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APPLYING ENVIRONMENTAL EXTERNALITIES TO U.S. CLEAN COAL TECHNOLOGIES FOR ASIA*

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ABSTRACT

The United States is well positioned to play an expanding role in meeting the energy technology demands of the Asian Pacific Basin, including Indonesia, Thailand, and the Republic of China (ROC-Taiwan). The U.S. Department of Energy Clean Coal Technology (CCT) Demonstration Program provides a proving ground for innovative coal-related technologies that can be applied domestically and abroad. These innovative U.S. CCTs are expected to satisfy increasingly stringent environmental requirements while substantially improving power generation efficiencies. They should also provide distinct advantages over conventional pulverized coal-fired combustors. Finally, they are expected to be competitive with other energy options currently being considered in the region.

This paper presents potential technology scenarios for Indonesia, Thailand, and the ROC-Taiwan and considers an environmental cost-benefit approach employing a newly developed method of applying *environmental externalities*. Results suggest that the economic benefits from increased emission control can indeed be quantified and used in cost-benefit comparisons, and that U.S. CCTs can be very cost effective in reducing emissions.

1. INTRODUCTION

Coal is an abundant resource found in many locations throughout the world. It is, and has been for many years, one of the most widely used energy sources for many aspects of everyday life including cooking, heating, transportation, industrial processes, and the production of electricity. Its use in the industrial and electric utility sectors is expected to grow as these sectors attempt, in general, to reduce their dependence on imported oil. Increased coal utilization is anticipated not only in those industrialized countries where demand for electricity and industrial products is growing steadily, but also in those developing and newly industrializing countries where opportunities to expand industrial production and provide electricity in a rapidly expanding society abound.

2. U.S. CCT DEMONSTRATION PROGRAM

Extensive research and development (R&D) continues in many developed countries to improve coal-based technologies so that the use of coal, a vast energy resource, can be expanded while strict environmental standards are maintained. Through the development of a slate of technological options, decision makers have been provided with greater latitude in balancing the needs of a growing population, desired economic expansion, environmental concerns, and costs. The scope of ongoing R&D includes improved coal cleaning processes, more efficient

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combustion technologies, and improved flue-gas cleanup systems, all of which provide for higher levels of sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate control without the production of large quantities of solid waste. The technologies under development are applicable to a wide range of conditions, including refurbished and new facilities, industrial and electric utility plants, and a wide range of coals.

In the United States, R&D on clean coal technologies (CCTs), a new generation of advanced, coal-based technologies, proceeds with numerous jointly funded demonstration projects. The U.S. Department of Energy CCT Demonstration Program is designed to move some of the most promising advanced coal-based technologies into the commercial marketplace over the next decade. These advanced technologies are expected to be environmentally cleaner and, in many cases, more efficient and less costly than conventional coal processes. The widespread interest in coal technologies and utilization is evidenced by the fact that many foreign countries and companies also have large coal R&D programs.[1,2]

3. THE ASIAN ENERGY AND ENVIRONMENTAL SITUATION IN BRIEF

Economic expansion and increased demand for electricity are rapidly occurring in Asia. With improvements in the overall standard of living comes an increase in the demand for electricity. The difference between base and peak demands also becomes larger. Electricity consumption has increased remarkably, reaching double-digit annual growth.

Indonesia is richly endowed with energy resources, including oil, natural gas, coal, hydropower, and geothermal energy. However, as a nation of islands, Indonesia faces severe transportation problems. For example, most exploitable coal reserves are located on Sumatra and Kalimantan, while the greatest potential energy demand is on Java. Although coal resources are estimated at 25-32 billion tonnes (Gt), measured reserves are estimated in the range of only 1.5 to 3 Gt; at least 400 million tonnes (Mt) are from the Ombilin (western Sumatra) and Bukit Asam (southern Sumatra) producing mines and at least 1 Gt from Kalimantan mines are currently being developed. Proven crude oil reserves of 8.5 billion barrels (1.6 billion tonnes coal equivalent [Gtce]) and probable reserves of 48 billion barrels (9 Gtce) are declining faster than new production is brought onstream, but they are sufficient to support present production levels for a number of years. Indonesia remains the world's largest exporter of liquified natural gas (LNG). Proven recoverable reserves of natural gas exceed 80 trillion standard cubic feet (3 Gtce).[3]

As long as Indonesian government policy calls for oil and gas for export, the huge requirement for future Indonesian electricity is expected to be met by domestic coal production, coal mine development, and construction of coal-fired electric generating plants. Coal production increased from 400,000 tonnes in 1981 to 12 Mt in 1990 and is expected to exceed 25 Mt in 1995 and 45 Mt in 2000. The government is promoting investment in the development of infrastructure, land transportation systems, ports, handling facilities, and ships. The pace of coal development, however, will depend on how quickly those reserves are developed and on the evolving price of alternative energy resources.[4]

Thailand: The Royal Thai Government wants the Electricity Generating Authority of Thailand (EGAT) to use natural gas and has provided a subsidy to keep the utility from switching to oil. Emphasis on substituting domestic natural gas for imported oil to the fullest extent possible continues despite the associated high development costs. Of an estimated 2.5 Gt of coal, Thailand has a proven reserve of 1.5 Gt, of which about 87% is lignite; this lignite is sufficient to sustain a generation capacity of about 1,700 MWe. Coal consumption, 12.6 Mt in 1991, is expected to reach 38 Mt in 2000. Imported coal would be needed to fuel new coal/lignite generating capacity beyond 1994. One alternative being considered is to construct new plants capable of burning both oil and coal, which would give Thailand the flexibility to respond to price changes in the future. Another alternative would be to combine low-sulfur lignite in northern Thailand with steam coal from China to increase the fuel's calorific content for some industrial users. This mixture, if Chinese coal prices stay low, could provide an attractive means of extending the life of the lignite reserves.[3]

Thailand intends not only to maximize the development of indigenous conventional coal reserves but also to increase the development of alternative energy resources including hydropower, biogas, oil shale, and geothermal energy. Sugar cane can be used in southern Thailand to provide local power needs; surplus power might be sold to the grid at an appropriate price. Nevertheless, imported coal is likely to be used for continued electricity production.[5] Thailand imports 85% of its pollution controls.[3]

Taiwan is heavily dependent on imported energy, with about 90% of its energy consumption derived from foreign sources. It is very dependent on Middle East oil supplies; about 80% of its imported crude comes from this region. Although poor in energy resources, Taiwan's energy demand has grown significantly because of its meteorlike economic rise and the accompanying tremendous surge in living standards for its 19 million people.[6]

Domestic Taiwanese coal resources are estimated at 200 Mt, with 120 Mt judged as exploitable reserves. However, increasing operating costs, ever-deepening mines, a decrease in the number of skilled coal miners, keen competition from relatively inexpensive imported coals, and several disasters resulting in the closing of many unsafe mines have all contributed to a reduction in domestic coal production. Production decreased from 5 Mt per year in the 1960s to less than 800,000 t in 1984 and is expected to decrease to approximately 100,000 t by the year 2000. Nevertheless, total coal demand is forecast to increase from 19 Mt in 1990 to 35 Mt by the year 2000 and to reach more than 56 Mt by 2010. Steam coal for electricity generation is expected to double from 9.7 Mt in 1990 to nearly 20 Mt by the year 2000 and then to double again to almost 40 Mt in 2010.[1,7]

Coal is widely regarded in Asia as a reliable, low-cost fuel for the production of large quantities of baseload electricity, and it is available from a diverse group of international suppliers. Coal imports have come principally from Australia, with the United States and South Africa also supplying significant quantities. Recently, however, imports from China and South Africa have increased at the expense of those from the United States and Australia. In general, government policy is such that coal imports will continue to be spread among several sources, so that these countries may take advantage of varying market prices while maintaining supply security.

With the rapid increase in coal demand, especially in steam coal for power generation (but also in coking coal for Taiwan's developing steel industry), environmental concerns and pollution controls have become important considerations. To develop and implement energy and environmental plans for Taiwan, several organizations and institutions -- including the Council for Economic Planning and Development, Environmental Protection Administration, National Corporation Commission, Bureau of Industry, Energy Commission, Taiwan Power Company (Taipower), Chinese Petroleum Corporation, and China Steel Corporation -- have become involved.[7] In Thailand, interested parties include EGAT, Petroleum Authority of Thailand, Metropolitan Electricity Authority, Provincial Electricity Authority, and National Energy Administration, among others.[5] And in Indonesia, National Electricity Authority (PLN) and Ministry of Mines and Energy are the key policymakers.[4]

Because of limited land areas and dense population as well as vigorous industrial and commercial activities, environmental quality in these countries has seriously deteriorated in recent years. However, environmental quality has become of greater concern to the public at large, with the environment and its protection recognized as prominent and urgent priorities. Pollution control, especially in Taiwan, has been foremost in the public focus in recent times.[7]

Since 1985, the Taiwanese government has required all major engineering projects, including coal-fired power plants, to undergo environmental impact assessments when the projects are still in the planning stage, before government review occurs. In addition and simultaneously, two major regulations must be satisfied -- the Air Emission Standards for Stationary Sources (1986) and Wastewater Effluent Standards (1987). SO_2 emissions from combustion must be less than 750 parts per million (ppm) (1990), decreasing to less than 500 ppm in 1993. Hence, high-efficiency combustion and pollution control equipment must be the focus.[7]

In Thailand, the government and EGAT have publicly stated their full commitment to the development of the power sector in an environmentally sound and sustainable manner. Environmental concerns in the next few years are expected to focus on (a) the impacts of rapid expansion of the power and mining facilities at the existing site at Mae Moh and (b) the adequacy of the existing environmental regulatory framework for formulating policy and standards, enforcing compliance, and monitoring the quality of the environment. Measures to strengthen the power sector environmental capabilities are also being emphasized.[5]

4. APPLIC'BLE CLEAN COAL TECHNOLOGIES FOR SELECTED ASIAN COUNTRIES

All new coal-fired power plants are expected to comply with government regulations on SO_2, NO_x, and particulate emissions. Taipower reports that all of its proposed coal-fired units will be equipped with modern flue-gas emission reduction devices (e.g., electrostatic precipitators, baghouse filters, flue-gas desulfurization devices, and de-NO_x devices) to reduce pollutants to their minimum practical levels.[8]

New coal-based generation requirements in the appropriate sizes for Taiwan, Thailand, and Indonesia create an opportunity for several of the CCTs currently under demonstration in the United States. Options to be considered include:

- A pulverized-coal (PC) fired plant with no SO_2-emission controls and moderate particulate control (this option is not under consideration for use in Taiwan but can serve as a reference case to demonstrate the effectiveness of emission control capabilities available in CCTs);
- A PC-fired plant with SO_2-emission control (flue-gas desulfurization or FGD) and a higher level of particulate control -- PC/FGD;
- An atmospheric fluidized-bed combustion plant -- AFBC;
- A pressurized fluidized-bed combustion plant -- PFBC; and
- An integrated coal gasification combined-cycle plant -- IGCC.

Estimates of the reduction levels and emission rates for air pollutants from these generic coal technologies are presented in Table 1. These values are considered representative of those for a family of variations within each technology and serve as the base-case estimates in this analysis. The values for SO_2 and particulate control given in this table do not necessarily represent the full capabilities of the advanced technologies. Instead, they are intended to represent improvements over the reference-case PC-fired plant under conditions believed representative in Asia. Values for carbon dioxide (CO_2) emissions are based on a release rate of 205 pounds per million British thermal unit (Btu) of heat input (369 kilograms per million kilocalories), adjusted by the efficiency of the technology and an assumed amount of limestone required for SO_2 control.

Table 2 presents selected characteristics of both indigenous coals and coals that could be imported from coal-supplying countries. These characteristics represent raw coal and are not necessarily the precise characteristics of the coal expected to be received at the plant site. The selected coals include both a high-sulfur and a high-ash coal from the United States, which are not necessarily the most commonly exported U.S. coals. Although both U.S. coals could also be beneficiated easily to remove substantial fractions of sulfur and ash, they are presented here to illustrate the increased environmental qualities of CCTs. In other words, although other coals could also be imported to Asian countries, these coals were selected to illustrate the points of these analyses.

The large expansion program undertaken by the selected Asian countries provides the opportunity to implement several CCTs. AFBC, PFBC, and IGCC units can be built in the sizes needed, use a variety of coals (which might be expected from a diversified supply system), and meet the emission standards set by the government. Additional CCT opportunities may exist in the retrofitting of some of existing oil-fired capacity. Conversion of some of these units to slagging combustors or to use coal-water mixtures could help to reduce operating costs as well as allow for a more diversified fuel supply than is currently achieved with imported oil. Such retrofit applications were not considered in the analyses described herein.

5. AMBIENT ATMOSPHERIC CONDITIONS -- SELECTED ASIAN COUNTRIES

Air quality monitoring remains limited in most of Asia. With the exception of Japan, air quality in Asia has generally worsened with industrialization and the lack of effective pollution controls. Not one United Nations Environment Programme (UNEP)/World Health Organization (WHO) site in Asia for monitoring air quality has yet complied with WHO standards for suspended particulates, and only half the stations met SO_2 standards between 1979 and 1985. (Analogous to the WHO standards are the U.S. National Ambient Air Quality Standards [NAAQS].)

Overall, Asia is said to exhibit no definitive trends with respect to its air quality; progress made in some cities to decrease certain pollutants is offset by setbacks in others. Compared with the industrialized countries, Asia lags far behind in controlling most air pollutants. For example, particulate levels in Manila increased more than 20% from 1974 to 1984.[9]

Taiwan's considerable efforts in industrialization and economic development have caused the air pollution concentrations to increase dramatically during the 1960s and 1970s,[10] principally because of:

1. A substantial increase in the number of industries;

2. The continued combustion of fuel oil, coal, and wood;

3. An increase in automobile exhaust emissions; and

4. A high population density.

Preliminary measurements of pollution in the heavily industrialized city of Kaohsiung in Taiwan appear comparable with those in other Asian industrial centers, as indicated in Table 3, which illustrates ambient air conditions for SO_2 and particulates in micrograms per cubic meter ($\mu g/m^3$). Although these data are somewhat dated, they illustrate the fact that the ambient air quality in Asian cities generally exceeds WHO guidelines for both SO_2 and particulates. Chow et al.[10] have called for long-term monitoring at more sites through the use of standardized procedures.

Particulates: The 10 cities with the highest levels of particulates worldwide are in developing countries of Asia; of 10 cities with the lowest concentrations, 9 are in industrialized countries. This difference may reflect the natural conditions found in cities in the developing world (i.e., some of the cities there have high levels of naturally occurring dust) as well as the stricter emission controls in force in cities of the industrialized world. Nonetheless, particulate levels in some Asian cities exceeded the WHO standards by factors of three to five.

In 1984, there were 170 monitoring stations reported for Taiwan, but most of these were identified as consisting of manual particulate measuring devices only; a monitoring center, 19 automatic, all-criteria stations, and one mobile van were said to have been planned.[13] At that time, particulates from stationary sources were reported to show a decreasing trend, while pollutants from mobile sources were reportedly on the rise. Taiwan has been characterized as moderately polluted and about 15 years behind Japan in its environmental protection efforts. Moreover, Tsai and Jenq[14] reported that candidate locations for air quality monitoring sites are still under study (perhaps as refinements) for Taipei.[15]

SO_2: Levels of SO_2 pollution in cities of developing countries do not appear to be as high as levels of particulate pollution; about half the stations recorded SO_2 levels that exceeded WHO standards. About 15% of the stations in industrialized countries also exceeded the standards. Trend data indicate neither a broad improvement nor a worsening of SO_2 pollution; approximately equal numbers of stations reported increases and decreases in SO_2 over the 1979-1985 period.[9] Recently, calculations for an East Asian (Japan, mainland China, Taiwan, South Korea, and North Korea) emissions inventory indicated that SO_2 emissions from Taiwan are similar to those of Japan and South Korea, with the principal emission sources being concentrated in the Taipei, Jilong, and Gaoxiong areas.[6]

6. ENVIRONMENTAL EXTERNALITIES - AN APPLICATION

Historically, decisions in electric power generation planning are usually made by considering traditional costs such as capital, operating and maintenance, and fuel costs and fixed charges. Social costs, which could be significant, are not incorporated explicitly into such decisions. These social costs could result in a net reduction in the welfare of individuals, and of society as a whole. Because these social costs and their effects are not represented in the price of energy, individuals have no way to explicitly value them. Hence, they remain unaccounted for in market decisions.[16] By accounting for external costs, the selection of energy sources and production of energy products can lead to an equilibrium, where the total cost of energy and energy products, together with the resulting social costs, can be brought to an economic minimum.

All energy conversion technologies pose some risk to society. Economists and social scientists continue to develop monetary values to represent loss of life, illness, global warming, decreased visibility, acid rain, and other consequences of electricity production. These monetary values, referred to as *environmental externality values*, have been translated to emissions through consideration of dose-response relationships and similar cause-and-effect principles. The term may be defined as those external or social costs related to any unpriced impacts created in the process of energy production and use, typically in the form of environmental damage, adverse health effects, and materials damage.[16]

In considering and applying externality costs rigorously, the necessary dose-response and physical damage functions involved must first be identified and quantified. Second, the validity of the economic value of statistical lives -- a very controversial concept -- needs to be considered and accepted. Third, the appropriate economic data need to be applied in deliberations, even though these data are usually costly and difficult to gather. And, fourth, it needs to be recognized that even with the appropriate data, significant uncertainty and imprecision in the estimates will continue to exist.[17]

The authors have developed a simplified two-step approach for the valuation of environmental externalities.[18,19] First, data on power-plant-generated emissions are calculated from various electric power generation options. These calculated emissions depend on plant type, plant age, fuel type, fuel grade, sulfur content, installed/operating emissions technology, and plant operating parameters such as heat rate, combustion temperature, and injection options. Second, the value for monetary damage to the environment is assessed, assuming conservative estimates for point source emissions.

Ambient air quality data have shown that the Asian region can generally be considered an area in nonattainment, in which significant health impacts can be expected. Externality values may be applied. By choosing the conservative, damage-based Lave values, which consider health impacts (one set of many such externality values), one may assign values for each type of power plant emissions: \$1090 per tonne of SO_2 emitted; \$495 for NO_x; \$1650 for particulates; and \$11 for CO_2. Szpunar and Gillette[18,19] demonstrated how the costs and benefits of controlling emissions -- specifically those from new, advanced-technology, coal-based, electric power plants to be sited in Indonesia, Thailand, and Taiwan -- might be considered. The reader is directed to the referenced works for additional details.

7. ARGONNE METHODOLOGY

Traditional methods for determining the costs of electricity production involve techniques for annualizing capital costs, incorporating operating and maintenance costs, and calculating fuel costs. These costs form the basis for establishing the price of electricity that consumers must pay. Utilities have acknowledged concerns related to environmental issues by ensuring compliance, incorporating the additional costs of compliance into the cost of electricity, and conducting some evaluation of the impacts or consequences of the emissions or residuals.

By combining the economic value of environmental impacts with the quantity of the electricity produced per unit of emission, an *environmental cost* of electricity production can be determined. This cost can be expressed in the same terms as are the more traditional costs (e.g., U.S. cents per kilowatt hour [kWh]) and can thus be combined with the traditional costs. It can also be directly compared with the traditional costs to illustrate the relative magnitudes of each cost.

For these analyses, a model was developed to estimate the traditional cost of electricity production for conditions representative of those in Indonesia, Thailand, and Taiwan. Externality costs were also estimated through the use of the emission rates (or control levels) for the individual technologies and the externality values. These costs were added to yield a total cost for each option.

A *figure of merit* was developed to illustrate the benefit-to-cost ratio for each advanced option relative to the reference case. This figure of merit is equal to the benefit of reduced atmospheric emissions divided by the increase in traditional cost of electricity production. A benefit-to-cost ratio of less than 1.0 means that the benefits are less than the additional production costs, while a ratio greater than 1.0 means that the benefits exceed the additional costs. A value of 1.0 means that the benefits of reduced atmospheric emissions exactly offset the additional cost of electricity production.

Several economic and technical assumptions were made to allow quantitative assessments of the emission control costs and the benefits of the advanced technologies. All technologies were considered to operate as baseload plants, with annual capacity factors of 70%. A previous evaluation indicated that a 600-MW facility would represent Indonesian new power plant requirements, a 300-MW plant would be more typical of new construction in Thailand, and 550-MW coal-fired units are anticipated for Taiwan. The analyses were performed in terms of constant U.S. dollars. Basic fuel costs ranging from U.S. $6.30 to $8.30 per million kilocalories ($1.60 to $2.10 per million Btu) were used.

For purposes of these analyses, it was assumed that all of the additional costs of the advanced technologies (when compared with the costs of the reference PC plant) are attributable to environmental controls. In reality, some of these additional costs could result from the desire to make the advanced technologies more reliable and more fuel flexible. By assigning all additional costs to environmental control, the results of the analyses will conservatively estimate (i.e., underestimate) the ratio of benefits to costs. Thus, the advanced technologies should provide, in practice, a ratio of environmental benefit to environmental control cost that is at least as high as the values presented in this paper.

The environmental externality values selected for these analyses are the higher of Lave's conservative externality values, which are neither the highest nor the lowest values that have been presented in the literature. These values, however, do represent the lowest estimated environmental externality values that include health effects. Thus, the use of these values also tends to result in a benefit-to-cost ratio that is conservative (lower) than those that would result from the use of other externality values that incorporate health effects.

8. ARGONNE RESULTS

The numerical results of these analyses include values for the traditional cost of electricity production (capital, operating and maintenance, and fuel) and for the cost of environmental externalities. As noted earlier, a ratio of the incremental benefits due to the reduction in emissions divided by the incremental cost in the traditional cost of electricity production is used as a figure of merit for these technologies.

Results from these analyses are shown in Tables 4 and 5. In every case, the results demonstrate a benefit-to-cost ratio greater than 1.0. In other words, over the variety of technology applications and coals considered, the value of the reduction in atmospheric emissions is estimated to be far greater, in many cases, than the additional cost that may be incurred in attaining the higher levels of emission control.

The benefit-to-cost ratios in Table 4 range between 1.5 and 127, while in Table 5 they range more narrowly, between 1.6 and 7.2. The highest ratios are for IGCC technology, with its high levels of particulate and sulfur control but costs comparable with those of the other technologies. The performance parameters used in these analyses do not necessarily represent the full capabilities of the technologies. Higher benefit-to-cost ratios are exhibited for coals with higher ash and sulfur contents, because even greater reductions in the quantities of atmospheric pollutants can be realized when these "dirtier" coals are used.

9. OBSERVATIONS AND OTHER CONSIDERATIONS

A more detailed examination of these results provides some additional insight into their significance.

Indonesia: The traditional cost of producing electricity in an IGCC plant in Indonesia burning Upper Freeport-quality coal is estimated at approximately 4.1 cents (U.S.)/kWh. The corresponding cost for the reference-case PC unit is approximately 3.7 cents/kWh. However, the cost of the environmental externalities due to air emissions from the IGCC is approximately 1.0 cent/kWh, while the emissions from the reference facility have a cost of about 5.8 cents/kWh. (These figures yield the benefit-to-cost ratio of 11.9 listed in Table 4 -- [benefit of 5.8 - 1.0] / [cost of 4.1 - 3.7].) Thus, when the 600-MW plant operates for a year at a capacity factor of 70%, the additional cost of electricity production is less than $15 million. However, the reduction in atmospheric emissions realized by using the IGCC technology rather than the reference-case technology reduces environmental externality costs by more than $176 million per year.

Thailand: A similar breakdown of the costs of an IGCC plant in Thailand, where plant capacity is 300 MW, shows that the reference-case PC traditional costs are nearly equal to those of the IGCC plant -- slightly more than 4.0 cents/kWh -- and that the costs of the reference-case plant are slightly less than that amount. However, the externality costs are 1.0 and 5.8 cents/kWh for the IGCC and reference plant, respectively. (These figures lead to the benefit-to-cost ratio of 127 listed in Table 4 -- [benefit of 5.8 - 1.0] / [cost of about 4.0 - about 4.0].) Thus, by spending less than $0.7 million per year for additional electricity production costs, savings of more than $88 million per year in externality costs can be realized.

Taiwan: The traditional cost of electricity production at an IGCC plant in Taiwan burning U.S. Upper Freeport coal is estimated at approximately 4.4 cents/kWh. The corresponding cost for the reference case PC-fired unit is approximately 3.8 cents/kWh. However, the cost of the environmental externalities due to air emissions from the IGCC plant is approximately 5.5 cents/kWh, while the emissions from the reference plant have a cost of about 9.6 cents/kWh. Thus, when the 550-MW plant operates for a year at a capacity factor of 70%, the additional cost of electricity production from the IGCC technology, as compared with the reference technology, is about $22.5 million. However, the reduction in atmospheric emissions realized by using the IGCC rather than the reference technology reduces environmental externality costs by $162 million.

As indicated in Tables 4 and 5, the estimated figures of merit for the other cases considered are lower than they are for this example -- but all ratios are greater than 1.0, which shows that an investment in U.S. CCTs would be more than repaid by reductions in costs from air pollution from the reference plant burning the same coal.

The environmental externality values involve considerable uncertainty with respect to the state of the science (e.g., atmospheric dispersion and health effects) and the selected economic values (e.g., the dollar value of a health impact or of visibility impairment). Sensitivity analyses were therefore performed on several parameters, including capital and operating costs, values of environmental externalities, and emission rates and emission control levels. Although the individual costs and benefits change, the basic conclusions remain the same. These are that (1) significant environmental benefits are likely to accrue when U.S. CCTs are used and (2) the value of these benefits will generally be much greater than the incremental cost resulting from reducing emissions.

Therefore, environmental externality values can be used as demonstrated here to make a quantitative estimate of the benefits to be derived, so that they can be compared with the traditional cost of electricity production.

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TABLE 1 EMISSION RATES AND REDUCTION LEVELS BY TECHNOLOGY					
Emission	Uncontrolled Pulverized Coal	Controlled Pulverized Coal	AFBC	PFBC	IGCC
SO_2 (%)	no controls	80	80	90	95
NO_x (ppm)	800	400	150	150	150
TSP (%)	80	90	90	95	99.99
CO_2 (lb/kWh)	2.0	2.1	2.2	1.9	1.9
N_2O (ppm)	1	1	1	1	1
CO (ppm)	120	120	200	170	5

TSP = total suspended particulates   ppm = parts per million   kWh = kilowatt hour

TABLE 2 REPRESENTATIVE COAL QUALITY CHARACTERISTICS					
Coal	Calorific Value (Btu/lb)	Calorific Value (kcal/kg)	Moisture (%)	Ash (%)	Sulfur (%)
Indonesia Ombilin	13,250	7,360	4.1	5.6	1.5
Indonesia Pt. Arutmin	11,160	6,300	4.0	15.0	0.7
Thailand Mae Moh Lignite	4,950	2,750	34.0	20.2	0.5
Thailand Krabi Lignite	4,150	2,310	30.0	26.0	3.5
Australia New South Wales	12,240	6,800	3.0	13.5	0.5
Australia Hunter Valley	11,510	6,390	9.0	12.7	0.5
Australia Ulan	10,880	6,050	--	16.3	0.7
South Africa Ermelo	11,240	6,240	--	12.6	1.0
South Africa Witbank	10,880	6,050	--	15.1	1.0
United States Upper Freeport	9,750	5,420	4.8	30.2	1.8
United States Illinois No. 6	10,270	5,710	9.5	16.8	4.2

TABLE 3 ANNUAL AVERAGE AMBIENT AIR QUALITY					
Country	City	Area Type	1978[a]	1979[a]	1980[a]
SO_2 ($\mu g/m^3$)		U.S. NAAQS = 80[b] -- WHO Guideline = 40 - 60[c]			
ROC - Taiwan	Kaohsiung	urban industrial	54-3780[d]	na	na
Thailand	Bangkok	suburban residential	na	10	na
		suburban industrial	15	9	na
Indonesia	Jakarta	city center residential	na	na	na
		suburban industrial	na	na	na
Malaysia	Kuala Lumpur	suburban residential	5	3	3*
		suburban industrial	43	15	22
Philippines	Manila	city center commercial	66	91*	75*
		suburban residential	46	58	62
		suburban industrial	91*	100*	79
PARTICULATES ($\mu g/m^3$)		U.S. NAAQS = 50[b] -- WHO Guideline = 60 - 90[c]			
ROC - Taiwan	Kaohsiung	urban industrial	200-300, 260 typical[d]		
		pristine mountain	150 typical[d]		
Thailand	Bangkok	suburban residential	137*	170	232*
		suburban industrial	162	167	170
Indonesia	Jakarta	city center residential	210*	255	275
		suburban industrial	129*	138	167
Malaysia	Kuala Lumpur	suburban residential	90	79	98
		suburban industrial	153	158	182
Philippines	Manila	city center commercial	87	73	79
		suburban residential	87	101	99
		suburban industrial	76*	82*	92*

a. Ref. 11.
b. Ref. 12, SO_2 converted from ppm to ug/m^3 -- ppm SO_2 x 2.7 x 10^3.
c. Ref. 9.
d. Ref. 10.
* = Insufficient data for reliable statistics.
na = not available.

TABLE 4 RATIO OF REDUCED COST OF ENVIRONMENTAL EXTERNALITIES TO INCREASED COST OF ELECTRICITY PRODUCTION[a] -- INDONESIA AND THAILAND

Country	Technology	Ombilin Bituminous	Pt. Arutmin Bituminous	Mae Moh Lignite	Krabi Lignite	Australia New South Wales Bituminous	U.S. Upper Freeport Bituminous
Indonesia	PC/FGD	1.5	2.1	--	--	1.7	4.7
	AFBC	1.5	1.8	--	--	1.4	3.9
	PFBC	2.7	3.9	--	--	3.3	9.5
	IGCC	3.0	5.2	--	--	4.1	11.9
Thailand	PC/FGD	--	--	5.5	10.7	1.4	3.9
	AFBC	--	--	6.2	9.4	1.6	3.9
	PFBC	--	--	11.1	21.0	3.1	8.7
	IGCC	--	--	38.9	69.9	28.2	127.3

[a] Ratio is based on the higher of the conservative environmental externality values established by Lave.

TABLE 5 RATIO OF REDUCED COST OF ENVIRONMENTAL EXTERNALITIES TO INCREASED COST OF ELECTRICITY PRODUCTION[a] -- TAIWAN

Technology	Australia Hunter Valley	Australia Ulan	South Africa Ermelo	South Africa Witbank	U. S. Upper Freeport	U. S. Illinois No. 6
PC/FGD	1.6	2.1	1.9	2.1	4.4	4.4
AFBC	1.6	2.1	1.9	2.2	4.2	4.7
PFBC	1.8	2.4	2.1	2.4	5.0	4.7
IGCC	2.6	3.4	2.9	3.4	7.2	6.1

[a] Ratio is based on the higher of the conservative environmental externality values established by Lave.