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BENEFITS OF ADVANCED TECHNOLOGY IN INDUSTRIAL COGENERATION

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Work performed for
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ABSTRACT

Many technical and institutional barriers are limiting the use of industrial cogeneration. Advanced technology energy conversion systems offer the potential for energy savings and can provide economic, and environmental advantages over currently available equipment which may reduce or eliminate some of the constraints limiting wider use of industrial cogeneration. Under the sponsorship of DOE's Division of Fossil Fuel Utilization the NASA is performing a study of advanced systems for industrial cogeneration called the Cogeneration Technology Alternatives Study. This broad study is aimed at identifying the most attractive advanced energy conversion systems for industrial cogeneration for the 1985-2000 time period and assessing the advantages of advanced technology systems compared to using today's commercially available technology. Energy conversion systems being studied include those using steam turbines, open cycle gas turbines, combined cycles, diesel engines, Stirling engines, closed cycle gas turbines, phosphoric acid and molten carbonate fuel cells and thermionics. Specific cases using today's commercially available technology are being included to serve as a baseline for assessing the advantages of advanced technology.

Cogeneration in a wide variety of representative industrial plant applications is being examined in the study. This includes plants selected from the most energy consuming U.S. industries; namely the chemical, primary metals, petroleum refining, paper, stone clay and glass, and food industries. Emphasis in the study is on the use of coal or coal-derived fuels. Cogeneration options being studied include both: 1) matching the plant electrical needs and using a supplementary boiler to provide additional heat if the on-site power system cannot provide enough heat and 2) matching the plant thermal needs and either purchasing electricity from a utility if the on-site power system does not provide sufficient electrical power or selling electricity to the utility if the on-site power system produces more electrical output than is needed on-site.

Analyses are being performed by two industrial contractor teams led by General Electric Co. and United Technologies Corp. and by in-house personnel at NASA's Lewis Research Center. Support in selected areas is also being provided by the Jet Propulsion Laboratory. The study began in October, 1977 will be completed in 1979. An overview of the study will be presented along with selected contractor and in-house results for the various systems including potential energy savings and energy cost reductions. Also presented are discussions of environmental advantages of advanced technology cogeneration systems and the sensitivitiy of results to study groundrules for fuel and electricity prices.

INTRODUCTION

Many technical and institutional barriers are limiting the use of industrial cogeneration. The Department of Energy (DOE) is responsible for the advancement of cogeneration technology using energy conversion systems (ECS) with both today's commercially available technology and advanced energy conversion system technology. In line with the latter responsibility, a study is being performed by the National Aeronautics and Space Administration (NASA) for DOE called the Cogeneration Technology Alternatives Study (CTAS).

The organization of the study is shown in Figure 1. The study is being performed for DOE's Division of Fossil Fuel Utilization by NASA utilizing two NASA Laboratories, the Lewis Research Center (LeRC) and the Jet Propulsion Laboratory (JPL). LeRC is responsible for management of the overall effort, management of the two industrial contracts and providing in-house analyses and evaluations to complement and supplement the contractor efforts. JPL support to LeRC in CTAS includes providing data on regional influences which might impact the relative attractiveness of the various advanced systems.[(1)] The primary source of the data for CTAS is provided by the two contractor teams led by the General Electric Company and the United Technologies Corporation. The major participants in the two contractor teams are shown in Table 1.

Two independent, parallel contracts of similar scope are being utilized by NASA LeRC to provide the opportunity to examine differences in design approaches and philosophies as well as differences in view of what technology advancements might be made commercially available for introduction in the 1985-2000 time period. NASA LeRC will then compare and evaluate the contractor results, reconcile ~~and~~ identify the causes of any differences where they exist, and provide insight into the relative attractiveness of the advanced systems from both the similarities and the differences between contractor results.

The CTAS efforts began in October, 1977 and will be completed in late 1979. This paper provides an overview of the study, presents preliminary results to date which illustrate the potential energy savings and energy cost reductions achievable with advanced technology

(1) A paper summarizing the JPL results to date for the regional influences assessment entitled "Regional Characteristics for Advanced Technology Cogeneration" by R. Manvi is included in the proceedings of this workshop.

systems, and discusses potential environmental benefits from advanced technology and sensitivity to fuel and electricity prices.

Objectives and Scope of CTAS

The objectives of the overall CTAS effort are to:

(1) Identify and evaluate the most attractive advanced energy conversion systems for implementation in industrial cogeneration for the 1985-2000 time period which permit increased use of coal or coal-derived fuels.

(2) Quantify and assess the advantages of using advanced technology systems in industrial cogeneration compared to using today's commercially available technology.

Table 2 lists the systems which are being examined in CTAS. Each system is being studied at advanced technology levels which might be made commercially available in the 1985-2000 time period. Steam turbines, open cycle gas turbines, combined cycles and diesel engines are also being examined at conditions representing today's commercially available technology. Results for the cases using these commercially available technology conditions are being used as a baseline for assessing the advantages of advanced technology.

Each advanced system is being examined using one or more fuels selected from the list shown in Table 3. Emphasis in the study is on the use of high sulfur coal, coal-derived liquid fuels and integrated on-site Low-Btu gasification of coal. Some emphasis is also being placed on the use of petroleum derived residual grade fuel as a "stepping stone" to the use of coal-derived liquid fuels. The specifications for the liquid fuel types used in the study represent minimally processed fuels which might be appropriate for use in the 1985-2000 period. The distillate grade fuels (coal-derived and petroleum derived) are along the lines of a No. 2 diesel fuel while the residual grade fuels are along the lines of a No. 5 oil.

The various energy conversion systems are being examined for application to the manufacturing sector of U. S. industry. Emphasis is being placed on representative plants selected from the six major industry groups listed in Table 4. These six major industry groups accounted for approximately 80% of the energy consumption in U. S. manufacturing industries in 1974. The sizes, electrical and thermal requirements and other factors for the representative plants chosen for inclusion in the study, have been projected to the 1985-2000 time period by the CTAS contractors, including reductions in energy demand from conservation measures which might be implemented by that time. The set of plants selected have a wide range of thermal and electrical requirements and represent a cross-section through the most energy intensive U. S. industries.

The focus of CTAS is on comparative evaluation of the various advanced systems being studied rather than on the merits of cogeneration itself or addressing any of the many institutional barriers which confront wider application of industrial cogeneration. Some of the factors which are being used to compare and evaluate the advanced system concepts are shown in Table 5.

Preliminary Results to Date

The methodology being employed in CTAS to provide the data needed for the comparisons and evaluation is shown in Figure 2. It is essentially a screening process which permits a narrowing down of the options considered at various points in the study to keep the number of cases examined to a manageable number while focusing on areas of potentially highest payoff. To date results on a per plant basis have been obtained for the potential savings in fuel energy and the energy cost savings for the advanced systems in cogeneration. These results represent the first major output of the study. Economic parameters, such as rate of return and payback period, will be calculated in subsequent work as well as an evaluation of the results on a national basis to assess the relative potential of the advanced systems for saving energy.

Two basic cogeneration options are being considered in CTAS, namely topping and bottoming. These options are illustrated in Figure 3. Emphasis in the study is on the topping cycle option and results will be presented here for this option only. For the topping cycle configuration three basic strategies are being examined. In the first strategy the energy conversion system is sized to match the process plant electrical needs and a supplementary furnace is used where necessary to provide additional process heat if the on-site system cannot provide enough. In the second strategy the system is sized to match the heat needs of the process plant and electricity is either purchased from the utility if the on-site system cannot provide enough electricity to supply the plant needs or electricity is sold to the utility if the system provides more electricity than is needed at the plant site. In addition to these two cogeneration strategies being considered by both contractors, UTC also examined a third approach to power plant sizing which maximized energy savings in certain situations which can occur when it is assumned that the process steam is produced at more than one pressure. For all strategies it has been assumed thus far in the studies that the utility burns coal.

The selection of the fuel for the conventional non-cogeneration boiler (Figure 4) can have a dramatic impact on the results for the systems as they are applied in the various cogeneration options and strategies. For the non-cogeneration boiler GE assumed that coal would be used wherever technically feasible while UTC assumed a residual grade liquid fuel (either petroleum or coal-derived) would be used. In addition GE also calculated results where residual grade liquid fuels are used in the non-cogeneration boiler.

Table 6 shows the scope of the contractor results. A total of approximately 85 representative industrial plants have been included in the study. Approximately 15 types of plants were studied in common between the two contractors. Each energy conversion system was examined over a range of configurations and system design parameters in addition to the variation in fuel/energy conversion system combinations noted in Table 6. In all nearly 6000 cases were examined for topping applications. On the basis of these results 270 cases have been selected for inclusion in the study of industry specific economics including cases representing each of the major system types identified in Table 2.

Figure 5 summarizes the results of the contractor efforts to date for fuel energy savings and energy cost savings. The values for the savings in both fuel energy and energy cost are percentage savings compared to the non-cogeneration situation. The energy cost savings include a capital cost contribution to energy costs as well as fuel, electricity, and operating and maintenance costs and are calculated on a levelized annual basis. Significant fuel energy and energy cost savings resulting from the use of advanced technology systems are shown in Figure 5. The differences between the GE and UTC results are caused by a variety of reasons in addition to the fuel type used in the non-cogeneration boiler. These include differences in analytical procedures, assumptions made for the various systems and industrial process plants, the system configurations studied and design choices made, and differences in the estimates of the capital costs of the various equipment. NASA LeRC is currently engaged in identifying the major causes of these differences and examining their significance. It should be pointed out that changes in some of the results may be warranted after the NASA evaluation is completed.

As mentioned previously, in addition to the assumption of the coal-fired non-cogeneration boiler, GE also ran their cases for a residual grade liquid fuel fired non-cogeneration boiler situation. This change increased the energy savings and energy cost savings, for both the commercially available and advanced technology cases, and changed the envelopes to a shape similar to the UTC envelopes shown in Figure 5. The assumption of whether the non-cogeneration fuel will be coal, a coal-derived liquid, petroleum oil, or natural gas will also be an important factor when the potential for oil and gas savings is assessed in the evaluation of results on a national scale.

Table 7 shows the process plant requirements used by GE and UTC for 9 of the 15 plant types studied in common. These 9 industries are being used in this paper to illustrate how well each of the advanced energy conversion systems types was able to meet a variety of industrial requirements compared to the use of commercially available technologies. With the exception of the meat packing plants, which were projected to operate between 2000 and 2500 hours per year, these plants are all high load factor plants operating near or above 8000 hours per year. Note in Table 7 the wide range of sizes, ratios of electrical power to thermal energy required, and process temperature requirements covered by this sampling of industries. Also note that even for the same type of industrial plants there are differences between the requirements as established by the two contractors. This was not surprising because of the diversity of industrial plants in a given industry and also the uncertainties of projecting plant requirements to the 1985-2000 time period.

Figure 6 displays preliminary results for the nine common industries and each type of advanced energy conversion system. Figure 6 indicates where the system results were better than was achieved using currently available technology. Results for the advanced systems were compared to the "best" of the commercially available technology cases on the basis of fuel energy savings and energy cost savings. For each industry one case using a commercially available technology system (steam with residual fuel or coal with flue gas desulfurization, or state-of-the-art diesel or gas turbine) was selected as a basis for comparison. This "best" current technology case in each industry was one which simultaneously had relatively good fuel energy savings and energy cost savings but not necessarily the highest fuel energy savings or energy cost savings. In addition to illustrating where the advanced system results were better than those for commercially available technology, these results indicate in a rough, first order fashion the relative ability of the various advanced systems to meet a wide range of industrial requirements. A next step planned is to quantify the magnitude of the potential improvements which arise from the use of advanced technology in the various industries.

The environmental impact from the various cogeneration options using advanced or commercially available technology is vitally important. Results to date indicate the potential for total emission reductions as high as 50 percent compared to the non cogeneration situation when emissions from the utility powerplant producing the purchased electricity are taken into account. However, on-site emissions were generally increased in the cogeneration cases because of the higher on-site fuel consumption. There can be exceptions however. For example, on some the low temperature fuel cell cogeneration systems on-site emissions were actually less than for the non cogeneration situation. Although not included in the cases studied, use of catalytic combustion concepts for the open cycle gas turbine would also show a reduction of on-site emissions.

All systems, with the exception of the diesel engine, met or bettered the emission guidelines established for the study. These guidelines were based on requirements of the new Source Performance Standards for Steam Power Plants and proposed new Source Performance Standards for Stationary Gas Turbines. Even with the projected advancements in combustion technology made for the diesel, NO_x emission still exceeded the guidelines. For the other systems use of fluidized bed combustion or projected advancements in gas turbine combustor technology have the potential economic reduction of powerplant emissions compared to today's commercially available equipment.

Sensitivity of Results to Assumptions

CTAS groundrules were established by NASA in cooperation with DOE in order to assure that the contractors' results could be compared on a common basis and that differences which occurred would not be caused by differences in the basic study assumptions. Table 8 identifies the areas where common groundrules were established for the study.

One area which can have a significant effect on the results and where considerable uncertainty exists is that of future prices for fuel and electricity. The fuel prices and electricity prices selected as base values for the study are shown in Tables 9 and 10 respectively. These values are based on information developed by the DOE Energy Information Administration and which was provided to NASA for use in the study. The coal-derived liquid fuels prices were assumed to be equal to the petroleum fuel price of the same grade.

In order to understand the sensitivity of the results for economic parameters such as energy costs and payback period, several example cogeneration cases were formulated by NASA and the effects of independent changes in the groundrules for fuel and electricity prices examined.

Two energy conversion system (ECS) types were selected for use in the examples and are designed ECS A and ECS B. ECS A is representative of a relatively high capital cost system which can burn coal. ECS B is representative of a relatively low capital cost system, which uses higher cost coal-derived liquid fuel. The capital cost and performance results for ECS A and ECS B are not unlike some of the results estimated by the CTAS contractors for steam and open cycle gas turbine systems respectively. These examples, however, were not intended as a comparison of steam and gas turbine systems but rather were aimed solely at providing an understanding of the sensitivity of the results to changes in the basic groundrules.

Two sets of industrial process plant requirements were also selected, one representative of a plant requiring a low power/heat ratio which is also an ideal match for ECS A and one which has a higher power/heat ratio, lying between the values well suited to ECS A and ECS B. The two basic strategies of matching plant electrical requirements and matching plant thermal requirements were applied as applicable to the four ECS/industry combinations. This results in cases where: the power and heat needs of the plant were simultaneously satisfied by the ECS; where electricity was purchased from the utility; where plant electrical needs were satisfied and a supplemental boiler was used to provide additional steam; and cases where electricity was sold to the utility. For all the cogeneration cases examined, those using ECS B, resulted in fuel energy savings equal to or greater than those using ECS A.

Independent variations of the price of the various fuels and the electricity price were made as well as a case where electricity and fuel costs were varied together. As expected significant variations in the results were found. Figure 7 illustrates the results for energy cost savings and simple payback period for the calculations where the price of electricity was varied while keeping the fuel prices at their base values. The bands in Figure 7 show the ranges in results for ECS A and ECS B for the two industrial process plant requirements and the various cogeneration strategies employed. (Simple payback period is defined here as the incremental capital cost of the cogeneration system above that of the non-cogeneration boiler divided by the first years savings in the sum of fuel and purchased electricity.) The significant variation of energy cost savings and payback period shown for relatively small changes in the price of electricity and the differences in the rates of change for the two ECS examples indicate the importance of a sensitivity analysis. Therefore examination of the sensitivity of results to changes in the fuel and electricity prices and other groundrules are being performed by each contractor as well as in-house at LeRC.

Concluding Remarks

The CTAS effort is aimed at providing data which will assist DOE in establishing R & D funding priorities for advanced energy conversion systems for industrial cogeneration. It is a broad study focusing on the technical issues important to comparsions of the various advanced technology systems being examined. Based on early outputs from the study advanced technology energy conversion systems appear to offer significant energy savings and energy cost savings advantages compared to the use of today's commercially available technology. Preliminary sensitivity analyses performed at LeRC indicate the importance of carefully examining the sensitivity of results to changes in the various study groundrules.

TABLE 1

CTAS CONTRACTOR TEAMS

	GENERAL ELECTRIC	UNITED TECHNOLOGIES
PROGRAM MANAGEMENT	G.E. - ENERGY TECH OPERATIONS	UTC - POWER SYSTEMS DIV
ENERGY CONVERSION SYSTEMS	G.E. INTERNAL DIVS DELAVAL, INC INST OF GAS TECH NORTH AMERICAN PHILLIPS CORP	UTC INTERNAL DIVS AEROJET ENERGY CONVERSION CO BECHTEL, INC CUMMINS ENGINE CO, INC DELAVAL, INC DR PHILLIP MYERS, CONSULTANT MECH TECH, INC RASOR ASSOC SULZER BROS., INC WESTINGHOUSE ELEC CORP
INDSTRIAL PROCESSES	G.E. INTERNAL DIVS DOW CHEM CO GENERAL ENERGY ASSOC KAISER ENGINEERS, INC J.E. SIRRINE	GORDIAN ASSOC

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TABLE 2

ADVANCED TECHNOLOGY CONVERSION SYSTEM CANDIDATES

STEAM TURBINE
OPEN CYCLE GAS TURBINE
COMBINED GAS TURBINE/STEAM TURBINE CYCLES
CLOSED CYCLE GAS TURBINE
DIESEL ENGINE
STIRLING ENGINE
PHOSPHORIC ACID FUEL CELL
MOLTEN CARBONATE FUEL CELL
THERMIONICS

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TABLE 3

CTAS FUELS

NATURAL GAS
PETROLEUM-DERIVED DISTILLATE
PETROLEUM-DERIVED RESIDUAL
COAL-DERIVED DISTILLATE
COAL-DERIVED RESIDUAL
COAL
LBTU GAS FROM COAL
HBTU GAS FROM COAL

STUDY EMPHASIS

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TABLE 4

CANDIDATE INDUSTRY GROUPS

~80% OF US INDUSTRIAL ENERGY CONSUMPTION	CHEMICALS & ALLIED PRODUCTS
	PRIMARY METALS INDUSTRIES
	PETROLEUM REFINING
	PAPER & ALLIED PRODUCTS
	STONE, CLAY, & GLASS PRODUCTS
	FOOD & KINDRED PRODUCTS
	OTHERS

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TABLE 5

MAJOR FACTORS FOR COMPARISON OF
ADVANCED ENERGY CONVERSION SYSTEMS

POTENTIAL FOR OIL & GAS SAVINGS

POTENTIAL FOR INCREASED OVERALL ENERGY EFFICIENCY

POTENTIAL FOR ANNUAL ENERGY COST SAVINGS

ENVIRONMENTAL CHARACTERISTICS

ECONOMIC ATTRACTIVENESS TO INDUSTRIAL USERS

ABILITY TO ACCOMMODATE A TRANSITION FROM PRESENT FUELS TO HEAVY OILS, COAL, & COAL-DERIVED FUELS

FUEL FLEXIBILITY

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TABLE 6

SCOPE OF CONTRACTOR EFFORTS

	GE	UTC
INDUSTRIAL PROCESSES/PLANTS	59	26
FUEL/ENERGY CONVERSION SYSTEM COMBINATIONS	40	36
COGENERATION STRATEGIES EXAMINED	2	3
COGENERATION SYSTEM CASES CALCULATED	*~3000	*~2800
CASES SELECTED FOR ECONOMICS STUDY	150	120

*MATCHES FOR TOPPING APPLICATIONS.

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TABLE 7

REPRESENTATIVE INDUSTRY CASES
COMMON TO BOTH CONTRACTS

	SIZE, MWe		POWER/ HEAT RATIO		PROCESS TEMP, °F	
	GE	UTC	GE	UTC	GE	UTC
MEAT PACKING	1.9	8.7	0.28	0.34	250° STM	140° HW; 300° STM
MALT BEVERAGES	6.0	2.4	.24	.14	250° STM	300° STM
NYLON	11.0	8.2	1.63	.94	274° STM	300, 500, 700° STM
CHLORINE	120.0	77.0	1.55	1.03	338° STM	300, 500° STM
ALUMINA	30.3	31.0	.11	.19	495° STM	500° STM
BLEACHED KRAFT	50.0	33.0	.22	.22	366° STM	140° HW; 300, 500° STM
NEWSPRINT MILL	31.3	130.0	.58	.68	366° STM	140° HW; 300, 500° STM
PETROLEUM	52.0	34.6	.13	.14	470° STM	500° STM
STEEL	280.0	200.0	1.05	.78	448° STM	500° STM

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TABLE 8

AREAS WHERE GROUND RULES HAVE
BEEN SPECIFIED BY NASA

FUEL CHARACTERISTICS

UTILITY CHARACTERISTICS

FUEL & ELECTRICITY PRICES

EMISSION GUIDELINES

CAPITAL COSTING APPROACH & ECONOMIC METHODOLOGY

OTHER

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TABLE 9

FUEL PRICES**

BASED ON DOE INPUT

FUEL	1985 BASE YR PRICE (1978 $/MMBUTU)	ESCALATION OF PRICE ABOVE INFLATION (%/YR)
DISTILLATE OIL*	3.80	1.0
RESIDUAL OIL*	3.10	1.0
COAL	1.80	1.0
NATURAL GAS	2.40	4.6 (1985-2000) 1.0 (>2000)

*PRICES FOR PETROLEUM & COAL-DERIVED LIQUID FUELS OF SIMILAR GRADES ARE ASSUMED TO BE THE SAME.

**SENSITIVITY OF RESULTS TO FUEL PRICES WILL BE EXAMINED.

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TABLE 10

ELECTRICITY PRICES

PURCHASE PRICE FOR UTILITY ELECTRICITY IN 1985 IS 3.3¢/kWhr.*

ELECTRICITY PURCHASE PRICE ESCALATES AT 1% ABOVE INFLATION.*

PRICE RECEIVED BY COGENERATOR FOR ELECTRICITY EXPORTED TO THE GRID IS 60% OF THE PURCHASE PRICE DEFINED ABOVE.

SENSITIVITY OF RESULTS TO THE PRICE OF BOTH PURCHASED & EXPORTED ELECTRICITY WILL BE EXAMINED.

*BASED ON DOE INPUT.

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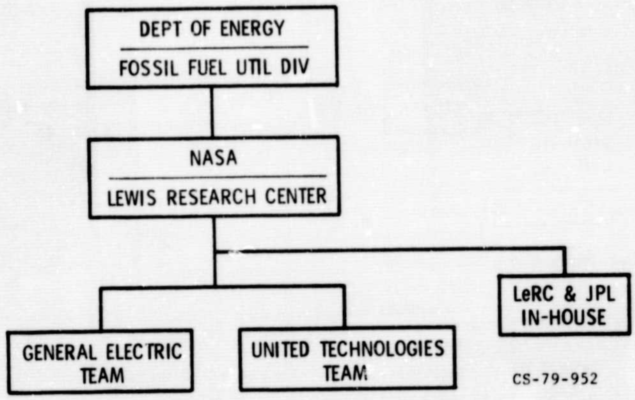

Figure 1. - CTAS organization.

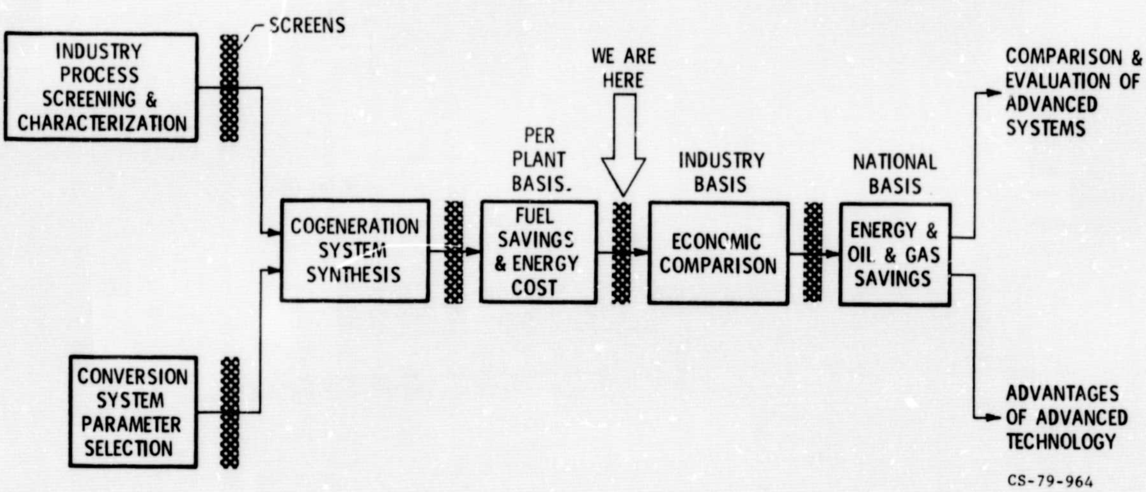

Figure 2. - CTAS methodology.

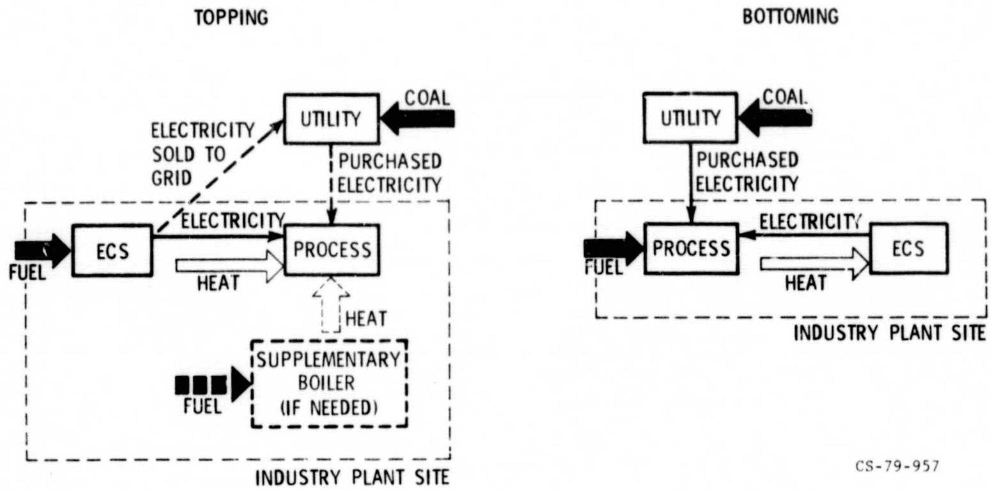

Figure 3. - CTAS cogeneration options.

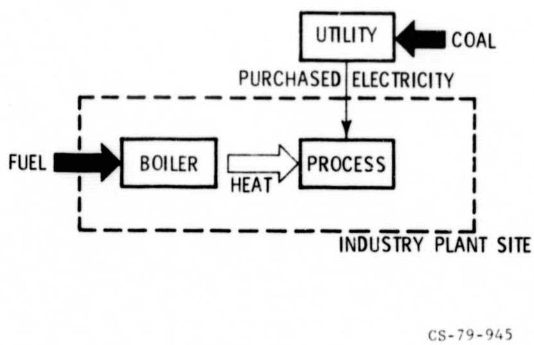

Figure 4. - CTAS noncogeneration case.

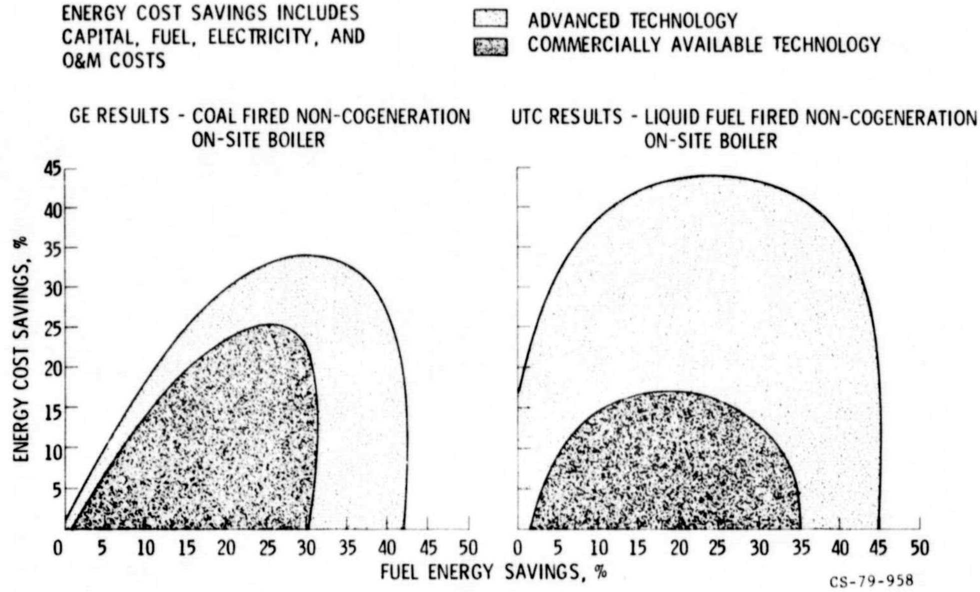

Figure 5. - Preliminary comparison of CTAS contractor results. Envelopes of attractive cases.

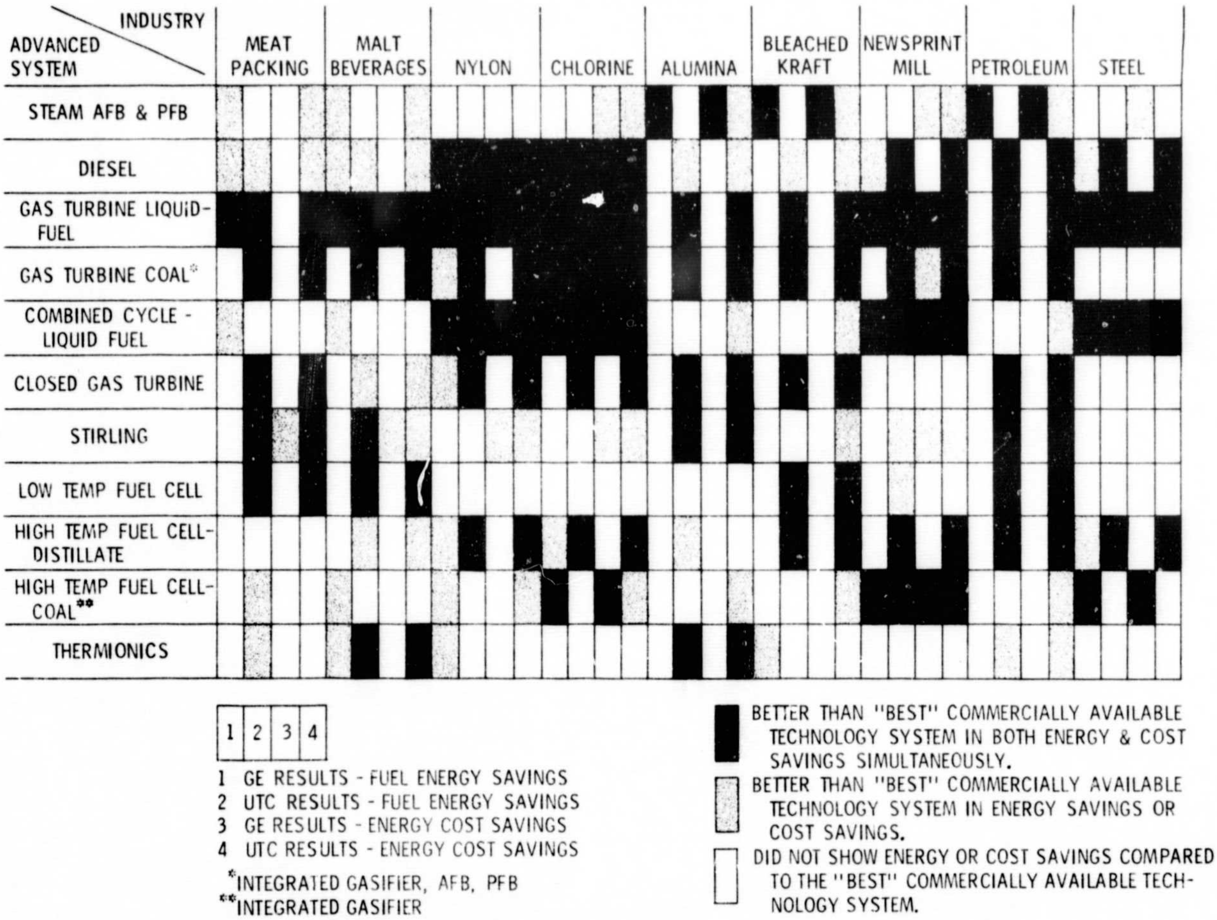

Figure 6. - Preliminary results for advanced systems in representative CTAS industrial plants.

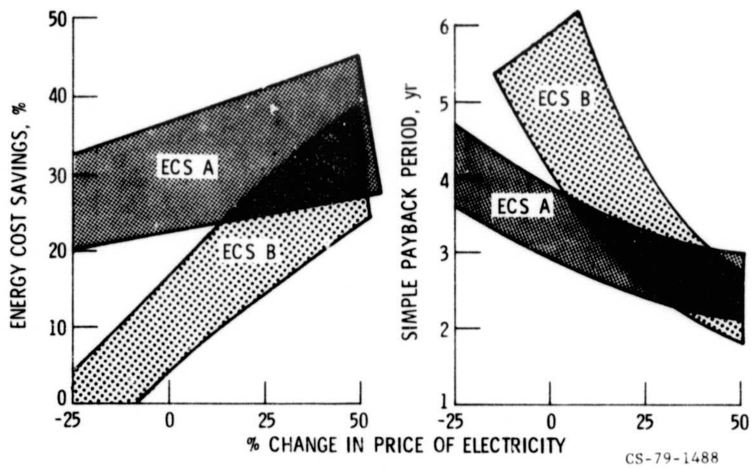

Figure 7. - Example cases to illustrate sensitivity of results to price of electricity.