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ENERGY AND SUSTAINABLE DEVELOPMENT: EFFICIENT UTILIZATION OF ENERGY RESOURCES

Issues in the transfer of clean coal technologies to developing countries

Report of the Secretary-General

SUMMARY

"Clean coal technology" refers to a variety of methods that reduce the amount of sulphur dioxide, oxides of nitrogen and particulates generated during combustion in power plants fuelled with coal or that reduce the emission of these pollutants. Such emissions have to be curtailed because they cause unhealthy ambient air, contribute to the formation of "acid rain" and contribute to the formation of smog at ground level and the depletion of the ozone at high altitudes. Commercially proven clean coal technologies are now available for retrofitting existing power plants. This report describes the issues and constraints involved in the transfer of these technologies to developing countries.

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INTRODUCTION

1. Coal is an abundant source of energy that has served mankind’s needs well since the beginning of the industrial age. Today, spurred by concern over the potential for global warming and acid precipitation, coal is often criticized as a major source of environmental degradation at the local, regional and global levels. However, for many developing countries the use of coal to fuel their energy and economic development offers the only alternative for the foreseeable future; the question posed by these countries is not "Shall we use coal?" but rather "How shall we use coal?".

2. It should first be recognized that many of the environmental problems identified have been solved. However, integration of environmentally benign coal technologies into energy planning in developing countries requires rethinking of the true costs and benefits of coal use, along with revised approaches to technology transfer and energy-facility financing. In particular, utilities and associated energy ministries must develop new approaches to the participation of both the domestic and the offshore private sector.

3. The term "clean coal technology" refers to a new generation of advanced coal utilization technologies that are environmentally cleaner and in many cases more efficient and less costly than conventional coal-using processes. These new energy and pollution control systems are the products of years of research and development in hundreds of governmental and private laboratories throughout the world. Several industrially advanced countries - namely Japan, the United States of America and the United Kingdom of Great Britain and Northern Ireland - have ongoing research programmes in clean coal technology demonstration and assessment. They include coal chemistry, coal combustion, and pollution control. The essential step is to translate the results of the laboratory test bench to the commercial market, particularly in developing countries. If their viability can be thus proved, clean coal technologies offer the potential for a cleaner environment and lower costs by contributing to the resolution of issues relating to acid rain, global climate change, future energy needs and energy security.

4. Clean coal technologies encompass methods developed to reduce the amounts of sulphur dioxide (SO_2), oxides of nitrogen (NO_x) and particulates that are generated during combustion in power plants fueled with coal and to reduce the emission of these pollutants. The United Nations has adopted a more broad-based definition, which considers clean coal technologies as all of the technological innovations that reduce environmental impacts throughout the coal fuel cycle. This includes mining and transportation activities, in addition to pre-combustion, combustion, post-combustion and conversion technologies.

5. The undesirable power plant emissions to be eliminated or reduced by these technologies were originally limited to the oxides of sulphur (mostly SO_2), nitrogen (N_2O, NO, $N0_2$, etc., collectively designated as NO_x), and also the emission of particulates. Carbon monoxide has now been added to the list. The United States Environmental Protection Agency (EPA) recently established limits for a number of other objectionable emissions from trace elements in coal or

generated in small quantities during combustion, sometimes referred to collectively as "air toxics".

6. SO_2 and NO_x emissions are pollutants which degrade the quality of ambient air, damage vegetation and exacerbate respiratory ailments; they also are precursors in the formation of acid rain, which clean coal technologies were designed to abate. There is currently some ambiguity as to whether proposed methods for the reduction of CO_2 (a "greenhouse gas" that may be contributing to the warming of the earth's climate through its absorption of reflected infrared radiation) are to be considered clean coal technologies.

7. It should be pointed out that clean coal technologies originated because of general dissatisfaction with the high cost and poor performance of the then commercially available flue gas desulphurization systems (FGDs, commonly known as scrubbers). However, the expression "clean coal technologies" in its current usage encompasses FGD systems, both the wet and dry lime/limestone systems that the clean coal technologies programme was created to replace or improve upon.

8. Many of the clean coal technologies that have been selected for research have not yet been proven. Other technologies, such as in-duct sorbent injection, although still in the early stages of demonstration, appear very promising and because of their projected low cost and relative simplicity of application, they should be easily transferable to developing countries.

9. Particulate control systems already in existence at the time the clean coal technology programmes were initiated, such as electrostatic precipitators and baghouse filters, are sometimes included in the current broad definition of clean coal technologies. Since the design and the performance of these systems are described in standard engineering textbooks, they will not be described here; however, the influence on their performance of other clean coal technologies will be discussed.

I. CLEAN COAL TECHNOLOGIES

10. The technologies briefly described below can be classified according to the stage at which they are applied - pre-combustion, combustion and post-combustion, or conversion. A list of all clean coal technologies is provided in the table.

A. Pre-combustion technologies

11. Coal cleaning is a beneficial pre-combustion technology that can be employed to reduce ash and sulphur content in the coal. Coal, as mined, contains various forms of carbon and sulphur, moisture, combustible gases, nitrogen, often sodium and potassium, inert material which mostly yields ash after combustion, and a variety of undesirable elements, such as mercury, which can be found in the ash or which vaporize during combustion. Coal cleaning was originally used to reduce the inert material for coal used in steel-making and to reduce the cost of long-distance coal transportation. It also improved the performance and reduced the maintenance of the boilers firing the coal. Coal

washing with water is the most prevalent method of cleaning coal; air can be used when water is not available. Quite importantly, coal washing removes a major fraction of the pyritic sulphur (FeS_2) in coal. Coal can be cleaned to various extents.

12. Coal cleaning has recently evolved to encompass a variety of advanced techniques which include the addition of chemicals (chemical coal cleaning) or other forms of energy. Such methods as selective agglomeration and advanced froth flotation are currently being pursued by laboratories and private companies. They are applicable to processes intended to convert coal into liquid or gaseous fuels. They are energy intensive and rather costly and will not be discussed here.

13. The benefits of physical coal cleaning in reducing emissions and improving the performance of coal-fired power plants have long been recognized. Reduction in the inert matter that is usually found in the coal results in improved boiler performance, lower maintenance costs and a decrease in the demand for pulverizers. Reduction in the ash, which causes equipment wear and tube erosion and can, deposited in tubes, impede heat transfer, results in a decreased demand for precipitators and for ash handling.

14. Physical coal cleaning was well established before the recent emphasis on clean coal technologies, although new equipment is being developed and old equipment continues to be improved. However, the contribution of coal cleaning to the reduction of emissions from power plants was not fully appreciated until recently. One reason may have been the fact that physical coal cleaning removes only the sulphur associated with the pyrites in the coal and not "organic" sulphur. Apparently, the wide occurrence of pyritic sulphur, the extent of its contribution to SO_2 emissions and the relative ease of its removal had not been appreciated. Pyritic coals are to be found - and indeed predominate - in many parts of the world and greatly contribute to SO_2 emissions. This is the case in the United States, where an Environmental Protection Agency (EPA) study in 1983 determined that in 24 power plants that had capacities over 500 MW, burned coal with over 1 per cent sulphur and had no FGD systems, coal washing produced an average reduction in sulphur emission of 29 per cent.

B. Combustion and post-combustion technologies

15. Combustion and post-combustion technologies can be divided into categories depending on the pollutant that they control: for example, SO_2 control technologies, NO_x control technologies, or combined SO_2/NO_x technologies.

16. SO_2 control technologies are comprised chiefly of flue gas desulphurization systems (FGD). They remove sulphur by chemical reaction with alkaline sorbents (typically lime or limestone) sprayed into the gas stream following combustion. FGD systems are also referred to as "scrubbers" because the combustion gases are thought of as being washed, or "scrubbed". Scrubbers can remove over 90 per cent of the SO_2 from the flue gases of power plants fired with high-sulphur coals; over 95 per cent removal efficiency can be achieved with enhanced reagents.

17. NO_x control technologies include low NO_x burners, staged combustion, reburning (with natural gas, or with coal), selective catalytic reduction and selective non-catalytic reduction. Upstream NO_x control processes include combustion modifications that reduce NO_x by introducing the combustion air at various points during combustion, resulting in "staged combustion", or by introducing the fuel at various points during combustion, resulting in "fuel staging". "Fuel reburning" and other methods are also used. Each method alone can generally achieve NO_x reductions of up to 50 per cent, and in combination with other methods, up to 90 per cent. Accurate instrumentation for measuring and controlling fuel and air flow and measuring temperatures and NO_x are necessary for the success of NO_x control. Downstream NO_x reduction can be carried out by various methods. One selective non-catalytic reduction, is accomplished by injecting and mixing ammonia, urea, or another nitrogen compound into the flue gas stream at the appropriate concentration and temperature range. Another method, selective catalytic reduction, also utilizes the injection of a nitrogen compound but has the NO_x reduction take place mostly in a downstream matrix of catalyst, such as vanadium, platinum, or titanium.

18. Combined SO_2/NO_x control technologies include fluidized bed combustion (specifically, atmospheric fluidized bed combustion, or AFB boilers), circulating fluidized bed combustion (CFB boilers), and pressurized fluidized bed combustion (PFB boilers), as well as coal cleaning and complementary technologies. Besides their ability to be fired with low-grade coal of varying properties, fluidized bed combustion boilers offer the advantages of generating little NO_x and eliminating the need for scrubbers; SO_2 can be removed in the combustion process by adding sorbent to the bed material which can absorb SO_2 as it is being formed during combustion.

19. Clean coal technologies are also referred to as "retrofit" or "repowering" technologies. Retrofit technologies curtail emissions without resulting in a substantial increase in a power plant's capacity, while repowering should bring about an increase over the plant's prior rating.

C. Conversion technologies

20. Certain processes convert coal to liquid or gaseous "clean" fuels - i.e., fuels not containing sulphur or nitrogen - or remove the sulphur or nitrogen components in an intermediate step prior to combustion. They include a variety of conversion processes, a number of cleaning processes for the liquid or gaseous fuel products, and a number of "integrated gasification combined cycle" processes, in which the coal is converted into a gaseous fuel of low-to-high BTU content through combustion with steam injection (and the use of oxygen rather than air, if high BTU content gas is required). In the integrated gasification combined cycle processes, the synthetic gas is not stored or transported but in subsequent steps is cleaned and immediately fired in gas turbine(s) to generate power, with the gasification and power generation steps integrated so as to minimize the losses usually associated with gasification. These processes have been sufficiently researched to be commercialized.

II. ISSUES RELATED TO TECHNOLOGY TRANSFER

A. Planning considerations

21. The selection of a clean coal technology to retrofit an existing power plant is not a straightforward procedure, because it involves many economic and technological factors and cannot be carried out in isolation, merely by considering the specific plant and the range of clean coal technologies available. Usually such decisions are carried out in the context of what is commonly known as an "environmental compliance strategy" in order to meet specific emission limits from various sources or overall region-wide emission rates over a certain period of time, as dictated by legislation or other agreements. As a minimum, the contribution of any particular plant to the country's generation mix and emission levels should be considered. For example, if a power plant is operated only infrequently, from a technological viewpoint, scrubbers might be an appropriate choice of clean coal technology. But their high initial cost might indicate that it is best to retire the plant or operate it (infrequently) with a premium, high-priced clean fuel such as gas or low-sulphur oil. Scrubbers may be preferable for a fairly new base-load coal-fired power plant, whose continued operation at high capacity factors will result in a low per kw/hr added cost to the power generated from the installation of the scrubber.

22. Another complication in selecting a clean coal technology process is that, in the case of an older power plant, it will be found advisable, at the time of the retrofit, to carry out refurbishment (and possible upgrading) of the plant so that its useful operating life can be extended. The high cost of installing most clean coal technologies is not justified unless it can be defrayed over several years of plant operation.

23. Moreover, when it comes to meeting area-wide emission levels from several power plants, it is more economical to reduce SO_2 emissions drastically by installing scrubbers in a few of the largest base-load plants and not to retrofit the others, allowing them to operate as before, without emission control devices. Assuming that good quality sorbent (lime or limestone) is available locally and at low cost, scrubbers can remove SO_2 from the flue gases at reasonable cost and at 98 per cent efficiency; in-duct sorbent injection systems have lower installation costs than scrubbers but remove SO_2 at lower efficiency. When several power plants are involved, the engineering economic analysis, disregarding other factors, can be quite complicated, best carried out using computers with spreadsheets which allow constant adjustment and manipulation of the various inputs.

24. However, environmental compliance usually involves more than economic and technical analysis on a utility system-wide basis. The adoption of a power plant emissions reduction strategy may seriously affect a country's economy. For example, in underdeveloped countries that rely on poor quality indigenous coal resources, switching to better quality (less polluting) coal or other fuels might entail not only the expenditure of scarce foreign currency but also the shutting down of local mines and considerable unemployment.

25. The planning of an emission reduction strategy is, therefore, many-faceted and complex. It should take into account not only a country's fuel resources, power generation and industrial sectors (and their growth projections) but also sectors such as transportation and residential and commercial heating and cooling. Often an overall programme using methods appropriate for each sector can achieve considerable overall emissions reduction, and at lower cost, than isolated sector-by-sector programmes.

26. The importance of specific legislative stipulations to the choice of clean coal technologies to be adopted by a country (and the overall cost of an emissions reduction programme) cannot be overstated. Such stipulations may include how emissions are to be measured, recorded and time-averaged, the age and size of boilers to which the emissions limits apply, how emissions are to be averaged by area etc. For example, allowing emissions to be expressed in monthly or yearly averages can result in considerable savings, since redundant equipment, necessary if the plant has to meet emission limits on the basis of hourly or daily averages, can be eliminated.

27. Since power plant emissions travel freely across national borders, emission reduction programmes (and legislation) should be planned on a regional basis. Otherwise, a country's costly emission reduction programme may benefit its downwind neighbour while its own air quality may be affected by poorly controlled emissions upwind.

28. Some of the current regulations regarding the allowable power plant emissions in the United States and in Germany are as follows: in the United States SO_2 emissions from existing power plants over 100 MW in size are to be reduced to under 2.5 lbs per million BTU of heat input by 1995, and to 1.2 lbs per million BTU of heat input by the year 2000. Low-NO_x burners should be retrofitted into those plants by 1995. New United States power plants should reduce SO_2 emissions by 70-90 per cent, depending on the sulphur content of the coal. In Germany, which has the strictest environmental laws in Europe, SO_2 emissions from power plants 110 MW and larger are to be kept under 0.3 lbs per million BTU of heat input and NO_x emissions under 100 ppm by volume.

B. Technical issues

29. Because physical coal cleaning by itself cannot, in most cases, remove enough sulphur to meet current emissions standards in developed countries, it is receiving little attention. However, it is particularly well suited to the developing countries and Eastern European countries that currently rely on coal for power generation and cannot afford the high cost of scrubbers. Physical coal cleaning is simple and low-cost and uses low-tech equipment that can be manufactured locally. Although it is not as effective as scrubbers, it can reduce emissions enough to permit the continued utilization of indigenous coal resources which the use of other clean coal technologies would have made uneconomical. In addition, when combined with other low-cost clean coal technologies, such as combustion of the reject stream from the coal cleaning plant in a fluidized bed boiler or pre- and post-combustion sorbent injection, physical coal cleaning can reduce SO_2 emissions still further.

30. Energy-sector planners and utility owners and operators in developing countries must often choose between installing new capacity (based on clean coal technology) and the rehabilitation of existing equipment (with possible retrofitting of clean coal process controls). Agenda 21 states that activities to promote sustainable energy development should give "special attention to the rehabilitation and modernization of power systems, with particular attention to developing countries". 1/ From the technical and financial standpoint, particularly in the short term, the promotion of energy-efficient alternatives to capacity expansion (even where the latter is a "clean" technology) through better utilization of existing capabilities is an attractive option for utilities. Not only are the incremental costs of the efficiency improvements less than that of new capacity, but life extension or repowering of an existing power plant can be accomplished in a relatively short time. The optional retrofitting of clean coal process controls would have to be evaluated in light of an environmental impact assessment and available financial resources.

31. Traditional least-cost planning criteria are being supplemented, and in some case superseded, by alternative approaches such as scenario, stochastic optimization, finance valuation and strategic risk trade-off. Although many of these planning tools have the inherent capability of incorporating environmental attributes into the decision-making process, the inability to provide sufficient environmental baseline data may inhibit the full valuation of environmental costs and benefits. In such instances, clean coal technologies developed in response to environmental standards and/or guidelines may not be evaluated in a proper manner.

32. While increasingly sophisticated models have been developed and employed to analyse these tradeoffs, including models that incorporate environmental costs and benefits into the planning process, their use in the power sector of developing countries has been limited. Three of the factors constraining their use are the costs of acquiring sufficient and robust quantitative information; subjective aspects of applying "weights"; and lack of acceptance by policy planners.

33. In the past, quantitative information referred to technical specification of equipment, including capital and anticipated operating costs, technical efficiency, and projected fuel costs. While this information is more readily accessible in developing countries now than in the past, more concern is now being placed on obtaining measurable (and therefore theoretically quantifiable) environmental baseline data. Few countries are equipped to undertake and maintain detailed environmental inventories. Where they are employed, questions have been raised regarding their usefulness in relation to their costs. A unified approach to environmental valuation assessing the usefulness of "screening" criteria and surrogate standards as well as quantification methodologies would be of benefit to energy planners, investors, equipment suppliers and other public agencies.

34. Utilities are reluctant to make investment decisions with significant front-end costs in the face of regulatory uncertainty, including the possibility of carbon taxes resulting from international climate conventions directed at global warming. While no immediate answer can be provided, this points out the need to incorporate uncertainty into forecasting and financial analysis.

35. The utility industry is inherently very conservative, in both developing and industrialized countries, with availability and reliability of the power supply as paramount objectives. As a result, "new" technologies have to establish a proven track record before they will attract the interest of utility operators or investors. To a great extent, this is an issue of perceived risk, and assurance must be given that the new technologies will work everywhere. One solution is for developers or vendors to prove the technology fully in a developed country first, and to lengthen the "migration time" to the recipient countries. For the private sector, it is cheaper and less risky to prove the technology in a more controlled setting first, and thus avoid the failure of expensive "demonstration" programmes.

36. The technical basis for clean coal technology decision-making is inherently complex, and also requires comprehensive training in project financial assessment. However, access by technical and professional staff to such training is often quite difficult in many developing countries. First, there is a perception that energy is not a "prestige" area, plus concern that trained professionals may be more liable to leave their jobs for better pay and more opportunity elsewhere. In addition, senior staff are often not free to undertake extended training programmes. Although innovative new approaches, such as allowing job-switching between the training organization, and the recipient organization are being pursued, and new training tools (e.g., remote live TV and targeted video tapes) are being employed, greater attention should be directed to conveying the benefits of training to the utility or ministry per se.

37. Technology transfer also requires an understanding of the institutional milieu as well as the physical aspects of projects in the developing country. In this sense, technology is not just hardware and software but also the supporting institutional arrangements and incentive structures. Ideally the assessment of clean coal technologies should identify all relevant institutions and research organizations, based on their functional capability and their statutory requirements. This information is also necessary for the implementation of long-term capacity-building through training of technical and managerial staff.

38. The ability to evaluate clean coal technology clearly is rooted in a clear understanding of coal chemistry and coal combustion physics. However, the ability to carry out the requisite basic research in most developing countries is constrained by the absence of funds and infrastructure. As an alternative, more constructive arrangements between developing and developed countries is required, along the lines of the North/South dialogue. Comprehensive programmes could be established to evaluate appropriate coal-based energy technologies; from a technical standpoint, this would be an intergovernmental or regional joint-venture process. One possible structure for such a programme might include the following categories: identification of technologies; evaluation; ranking; selection; research and development; prototype demonstration; commercialization; dissemination.

C. Economic and policy issues

39. An increasingly important consideration for any developing country - particularly for a rapidly industrializing economy - is the assurance of energy security through diversified types of electricity generation, including fossil fuel and renewable energy. Clean coal technologies should be evaluated with this consideration in mind.

40. The increasing need in industrialized countries in recent years to reduce power plant emissions and the corresponding increase in the cost of emission controls for new power plants (more than 30 per cent of the total cost) is shown in the figure below. The cost of retrofitting and operating clean coal technologies in existing plants is even higher, often exceeding the original plant cost. It should be pointed out that this additional, but necessary, investment does not result in additional production which can be sold; it only increases the cost of the electricity generated.

41. In the past, traditional financing structures and regulations placed government at the centre of ownership and control of project development. New financing for clean coal technology initiatives will create new roles for government; in some instances, the role will be limited to the technical and operational project phase. In addition to the inherent loss of control that this implies, new structures have the potential to generate institutional opposition at both the managerial and employee level.

42. A significant managerial and political concern is how to work with employees and unions as new coal technologies are being adopted. Improved efficiency invariably leads to a reduction in the workforce for the facility in question. This is, of course, not a problem exclusive to developing countries; the United States has seen a workforce reduction of 25 per cent in the electrical power sector in the last year, and further reductions are anticipated. However, the associated improvement in worker safety associated with many new technologies, in conjunction with programmes for worker "buy-out", relocation, or even employee purchase of the company, can go far to mitigate opposition. Developers of clean coal technologies ideally should seek to include local partners in joint-venture private sector investment, in order to help identify and focus on the long-term strategic issues.

43. Private power initiatives and independent power producers can provide a financially and environmentally attractive alternative to capacity expansion programmes and provide incentives for state-owned and parastatal utilities to modify existing tariff structures and operating procedures. Even when government-owned or parastatal utilities choose to subsidize specific sectors of the population, marginal cost-pricing should be incorporated into the financial assessment of clean coal technologies.

44. Ultimately, tariff reforms based on marginal cost-pricing which make the sector credit-worthy should be an integral part of a national energy strategy. More than any other single factor, they will encourage the introduction of clean coal technologies, where appropriate. However, potential development partners and equipment suppliers from advanced countries also need to recognize that the

variety of political, economic, and social conditions in individual countries underscore the need for country-specific approaches.

45. In many instances Governments have adopted an aggressive policy of privatization, either in conjunction with or separate from independent producers of electricity. Generally, the independent power producer or the operator of a privatized facility has access to clean coal technologies that are inherently energy-efficient. Since energy efficiency converts to an economic incentive for the owner/operator, all parties can benefit. The off-shore investor community, likewise, is increasingly cognizant of international environmental guidelines in project evaluation; compliance with existing regulations in the country constitutes a basic requirement for satisfying investors.

Notes

1/ Report of the United Nations Conference on Environment and Development, Rio de Janeiro, 3-14 June 1992 (United Nations publication, Sales No. E.93.I.8 and corrigenda), vol. I. Resolutions adopted by the Conference, resolution 1, annex II, sect. II, chap. 9.12 (c).

Table. Clean coal technologies

Pre-combustion cleaning	Clean combustion	Post-combustion cleaning	Conversion	Other
Physical Fine grinding (micronization) Advanced froth flotation Heavy media cyclones Micronization w/limestone Microbubble flotation Advanced drying Chemical Molten caustic leaching Organic solvent Microbial Bioleaching	Combustor/burner types Slagging combustors Limestone injection multistage burners Gas reburning Advanced low-NO_x burners Fuel types Coal-water slurries Coal-gas co-firing Coal-water-gas co-firing Atmospheric fluidized bed combustion Circulating bed Bubbling bed Pressurized fluidized bed combustion Circulating bed Bubbling bed	In-duct injection Sorbent injection Catalytic reduction Post-combustion devices Furnace injection w/water activation reactor Fluid-bed absorption Sorbent injection/high-temperature baghouse Advanced scrubbers/FGD devices Spray dryers Regenerable scrubbers Dual alkali scrubbers Electron beam scrubbers Ion exchange membrane FGD Large module forced oxidation limestone scrubbers Particulate removal Electrode precharger enhancements to precipitators High-temperature baghouses Scrubber additives Oxidation inhibitors Buffers Selective catalytic reduction	Mild gasification Gasification with once-through methanol production Underground coal gasification Coal liquefaction Direct Indirect Coal/oil coprocessing Gasification combined-cycle Gasification with fuel cells	Magnetohydrodynamics Direct coal-fired turbines Fuel cells

Source: "Clean coal technologies for developing countries" (TCD/NRED/E.19).