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## U.S. Fossil Fuel Technologies for Thailand

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## PREFACE

". . . Technology can play a major role in improving competitiveness in a global market. . . . DOE, as the advocate for energy in the Federal government, has the responsibility to provide leadership with other elements of government in developing a policy environment that is conducive to making U.S. energy technology more competitive in world energy markets."

*Abstract, R&D Initiatives for  
Energy Competitiveness*  
Energy Research Advisory Board,  
March 1988

"The Federal government and the coal industry should pursue a broad, integrated and coordinated strategy to promote the use of coal in developing countries for power generation in the interest of national security and expanded coal exports."

*Improving International  
Competitiveness of U.S. Coals  
and Coal Technologies*  
National Coal Council,  
June 1987

"The Clean Coal Technology Program of the United States offers an opportunity to provide a marketing advantage to coal exporters by linking the sales of U.S. coals with clean coal technologies that have been commercially proven in domestic markets. Combining the coal and the technology in a package offering proven and effective environmental and economic benefits may be especially attractive to countries which are just beginning to develop coal-based energy systems."

*Report of the Federal Coal Export  
Commission*  
U.S. Department of Commerce,  
May 1988

## FOREWORD

The U.S. Department of Energy (DOE) is working with other federal agencies and with industry on a broad and flexible range of initiatives to improve the U.S. trade balance and energy security through increased exports of coal and coal technology.

The wise and productive use of energy and energy technology is a key factor in every country for the development and maintenance of economic well being and national security. Energy helps to meet the personal needs of people in their homes and fuels the industries that employ them. Energy is a significant component of agricultural and manufactured goods for export. These exports in turn help earn the hard currency needed to import critical skills and products from abroad that are essential to assist in the continuing process of national development.

The availability, cost, and effectiveness of energy deployment directly affects national productivity and competitiveness.

The United States is blessed with a wide range of energy resources and has continuously been a world leader in the development of energy technologies. In particular, the large and varied U.S. coal resource and its high level of coal utilization in the world give the United States unparalleled scope and capability in this fuel and technology field. This leadership is being continued and strengthened through a multibillion dollar presidential initiative to develop and demonstrate a suite of advanced clean coal technologies (CCTs). This commitment to improved coal utilization and a quality environment is unmatched by any other nation.

As Secretary of Energy John S. Herrington noted (1)\* in early 1987:

America is determined to become the "world's showcase" of new clean coal technology. In addition to accelerating our environmental progress here at home, new clean coal options can help strengthen the common bonds of cooperation with our international neighbors and provide new articles of trade.

Discussions between U.S. industry and federal agencies have suggested that the government might be helpful in collecting and disseminating information regarding development of markets for coal and coal technologies. In response, DOE, Office of Fossil Energy, has been screening world energy markets to identify opportunities for using the technological innovations we are advancing domestically as the basis for encouraging other countries to look to U.S. coal and coal technologies to meet their energy needs in the future.

The initial focus of this information collection activity has been on three selected developing countries: Costa Rica, the Dominican Republic, and Thailand.

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\*Throughout this report, numbers in parentheses are keyed to the alphabetized bibliography, which contains cited references and other relevant documents.

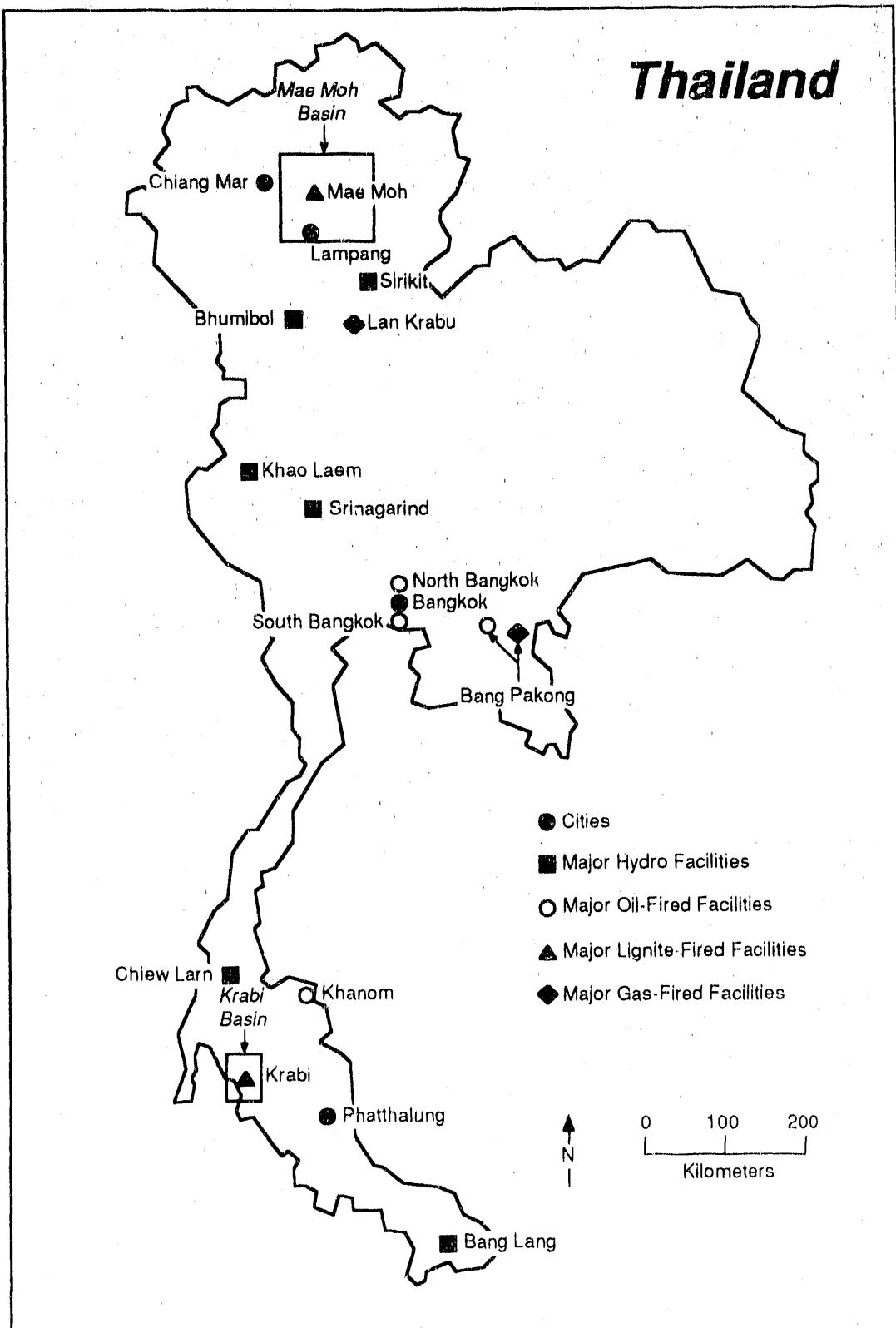
Clearly, newly industrialized countries, as well as other developing countries, represent potentially favorable market areas as well. Similarly, while the technological driving force is the suite of emerging CCTs for electric power generation and commercial/industrial use, it is recognized that the currently established suite of U.S. coal technologies may also support market opportunities abroad as precursors to relationships that can continue with CCT products.

The various Fossil Energy initiatives have actively sought the input and participation of other interested federal agencies. Indeed, the U.S. Agency for International Development helped to sponsor the early studies that identified specific countries for more intensive follow-on activity (Appendix A). The results of these initial efforts are presented in this report and its companion documents for review, use, and comment by U.S. industry. Because the objective of these efforts is to assist U.S. industry in increasing exports and improving the U.S. trade balance, constructive industry review and comment will contribute greatly to the selection and emphasis of subsequent phases of the Fossil Energy initiatives.

International trade is founded on the concept of mutual benefit. The energy fuels and technology skills possessed by the United States and its industry offer increased development capabilities and improved economic well being for international purchasers of these capabilities. Their increased economic stability and participation in the international marketplace aids world stability and security. In turn, U.S. security and other important national objectives are enhanced. The success of these initiatives must ultimately be reflected, however, in the quality and vigor of U.S. private sector actions and in the active cooperation and support of energy users in potential host countries.

This work, which was completed in July 1988, was presented at a public meeting on U.S. fossil fuel technologies for developing countries, held on July 21, 1988, in Washington, D.C. Although some of the country profile data are now dated, the opportunities for energy projects appear to remain valid. This information is therefore being published in the public interest.

# Thailand



## **U.S. FOSSIL FUEL TECHNOLOGIES FOR THAILAND**

by

**W.A. Buehring, G.E. Dials, J.L. Gillette,  
C.B. Szpunar, and P.A. Traczyk**

### **ABSTRACT**

The U.S. Department of Energy has been encouraging other countries to consider U.S. coal and coal technologies in meeting their future energy needs. Thailand is one of three developing countries determined to be a potentially favorable market for such exports. This report briefly profiles Thailand with respect to population, employment, energy infrastructure and policies, as well as financial, economic, and trade issues. Thailand is shifting from a traditionally agrarian economy to one based more strongly on light manufacturing and will therefore require increased energy resources that are reliable and flexible in responding to anticipated growth. Thailand has extensive lignite deposits that could fuel a variety of coal-based technologies. Atmospheric fluidized-bed combustors could utilize this resource and still permit Thailand to meet emission standards for sulfur dioxide. This option also lends itself to small-scale applications suitable for private-sector power generation. Slagging combustors and coal-water mixtures also appear to have potential. Both new construction and refurbishment of existing plants are planned.

### **SUMMARY**

Electricity demand in Thailand has been growing rapidly for several years and is expected to continue to do so into the next century. Thailand intends to maximize the development of indigenous coal reserves, and it exhibits an environmental awareness that is somewhat atypical for a developing country. Thailand's high economic growth rate and favorable investment policies make it attractive for both domestic and foreign investors. Thus, significant trade opportunities for U.S. businesses exist in Thailand's electric and industrial power markets.

This report characterizes Thailand's energy situation; discusses the financial, economic, and trade issues; and summarizes energy project opportunities in Thailand.

Thailand has several types of natural energy resources, including lignite. Additional discoveries of high-quality lignite will provide a relatively inexpensive source of fuel starting in the mid-1990s. However, for the near term, Thailand will likely depend on imported oil and perhaps coal to supplement domestic production. The 1987

peak electrical demand was 4,734 MW, which represented a 13 percent increase from 1986. The Electricity Generating Authority of Thailand (EGAT) has an ambitious investment program for new capacity to meet this rapidly growing demand. As of September 1987, the EGAT-owned generation capacity was 6,926 MW; in addition, it purchases power from Laos and Malaysia. To meet increasing demand with the use of lignite, EGAT has two 300-MW lignite-fired units at Mae Moh and plans for adding seven 300-MW units by 1995. Two 75-MW units are planned for construction in southern Thailand.

Thailand's pro-business stance, conservative fiscal and monetary policies, abundant natural resources, skilled labor, and growing infrastructure all help to create a generally good investment climate. Thailand had a steady economic performance in 1987 as the country moved closer to the threshold of a newly industrialized country. One of the major objectives of the country's Sixth National Economic and Social Development Plan for 1987-1991 (12) is to raise Thailand's level of development.

Conditions in Thailand led to several U.S. advanced fossil fuel technologies being selected for consideration in conjunction with potential project opportunities. These technologies are the atmospheric fluidized bed combustor, coal-water mixtures, and the slagging combustor. These technologies could play a major role in the capacity expansion and/or conversion opportunities listed in Table S.1. The total value of such projects could approximate U.S. \$3.3 billion.

**TABLE S.1 Opportunities for Energy Projects in Thailand**

Sector and Industry	Unit Capacity (MW)	Estimated Annual Coal Demand (kilotonne HCE) <sup>a</sup>
Public utility		
New	5 x 300	3,000
	2 x 75	300
Retrofit	5 x 300	3,000
Private		
Industrial park	1 x 50	100
Industrial cogeneration	3 x 5	30
Cement industry	<u>b</u>	<u>600</u>
Totals	3,215	7,030

<sup>a</sup>HCE: hard coal equivalent (12,600 Btu/lb).

<sup>b</sup>Capacity measured in terms of tonnes of cement rather than electrical capacity.

## 1 THAILAND PROFILE

### 1.1 HUMAN AND POLITICAL PROFILE

The population of Thailand is estimated at 55 million, of which approximately 8.3 million live in the greater Bangkok area (6 million in central Bangkok, the capital). The population of the greater Bangkok area is expected to increase to 9.3 million by 1991, when it will rank among the 15 largest cities in the world. In its attempts to relieve congestion in Bangkok, the government has engaged in a major campaign to promote development outside this urban area. The eastern seaboard and other new economic zones are targeted for large industries.

The Sixth National Economic and Social Development Plan (1987-1991) has a target of 3.9 million new jobs to alleviate both rural and urban unemployment. Currently, only about 7 percent of the work force is employed in industry. Estimates for technical and related workers in manufacturing, electricity, gas, and water are 23,000 in 1986; potential scientists and engineers number 20,000, while potential technicians number 47,000. Overall, Thailand has a well-educated and capable work force for the industrial development that lies ahead (Figure 1).

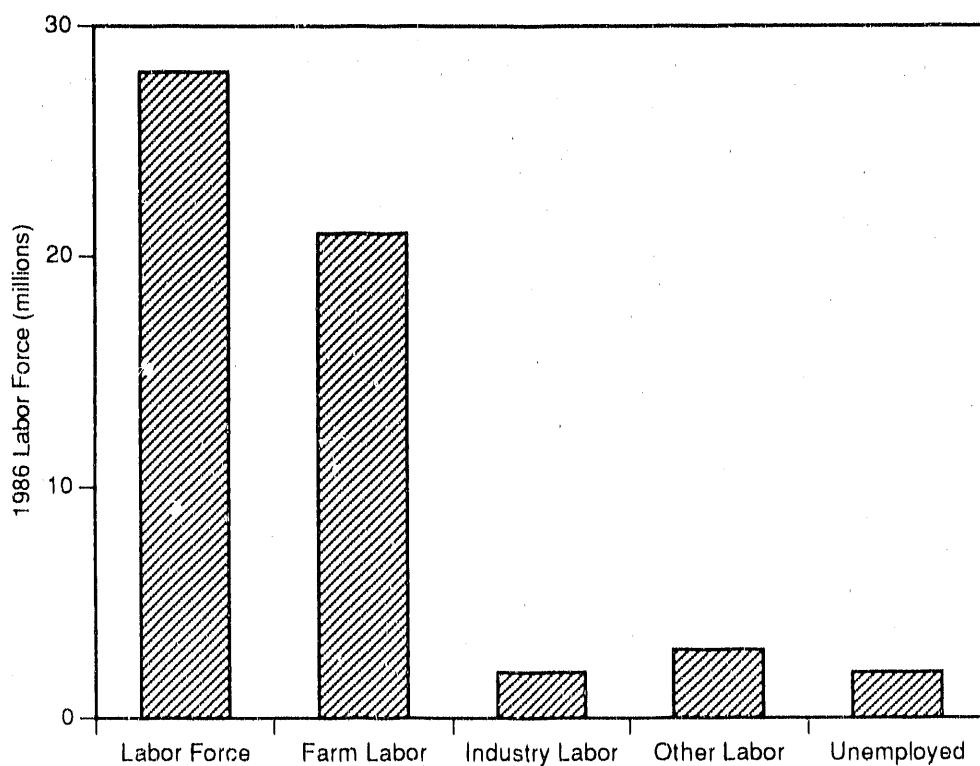


FIGURE 1 Thai Labor Force (Source: Ref. 5)

Thailand has been a constitutional monarchy since 1932. The king has considerable influence and has played an important role in maintaining the current stability. There are 73 provinces in Thailand, each of which is governed by a provincial governor, appointed by the minister of interior.

The present constitution, which took effect in 1978, provides for a parliament of 225 appointed senators and 301 elected members of a house of representatives. At the national level, executive power is administered and legislation is proposed by the cabinet, on which all the ministries are represented. The cabinet is chaired by the prime minister, whose post was established in 1933. The first 25 years of constitutional government saw the prime minister's power gradually increase. Since 1958, prime ministers have played the dominant role in running the country. A major change in power occurred in 1974 with a violent coup d'état. The current prime minister has been in office since 1978 and has provided a relatively stable political environment that has supported economic growth.

A number of government agencies are principal actors in the energy sector. These include the National Energy Administration (NEA), the Petroleum Authority of Thailand, the Electricity Generating Authority of Thailand (EGAT), the Ministry of Industry, and, only recently, the National Environment Board. The NEA has attempted to provide overall guidance for the energy sector, but the other organizations operate independently and have not officially followed NEA's lead. Cooperation among these agencies occurs on a personal level to a limited extent.

## 1.2 ENERGY OVERVIEW

Responsibility for policy formulation, energy services, and regulation is dispersed among several agencies in Thailand. The agency responsible for energy generation is EGAT. The Thai government encourages EGAT to use natural gas and has provided a subsidy to keep the utility from switching to imported oil for economic and national security reasons. Thailand intends to maximize the development of indigenous coal reserves and increase the development of alternative energy resources, including micro-hydro, biogas, oil shale, and geothermal. The government recognizes the need for increased reliable energy generation with the expected growth in the manufacturing, industrial, and service sectors of the economy.

Thailand has several natural energy resources, including natural gas, lignite, hydropower, and some oil. Among the renewable resources are forest products, rubber tree waste, sugar cane processing residue (bagasse), and sugar cane field waste. The electrical sector, like the industrial sector, has experienced and is expected to continue to have very high growth rates. Therefore, additional generating capacity is needed. EGAT has an ambitious investment program for new capacity, but demand is exceeding estimates. The investment program will not be adequate. The electric power sector currently accounts for more than 60 percent of the government investment in public enterprises.

New discoveries of high-quality lignite will provide a relatively inexpensive source of fuel starting in the mid-1990s. This development will help considerably in

meeting demand, particularly in southern Thailand. For the near term, and for some time into the future, Thailand will depend heavily on imported oil to meet domestic energy needs. In 1980, the country depended on imported oil for more than 75 percent of its total energy requirements. Since then, dependence on imported oil has been reduced by about one-third. A rapidly growing domestic industrial demand for power will promote greater use of conservation methods and cogeneration. EGAT is releasing its tight grip on private power sales to encourage private investment in power generation. The EGAT expansion plans emphasize increased reliance on lignite for power generation.

Increased use of lignite will have environmental consequences. In the absence of pollution regulations, new investment in lignite combustion equipment could ignore the need for pollution control. However, the Thai government is expected to issue pollution regulations in the next few years. Thus, potential opportunities for utilization of clean coal technologies (CCTs) would be enhanced. Project opportunities have been identified in both the electric and industrial sectors.

## **1.2.1 Electric Utility Situation**

### **1.2.1.1 Electricity Demand**

Electricity demand in Thailand has been rapidly growing for several years and is expected to continue to grow into the next century. The 1987 peak demand was 4,734 MW, which represented a 13.2 percent increase from 1986 (11). This large increase is the result of the rapid economic recovery that has recently taken place in Thailand. In 1986, about 46 percent of the electricity produced was used in the industrial sector, about 27 percent in commercial facilities, and 26 percent in the residential sector, with the remaining 1 percent consumed in street lighting, agriculture, and other activities (3). For Thailand's population of 55 million, per capita electricity consumption in 1986 was about 420 kWh. The projected growth rate for peak demand is 8.2 percent/year through 1991, when it is expected to reach 6,481 MW. The growth rate is expected to decrease slightly to about 7.3 percent/year in the 1992-1996 period and to 5.1 percent/year in the 1997-2001 time frame. The anticipated peak demands for 1996 and 2001 are 9,202 MW and 11,821 MW, respectively (11).

About 62 percent of the households in Thailand are electrified (3). This figure represents approximately 6 million households. However, electricity usage is not uniform throughout the country. About one million of the electrified homes are in the greater Bangkok area; they represent about 89 percent of the population in this area. About 40 percent of the electricity used in the residential sector is consumed in these one million households. About half of the electrified homes outside the Bangkok area qualify for what is called a lifeline tariff because they use less than 35 kWh/month. About 54 percent of the consumption in the commercial and industrial sectors also occurs in the greater Bangkok area.

#### **1.2.1.2 Geographic Pattern of Power Consumption**

Thailand is divided into four major regions. The Central Region (Region 1) covers central Thailand and includes Bangkok. Approximately one-third of the total population lives in this region, with 65 percent of these people living in electrified homes. This region consumes about 78 percent of the electrical energy, with about 50 percent being used in the greater Bangkok area and two adjoining provinces.

In the Northeast (Region 2), which also has about one-third of the total population of the country, 56 percent of the population lives in electrified households. This region accounts for only 8 percent of the total national electricity consumption.

Southern Thailand (Region 3) has about 12 percent of the population, with 6 percent of the total electricity consumption. Approximately 48 percent of the households are electrified.

In the North (Region 4), the population is about 20 percent of the national total. Roughly 55 percent of the households are electrified, with the total electricity use at 8 percent of the national total.

The growth rates and the benefits associated with increased electrical use are regionally dependent. The average annual demand growth in the 1987-2001 period is estimated to be approximately 6 percent in the greater Bangkok area and 8 percent in the rest of the country. The annual growth in electricity sales is expected to average 7 percent in the Bangkok area and 8 percent in the other areas.

#### **1.2.1.3 Generating Capacity**

The responsibility for power generation has been given to EGAT, which was formed in May 1969. EGAT also is responsible for production and sale of indigenous lignite resources and for power transmission. The Metropolitan Electricity Authority (MEA) is responsible for distributing electricity within the greater Bangkok area and Nonthaburi and Samut Prakan provinces. The Provincial Electricity Authority (PEA) distributes the power in the rest of the country. EGAT also has 10 direct customers to whom it sells power. These customers include cement companies, oil refineries, and military installations. About 765 MW of privately owned capacity in Thailand is used to meet in-house demand.

As of September 1987, the EGAT-owned generation capacity in Thailand was 6,926 MW (Table 1). In addition, EGAT purchases surplus power from the Nam Ngum dam in Laos and has a power exchange agreement with the facility at Sadao in Malaysia.

#### **1.2.1.4 Distribution**

The standard transmission voltages are 500, 230, 115, and 69 kV at 50 Hz. The four regions of the EGAT system are connected via 230- or 115-kV transmission lines. As the generation system is expanded, the transmission system is upgraded or expanded in a consistent fashion. The Central-Southern Tie Line forms a major link between central

and southern Thailand, and a second such link is being considered. The connection between southern Thailand and northern Malaysia has been in operation since February 1981. A second connection is under consideration that would enable power transfers of 100, 200, or 300 MW between the two countries.

Transmission and distribution losses are estimated at 10 or 11 percent of the dispatched output, but have been as low as 8 to 9 percent for some years (3,11).

#### 1.2.1.5 Natural Gas and Oil

In 1987, the gas-fired steam and combined cycle units made up approximately 46 percent of the capacity and produced about 48 percent of the electricity. Heavy oil units accounted for only 5 percent of the capacity but produced about 11 percent of the electricity. This difference appeared even though the price of natural gas was lower than the price of oil. As an explanation, gas production records indicate that EGAT was limited to an average of 354 million cubic feet per day. With this constraint, the electricity production from these units was limited to about 13,690 GWh, or an average capacity factor of about 49 percent. The lignite units operate at their maximum capacity factor, and the hydro units are predominantly used in the peaking mode; therefore, the heavy oil units are used to produce the power that would have come from the gas units if there had been sufficient gas supply. The production of natural gas is expected to increase in the next few years, but there will continue to be a constraint on the use of natural gas for most years in the planning period. A second 75-MW barge-mounted plant burning oil or gas is currently under construction at Khanom in southern Thailand and will be operational in December 1988.

#### 1.2.1.6 Hydropower

As noted above, the hydroelectric capacity in Thailand is used predominantly as peaking capacity. Thus, even though the hydro capacity is about 32 percent of the total, it produced only about 16 percent of the energy, for an average capacity factor of about 27 percent. Even the largest hydro units (200 to 400 MW) have capacity factors of only 30 percent or less.

#### 1.2.1.7 Lignite

EGAT has undertaken an aggressive expansion plan in order to meet future demand. Two 300-MW lignite-fueled units are under construction at Mae Moh (in the

TABLE 1 EGAT-Owned Generation Capacity, 1987

Type	MW
Hydroelectric	2,250
Oil-fired steam	342
Gas-fired steam	2,400
Lignite-fueled	865
Gas-fired combined cycle	772
Gas turbines	265
Diesel	32
Total	6,926

Source: Ref. 10

North) and are expected to be on-line in July 1989 and December 1990. Many other construction and renovation projects have been identified by EGAT as being needed by 2001 to meet expected demand. Approximately 7,536 MW of additional capacity (beyond the 675 MW currently under construction) has been planned to meet this demand and to account for the 467 MW of anticipated retirements. These projects are in various stages of planning.

#### 1.2.1.8 Expansion Plans

There are significant differences in electricity demand among the geographic regions of Thailand. Generating capacity and the anticipated need for additional capacity also differ.

**Central.** In the Central Region (Bangkok and 26 surrounding provinces), the base load demand is met with oil- and gas-fired steam plants at South Bangkok and Bang Pakong, along with the gas-fired combined cycle units at Bang Pakong. Current plans for this region call for expansion of the combined cycle capacity by 600 MW by January 1992. An additional 180 MW of hydro capacity will be operational at Srinagarind in April 1992 and will be used as peaking capacity. A 550-W gas/oil unit at Bang Pakong will be operational in December 1992 and a similar unit in November 1995. Four hydro plants of 145 MW each are planned for Upper Quae Yai in late 1996 and early 1997. Five 600-MW coal-fired units to be added between 1997 and 2001 complete the expansion plan for the region.

A total of 5,460 MW of new capacity is projected for this region. This figure represents almost two-thirds of the total capacity additions projected for Thailand in the 1987-2001 time frame. In addition to this new capacity, there are plans to do a considerable amount of renovation at both the North and South Bangkok oil/gas-fired plants. These plants represent more than 1,500 MW of capacity.

**Northeast.** The base load demand in the Northeast (16 provinces) is met by importing power from the Central Region and purchasing power from the Nam Ngum dam in Laos. Twin 105-MW gas-fired combined cycle units are under construction at Nam Phong and are expected to be operational in November 1989 and January 1991. Four 34-MW hydro units at Pak Mun are planned for operation in December 1993. Thus, total planned additions in the Northeast are 346 MW.

**South.** This region (14 provinces) includes the Krabi Basin, where lignite reserves have been found and are now being used to only a limited extent. Base-load demand in this region is currently met by the twin 20-MW lignite-fueled units at Krabi (a third 20-MW unit has already been retired, and the twin units are scheduled for retirement in 1990), the 75-MW barge-mounted, oil-fired unit at Khanom, the 30-MW oil-fired plant at Surat Thani, and the 115-kV Central-Southern Tie Line. The South is also connected to Malaysia via a 132-kV tie line to help meet peak demand.

This region is expected to experience a rapid increase in demand. It is therefore anticipated that an additional 1,000 MW of generation capacity will be needed by 1997. The most recent EGAT plans show only a 75-MW lignite plant at Krabi to begin operation in November 1992 and another 75-MW lignite plant at Sin Pun to begin operation in October 1995 (11). Thus, there appears to be a great need for additional capacity to be planned and constructed in this region. The new lignite discovery at Saba Yoi has given EGAT a major new source of fuel for power generation in the South. EGAT has expressed an interest in implementing a major new power project there at the same time it prepares the infrastructure for mining operations. The earliest date for possible power generation from Saba Yoi is the mid-1990s. A proposed feasibility study for Saba Yoi will be completed in 1991. Upgrading the Central-Southern Tie Line is another option that EGAT will consider if demand in the South exceeds the generating capacity.

**North.** The Mae Moh lignite reserves are in the North, which also includes the upper part of Central Thailand. This lignite is burned in power plants that provide the bulk of the base-load power. Expansion is based on further utilization of the lignite, with seven 300-MW units planned to begin operation between now and April 1995.

**Planning Criteria.** Table 2 presents a detailed summary of the EGAT expansion plan through the year 2001. EGAT uses three basic planning criteria when considering expansion of its generating system. The first deals with the loss of the largest units in

TABLE 2 EGAT Capacity, 1988-2001 (MW)

Year	Hydro	Oil/ Steam	Gas/ Steam	Lignite	Coal	Comb. Cycle	Peaking	Total
1988	2,250	342	2,400	865	0	772	297	6,926
1989	2,250	418	2,400	1,165	0	772	297	7,301
1990	2,250	418	2,400	1,165	0	772	437	7,441
1991	2,250	418	2,400	1,425	0	982	465	7,939
1992	2,430	418	2,400	1,725	0	1,582	265	8,819
1993	2,430	418	2,950	1,800	0	1,582	145	9,324
1994	2,646	418	2,950	2,400	0	1,582	100	10,095
1995	2,646	418	2,950	3,000	0	1,582	100	10,695
1996	2,646	418	3,500	3,075	0	1,582	100	11,320
1997	3,226	418	3,500	3,075	0	1,582	100	11,900
1998	3,226	388	4,100	3,075	0	1,582	100	12,470
1999	3,226	388	4,100	3,075	1,200	1,582	100	13,670
2000	3,226	388	4,100	3,075	1,800	1,582	100	14,270
2001	3,226	388	3,900	3,075	2,400	1,582	100	14,670

Source: Ref. 11

the system. This criterion defines system firm generating capacity as being equal to the total available capacity of hydro and thermal plants minus the available capacity of the first and second largest units in the system.

A second criterion is that of the reserve margin. The reserve margin is equal to the difference between the total available capacity and the peak load, divided by the peak load. History has shown that the EGAT system requires a reserve margin of about 25 percent to ensure that the loss of load probability (the third criterion) will not exceed 1 day/year. However, recent government policy and the limitations of foreign currency borrowing have dictated that the reserve margin be reduced to 15 to 20 percent for planning purposes.

The third and final criterion used in system planning is loss of load probability (LOLP). This parameter considers the outage rates of each unit in the system and combines them into a measure of overall system reliability. In the past, EGAT has used an LOLP of less than 1 day/year as a planning criterion. As noted above, however, new restrictions on reserve margin have limited EGAT's ability to maintain this LOLP level. The most recent EGAT expansion plan will have annual LOLPs in the range of 0.3 to 2.5 days/year.

### **1.2.2 Industrial Energy Sector**

#### **1.2.2.1 Major Industries**

Thailand is on the verge of being classified as a newly industrialized country, along with Hong Kong, South Korea, and Taiwan. Manufacturing has been a leading source of growth in the Thai economy. Throughout the 1960s and early 1970s, the government influenced the structure of the manufacturing sector primarily through policies designed to encourage import substitution. Thailand now has a very sophisticated industrial capability that includes iron and steel products and electronic equipment as well as assembly plants for motor vehicles, engines, refrigeration and air conditioning equipment, and agricultural machinery, along with cement, textiles, chemicals, and transport equipment.

With the development of natural gas fields in the Gulf of Siam, the Thai government embarked on a U.S. \$5 billion industrial development plan for petrochemical and other heavy and light industries along the eastern seaboard. An economic downturn in the mid-1980s caused some of those projects to be shelved. The existing industrial centers are located in or around Bangkok, but attempts are being intensified to attract manufacturers to regional areas outside Bangkok.

One of the largest industrial energy consumers is the cement industry (15). Siam Cement, the largest private industrial company in the country, resisted using indigenous lignite because the high ash content made it not worth the high transport cost. However, by mixing the lignite with steam coal imported from the People's Republic of China, an

adequate Btu level is obtained and the problem of ash sufficiently mitigated. The cement industry is now importing 600,000 tonnes of steam coal per year to mix with indigenous lignite.

Except for agricultural processing plants that use biomass (agricultural waste) as a source of fuel, most industries currently depend on fuel oil for meeting their energy needs. However, lignite represents a less expensive and more reliable source of fuel. While few companies are decommissioning their current oil-fired systems to install lignite-fired equipment, new systems are more frequently designed for lignite.

#### **1.2.2.2 Cogeneration**

About 400 MW of cogeneration capacity is currently used to supply the in-house needs of Thai industry (10). No power generated from this capacity is sold to EGAT, either because the in-house needs are just met or because there is no agreed price or policy for such transactions. Because the majority of this capacity is fueled with agricultural wastes (particularly bagasse from the sugar industry), the supply from these sources is seasonal. With the recent interest in lignite-fired boilers, a new opportunity exists for cogeneration.

In some cases, such as in industrial parks, economies of scale can be achieved if a private power and steam generating facility can serve more than one user. To date, there has been little interest in planning such a facility because private power was not permitted to be sold. EGAT holds the monopoly and appeared to want to keep that status. The Thai government is now encouraging the devolution of state authority to the private sector. EGAT has acknowledged its inability to make the necessary investment for new power generation. It is viewing favorably the purchase of power from a private power project sponsored by the Agency for International Development (AID), with sugar cane trash as fuel. EGAT is looking to the private sector to invest in new generating capacity. Industrial estates such as Bangpoo are prime areas for lignite-fired cogeneration facilities.

#### **1.2.2.3 Fuel Prices**

The 1987 prices for fuel delivered to EGAT are given in Table 3. Projections to 2001 indicate annual increases of about 4 percent for fuel oil, 2 percent for imported coal, 3 percent for natural gas, and less than 0.5 percent for lignite.

### **1.2.3 Natural Energy Resources**

The more important energy resources are offshore and onshore natural gas, lignite, hydropower, and oil/condensates. Renewables represent an additional resource for power generation.

### 1.2.3.1 Natural Gas

Natural gas resources are found both offshore and onshore. Major natural gas reserves have been discovered in the Gulf of Thailand. The proven and recoverable reserves are estimated at 3.4 trillion cubic feet (15). Currently, the Erawan and Platong fields, which together total 1.53 trillion cubic feet of proven reserves, are supplying about 400 million cubic feet/day. Of this, about 300 million cubic feet/day are being used by EGAT for gas-fired steam units, gas-fired combustion turbines, and gas-fired combined cycle units. Most of this capacity is located near Bangkok.

Natural gas has also been discovered at Nam Phong in northeastern Thailand and at Lan Krabu in northwestern Thailand. The proven reserve of 0.28 trillion cubic feet at Nam Phong will be used first in twin 105-MW gas-fired combined cycle units currently under construction. EGAT plans to develop a total of 600 MW of combined cycle power generation for Nam Phong. The Lan Krabu site is supplying about 17 million cubic feet/day for 120 MW of power from gas turbines.

EGAT is by far the largest user of natural gas in Thailand, with feedstock being the second largest use (11,15). Historically, gas use by EGAT has been in excess of 90 percent of the total natural gas use in Thailand. However, production levels are currently limited and the suppliers have put a high price on their product. The Thai government wants EGAT to use natural gas and has given it a subsidy to keep it from switching to oil. Production from the gas fields is projected to increase from the 429 million cubic feet/day in 1987 to about 1,100 million cubic feet/day by 1995 and then remain nearly constant through 2001. A large increase in feedstock consumption is projected for 1990, when usage will go from 70 to 157 million cubic feet/day. It is then expected to grow to a level of 227 million cubic feet/day in 1994 and remain steady through 2001. Industrial use is expected to grow from the 5 million cubic feet/day used in 1987 to about 110 million cubic feet/day in 2001.

The net result of the increased production and the increased usage in the feedstock and industrial sectors is that EGAT is projected to have an adequate gas supply only until the mid- to late 1990s. Planned consumption levels appear to be changing as a result of increased use of inexpensive domestic lignite. Many industries are reluctant to use natural gas because of the current high price.

### 1.2.3.2 Lignite

In 1986, approximately 5.5 million tonnes of lignite were mined in Thailand (15). EGAT used 4.7 million tonnes in the production of electricity and the cement industry

TABLE 3 1987 Fuel Prices

Fuel	U.S. \$/million Btu
Fuel oil	2.74
Imported coal	1.60 (\$44/tonne)
Natural gas	2.44
Indigenous lignite	1.58 (\$18.40/tonne)

Source: Ref. 11

used about 0.5 million tonnes. This latter use is rapidly growing, as shown by comparing current use to the 4,000 tonnes used in 1980.

Lignite reserves of 614 million tonnes have been proven at the Mae Moh mines in the Northern Region. It is estimated that these reserves are capable of supporting approximately 3,000 MW of capacity throughout the lifetime of the power plants. About 825 MW of capacity is currently associated with this resource, and there are plans to add seven 300-MW units between now and April 1995.

At present, about 5.5 million tonnes of lignite are mined annually from Mae Moh. The energy content is about 5,200 Btu/lb, with an ash content of about 30 percent. Siam Cement is using Mae Moh lignite, combining it with imported steam coal from China and Australia to increase the energy content.

The Northern Region has a second source of lignite in Chiang Mai province at Wiang Haeng. Total reserves there are estimated at 107 million tonnes with about 25 million recoverable.

Lignite reserves also exist in the South. The Krabi Basin has total reserves of 120.7 million tonnes, of which about 20 million are recoverable. The quality of the lignite is quite variable, but the average energy content appears to be about 4,150 Btu/lb. It contains about 23 to 28 percent moisture, 26 percent ash (with only a small fraction of the ash in the form of calcium oxide), and 3 to 4 percent sulfur. Two 20-MW units are using this lignite and are expected to use less than one million tonnes before their retirement in 1990. Thus, approximately 13 million tonnes remain available for future generation facilities. This fuel should be sufficient for a 75-MW power plant to operate at base load for 25 to 30 years. The current plan calls for operation of such a plant beginning in November 1992.

Other lignite reserves have been found at Sin Pun, about 60 km northeast of the Krabi Basin. This lignite is believed to be of better quality than the Krabi lignite but to have slightly more sulfur. The proven reserves are currently given as more than 10 million tonnes. This quantity should also be enough to fuel a 75-MW plant for its lifetime. The current plan calls for this facility to begin operation in October 1995.

A major new discovery of lignite reserves was made in Saba Yoi in 1987. At least 50 million tonnes of recoverable reserves have been located. Additional exploration in the area is expected to result in the discovery of many times this initial amount. An important feature of this new discovery is the high quality of the lignite. The energy content is at least 6,500 Btu/lb and may average as high as 7,600 Btu/lb or more. Also, the sulfur content is less than that of the other deposits in Thailand.

#### 1.2.3.3 Hydroelectric

The hydropower potential is estimated at 9,300 MW, excluding the two international rivers (the Mekong and the Salween); EGAT has already harnessed about 2,250 MW of this. Hydroelectric capacity currently represents about one-third of the installed power generating capacity, and there are plans for almost 1,000 MW of

additional hydro capacity within the next 10 years. An additional 900 MW are under study.

The NEA is emphasizing small-scale hydropower, for which the potential is estimated at 3,000 MW over 100 sites. Most of the existing and planned hydro capacity is found in three of the four regions, the exception being the Southern Region. As noted earlier, however, the hydro capacity is used in the peaking mode, with an average capacity factor of less than 30 percent.

For the long term, the Mekong River and its tributaries represent a major hydropower resource. About 19,000 MW can be obtained from seven sites along the river. The tributaries in Laos alone can produce an estimated 18,000 MW. However, exploitation of these resources will require more cooperation among the riparian countries of Kampuchea, Laos, Thailand, and Vietnam than is currently possible.

#### **1.2.3.4 Oil/Condensate**

Thailand also has some oil reserves, with approximately 43 million bbl in proven reserves and another 335 million bbl classified as probable (8,15). The production rate has been quite low, however, with the result that in 1986 about 87 percent of the crude oil refined in Thailand was imported. In northern Thailand, a small reserve produces about 1,000 bbl/day. The condensate contributions from the Erawan/Platong group of offshore gas fields are more substantial, at about 10,000 bbl/day. The Sirikit oil field at Lan Krabu produces about 15,000 bbl/day. No increase in production is expected.

In 1986, the refinery capacity in Thailand was 194,000 bbl/day, and the average production rate was 186,400 bbl/day. About 63 percent of these products was used in the transportation sector, 13 percent in manufacturing, 8 percent in agriculture, and 8 percent by EGAT.

#### **1.2.3.5 Renewables**

Thailand intends to maximize development of indigenous conventional reserves but also increase the development of alternative energy resources, including bagasse, biogas, and geothermal. A resource already used to some extent for power generation in the private sector is rubber tree waste. These are the trees removed for new plantings. Another resource for which use is only now being planned is sugar cane trash. This is the residue left in the fields after harvesting. AID has examined the potential for using sugar cane trash in the South for local power needs. An AID study identified a capability to provide 260 MW of year-round power, from which a surplus can be sold to the grid at a price that fits EGAT's long-term marginal cost.

#### **1.2.4 Energy Transportation Infrastructure**

The Thai government's approach to the transport sector is determined by two main considerations: the near completion of the national highway system and energy

conservation. The former consideration dictates a slowdown in highway spending and a shift toward concentration on provincial and rural roads, and toward improved maintenance and rehabilitation of the entire road system. On the other hand, energy efficiency in the transport sector, which accounts for about 40 percent of petroleum product consumption in Thailand, is expected to be improved by a shift from the road subsector to rail and water transport. This shift is favored on the premise that past heavy investments in roads were justified only by previously cheap oil, discouraging the development of alternative, more energy efficient modes of transport.

#### **1.2.4.1 Land Transport**

The network of paved roads has expanded significantly, from an estimated 8,500 km in 1962 to 130,000 km in 1980, consisting of 14,000 km of national highways, 30,000 km of provincial roads, and 85,000 km of rural roads. Correspondingly, the vehicle fleet has also grown from about 300,000 to about 2 million over the same period. In contrast, the railway network, totaling 3,800 route-km, hardly expanded during that same period. Road freight and passenger traffic grew on the order of 7 to 9 percent per annum, railway passenger traffic grew by 8 percent per annum, and railway freight traffic grew by only 4 percent per annum despite subsidized tariff support. Significant amounts of minerals currently are transported by rail.

Substantial expansion of public investments in transport modes other than road transport, and in particular in railways, is being assessed. Road transport, which currently accounts for 80 to 90 percent of total traffic in Thailand, consumes about 95 percent of total fuel used in the transport sector. Therefore, increased efficiency, improved maintenance, and gradual fleet modification on roads are likely to save more energy than large and costly expansions in railway service.

Significant road sector development is being accompanied by development of an efficient trucking industry in the private sector. Trucking is now the primary means of hauling lignite. Little, if any, lignite is moved by rail. Although a possibility, no rail spurs have yet been planned to accommodate the new lignite discovery at Saba Yoi.

#### **1.2.4.2 Water Transport**

To support industrial and regional development of the eastern seaboard area, a major deep-sea port is under construction at Laem Chabang. But no date is reported for its completion because of a relatively low growth in port demand in general. Although the government had planned to expand the deep-sea port at Sattahip, it has concluded that private industry would not be attracted to the upgraded port.

### 1.3 FINANCIAL, ECONOMIC, AND TRADE ISSUES

#### 1.3.1 Impact of Financial, Economic, and Trade Issues

Thailand is committed to trade and welcomes foreign private investment. Thailand's pro-business stance, conservative fiscal and monetary policies, abundant natural resources, skilled labor, and impressive infrastructure all help to create a generally good investment climate. Thailand had a steady economic performance in 1987 as the country moved closer to the threshold of a newly industrialized country. The 28 percent increase in exports was the catalyst in the 6 percent growth in real gross domestic product. One of the major objectives of the Sixth National Economic and Social Development Plan is to raise Thailand's level of development. In the near term, the Thai government will address the solution to the trade and domestic budget deficit problems as well as ways to increase employment, manage problems of natural resources and environmental deterioration, and promote equity among its people.

#### 1.3.2 Financial Trends

A set of key financial indicators assists in measuring the viability of a country's economic activity and its future prospects for development. These key economic indicators include trade balance, current and capital accounts, foreign reserves, and exchange rates (Table 4). Thailand's total export/import levels are depicted in Figure 2. The 1986 levels by country are shown in Figure 3.

##### 1.3.2.1 Balance of Payments

The balance of payments monitors a country's international economic activities. Balance of payments deficits may result from transitory factors, such as a crop failure or a labor strike in a major export industry, or from more deep-seated and persistent causes, such as low productivity growth or strong cost-push inflationary forces. The current account in 1987 ran a deficit, but capital movements into Thailand kept the balance of payments in a surplus amounting to about U.S. \$700 million.

##### 1.3.2.2 Current Account

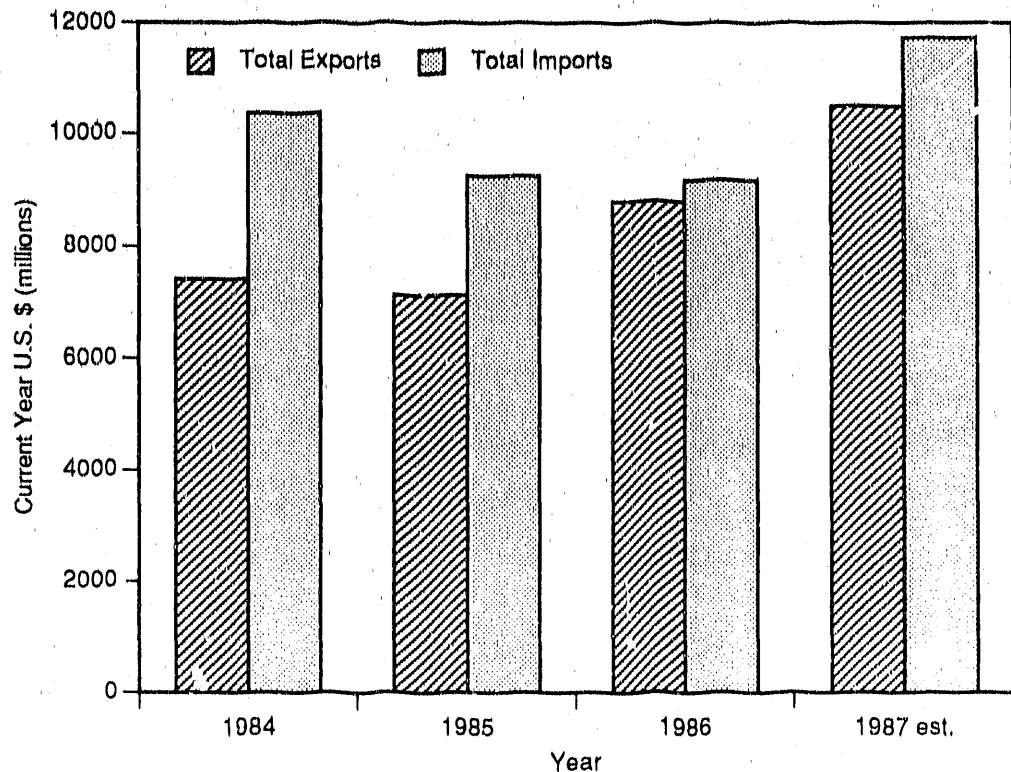
The current account includes unilateral transfers and private remittances, in addition to the balance on goods and services or balance of trade. The decline in oil prices had a dramatic effect on Thailand's current account in 1986, and the terms of trade improved some 10 percent. There was a savings of approximately U.S. \$1 billion on petroleum imports. During 1986, the "Visit Thailand Year," tourist arrivals increased roughly 20 percent, which also helped the current account run a slight surplus. In 1987, however, the current account reversed itself and ended with a deficit of U.S. \$600 million because of the sharp increase in imports sustaining the economic growth of Thailand.

**TABLE 4 Thailand: Key Economic Indicators (in millions of current year U.S. dollars, representing period averages, unless otherwise indicated)**

Indicator	1984	1985	1986	1987 <sup>a</sup>
<b><u>Income, Production, and Employment</u></b>				
GDP at current prices	40,486	36,862	40,189	-
GDP at constant (1972) prices	14,586	13,018	13,902	-
Per capita GDP at current prices	803	719	771	-
Gross fixed capital formation at current prices	9,678	8,551	8,875	-
Personal income	32,360	29,641	32,198	-
Labor force (in thousands)	26,380	27,140	27,910	-
Unemployment rate (%)	5.1	6.1	6.8	-
<b><u>Money and Prices</u></b>				
Money supply	3,948	3,320	4,068	-
Interest rates, commercial bank prime Indices (1976 = 100)	16.90	16.04	13.51	-
Wholesale price	169.1	169.0	168.4	-
Consumer price	189.5	194.1	197.7	-
<b><u>Balance of Payments and Trade</u></b>				
Gold and foreign exchange reserves	1,695	2,708	3,776	5,000
External public debt	7,633	9,478	11,015	-
Annual debt service, total	2,033	2,189	2,402	-
Balance of payments	448	459	1,278	-
Balance of trade	-2,957	-2,130	-386	-230
Total exports, FOB	7,413	7,125	8,802	10,500
Exports to U.S.	1,273	1,401	1,576	1,540
Total imports, CIF	10,370	9,255	9,188	11,730
Imports from U.S.	1,382	1,048	1,314	781
Exchange rate (baht per U.S. \$1.00)	23.64	27.14	26.27	25.50

<sup>a</sup>Estimated.

Source: Ref. 5



**FIGURE 2 Thailand's Exports versus Imports (Source: Ref. 5)**

### 1.3.2.3 Capital Account

The capital account encompasses the purchase of stocks, bonds, or real assets in a nation by another country. The Securities Exchange of Thailand attracted substantial foreign investment in 1987. The exchange's net worth in 1987 was U.S. \$475 million, compared with only U.S. \$96 million in 1986 (16). The Thai government perceives that the most efficient way to attain long-term financial potential and mobilize equity funding from abroad is to develop Thailand's capital market. Of the registered capital investors seeking investment incentives between 1960 and 1985, 28 percent represent foreign investment. Japan is the leading investor with 7.6 percent of cumulative registered capital and the United States is second at 4.7 percent, with Taiwan third at 2.6 percent (Table 5).

### 1.3.2.4 Exchange Rates

Exchange rate variations allow individual countries to control their own money supplies. The main impetus to the steady rise in manufactured exports has been the decline of the U.S. dollar-linked baht. The first push came in 1984 with a 14 percent devaluation of the baht against the dollar. This was a difficult decision for Thai policymakers for whom the baht/dollar peg had been the foundation of monetary stability. The devaluation decision involved considerations of exchange rate stability and potential growth. The rate as of January 1988 was 25.5 baht per U.S. \$1.00.

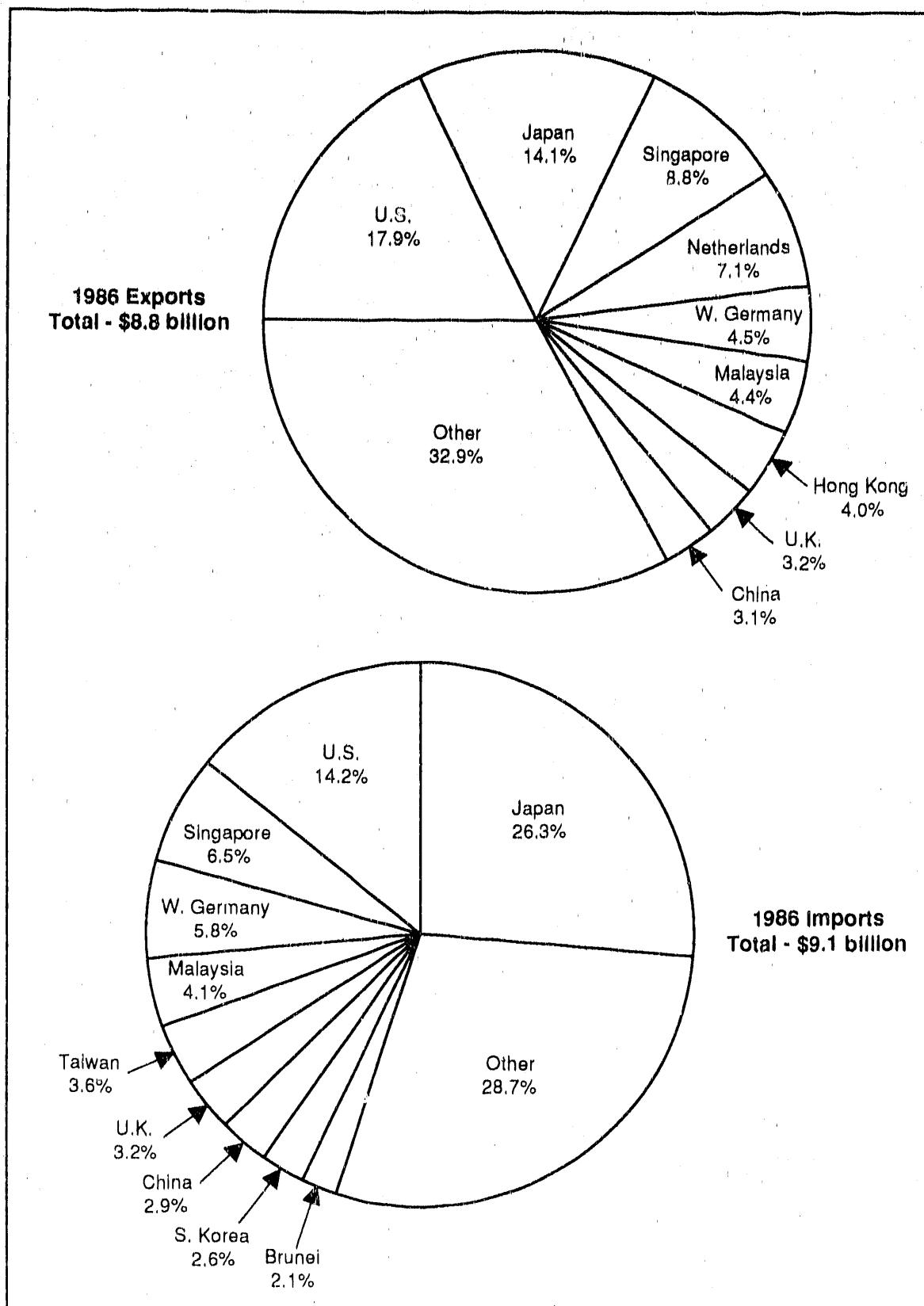


FIGURE 3 Thailand's 1986 Exports and Imports by Country (Source: Ref. 17)

**TABLE 5 Application for Investments (in millions of current year U.S. dollars)**

Country	Jan.-Sept. 1986		Jan.-Sept. 1987	
	No. of Projects	Investment (\$)	No. of Projects	Investment (\$)
Europe	26	128	74	516
Hong Kong	12	47	36	132
Japan	26	315	140	1,105
Taiwan	32	121	125	380
USA	18	97	37	372

Source: Ref. 17

#### 1.3.2.5 Foreign Exchange Reserves

Thailand's growth has been attained with price stability. The international reserves reached the level of about U.S. \$5 billion in the latter part of 1987. Manufactured goods are becoming increasingly important sources of export earnings. Thailand is one of the few developing countries that is a net exporter of food products, and it ranks as one of the world's leading exporters of rice.

#### 1.3.2.6 Inflation

The consumer price index, as a measure of inflation, has remained within the 2-3 percent range since 1984. Consumer prices, estimated to have risen by 2 percent in 1987, are expected to increase 3-4 percent in 1988.

#### 1.3.3 Incentives to Trade

The Board of Investment (BOI), established in 1977 under the Investment Promotion Act, is the central investment planning authority in Thailand. The BOI's role is to encourage foreign and domestic investment, particularly in sectors and locations most appropriate for the country's overall economic development. While laws such as the Alien Business Law of 1972 prohibit majority ownership in a company by non-Thai individuals, there are numerous incentives designed to promote investment in the country.

### **1.3.3.1 Investment Promotion Act**

This act, administered by the BOI, defines priority areas for investment, identifies investment opportunities, and establishes the basis for "promoted" activities. Promoted entities may be granted certain guarantees and privileges including, but not limited to, the following:

- Exemption from or reduction in import duties and business taxes on imported machinery;
- Remittance of foreign currency covering the return of capital, profits, interest, and principal on foreign loans, royalties, fees, or other obligations; and
- Exemption from income tax on net profits for three to five fiscal years, depending on the size of the investment or number of workers.

### **1.3.3.2 Industrial Free Zones**

Additional exemptions or reductions are generally available for enterprises, whether or not export-oriented, that are established in one of the nine Industrial Free Zones in Thailand. These zones are intended to disperse economic growth throughout the country and extend social services to the rural provinces. The BOI will grant benefits such as reductions of business taxes on the sale of products for a maximum of five years; exemption from import duties and business taxes on raw materials; and reduction by 50 to 75 percent of company income taxes for a further period of five years for companies located in a designated industrial estate.

### **1.3.3.3 Exchange Control Act**

The BOI must approve the repatriation of investment funds, dividends, profits, and returns to those companies not covered under the two aforementioned scenarios. Approval to repatriate the investment funds, dividends, or profits of direct and portfolio investment, is granted in, but not limited to, the following cases:

- After deduction of income and other taxes and after appropriation of reserves;
- Transfer of up to 50 percent of the net profit for the first six months of the accounting year; and
- Transfers of large funds may be permitted only in installments so as to prevent undue fluctuations in the exchange rate.

### 1.3.4 Financing, Insurance, and Investment Options

Various investor options exist for project financing. These financing options differ among lenders, but include long-term capital project financing, reimbursable grants on a cost-sharing basis, and direct short-term financing. The options will include financing sources such as government agencies, multilateral institutions, and private investment firms. These sources could include, but are not limited to, the following:

- *U.S. government*

Trade and Development Program (TDP)

Agency for International Development (AID)

Overseas Private Investment Corporation (OPIC)

- *Multilateral institutions*

International Finance Corporation (IFC)

Asian Development Bank (ADB)

World Bank (WB)

- *Private investment firms*

Commercial banks

Investment banking firms

Insurance for the investor may be obtained through select private banking and investment sources that have programs designed to secure investment risk. The key federal agency responsible for ensuring the security of U.S. investment is OPIC. For qualified investors, OPIC offers insurance against inconvertibility of foreign earnings, expropriation or confiscation, war, revolution, insurrection, and civil strife. OPIC also offers additional insurance and finance programs for U.S. investors in energy projects.

Alternative investment strategies, dependent on the extent of control and/or commitment desired by the investor, include, but are not limited to, licensing, partnerships, and turnkey project arrangements. A joint venture has not been recognized as a legal entity under the civil and commercial code.

### 1.3.5 National Trade Objectives

The Thai government's economic development policies are based on a liberal, export-oriented, free market philosophy. With sound monetary and fiscal policies and favorable investment incentives, the government is managing the economic expansion and growth so that the benefits reach an increasing proportion of Thai society.

#### 1.3.5.1 Monetary and Fiscal Policies

In 1987, the financial system experienced excess liquidity. To maintain a check on inflation, the Central Bank of Thailand is reducing liquidity in the money markets to halt an expected increase in commercial bank lending activities resulting from the recent

economic growth. This constrictive monetary policy is intended to fuel domestic growth by increasing exports and the concomitant export earnings base by trying to limit an anticipated increase in imports resulting from increased domestic purchasing power. Fiscal policy is targeted to further reduce the largely yen and dollar debts. Preliminary plans for the 1989 fiscal budget anticipate that expenditures will increase by 11 percent and that the deficit will be in the range of 2.8 percent of gross domestic product.

#### **1.3.5.2 Development of Urban and Specialized Zones**

The development of the economic base in communities at the metropolitan level, in cities in the regional areas, and in new economic zones is considered an important strategy for the future. Urbanization is a result of the changing economic structure of Thailand as a newly industrializing country. The Sixth National Economic and Social Development Plan sets a strategy for dispersing development of urban and new economic zones in different parts of the country. A wide range of tax incentives is providing the impetus for industry to locate in the Bangkok metropolitan area and to develop the eastern seaboard.

#### **1.3.5.3 The Treaty of Amity and the General Agreement of Tariffs and Trade (GATT)**

Under provisions of the 1966 Treaty of Amity and Economic Relations between Thailand and the United States, U.S. firms are accorded national treatment except when engaged in communications, transport, fiduciary functions, banking involving depository functions, or domestic trade in indigenous agriculture. The GATT provides Thailand with reduced tariff barriers under the Generalized System of Preferences and with an orderly structure for international trade with the United States and other GATT member nations.

#### **1.3.6 Other Factors**

The importance of providing adequate electrical power for the continued economic and industrial development of Thailand cannot be understated. Thailand is of importance to the United States for several reasons. Thailand is a strong, reliable ally of the United States in South Asia, and its stability and continued economic growth are important to U.S. foreign policy in the region. The United States has a vested interest in the ability of Thailand to service its debts to international and commercial banks. The repayment of these loans depends on strong and continuous economic growth, facilitated through expansion of the manufacturing sector. This growth requires dependable energy inputs to guarantee production and output. Also, the expansion needs of the Thai power sector provide opportunities in which U.S. technologies and services have a comparative advantage; therefore, significant trade opportunities exist (9).

Thailand is progressing toward and encouraging diversification to shift to a light manufacturing economy from a traditionally agrarian one. This shift will require energy generation that is reliable and able to keep pace with the growing manufacturing exports

to meet the planned sectoral expansion under Thailand's Sixth National Economic and Social Development Plan.

See Appendix C for a listing of major U.S. companies operating in Thailand.

## 2 OPPORTUNITIES FOR ENERGY PROJECTS IN THAILAND

Given Thailand's large lignite resources and a rapidly growing demand for electricity, the atmospheric fluidized bed combustor (AFBC) in sizes of 50 MW and larger appears to be a viable candidate for electric sector opportunities in Thailand. This technology will allow this domestic resource to be used while meeting the Thai standards on sulfur dioxide ( $\text{SO}_2$ ) emissions. If current practices are changed so that private sector power generation is expanded (some exists today under special circumstances), the AFBC technology in units of 25 MW or greater may be competitive with other options available for this purpose.

Cost and performance information on standard coal plants for power generation, AFBCs, and other CCT systems is provided in Appendix B. (The costs given in the illustrations are for installations in the continental United States.) Other technologies in this set, such as gasification, may also prove to have potential application in Thailand, depending on the magnitude and nature of the energy demand and the relative costs of competing fuels.

For example, another opportunity in Thailand concerns conversion of several aging oil-fired stations. These units include approximately 1,600 MW of capacity and are scheduled for renovation in the early to mid 1990s. Slagging combustors and coal-water mixtures (CWMs) appear to have some potential application in this situation. However, because of the characteristics of the indigenous Thai lignite, the coal used with either of these options would likely have to be imported. Nonetheless, such imports would replace imported oil, possibly at a competitive cost. These opportunities also will be briefly examined in the following sections.

### 2.1 ELECTRIC UTILITY SECTOR

As noted in Section 1.2, EGAT has significant capacity expansion plans calling for utilization of lignite-fired power plants, especially in the Northern and Southern Regions. In the very near term, EGAT plans to build a lignite-fired unit in the South. And, it has expressed strong interest in obtaining U.S. assistance in revising its prefeasibility study for a lignite-fired power plant there. Although this project was thought to be ready for award, the discovery of a large new lignite deposit in the vicinity of Krabi led EGAT to reevaluate the project. A U.S. AFBC unit is considered a good possibility.

For the medium term, EGAT's expansion plan calls for construction of more than 1,500 MW of new lignite-fired capacity by the mid-1990s, sustainable by domestic reserves. Thus, demonstration of U.S. AFBC or other technology in a small-scale application could lead to significant scale-up potential and utilization opportunities in the numerous 300-MW plants to be built in the North. Also, support of the Thai effort to further the development and use of the domestic lignite resources could encourage consideration of U.S. coal imports for facilitating plant start-up (and until domestic volume supply equilibrates with demand), for quality blending, or for coal demand in other sectors of the economy (e.g., in the cement sector).

### 2.1.1 Atmospheric Fluidized-Bed-Combustor Application for EGAT

The Krabi Basin has approximately 20 million tonnes of proven lignite reserves. These reserves are of lower quality by world-class standards, in that they are characterized by high moisture, ash, and sulfur contents, and possess calorific value on the order of 4,360 Btu/lb. Better quality lignite has been discovered at Sin Pun, about 60 km northeast of Krabi. Estimates exceed 10 million tonnes of recoverable reserves.

Design and performance criteria must adhere to the Thai National Environmental Board's requirements for approximately 70 percent SO<sub>2</sub> removal; nitrogen oxides (NO<sub>x</sub>) emissions are expected to be within guideline limits, and particulates are expected to be controlled by a baghouse system.

Several options are presented in Table 6 for 50- and 100-MW unit applications. These estimates are based on an annual fixed charge rate of 11.2 percent and levelization factors of 1.0 and 1.6 for lignite and oil, respectively. Note that the 50-MW AFBC and oil-fired options are essentially equivalent in cost. However, the AFBC unit would use indigenous rather than imported fuels, an important consideration. For the larger unit, the AFBC would fare better because of a better economy of scale.

The AFBC appears more economical than pulverized coal injection (PCI) with dry flue gas desulfurization (FGD). Because the Thai National Environmental Board will probably require a FGD system, PCI without FGD is not a likely alternative. Furthermore, a PCI plant would not possess the flexibility to handle the varying,

TABLE 6 Electricity Cost by Option (costs in 1987 U.S. dollars)

Component	50-MW Unit			100-MW Unit		
	AFBC	Oil	PCI/ dry FGD	AFBC	Oil	PCI/ dry FGD
Capital cost (\$/kW)	1,870	1,360	2,020	1,560	1,150	1,830
Heat rate (Btu/kWh)	11,730	10,490	11,560	11,730	10,490	11,560
Fixed operating and maintenance (\$/kW/yr)	40.8	24.4	53.2	29.5	16.1	38.0
Variable operating and maintenance (mills/kWh)	3.2	1.6	4.0	3.2	1.6	4.0
Levelized fuel cost (\$/10 <sup>6</sup> Btu)	1.96	3.50	1.96	1.96	3.50	1.96
Levelized electricity cost (mills/kWh)	64.3	65.3	69.2	59.5	62.0	66.3

Source: Based on information from Ref. 4

nonhomogeneous lignite quality anticipated from the Krabi basin. Thus, the AFRC is a strong potential candidate, meriting more detailed study.

### 2.1.2 Metropolitan Electricity Authority Refurbishing

In 1993, 240 MW of oil-fired capacity at the MEA's North Bangkok Station is scheduled to undergo renovation (11). In addition, 1,300 MW is scheduled to undergo renovation at the South Bangkok Station in 1995. These overhauls offer the opportunity for replacement by slagging combustors or a CWM application.

Renovation costs have been estimated at \$50 million (\$210/kW) for North Bangkok and \$60 million (\$46/kW) for South Bangkok. These renovations will extend the lifetime of the plants by about 20 years. However, these plants would continue to be fueled with heavy fuel oil. Options for conversion to coal are also available, and costs can be estimated. For this purpose, we will assume that the life-extension renovation already planned can be modified so that no derating will occur (an optimistic assumption). We will also assume capital costs of \$200/kW for CWMs and \$300/kW for a slagging combustor and a 10% interest rate (Table 7).

An assumed leveled cost of oil was estimated at \$3.90/million Btu, yielding a comparative electricity cost of 41 mills/kWh for a renovated oil-fired plant. Therefore, the potential appears to exist for applying CWMs or slagging combustors in retrofitting

TABLE 7 MEA Options — Electricity Case (costs in 1986 U.S. dollars)

Component	CWMs	Slagging Combustor
Capital cost (\$/kW)	200	300
Heat rate (Btu/kWh)	10,000	9,900
Marginal operating and maintenance cost above oil-fired unit (mills/kWh)	0.5	3.0
Fuel price <sup>a</sup> (\$/10 <sup>6</sup> Btu)	3.50	1.60
Adjusted cost of electricity (mills/kWh)	39.7	25.1

<sup>a</sup>Based on using U.S. coal delivered at a cost of \$40/tonne, because indigenous lignite is not appropriate for either technology.

the Bangkok oil-fired units. Specific areas to be addressed, in addition to more detailed economic analyses, include:

- The extent of derating that may occur, particularly with CWMs, and/or means to mitigate this effect; and
- The extent to which some of the planned renovation costs could be avoided or refocused as part of the specific design process to convert to slagging combustors or CWMs.

## 2.2 PRIVATE INDUSTRY

Power demand is growing much faster than EGAT's supply, even with a stepped-up investment program. Thus, the government is considering the approval of private power generation with possible sale to EGAT or third parties.

Opportunities for industrial-park power generation may exist in the private sector, where gas-fired turbines are being considered. Estimates made for small industrial lignite-fired boilers indicate that the cost of self-generated electricity is likely to be greater than the cost of buying electricity from EGAT. However, the AFBC has economic potential for self-generated power at sizes on the order of 25 MW and above. Thus, small-scale applications of this technology appear to merit closer examination.

Finally, the cement industry has almost completely converted to coal. Approximately 500,000 tonnes/year are imported from the People's Republic of China, whereas about 150,000 tonnes/year come from Australia. Some options may exist to link a fossil energy technology project to U.S. coal imports for the cement industry, where possible trade or commerce incentives arise or where financial or technical assistance appears warranted.

## 2.3 REMARKS

From the foregoing analyses of the energy development needs of Thailand and the potential applicability of U.S. fossil fuel technologies, it appears that opportunities exist for energy project development. Possible clean coal technologies for utilization in Thai electric power generation include the atmospheric fluidized bed combustor, with slagging combustors or a coal-water mixture application for the North and South Bangkok renovations.

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## APPENDIX A

## SCREENING OF CANDIDATE COUNTRIES

The "U.S. Fossil Fuel Technologies for Developing Countries" project was initiated by the U.S. Department of Energy, Office of Fossil Energy (DOE/FE), in June 1987, to evaluate, analyze, identify, and develop market opportunities for U.S. fossil fuel technologies for developing country power generation and/or industrial utilization in the Asian, Near East, and Latin American/Caribbean regions. This effort is intended to result in enhanced transfer of U.S. fossil energy technology and increased competitiveness of the U.S. fossil energy industry in developing countries.

This appendix summarizes the initial screening of candidate countries, a task accomplished by Argonne National Laboratory (ANL) through funding provided by DOE/FE and the U.S. Agency for International Development (AID). The approach used is presented in Figure A.1, with the initial results being detailed in Table A.1. The starting place was a listing of 75 AID-assisted countries.

The general objectives for evaluating candidate countries were formulated to include the existence of conditions favorable to a coal-oriented project, the chance of successfully implementing and completing the project, the opportunity for in-country replication of a successful project, and the opportunity for transferring the knowledge and experience related to the project to other countries. The purpose of the standardized screening approach was not to eliminate judgment through the use of absolute screens, but rather to provide a reasonable method for reducing the candidate list to an appropriate smaller group for further study. The criteria used were:

1. Country is a "priority" AID-assisted country -- among the top 37 (upper 50 percent) recipients of FY 1987 Development Assistance (DA) and Economic Support Funds (ESF), AND country receives project-type assistance.
2. Country has proven coal reserves of more than 20 million tonnes OR country imported more than 10,000 tonnes of coal in 1984, OR country imported U.S. coal in 1984, 1985, or 1986.
3. County has installed thermal capacity greater than or equal to 100 MW.
4. Country has a history of high electricity consumption growth (greater than 5 percent/year between 1973 and 1984), OR projections indicate that future power demand growth will be higher than 4 percent/year.

Eighteen countries in the Asian, Near East, Latin American, and Caribbean regions passed all four criteria (Table A.1). In addition, Jamaica, which would have been eliminated by the low demand projection, was added to this list based on specific

plans for this country to add 66 MW of coal-fired generation capacity in the early 1990s and the recognition of recent high load growth and uncertainties in demand projections. The countries that passed include:

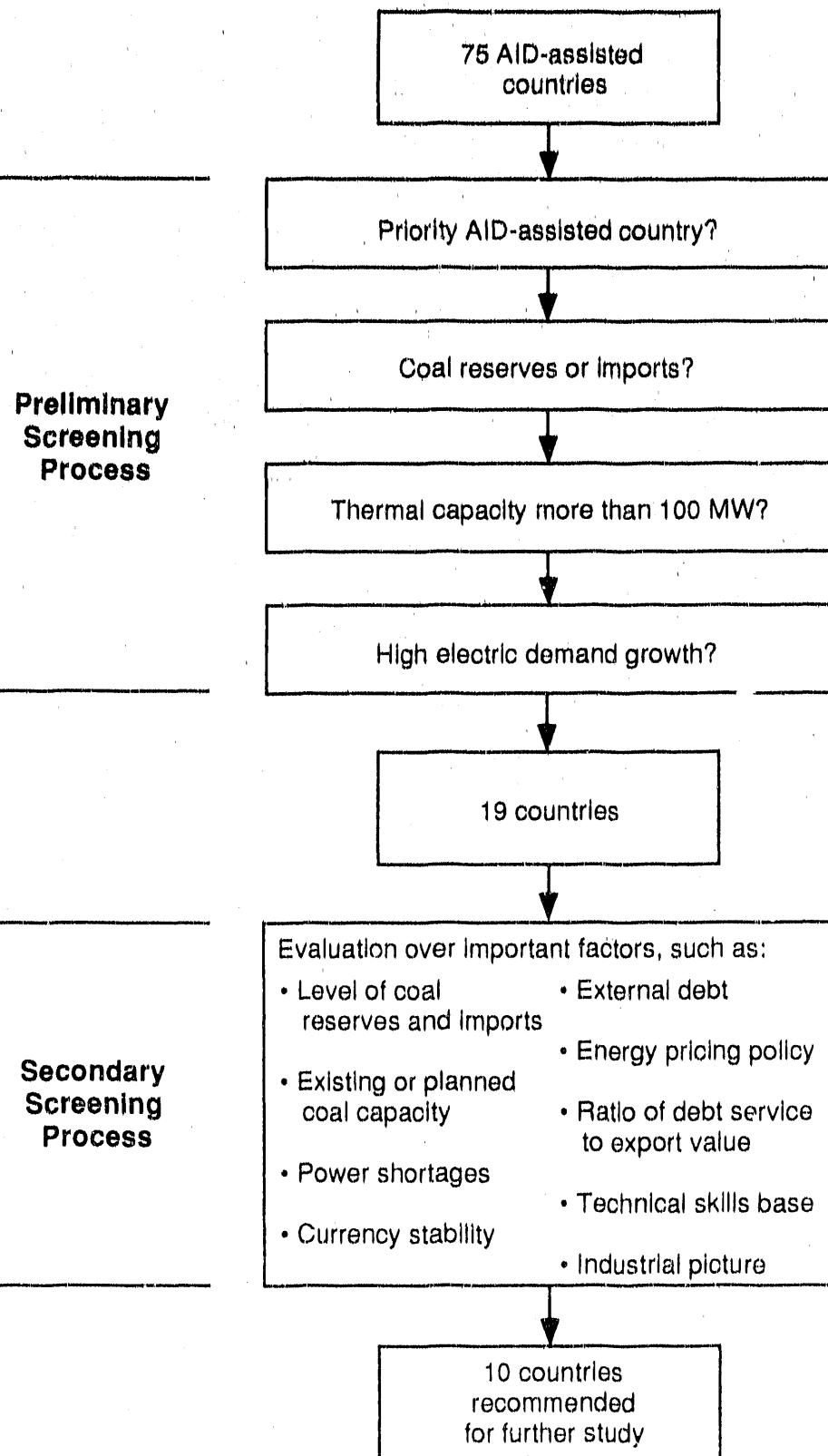
<u>Asian</u>	<u>Near East</u>	<u>Latin American/Caribbean</u>
Bangladesh	Egypt	Bolivia
India	Jordan	Costa Rica
Indonesia	Morocco	Dominican Republic
Pakistan	Tunisia	Ecuador
Philippines		Guatemala
Thailand		Honduras
		Jamaica
		Panama
		Peru

These 19 countries were examined in more depth than was possible for the 75 countries involved in the preliminary screening process. The 19 country profiles that were developed covered important technical, financial/economic, social/institutional, and other practical factors affecting the electrical generation and industrial sectors. Some of the important factors considered are listed in Figure A.1.

The result was identification of 10 countries that were the most favorable for further study in conjunction with the technology and vendor analyses to be conducted. Those countries are:

Costa Rica  
 Dominican Republic  
 Ecuador  
 India  
 Indonesia  
 Jamaica  
 Jordan  
 Pakistan  
 Philippines  
 Thailand

Subsequent discussions among DOE/FE, AID, and ANL led to an emphasis on three of the above countries for the development of more detailed country profiles and analysis of project opportunities. These three countries are Costa Rica, the Dominican Republic, and Thailand.



**FIGURE A.1 Summary of Screening Process**

TABLE A.1 Countries Meeting Screening Criteria

Country	Criteria				
	1	2	3	4	Pass
Afghanistan	No <sup>a</sup>	Yes	Yes	Yes	No
Bangladesh	Yes	Yes	Yes	Yes	Yes
Belize	No	No	No	No	No
Bolivia	Yes	Yes	Yes	Yes	Yes
Botswana	No	Yes	Yes		No
Burkina Faso	No	No	No	Yes	No
Burma	No	Yes	Yes	Yes	No
Burundi	No	No	No	Yes	No
Cameroon	Yes	No	No	Yes	No
Cape Verde	No	No	No	No	No
Central African Republic	No	No	No	No	No
Chad	No	No	No	No	No
Comoros	No	No	No	Yes	No
Congo	No	No	No	Yes	No
Costa Rica	Yes	Yes	Yes	Yes	Yes
Cyprus	No	Yes	Yes	No	No
Djibouti	No	No	No	Yes	No
Dominican Republic	Yes	Yes	Yes	Yes	Yes
Ecuador	Yes	Yes	Yes	Yes	Yes
Egypt	Yes	Yes	Yes	Yes	Yes
El Salvador	Yes	No	Yes	Yes	No
Equatorial Guinea	No	No	No	No	No
Fiji	No	Yes	Yes	Yes	No
Gambia	No	No	No	Yes	No
Ghana	No	No	Yes	No	No
Guatemala	Yes	Yes	Yes	Yes	Yes
Guinea	No	No	Yes	No	No
Guinea-Bissau	No	No	No	Yes	No
Haiti	Yes	Yes	No	Yes	No
Honduras	Yes	Yes	Yes	Yes	Yes
India	Yes	Yes	Yes	Yes	Yes
Indonesia	Yes	Yes	Yes	Yes	Yes
Ireland	No	Yes	Yes	No	No
Israel	No	Yes	Yes	Yes	No
Jamaica	Yes	Yes	Yes	No	No
Jordan	Yes	Yes	Yes	Yes	Yes

TABLE A.1 (Cont'd)

Country	Criteria				
	1	2	3	4	Pass
Kenya	Yes	Yes	Yes	Yes	No <sup>b</sup>
Lebanon	No	Yes	Yes	No	No
Lesotho	No	No		Yes	No
Liberia	Yes	Yes	Yes	No	No
Madagascar	No	Yes	No	No	No
Malawi	No	Yes	No	Yes	No
Mali	No	Yes	No	Yes	No
Mauritania	No	No	No	No	No
Mauritius	No	No	Yes	Yes	No
Morocco	Yes	Yes	Yes	Yes	Yes
Mozambique	No	Yes	Yes	Yes	No
Nepal	No	Yes	No	Yes	No
Niger	Yes	No	No	Yes	No
Oman	Yes	No	Yes	Yes	No
Pakistan	Yes	Yes	Yes	Yes	Yes
Panama	Yes	Yes	Yes	Yes	Yes
Peru	Yes	Yes	Yes	Yes	Yes
Philippines	Yes	Yes	Yes	Yes	Yes
Portugal	No	Yes	Yes	Yes	No
Rwanda	No	No	No	Yes	No
Sao Tome	No	No	No	Yes	No
Senegal	Yes	No	Yes	Yes	No
Seychelles	No	No	No	Yes	No
Sierra Leone	No	No	Yes	No	No
Somalia	Yes	No	No	Yes	No
South Africa	No	Yes			No
Spain	No	Yes	Yes	No	No
Sri Lanka	Yes	No	Yes	Yes	No
Sudan	Yes	No	Yes	Yes	No
Swaziland	No	Yes			No
Thailand	Yes	Yes	Yes	Yes	Yes
Togo	No	No	No	Yes	No
Tunisia	Yes	Yes	Yes	Yes	Yes
Turkey	No	Yes	Yes	Yes	No

TABLE A.1 (Cont'd)

Country	Criteria				
	1	2	3	4	Pass
Uganda	No	No	No	No	No
Uruguay	No	No	Yes	No	No
Yemen	Yes	No	Yes	Yes	No
Zaire	Yes	Yes	No	No	No
Zambia	No	Yes	Yes	Yes	No

## Legend:

1 = Top 50 percent of AID-assisted countries (top 37 recipients FY 1987 DA and ESF) AND receives technical/project assistance.

2 = Proven recoverable coal reserves greater than 20 million tonnes OR country imported more than 10,000 tonnes coal in 1984 OR country imported U.S. coal in 1984, 1985, or 1986.

3 = Thermal power capacity greater than or equal to 100 MW.

4 = Past growth in electricity consumption greater than 5 percent/year (1973-1984) OR power demand projections greater than 4 percent/year.

<sup>a</sup>Humanitarian assistance projects implemented through the Afghan Resistance Alliance.

<sup>b</sup>Study is considering countries in the Asian/Near East and Latin American/Caribbean regions only.

## APPENDIX B

## AMERICA'S CLEAN COAL COMMITMENT

## Executive Summary\* . . .

Significant opportunities exist for new clean coal technologies because of past expenditures and a national commitment to future support.

For the last decade, the U.S. has been pursuing opportunities to develop advanced clean coal technologies. A solid technical foundation now exists, and using it, the nation has begun to embark on a major expansion of clean coal technology development and demonstration.

Innovative clean coal technologies can generally be grouped into two categories: (1) retrofit technologies which can be used on existing plants to reduce emissions, and (2) repowering technologies that replace a significant portion of the original plant and often increase capacity while reducing emissions.

These emerging technologies offer significant improvements in cost-effective environmental performance, compared to previous alternatives. For example, advanced physical coal cleaning can potentially reduce  $\text{SO}_2$  emissions by 65%, more than double the effectiveness of conventional techniques, and chemical and microbial cleaning may boost that effectiveness to 90% or more.

Retrofit techniques such as the limestone injection multistage burner, slagging combustors, gas reburning, in-duct sorbent injection, and advanced flue gas cleanup, used separately or in combinations, can control both  $\text{SO}_2$  and  $\text{NO}_x$  and produce an environmentally safe waste product. Although the sulfur emission reduction potentials of some of these technologies are lower than conventional flue gas scrubbing, the reduction levels will likely be sufficient to meet possible future requirements for existing plants.

Repowering technologies, such as integrated gasification combined cycle (IGCC) and fluidized bed combustion (FBC) are able to reduce both  $\text{SO}_2$  and  $\text{NO}_x$  emissions. In the case of IGCC, sulfur emission reductions greater than 99% have been achieved, while pressurized FBC is capable of lowering sulfur emissions by 95%. IGCC technologies can also reduce  $\text{NO}_x$  emissions by 40% compared to a conventional coal-fired power plant, while pressurized FBC technologies can achieve a  $\text{NO}_x$  reduction of up to 85%.

Many of these retrofit and repowering options are in the demonstration stage today. They will be technologically available either in the late 1980s or early 1990s.

In addition to improved environmental performance, the new clean coal technologies, particularly repowering concepts, also offer substantial technical and economic benefits. Repowering an existing power station, with IGCC for example, can

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\*The following text is excerpted from Ref. 1.

improve its power output by up to 150%. This boost in power production offsets most of the capital costs of refurbishing an aging plant, thereby resulting in only a minimal impact on the cost of electricity.

*The Nation has built a solid R&D foundation for clean coal technologies.*

America's commitment to clean coal technologies began in hundreds of research laboratories and test sites in the 1960s and 70s. In the aftermath of the 1973 oil embargo, the U.S. coal research program was driven largely by a goal of displacing liquid and gaseous fuels. Beginning in 1980, however, the program began to concentrate more on innovative technologies that could control  $\text{SO}_2$  and  $\text{NO}_x$ . The principal motivation in the decade of the 1980s has been to address growing concerns about environmental issues, such as acid rain, and the compatibility of increased coal use with the nation's environmental goals.

From 1980 to 1985, the U.S. -- through both public and private financing -- spent approximately \$3.2 billion on the development of new coal technologies. Of this, the research, development and demonstration of new coal-based technologies to control  $\text{SO}_2$  and  $\text{NO}_x$  accounted for more than \$1.6 billion.

The progress made as a result of these expenditures provides the technological basis for proceeding with full-scale demonstrations of promising new clean coal technologies.

*The U.S. is rapidly becoming the world's showcase for clean coal technology.*

America's [current and continuing] clean coal commitment is a national effort involving the federal government, state governments and private sponsors ... [Through this joint endeavor,] the nation is meeting its commitment to a cleaner environment in concert with increasing the use of American coal.

Coal's abundance (80% of the nation's known fossil fuel resources) makes it one of America's most important strategic resources in building a more secure energy future. Coal can be one of the nation's most productive domestic energy sources well into the 21st Century and beyond. If coal is to reach its full potential, however, economically competitive, advanced coal-using systems must be developed which are sensitive to diverse energy markets and site-specific factors as well as stringent environmental requirements.

America's clean coal commitment has the potential to:

1. Control large amounts of the  $\text{SO}_2$  and  $\text{NO}_x$  released from coal-fired power plants including those in the environmentally sensitive Northeast.

2. Return economic benefits to American consumers by permitting clean energy to be generated without financially constraining capital investments for environmental controls.
3. Retrofit and repower aging coal-fired power plants, particularly in the East.
4. Use high-sulfur coals, thereby avoiding the social disruptions associated with massive coal switching, and
5. Reduce acid rain related emissions -- especially from aging power plants in the nation's northeast quadrant.

How rapidly these innovative clean coal technologies will be deployed depends upon many factors. Two of the important are (1) technology risk -- concern about the performance and reliability of the technologies -- and (2) market demand -- influenced, for example, by the growth in demand for electricity and the future regulatory environment.

America's . . . clean coal commitment directly addresses the technological risk. By developing and demonstrating new technologies at commercial or near-commercial scale, the risk of commercial deployment is reduced. And it can give America a substantial marketing advantage in international trade by permitting the "packaging" of U.S. coal along with the technology to use it cleanly and efficiently.

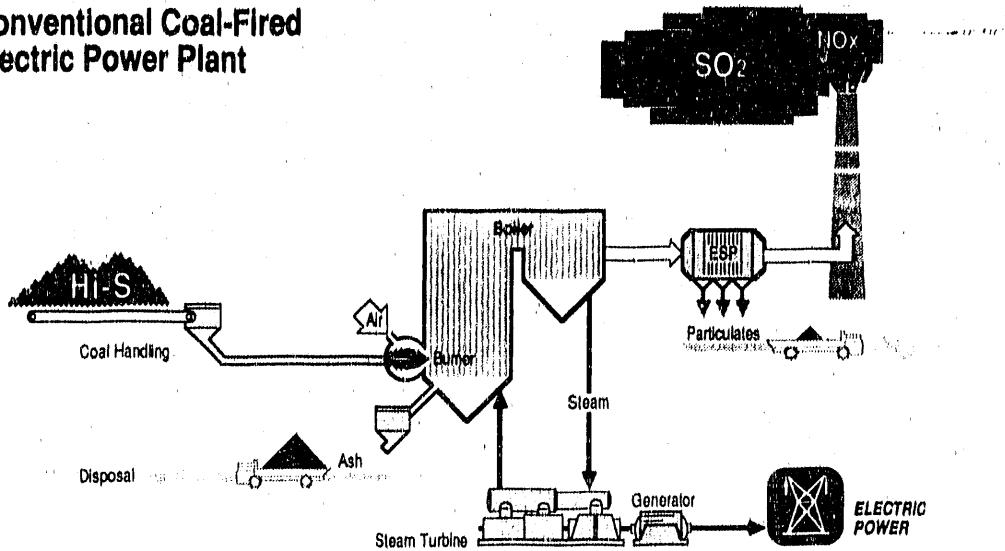
America's clean coal commitment comes at a time when the nation's environmental consciousness -- and that of our global neighbors -- is on the rise. It also coincides with the national goal established by the President to assure American competitive preeminence in the 21st Century.

Perhaps most importantly, America's clean coal commitment represents a public and private sector partnership that can make coal an environmentally attractive fuel for the future, a fuel for energy security, and a fuel for continued economic growth.

### **Technologies**

The illustrations and summary text on the next 10 pages have been reproduced from Ref. 1.

## Conventional Coal-Fired Electric Power Plant



## Conventional Coal-Fired Electric Power Plant

### How Does It Work?

The conventional coal-fired power plant, which is usually equipped with particulate removal devices only, is used as the base technology in this briefing. The sulfur emissions from this type of plant are tied to the sulfur content of its coal feed. The subsequent technologies described in this Appendix involve  $\text{SO}_2/\text{NO}_x$  emission control procedures. These technologies are compared with the base technology to highlight their attributes in terms of their  $\text{SO}_2$  and  $\text{NO}_x$  removal abilities and associated costs.

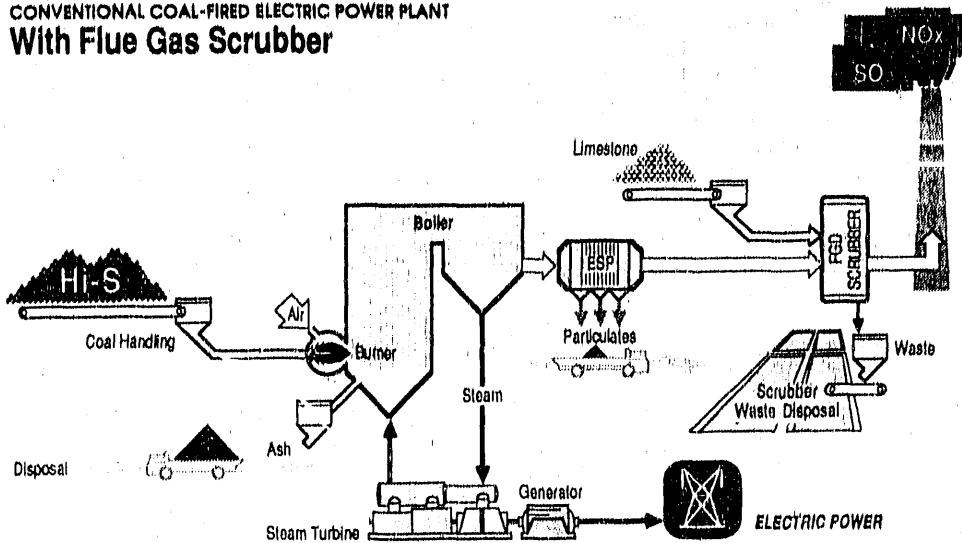
Conventional coal-fired power plants may vary in size from less than 100 MW to more than 2000 MW and may be used in base-load and/or intermediate-load applications. The efficiency of the energy conversion from raw coal feed to the production of electricity is 35-38 percent. The cost of capital for a new plant in the 350-1000 MW size is from \$1,500-\$1,800 per kw. With routine maintenance, a plant is expected to perform at design specifications for about 30 years. The operating and maintenance costs range from 15-25 mills per kWh. The net heat rate for conventional plants range from 8,000-11,000 Btu per kw.

Coal combustion may be carried out in pulverized coal burners, cyclone furnaces, or various stoker and grate arrangements. In pulverized coal boilers, pulverized coal is blown into the furnace. A significant amount of the incombustible fines leave with the combustion gases as fly ash, and the remainder is collected as bottom ash. In cyclone furnaces, coal is fed into the furnace tangentially, which increases the residence time and promotes thorough combustion. However, the increased combustion temperatures also result in increased  $\text{NO}_x$  formation. In stoker-fired boilers, coal enters the firebox on moving grates. The combustible gases ignite and generate steam in the boiler. The solids continue to burn as they travel through the furnace toward the ash collector at the end of the grate.

Heat from the combustion gases is transferred to the water circulating in the boiler tubes. After a series of heat exchange operations within the boiler, saturated or superheated steam is generated. This steam then expands through a steam turbine, its velocity increases, and its temperature and pressure decrease. The high velocity steam impinges on the turbine blades causing rotation. The mechanical energy from the turbine is converted to electrical energy by the generator.

Conventional boilers have either a wet or dry bottom. In wet bottom design, when coal is burned ash, becomes molten and runs to the bottom of the boiler. Hence, these boilers require coal with low ash fusion temperature. In contrast, in boilers with dry bottom designs, coal ash is not supposed to liquefy; so, these boilers require coal with high ash fusion temperatures. Power plant coal pulverizers are also designed for specific types of coal. If an alternative coal is more difficult to grind or contains too much ash, then the pulverizer cannot provide adequate fuel to the boiler. Although coal sulfur content does not significantly impact combustion, it does impact the performance of electrostatic precipitators. For coals containing less than 1 percent sulfur, performance of an electrostatic precipitator designed for high sulfur coals becomes less effective.

## CONVENTIONAL COAL-FIRED ELECTRIC POWER PLANT With Flue Gas Scrubber



COMPARED WITH CONVENTIONAL TECHNOLOGY*					
SO <sub>2</sub> EMISSION REDUCTION	NO <sub>x</sub> EMISSION REDUCTION	PLANT EFFICIENCY	POWER OUTPUT	INCREMENTAL ELECTRICITY COST	CAPITAL COST
90% AND HIGHER	No Change	Decrease	Moderate Decrease	No Change	9-11 MILLION/KWH \$180-200 PER KW

\* CONVENTIONAL COAL-FIRED ELECTRIC POWER PLANT

## Flue Gas Scrubber

### How Does It Work?

Flue gas scrubbing is a commercial technology that has been utilized in many power plants, especially those burning high-sulfur coal. It involves reduction of SO<sub>2</sub> from the combustion flue gases prior to atmospheric emissions by chemical reaction with alkaline sorbents.

In a wet flue gas scrubber, the gas produced in coal combustion is typically sprayed with a slurry made up of water and an alkaline reagent, usually limestone. The SO<sub>2</sub> in the flue gas reacts chemically with the reagent in the slurry forming calcium sulfite and/or calcium sulfate, which is removed and disposed of in the form of a wet sludge having the consistency of toothpaste. This wet sludge is composed of calcium sulfite, calcium sulfate, water, and unreacted limestone.

Scrubbers have been widely deployed, some removing more than 90 percent of the SO<sub>2</sub> emissions from high-sulfur coals. Scrubbers are relatively costly to install and may cost as much as \$250 per kw capacity. Also, a flue gas scrubber is costly to operate. It consumes from 5-8 percent of the plant's output to run pumps, fans, and a flue gas reheat system. It has high maintenance costs and consumes a large amount of water (500-2500 gallons per minute for a 500 MW unit). Further, there are reliability problems due to plugging and fouling of the equipment and corrosion of fans and downstream ductwork. Large space is required to handle scrubber waste--typically one acre-foot per MW per year.

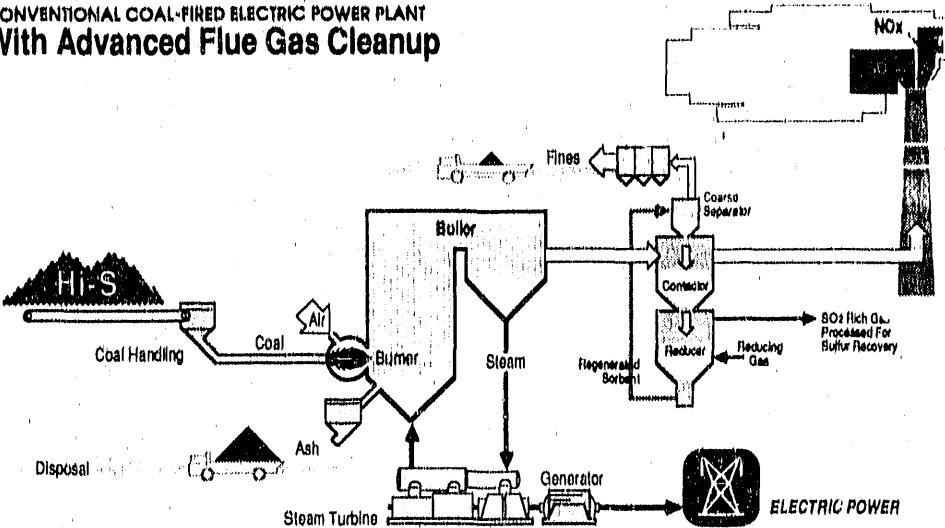
An alternative approach is the dry scrubber, or spray dryer. In a dry scrubber, the reagent slurry--usually lime--is injected into an absorber vessel in a finely atomized form. The droplets evaporate in the hot gas, leaving only dry, reacted particles for collection in a conventional baghouse or electrostatic precipitator.

Although the dry scrubber is simpler, it has not been used successfully on high-sulfur coal which may require 90 percent control. A dry scrubber may, in fact, be more costly than a wet scrubber, due to the increased cost of the reagent, for grass roots installation.

### What Are Its Attributes?

- The wet flue gas scrubber can achieve over 90 percent SO<sub>2</sub> removal from flue gases. However, it is costly to install, operate, and maintain.
- NO<sub>x</sub> emission is not affected by a wet or dry flue gas scrubber.
- Flue gas scrubbing reduces the overall efficiency of a coal-fired power plant from 35-38 percent to 32-35 percent
- Large amounts of scrubber sludge are produced (in the order of 1 acre-foot per MW per year). Therefore, sludge handling requires large amounts of space

**CONVENTIONAL COAL-FIRED ELECTRIC POWER PLANT  
With Advanced Flue Gas Cleanup**



**COMPARED WITH CONVENTIONAL TECHNOLOGY\***

SO <sub>2</sub> EMISSION REDUCTION	NO <sub>x</sub> EMISSION REDUCTION	PLANT EFFICIENCY	POWER OUTPUT	PLANT LIFE	INCREMENTAL ELECTRICITY COST	CAPITAL COST
90% AND HIGHER	High	Decrease	Small Decrease	No Change	10-12 MILL\$/KWH	\$175-190 PER KW

\* CONVENTIONAL COAL-FIRED ELECTRIC POWER PLANT

## Advanced Flue Gas Cleanup

### How Does It Work?

There is a great deal of activity involved in the development of advanced flue gas cleanup devices. A number of processes are under development. Examples of the types of processes under development include the use of electron beam radiation for process enhancement and the use of metal oxides both for SO<sub>2</sub> control and as a catalyst for the selective catalytic reduction of NO<sub>x</sub> by ammonia. These processes are primarily applicable to greenfield units but may also prove useful for the retrofit of existing units.

The copper oxide fluidized bed process is undergoing proof of concept testing at the present time. Alumina spheres are coated with copper oxide and suspended in a bed that is fluidized using the flue gas laden with SO<sub>2</sub> and NO<sub>x</sub>. The copper oxide reacts with SO<sub>2</sub> to produce copper sulfate, which is combined with natural gas to regenerate the copper oxide. The NO<sub>x</sub> reacts with ammonia (in the presence of copper sulfate, which serves as a catalyst) to produce molecular nitrogen. The moving bed contactor, also under development, is less mature but potentially cheaper than the fluid bed contactor.

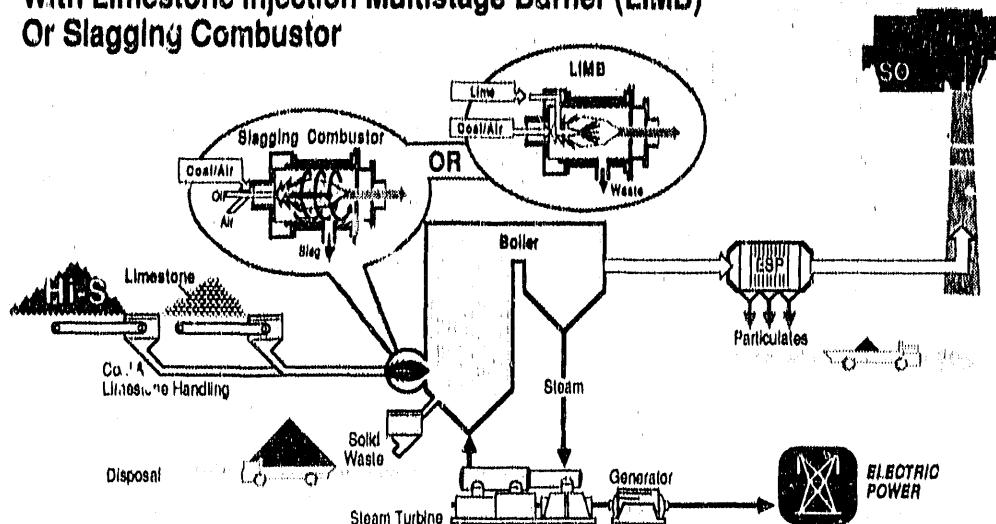
Electron Beam Processes present alternate approaches that appear to be attractive. Irradiation of flue gas with electron beams produces, under the proper temperature and humidity conditions, an abundant supply of free radicals, ions, monoatomic species, and secondary electrons which promote the oxidation of SO<sub>2</sub> and NO<sub>x</sub> to sulfuric and nitric acids, respectively. Two separate processes based on this phenomenon have been under development. The first uses a lime spray dryer upstream of the electron beam chamber. The second uses ammonia injection to react with the acids and form ammonium salts.

In the first approach, part of the reaction is between the flue gas and lime slurry in a spray dryer. Efficiency is improved in an electron beam chamber, and the reactions are completed in a fabric filter baghouse. In the second approach, the flue gas is irradiated in the presence of ammonia.

### What Are Its Attributes?

- It is capable of reducing SO<sub>2</sub> and NO<sub>x</sub> emissions by 90 percent.
- It is capable of achieving high reductions in NO<sub>x</sub> emissions; more than other retrofit technologies
- While initially developed for new applications, it can be economically competitive in certain retrofit applications, particularly where deep NO<sub>x</sub> removal is required.
- It is capable of either regenerating the sorbent or producing a fertilizer (E-beam ammonia).
- Unlike flue gas scrubbers, it does not produce large quantities of scrubber sludge. Hence, even though the capital costs are in the same range as those for flue gas scrubbers, the overriding advantages are many.

**CONVENTIONAL COAL-FIRED ELECTRIC POWER PLANT  
With Limestone Injection Multistage Burner (LIMB)  
Or Slagging Combustor**



**COMPARED WITH CONVENTIONAL TECHNOLOGY\***

	SO <sub>2</sub> EMISSION REDUCTION	NO <sub>x</sub> EMISSION REDUCTION	PLANT EFFICIENCY	POWER OUTPUT	PLANT LIFE	INCREMENTAL ELECTRICITY COST	CAPITAL COST
LIMB .....	50-60%	Moderate	Decrease	Small Decrease	No Change	5-8 MALKW/H	\$80-110 PER KW
SLAG. COM. ...	50-90%	Moderate	Small Decrease	Small Decrease	Slight Extension	1-2 MALKW/H	\$50-80 PER KW

\* CONVENTIONAL COAL-FIRED ELECTRIC POWER PLANT

## Limestone Injection Multistage Burner or Slagging Combustor

### How Does It Work?

The slagging combustor is an advanced device that will control or remove objectionable sulfur and particulate matter from coal-derived fuel before it is injected into retrofitted boilers or heaters. Although these combustors are primarily intended for retrofit applications, they will also be applicable and appropriate for incorporation into the design of new facilities that can utilize their compact size and flexibility of coal use. The limestone injection multistage burner (LIMB) approach is identical in application to retrofit and new installations as is the slagging combustor. The coal, either as a dry pulverized fuel or as a coal liquid mixture, is fed into the combustor in the conventional manner (pulverized coal firing) or pumped under pressure and injected as a slurry.

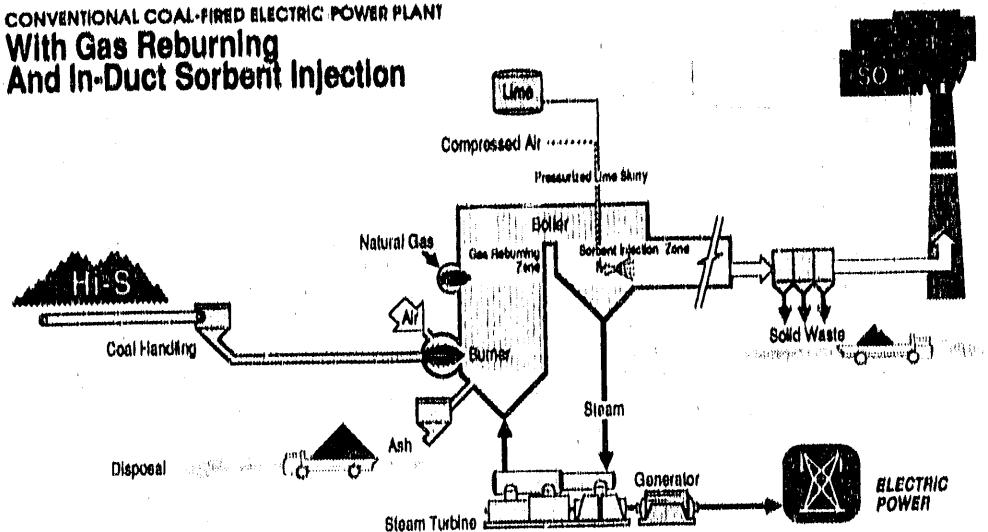
In the slagging combustor, the fuel is injected radially from a central injector, whereas the air is fed tangentially around the periphery. The interaction of the air moving circumferentially and the coal particles or droplets moving axially and radially outward results in a continuous flow of air across a burning particle, thereby providing more rapid and efficient combustion of the coal. Points of air injection can be placed in such a manner as to provide staged combustion to control NO<sub>x</sub> formation.

Sulfur dioxide control is achieved by the injection of alkali compounds, e.g., limestone, during combustion or with the fuel. The slagging combustor controls particulate emission by converting the ash into molten slag which, together with the solid sulfides and sulfates produced by the injection of limestone, are removed before the hot gases enter the boiler or heater passage areas. In the LIMB, the limestone is introduced into the combustor or into the combustion gases of a burner operating at a temperature that produces dry ash. The particulates, including the reacted sorbent and sulfur, are carried through the boiler passageways and subsequently captured by either a baghouse or electrostatic precipitator before exhausting the flue gas to the atmosphere through the stack.

### What Are Its Attributes?

- There are no special coal handling requirements other than the addition of a limestone feed system.
- The slagging combustor produces a molten slag containing the ash and captured sulfur as a solid waste prior to boiler entry.
- The removal of ash as slag rejection is 80-90 percent.
- NO<sub>x</sub> reduction is achieved by staged combustion.
- NO<sub>x</sub> reduction of 50-70 percent relative to wall-fired, pulverized-coal combustors is achieved.
- Slagging combustors have the potential to replace existing cyclone boilers, which are very high NO<sub>x</sub> emitters.
- Coal liquid fuel can simplify fuel storage, handling, and feed systems.
- Injection of sulfur sorbent either with the fuel or separately into the combustor or into the combustion gases eliminates the need for a flue gas desulfurization system.
- High-sulfur, high-ash, and low-fusion temperature coals can be used.

## CONVENTIONAL COAL-FIRED ELECTRIC POWER PLANT With Gas Reburning And In-Duct Sorbent Injection



### COMPARED WITH CONVENTIONAL TECHNOLOGY\*

SO <sub>2</sub> EMISSION REDUCTION	NO <sub>x</sub> EMISSION REDUCTION	PLANT EFFICIENCY	POWER OUTPUT	PLANT LIFE	INCREMENTAL ELECTRICITY COST 2-4 MILLION Plus Gas Price Factor For Reburning	CAPITAL COST \$50-110 PER KW
55-75%	Moderate	Small Decrease	Small Decrease	Slight Extension		

\* CONVENTIONAL COAL-FIRED ELECTRIC POWER PLANT

## Gas Reburning and In-duct Sorbent Injection

### How Does It Work?

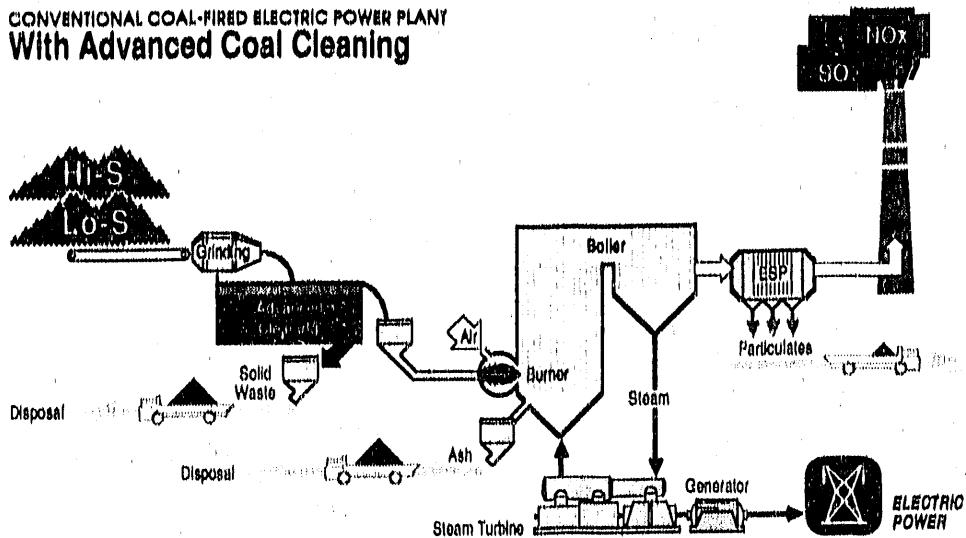
Gas reburning uses a small amount (10-20 percent of total fuel input) of natural gas which is injected above the normal heat release zone of the furnace to form an oxygen deficient zone. The NO<sub>x</sub> produced in the primary heat release zone is "reburned" in the oxygen deficient zone and partially reduced to molecular nitrogen. Finally, burnout air is introduced above the reburning zone to complete the combustion process. Since the natural gas contains neither sulfur nor ash, emission of both are reduced in direct proportion to the amount of gas used.

In-duct sorbent injection involves the spray injection of calcium based sorbents close to the center of the duct and downstream from the combustion zone. The direction of the injection is cocurrent with the gas flow, and as the cone of spray expands, the gas within the cone cools and the SO<sub>2</sub> is rapidly absorbed by the spray droplets. The finer the sorbent droplets, the more reactive they are. Several in-duct sorbent injection processes are under development. The mode of spraying, the position of the spray mechanism in the duct, and the nature of the sorbent may vary depending on the process. However, the basic principles of all processes are similar. Captured as dry calcium sulfate particles, SO<sub>2</sub> is removed in the downstream particulate collection equipment along with the flyash and the unreacted sorbent.

### What Are Its Attributes?

- A moderate amount of SO<sub>2</sub> and NO<sub>x</sub> reduction is obtained at a cost that is significantly less than the cost to use a scrubber.
- A dry and nontoxic solid waste is produced that can be disposed of easily.
- It can easily be retrofitted to an existing unit without requiring a major investment or a lengthy outage.
- While there is a small decrease in efficiency due to the small amount of energy needed to operate the equipment, there is an improvement in the operation of the boiler because of the reduced loading of ash into the boiler.

# CONVENTIONAL COAL-FIRED ELECTRIC POWER PLANT With Advanced Coal Cleaning



#### COMPARED WITH CONVENTIONAL TECHNOLOGY™

SO <sub>2</sub> EMISSION REDUCTION	NO <sub>x</sub> EMISSION REDUCTION	PLANT EFFICIENCY	POWER OUTPUT	PLANT LIFE	INCREMENTAL ELECTRICITY COST	CAPITAL COST
30-90%	No Change	Small Increase	No Change	Slight Extension	6-21 MILL\$/KWH	Additional Fuel Cost Only

#### • CONVENTIONAL COAL-FIRED ELECTRIC POWER PLANT

## Advanced Coal Cleaning

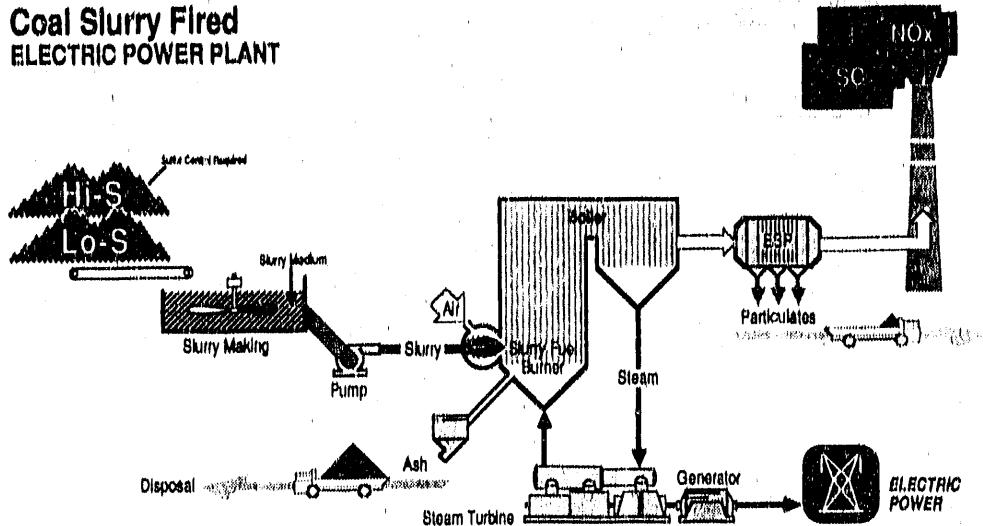
## How Does It Work?

Sulfur exists in coal in two basic forms, commonly called pyritic and organic. Pyritic sulfur is iron pyrite which exists in the coal as discrete small particles. Because this mineral looks like gold, it is sometimes referred to as "fool's gold." Organic sulfur is composed of sulfur molecules chemically bound to the complex coal molecule. Of the coal which is burned today, approximately 36 percent is cleaned by conventional coal cleaning plants. Conventional cleaning extracts the heavier forms of mineral matter, such as ash and pyritic sulfur, from the coal. Since the coal is lighter than the ash and pyrite, it can be essentially "floated" and thereby separated. However, none of the organic sulfur is removed by these conventional processes. For those coals cleaned, the sulfur reduction ranges from 10-30 percent depending on the parent coal and the cleaning technology applied. Coal cleaning technologies can be grouped into two categories: physical and chemical. Physical cleaning technologies, such as those being used commercially today, separate the ash and pyritic sulfur from the coal using physical differences. Therefore, the reduction of sulfur emissions is limited to the percent of pyritic sulfur in the coal. Chemical and microbial coal cleaning involves the introduction of chemical or microbial agents which react with the sulfur, including organic sulfur, ash, and sometimes the coal itself, to remove ash and sulfur. No chemical or microbial coal cleaning technology is now in commercial use.

## What Are Its Attributes?

- Chemical cleaning has the potential of removing over 90 percent of the sulfur from coal, but the processing costs are greater than the costs of physical techniques.
- Reduced ash levels and improved coal quality have the potential of helping to offset the costs of cleaning the coal (e.g., reduced transportation costs, and improved powerplant availability and reliability due to reduced ash levels).
- New coal cleaning plants would typically be built near coal mines.
- Advanced physical cleaning technologies include several processes with the potential of removing 65 percent of the total sulfur in coal. The chemical technologies range from treatment with hot caustic (capable of removing 90 percent of the sulfur and 98 percent of the ash) to removal of organic sulfur using microorganisms.
- The waste from coal cleaning consists of solid mineral matter and is typically disposed of at the mine site.
- As nitrogen oxides are formed during combustion, coal cleaning does not reduce NO<sub>x</sub> emissions.

## **Coal Slurry Fired ELECTRIC POWER PLANT**



#### COMPARED WITH CONVENTIONAL TECHNOLOGY\*

SO <sub>2</sub> EMISSION REDUCTION	NO <sub>x</sub> EMISSION REDUCTION	PLANT EFFICIENCY	POWER OUTAGE	PLANT LIFE	INCREMENTAL ELECTRICITY COST	CAPITAL COST
10-90%	No Change	Small Decrease	Small Decrease	No Change	11-23 MILLION/KWH	\$20-50 PER KW

## CONVENTIONAL COAL-FIRED ELECTRIC POWER PLANT

## Coal-Liquid Slurry Fuel

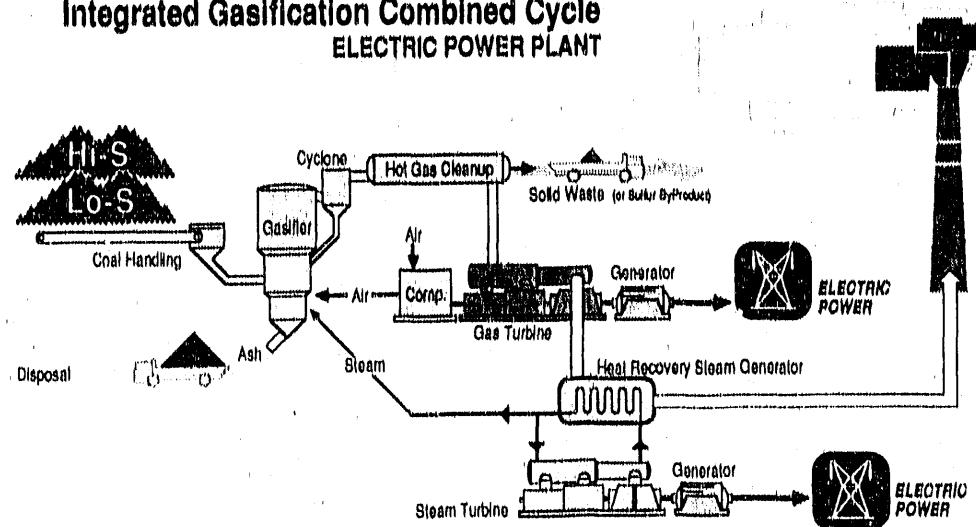
## How Does It Work?

The slurry fuel burning system is not unlike a pulverized coal-fired boiler, except that its feeding operation is easier and its fuel relatively cleaner. Coal in the form of a slurry is pumped under pressure into the burner manifold where it is injected into the combustion chamber. With the proper combustor design, high combustion efficiencies can be achieved. Use of coal slurry fuels will not have any significant adverse effect on system efficiency nor any adverse effect on unit life. The preparation and use of a coal slurry fuel may increase the cost of utilization; however, the advantages of coal slurry fuels, i.e., transportability, ease of handling, safety, ease of feeding into the combustor, use of cleaner coal resulting from the fuel preparation process, etc., may offset the effects of increased utilization costs. Use of coal slurries prepared from standard pulverized coal will necessitate the same pollutant control processes as with pulverized coal-fired systems. However, most coal slurry fuels are produced as clean fuels, thus reducing to a minimum the pollution control requirements at the user site.

## What Are Its Attributes?

- The fuel preparation process achieves significant reductions in SO<sub>2</sub> and particulate emissions.
- It is possible to reduce SO<sub>2</sub> emissions by more than 60 percent.
- It significantly reduces the quantity of waste produced at the user site.
- It eliminates coal pile run-off pollution control requirements.
- It provides ease of transport, storage, handling, and feeding.
- Increased injection pressures permit better fuel dispersion and, subsequently, higher combustion intensity and, therefore, unit size reduction.
- It provides for direct use in slurry form of wet coals produced from coal cleaning processes, without the added cost of coal drying required for pulverized feed systems.
- It significantly simplifies the feed system of a pressurized fluidized bed combustion system.

## Integrated Gasification Combined Cycle ELECTRIC POWER PLANT



COMPARED WITH CONVENTIONAL TECHNOLOGY*					
SO <sub>2</sub> EMISSION REDUCTION	NO <sub>x</sub> REDUCTION	PLANT EFFICIENCY	POWER OUTPUT	INCREMENTAL PLANT LIFE	CAPITAL COST
95-99%	Moderate	Moderate Increase	50-150% INCREASE	Moderate Extension	1-2 MILLION KWH \$1,100-1,300 PER KW

\* CONVENTIONAL COAL-FIRED ELECTRIC POWER PLANT

## Integrated Gasification Combined Cycle (IGCC)

### How Does It Work?

In a gasification reactor, coal is reacted with air and steam at a high temperature. This causes the coal to be converted to a gas composed predominantly of hydrogen, carbon monoxide, and hydrogen sulfide. The ash, which is not gasified, can then be easily separated. The sulfur in the coal is converted into hydrogen sulfide which eventually can be converted to elemental sulfur or some solid waste material. The cleaned gas stream is combusted in a gas turbine. While the gas turbine is similar to jet engines that power an aircraft, it is specifically designed to run electrical generators. The combusted gases which exit the gas turbine are still hot enough to generate steam which can then run a steam turbine to produce additional electricity. The name "combined cycle" is derived from the fact that both gas and steam turbines are in the system.

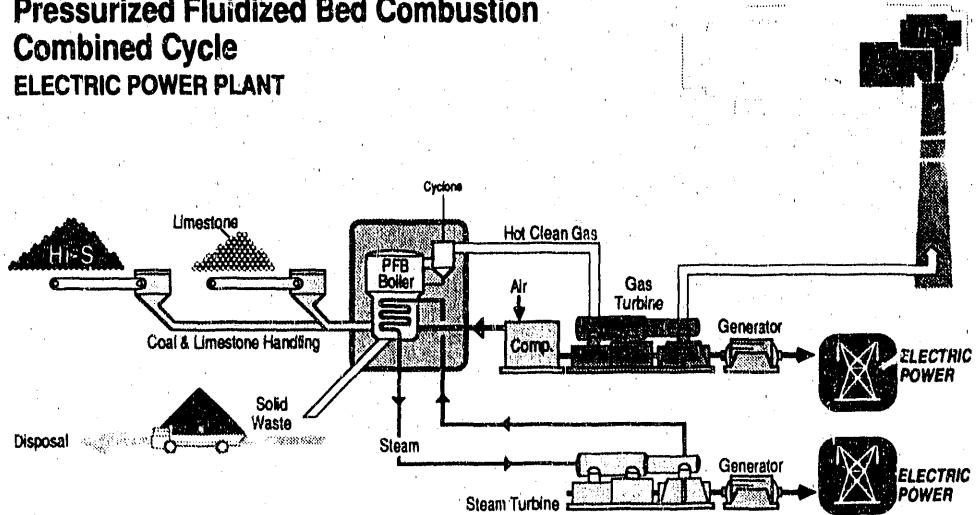
### What Are Its Attributes?

- There are no special coal handling requirements other than the potential to add limestone to the coal feed.
- Gases require hot particulate and sulfur cleanup before entering the gas turbine. No flue gas cleanup is required.
- Combined cycle plants, in addition to increasing the efficiency of energy production, can be composed of standardized modules in 100-200 MW sizes applicable to large and small utilities. This leads to easier installation, less construction time, and relatively lower cost without the usual economy of scale penalties.
- The waste generated is a dry, benign solid that can be disposed of easily or usefully employed (e.g., elemental sulfur or material for road or building construction).
- The space required for IGCC expansion is of the same order of magnitude as would be required for a scrubber.
- It is relatively non-sensitive to coal feedstock.
- Sulfur removal levels of over 99 percent have been demonstrated. These emission levels are well below the existing emission standard of 90 percent removal for new plants.
- Nitrogen oxide removal levels of 40 percent have been demonstrated.

### What Repowering Potential Does IGCC Have For Targeted Plants?

In repowering with IGCC, a gasifier, gas stream clean-up unit, gas turbine, and waste heat recovery boiler are added; in most cases, these replace the existing coal boiler. The remaining equipment is left in place, including the steam turbine and electrical generator. The result is an extension of plant life to essentially that of a new plant, an increase in efficiency from a nominal 35 percent to over 40 percent, and an increase in overall plant output of 50-150 percent with significantly reduced overall emissions. The incremental cost of the additional capacity is low compared to the cost of a new plant.

## Pressurized Fluidized Bed Combustion Combined Cycle ELECTRIC POWER PLANT



COMPARED WITH CONVENTIONAL TECHNOLOGY*					
SO <sub>2</sub> EMISSION REDUCTION	NO <sub>x</sub>	PLANT EFFICIENCY	POWER OUTPUT	PLANT LIFE	INCREMENTAL ELECTRICITY COST
90-95%	Moderate	Slight Increase	40-50% INCREASE	Moderate Extension	4-6 MILLION PER KW

\* CONVENTIONAL COAL-FIRED ELECTRIC POWER PLANT

## Pressurized Fluidized Bed Combustion

### How Does It Work?

Pressurized fluidized bed combustion (PFBC) utilizes a furnace in which a bed of coal and limestone (sorbent) is suspended in a stream of upward flowing pressurized air. The suspended particles behave like a fluid. During combustion, tubes with flowing water that are located within the bed are heated to form steam. The steam generated is then sent to a steam turbine for the generation of electricity. Increased system efficiency is realized by combined cycle operation through the incorporation of a gas turbine to recover additional energy from the pressurized products of combustion. A distinctive aspect of fluidized bed combustion is that when coal and a sorbent are injected into the bed, SO<sub>2</sub> reacts with the sorbent to produce a dry and benign solid.

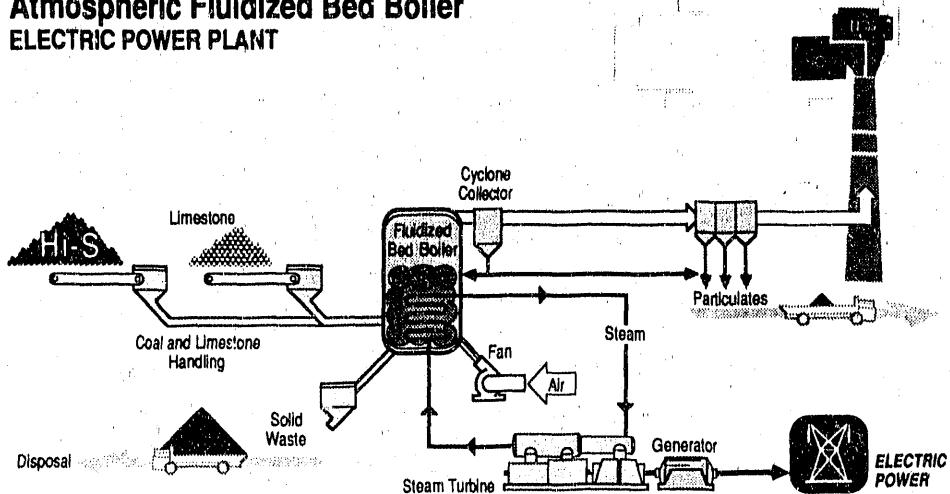
### What Are Its Attributes?

- There are no special coal handling requirements other than the addition of limestone to the coal feed.
- Gases require hot particulate cleanup before entering the gas turbine. No flue gas cleanup is required.
- The fluid-like motion of the solids in the combustion chamber promotes turbulent mixing that improves combustion efficiency and the in situ capture of sulfur dioxide, eliminating the need for add-on removal units.
- The superior mixing also permits combustion at substantially lower and more evenly distributed temperatures. This results in the reduced formation of nitrogen oxides.
- Elevated pressures permit higher combustion intensity and reduce the size of the unit.
- Combined cycle plants, in addition to increasing the efficiency of energy production, can be composed of standardized modules. This leads to ease of installation and a relatively lower cost without the usual economy of scale penalties.
- Modularity provides for staged construction which permits smaller increments of capacity, thereby shortening construction time and lowering financing requirements.
- The space required for PFBC expansion is of the same order of magnitude as would be required for a flue gas scrubber.
- Combustion occurs at temperatures below the ash melting point so that solids accumulation and boiler tube erosion and corrosion are minimized.
- Since it is relatively non-sensitive to feedstock, all types of coals or coal wastes can be used.
- The waste generated is a dry, benign solid that can be disposed of easily or usefully employed (e.g., as material for road or building construction).

### What Repowering Potential Does PFBC have For Targeted Plants?

Since type or size of boiler can be repowered by PFBC technology using the existing plant area, coal and waste handling equipment, and steam turbine equipment, the life of the targeted plant can be extended. Although the initial cost may be somewhat high, there are no net incremental operating costs; unlike a scrubber, PFBC efficiency is not degraded by parasitic losses. Also, the addition of the gas turbine provides an increase in plant capacity of about 40 percent.

## Atmospheric Fluidized Bed Boiler ELECTRIC POWER PLANT



COMPARED WITH CONVENTIONAL TECHNOLOGY*						
SO <sub>2</sub> EMISSION REDUCTION	NO <sub>x</sub> EMISSION REDUCTION	PLANT EFFICIENCY	POWER OUTPUT	PLANT LIFE	INCREMENTAL ELECTRICITY COST MILLS/KWH	CAPITAL COST PER KW
85-90%	Moderate	No Change	10-15% INCREASE	Moderate Extension	6-8	\$700-900

\* CONVENTIONAL COAL-FIRED ELECTRIC POWER PLANT

## Atmospheric Fluidized Bed Combustion

### How Does It Work?

A fluidized bed combustor is a furnace in which a bed of solid particles is suspended in a stream of up-flowing air. The suspended particles behave like a fluid. During combustion, tubes with flowing water that are located within the bed and/or above the bed in the flue gas path are heated to form steam. The steam generated is then sent to a steam turbine for the generation of electricity. The distinctive aspect of a fluidized bed combustor is that when coal and a sorbent--such as limestone--are injected into the bed, sulfur dioxide is absorbed by the sorbent to produce a dry and benign solid. Atmospheric Fluidized Bed Combustion (AFBC) operates at or near atmospheric pressure.

### What Are Its Attributes?

- There are no special coal handling requirements other than the addition of limestone to the coal feed.
- The flue gases require only particulate removal.
- The fluid-like motion of the solids in the combustion chamber promotes turbulent mixing that improves combustion efficiency and the capture of sulfur dioxide.
- The superior mixing also permits combustion at substantially lower and more evenly distributed temperatures, thus reducing formation of nitrogen oxides.
- Combustion occurs at temperatures below the ash melting point so that solids accumulation and boiler tube erosion and corrosion are minimized.
- Since it is relatively non-sensitive to feedstock, all types of coals or coal wastes can be used.
- The waste generated is a dry, benign solid that can be disposed of easily or usefully employed (e.g., as material for road or building construction).

### What Repowering Potential Does AFBC Have For Targeted Plants?

An example of AFBC utility repowering is the Northern States Power project at its Black Dog Station. The existing 85 MW pulverized coal boiler was upgraded to 125 MW with a bubbling bed design AFBC boiler. It began operation in the fall of 1986. This project has resulted in a considerable reduction of SO<sub>2</sub> and NO<sub>x</sub> emissions and has realized an extremely favorable economic advantage.

Since any type or size of boiler can be repowered by AFBC using the existing plant area, coal and waste handling equipment, and steam turbine equipment, the life of the plant can be extended. Although the initial cost may be high, there are no net incremental operating costs; unlike a scrubber, AFBC efficiency is not degraded by parasitic losses. In many cases (e.g., where the capacity of the boiler has been reduced because of aging, or the turbine generator has greater capacity than the boiler, or both), AFBC can be used to repower an existing boiler and, in addition to controlling SO<sub>2</sub> and NO<sub>x</sub> emissions, can increase the boiler's capacity. The cost of controls is significantly reduced because of the value of the increased capacity.

## APPENDIX C

## MAJOR U.S. COMPANIES DOING BUSINESS IN THAILAND

Ahrens Grimm-Carrier  
American International Assurance  
AT&T  
AT&T Micro Electronics  
Bank of America  
Burns & Roe  
Colgate-Palmolive  
DuPont  
Exxon  
Firestone  
General Telephone Directory  
Company  
Goodyear  
Hilton  
HMC Polymers Company

Hughes Aircraft Service  
IBM  
Kodak  
Mobil  
National Semiconductor  
Northwest Airlines  
Phelps Dodge  
Texas Pacific  
3M  
Transpo International  
Union Carbide  
United Airlines  
Varel Manufacturing

-- plus most Fortune 500 Companies

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