerning the supply of process heat, it seems likely that the relative costs of the various energy systems would parallel the estimates given in Fig. 4 for industrial steam. It should be emphasized, however, that neither the coal nor nuclear systems discussed are presently used for process heating.

## Concluding Remarks

15. Large HTGR's could supply industrial steam and, with some modifications, process heat. The chemical and petroleum refining industries are the most promising applications because of the large quantities of thermal energy required. The mismatch in size between present-day nuclear plants and industrial energy consumption, coupled with the need for multiple units to provide reliability, will limit applications to joint uses of a nuclear power station. One desirable arrangement is for an electric utility to generate both electrical energy for the grid and thermal energy for local industries. In those places in the Gulf Coast region where this arrangement can be implemented, the HTGR would have significant economic advantages over alternative coal-based energy systems.

## REFERENCE

1. QUADE R.N. The high-temperature gas-cooled reactor as a source of high-temperature process heat. Gulf General Atomic Report A12453 (PH215) January 5, 1973.

## Figure Captions

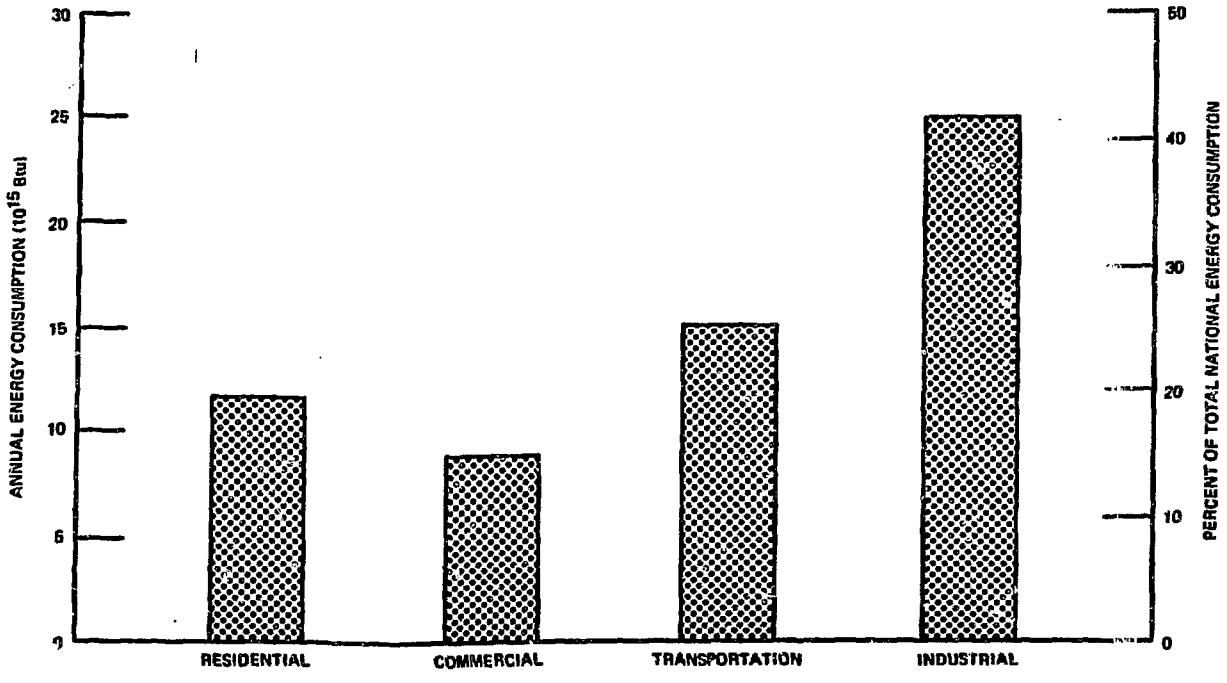
Fig. 1. Energy use in the United States by four economic sectors, 1968.

Fig. 2. Industrial uses of energy by form, 1968.

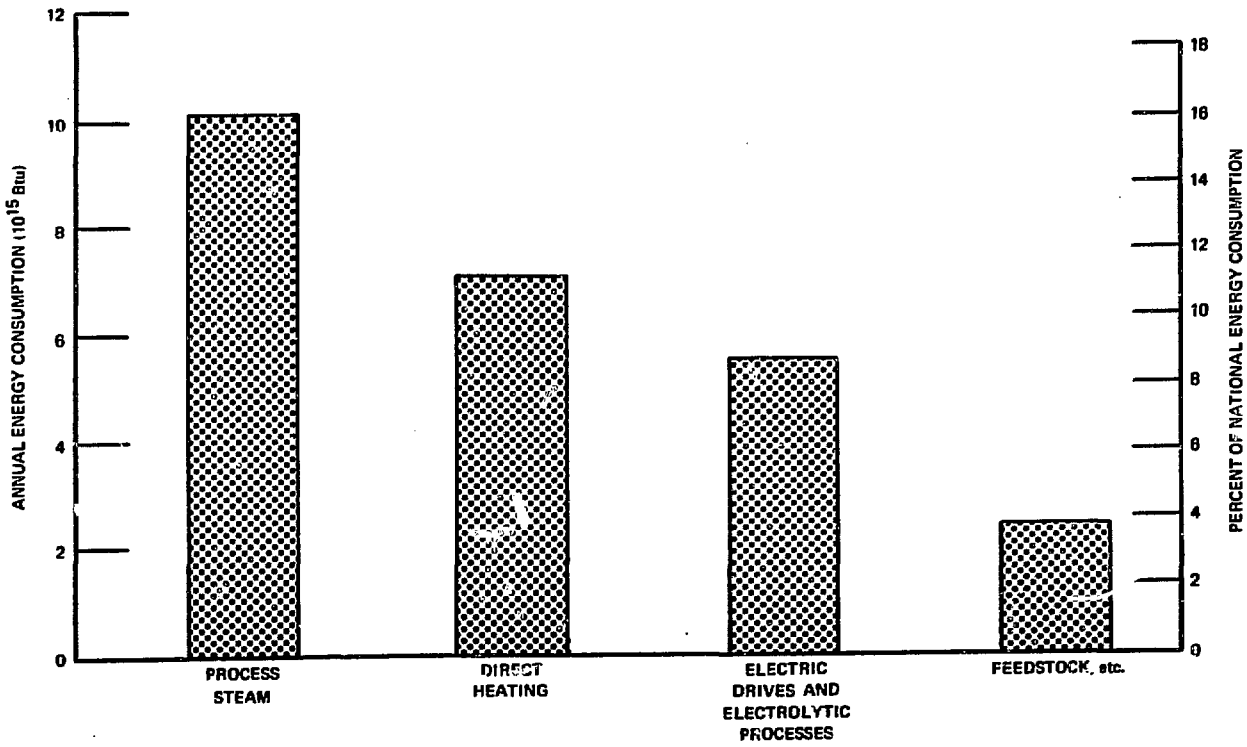
Fig. 3. Industrial uses of energy by industrial category, 1968.

Fig. 4. Comparative costs of producing industrial steam, U.S. Gulf Coast, 1974.

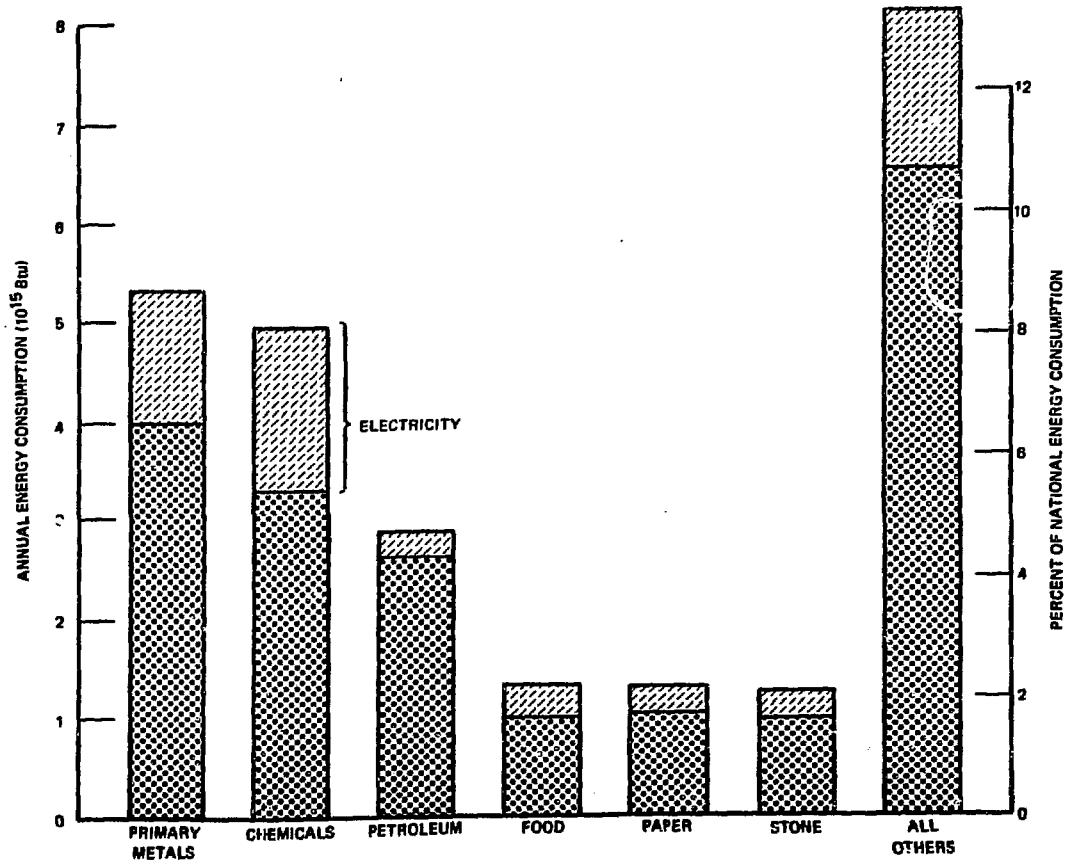
ORNL-DWG 72-13450

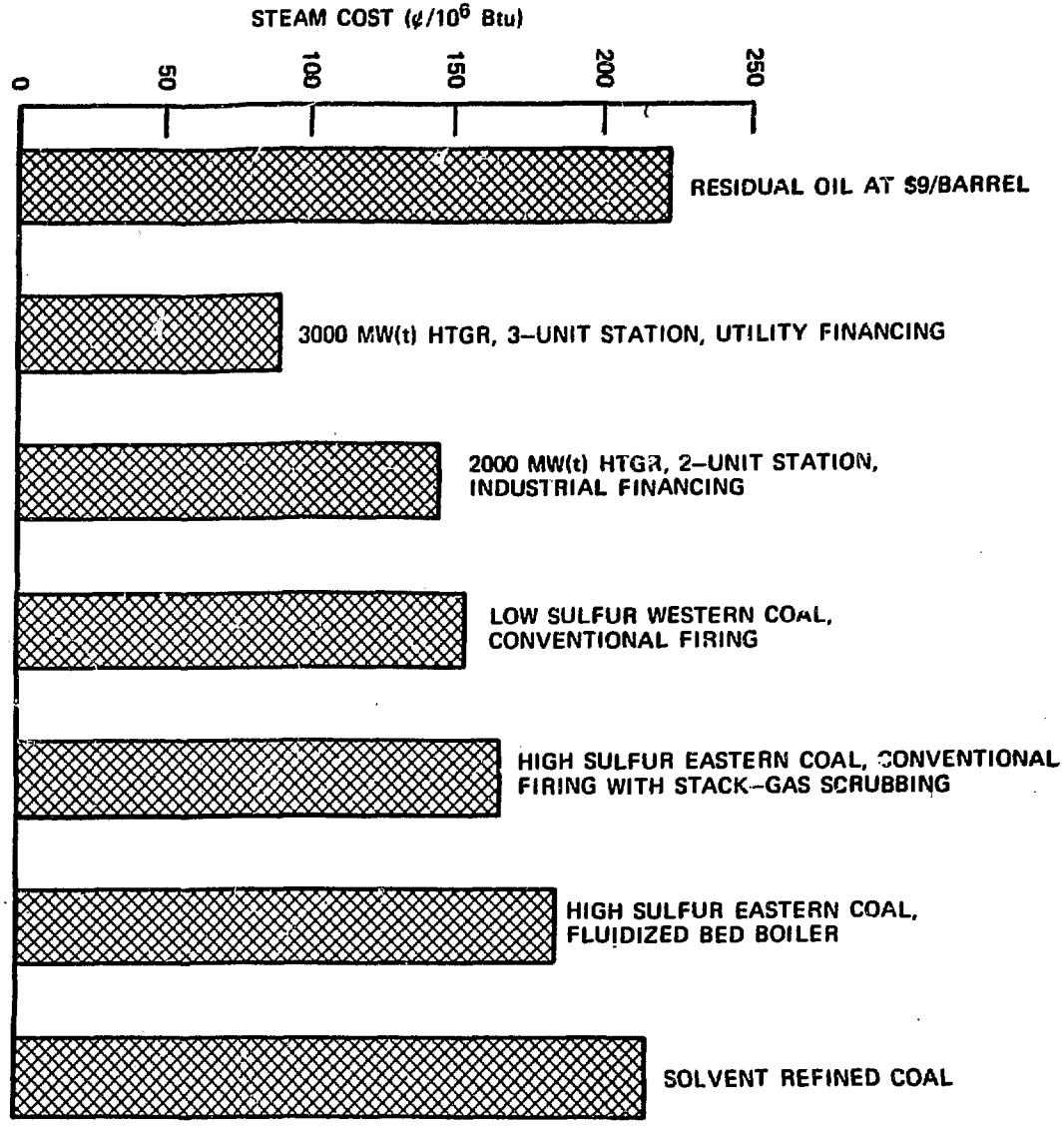


ORNL–DWG 72–13451



ORNL-DWG 72-13452






COMPARATIVE COSTS OF PRODUCING INDUSTRIAL STEAM, U. S. GULF COAST

ORNL-DWG 74-7017