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Environmentally sound and efficient fossil energy technologies

Report of the Secretary-General**

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** More detailed information is available in the Division for Sustainable Development, Department of Economic and Social Affairs.

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I. Introduction

1. Most global energy needs today are provided by fossil fuels. Current practices of production, distribution and the scale of resource use threaten the assimilative capacity of the environment at local, regional and global scales. Thus, there is a clear need to increase the efficiency of fossil energy use, improve the environmental compatibility of fossil technologies, and shift to fossil fuels with lower environmental impacts, such as natural gas.

2. The world will have a secure supply of fossil fuels for more than 100 years; therefore, if measures are taken to realize the large potential for improving efficiency and to engineer a shift to advanced fossil fuel technologies as well as natural gas, many environmental problems will be mitigated. The present report does not evaluate the possible impact of such approaches on global carbon dioxide emissions: although widespread adoption of the improved technologies discussed would have a positive impact in moderating their growth, more comprehensive energy policies are needed to address that issue.

3. For almost two centuries, global primary energy consumption has grown at an average rate of about two per cent per year, doubling about every three decades: recently, between 1990 and 1996, it increased at an average annual rate of about 1 per cent (Nakićenović et al., 1996; British Petroleum, 1997).[1] Consumption has increased 34-fold since 1860, from about 260 million tons of oil equivalent (Mtoe) to 9 gigatons (or 9 billion tons) of oil equivalent (Gtoe) in 1990, including about 1.1 Gtoe of traditional energy forms, such as biomass, animal dung and wastes.

4. Most of the historical increase in global primary energy consumption has occurred in the developed countries, resulting in large consumption inequalities across the world. Their 25 per cent share of the world's population consumes almost 80 per cent of global energy. It is estimated that about two billion people in the world still do not have access to modern energy services. About 85 per cent of all energy used to date has been consumed by less than 20 per cent of the cumulative global population, mainly in the industrialized countries since 1860.

5. In 1990, 9 Gtoe of primary energy produced 6.4 Gtoe of final energy delivered to consumers, resulting in an estimated 3.3 Gtoe of useful energy after conversion in end-use devices. The delivery of 3.3 Gtoe of useful energy left 5.7 Gtoe of rejected energy (International Institute for Applied Systems Analysis and World Energy Council, 1995; Nakićenović et al., 1996; Gilli et al., 1995). Most rejected energy is released into the environment as low-temperature heat, with the exception of some losses and wastes, such as the incomplete combustion of fuel. The global efficiency of converting primary to final energy is about 71 per cent. In the electricity sector, thermodynamic conversion efficiencies range from 32 to 34 per cent for single-cycle processes, and from 40 to 42 per cent from combined-cycle processes, while the ratio of final to useful efficiency is estimated at 52 per cent. The resulting global energy efficiency of converting primary to useful energy is 37 per cent.

6. Differences in energy efficiencies among regions are the result of many factors: energy mix, endogenous resources, pricing, level of economic development etc. Fossil fuels have relatively low conversion rates from final to end-use applications and relatively high rates from primary to final. The opposite is the case for electricity: it has relatively low primary to final efficiency but very high efficiency in end-use applications. Efficiency is highest in the developing economies (about 80 per cent) and lowest in economies in transition (69 per cent). The regional final to useful energy efficiencies range from 30 per cent in the economies in transition to 53 per cent in the market economies. Thus, even the most efficient technologies may not be sufficient to offset the energy-intensive lifestyles prevailing in very affluent market economies (Nakićenović, 1993).[2]

7. Generally, countries with lower per capita economic activity, measured at market exchange rates, have higher energy intensities (energy use in physical units per unit of gross domestic product (GDP)) than countries with higher per capita economic activity. Countries with very high rates of economic growth usually also exhibit high rates of energy intensity improvement, while economies with low or negative rates of growth have stagnating or increasing energy intensities.[3] Developing countries are also characterized by a relatively high share of traditional energy use in total energy consumption. Considering only commercial energy in such calculations further reduces the apparent energy intensities of developing countries, but that measure may indicate increasing energy intensities for some of them. Even when such adjustments are made, there is a clear tendency towards diminishing energy requirements per unit of economic activity as GDP per capita increases for developing countries as a whole.

8. Assumptions about future efficiencies of energy technologies and their environmental impacts have a central role in energy and economic scenarios and projections. Morita and Lee (1997) have developed a unique database of energy scenarios and projections from all the available literature that includes about 400 different analyses of future energy and economic developments. The higher scenarios of future energy requirements, both in 2050 and 2100, correspond to

an annual growth rate of about two per cent, exactly in line with historical experience (Makarova et al., 1997).[4] Furthermore, many scenarios assume continued growth in demand for fossil energy, although at a lower rate than total energy demand.

II. Fossil energy and the environment

9. Virtually all fuel cycles have negative environmental impacts. Combustion of fossil fuels is the largest source of atmospheric pollution, involving sulfur and nitrogen oxides, unburned hydrocarbons, particulate matter and carbon monoxide, all of which directly affect human health, as well as carbon dioxide. Such pollution arises in all stages of the fossil fuel cycles, starting with resource extraction through end uses, such as in automobiles and heating devices. Adverse impacts include health risks, accidents, pollution and global climate change.[5]

A. Health and accidents

10. Often, the underlying causes of adverse health and environmental impacts of energy derived from fossil fuels are associated with poverty. Indoor air pollution is a source of increased health risks that affects both urban and rural households, mostly in developing countries. The main source is the burning of biomass and coal for cooking and heating, with health risks being particularly high for women and children (World Energy Council, 1995a). The problem can be largely mitigated by improving the efficiency of cooking and heating stoves. That improvement could have the multiple benefits of reducing pollution, energy requirements and deforestation. However, the provision of efficient stoves is costly and sometimes encounters cultural and lifestyle barriers, so that only more fundamental social changes and – most importantly – development itself can really alleviate it significantly (World Energy Council, 1995a). There are also health risks to workers engaged in coal mining.

11. One of the risks of fossil energy, in addition to the health impacts of air pollution, is the occupational and public risk of mortality from all stages of the fuel cycle. Both immediate and delayed occupational risks are estimated to be distinctly higher for coal fuel cycles than for oil or natural gas. Occupational coal risks are substantially lower for surface compared with underground mining. In general, the immediate public risks are mostly associated with transportation accidents and adverse health effects from air pollution. For energy transport, this means that dedicated energy infrastructures, such as pipelines, greatly reduce the public exposure to fossil fuel cycle risks.

B. Local, regional and global environmental impacts

12. Although the solution of urban and rural air pollution as a result of fossil fuel use will require creative and varied actions, there are a number of general and mostly structural future developments that could lead to further air pollution reductions.[6] The basic premise is that with development, the main sources of air pollution would shift from distributed and varied small end-use sources to larger energy conversion technologies. Abatement measures would be cheaper and presumably also easier to implement for larger conversion systems, such as power plants (International Institute for Applied Systems Analysis and World Energy Council, 1995).

13. Historical experience shows that this has in fact occurred. Unfortunately, the resulting impacts have changed from indoor and local air pollution to regional and global environmental problems. Emissions of sulfur and nitrogen oxides, especially from large sources, such as power plants, have regional impacts, such as acidification of soil and water, a regional environmental problem of principal concern. The problem has been compounded by the fact that one abatement strategy often used to counter local air pollution problems has been "tall stack policies" for fossil power plants. And emissions of carbon dioxide have an impact on global climate change.

14. In the past, acidification has generally been regarded as a problem confronting mostly the industrialized countries (World Energy Council, 1995a). However, emissions are increasing to serious levels in many developing countries and with them damage due to acidification, particularly in parts of Asia and South America. If present trends continue, sulfur dioxide emissions for South and East Asia will exceed the combined emissions of North America and Europe in two decades. If nothing is done, widespread problems of acidification in Asia, such as reduced agricultural yields, are considered to be only a matter of time, and in some regions of China serious acid rain problems are already evident (World Energy Council, 1995a). Fortunately, awareness of the adverse environmental and human health problems associated with sulfur and particulate emissions is increasing throughout the world.

15. Effective measures exist for reducing sulfur and nitrogen emissions from power plants. The main issue is financing the capital requirement of such abatement

measures. A shift from coal to natural gas would also reduce the emissions of both sulfur and nitrogen as well as carbon dioxide.

III. Fossil energy supply

16. Today, fossil fuels provide about 75 per cent of all primary energy consumed in the world. The most dominant fuel is crude oil, accounting for 33 per cent of the total, followed by coal and natural gas, accounting for 24 and 18 per cent of the total, respectively. The geological potential of fossil fuel resources is vast but finite. Their availability is, to a large degree, a function of extractive technologies.

17. Ultimately recoverable oil and natural gas deposits are large, and proven reserves are expected to increase in the future in line with growing oil and gas production (Rogner, 1997; Adelman and Lynch, 1997).[7] Coal is known to be even more abundant, so that extraction is more a question of economic, environmental and other considerations rather than availability of appropriate deposits. Conventional oil reserves are limited by comparison. Much of the abundant occurrences of hydrocarbons consist of coal and unconventional oil and gas. Extraction and use of all fossil fuel sources of energy are associated with adverse environmental impacts. Thus, improvements in efficiency and environmental compatibility of fossil energy technologies are important prerequisites for utilization of such fossil fuels. This is especially important for developing countries rich in coal resources.

IV. Energy conversion and distribution

18. For the most part, fossil energy is not used directly but is first converted and transformed into electricity and fuels, such as gasoline, jet fuel, heating oil and natural gas delivered to end-users. More than a third of fossil primary energy is required for conversion and delivery to final users, and most of those requirements are for electricity generation. On average, the current global efficiency of electricity generation is about 30 per cent and of oil refineries about 90 per cent. Other forms of final energy delivered to households, such as coal and natural gas, require relatively little processing compared with electricity and oil products, so that their conversion efficiencies are high by comparison, ranging from about 60 to almost 90 per cent. Therefore, at least from an efficiency point of view, the most important energy conversion processes are oil refineries and electric power plants. Efficiency improvements in those areas would significantly reduce overall energy requirements, emissions and possibly cost as well.

19. Improvement in conversion efficiencies is an important measure for reducing primary energy requirements per unit of energy service, and also for reducing the amounts of fuel required and the environmental impacts at all scales. Technological change, together with prudent maintenance and operating practices, are among the key factors for increasing conversion efficiencies. Crude oil refining, for example, is an energy-intensive process that uses refining by-products as a source of energy as well as purchased energy forms, such as electricity and natural gas. As noted, the average efficiency of oil refining is about 90 per cent in the Organisation for Economic Cooperation and Development (OECD) countries, but refinery efficiency can vary significantly, depending on the type of crude oil being processed and the design of the refinery: efficiency can be as low as 80 to 85 per cent in some developing countries. Refining efficiencies have improved considerably, however, during recent decades: at a rate of about one per cent per year in North America and about 1.5 per cent per year in the developing countries. The potential for improvement is considerable; improvement potentials for efficiency are estimated at 20 per cent by 2010 and more than 30 per cent by 2020 (World Energy Council, 1995b). However, one obstacle is the high capital costs of highly efficient technologies for complex refineries. According to a recent World Energy Council (1995b) report, advanced refinery capacity costs are in the region of about $70,000 to $90,000 per ton. In an industry where payback periods for new investments are about five years, efficiency investments may not always be competitive with other alternatives.

20. Historically, the efficiency of converting fossil fuels to electricity has increased dramatically. Today, fossil fuel power plants generate power from steam and gas turbines, or a combination of the two in a combined cycle, and can achieve net efficiencies of almost 40 per cent, while the best available natural gas combined-cycle turbine power plants achieve more than 50 per cent efficiency. Efficiency gains have been achieved though technological improvements of conversion efficiencies, fuel switching from coal to natural gas, and change from steam engines to turbines and combined-cycle schemes. Another source of efficiency gains has been economies of scale. Conversion efficiency has increased by a factor of 10 in about 90 years, corresponding to an improvement rate of about 2.5 per cent per year.

21. Current technological measures to improve efficiency include the introduction of combined-cycle, gas-fired plants and coal-fired plants with supercritical steam cycles. At the same time, environmental considerations often require the addition of flue-gas clean-up systems for pollutants, such as

sulfur and nitrogen oxides, and in future perhaps also carbon scrubbers. Recent innovative plant design and integration have succeeded in both improving efficiency and reducing emission (over and above those directly linked to the efficiency factor). For example, integrated gasification combined-cycle (IGCC), pressurized fluidized bed (PFB) combustion technologies and fuel cells all reduce most of the emissions significantly, which eliminates or reduces the need for environmental add-ons.

A. Cleaner fossil fuel conversion technologies

1. Natural gas and combined-cycle

22. Today, the most economically and environmentally sound fossil power plants are natural gas combined-cycle plants. The most efficient units now on the market achieve conversions of 95 per cent and 52 per cent net efficiency. Further efficiency improvements by a few percentage points are expected in the next few years. Combined-cycle technology represents a hedge against the uncertainty of future environmental policy priorities, and it also represents a least-regret cost-effective investment strategy. That is, the economics of combined-cycle technology are affected by three factors: (a) the availability of low-cost natural gas or fuel oil, (b) environmental policies mandating lower emissions, and (c) relatively low capital costs.

2. Cleaner and more efficient coal technologies

23. Another way of achieving high conversion efficiencies and low emissions is the use of coal in conjunction with combined-cycle technology. In essence, most clean coal technologies involve the marriage of gas turbines and coal or coal-based fuels (Bajura and Webb, 1991). Clean coal technologies fall into several categories: clean combustion processes, such as PFB technologies; coal gasification and combustion of the synthesis gas in a combined-cycle gas turbine; direct and indirect coal-fired turbines; fuel and pure oxygen gas turbines; magneto-hydrodynamic (MHD) generators; carboniferous fuel cells; and the separation of hydrogen from coal (hydrocarb process). PFB technologies and such integrated systems as IGCC technologies are either already operational or rapidly approaching the stage of commercial availability. Direct coal-fired systems are in the prototype development stage. The same is true of fuel cells, while MHD generator development and hydrocarb process are in the proof-of-concept stage.

B. Comparison of cleaner fossil fuel technologies

24. The table summarizes the salient characteristics of the clean fossil technologies that are likely to contribute to the improvement of energy conversion efficiencies during the next decades and to a reduction of environmental impacts at all scales, as well as representative estimates for economic and technical characteristics of those technologies. Unfortunately, there are few really comparable data sources in the literature.

25. Clearly, the characteristics of the combined-cycle natural gas power plants and the conventional coal power plants could vary from location to location due to many different factors, and the numbers shown are indicative of the costs and performance of such facilities. The situation is quite different for technologies still under development. The likely characteristics of such facilities are not known with any degree of certainty, and their cost data are particularly speculative. They are given so as to show orders of magnitude but may clearly change radically until such power plants can be purchased commercially.

26. The table provides estimated capital, fixed and variable costs of clean fossil technologies, many of which are still at a developmental stage indicating an electricity generation cost range of about three to more than six cents per kilowatt-hour. The lowest costs are for electricity generated by natural gas combined-cycle power plants. The electricity generating costs are given with and without fuel costs. Fuel costs are based on an acquisition price of $50 per ton of coal ($54 per kilowatt-year) and $2.5 per million British Thermal Units ($75 per kilowatt-year) of natural gas (including transportation costs), again indicating the inherent uncertainty associated with such estimates. Indeed, some of the large differences in capital costs of the clean fossil technologies are balanced by differences in fuel costs (International Atomic Energy Agency, 1991). Technologies with high capital costs tend to have lower fuel costs. The lower capital costs of combined-cycle technology give more financing flexibility for utilities that have to raise capital that competes with other investment opportunities. This also demonstrates some of the economic advantages of combined-cycle technology in current market conditions.

27. The thermal efficiency of advanced fossil power plants exceeds 40 per cent, and goes beyond the 55 per cent mark

Characteristics of cleaner fossil electricity generating technologies

(Estimated costs in 1990 United States dollars)

System	*Units*[a]	*Conventional coal*	*PFBC coal*	*IGCC coal*	*DCFT coal*	*ICFT coal*	*Combined-cycle natural gas*
Power	MW	400	400	1 250	200	200	400
Capital cost	$/kW	1 300	1 750	1 350	2 100	1 430	650
Fixed O&M cost	$/kW/yr	36.4	56	37.8	71.4	30	16.3
Variable O&M cost	$\$/kWyr_e$	42.9	26.3	27.2	30.7	25.4	5.9
Efficiency	%	38.8	45	44.3	43.2	51.7	52.6
Fuel use	BTU/kWh_e	8 800	7 600	7 700	7 900	6 600	6 490
Fuel cost	$/GJ	2.05	2.05	2.05	2.05	2.05	2.4
Life time	years	35	30	35	30	35	35
Load factor	%/yr	80	80	80	70	75	80
Cost (excl. fuel)	$/	0.0229	0.0291	0.0218	0.04	0.0196	0.0094
Total electricity generating cost	$\$/kWh_e$	0.0468	0.0486	0.0415	0.0608	0.0368	0.0265
Carbon emissions	kgC/kWh_e	0.232	0.2	0.203	0.208	0.174	0.109

System	*Units*[a]	*MHD coal*	*MCFC coal*	*MCFC natural gas*	*SOFC coal*	*SOFC natural gas*
Power	MW	150	650	200	165	165
Capital cost	$/kW	2 600	1 650	1 150	1 240	860
Fixed O&M cost	$/kW/yr	78	16.5	15	12.4	11.2
Variable O&M cost	$\$/kWyr_e$	87.6	92	87.6	78.8	74.5
Efficiency	%	55	50.5	52.9	49.7	54.2
Fuel use	BTU/kWh_e	6 200	6 750	6 450	6 860	6 300
Fuel cost	$/GJ	2.05	2.05	2.4	2.05	2.4
Life time	years	30	30	30	30	30
Load factor	%/yr	70	75	75	75	75
Technology cost (excl. fuel)	$\$/kWh_e$ ac	0.0535	0.0313	0.025	0.0246	0.0197
Total ac electricity generating cost	$\$/kWh_e$	0.0769	0.0564	0.0153	0.0484	0.0442
Carbon emissions	kgC/kWh_e	0.163	0.178	0.108	0.181	0.106

Note: DCFT = direct coal-fueled turbines; ICFT = indirect coal-fired turbines; IGCC = integrated gasification combined-cycle; PFBC = pressurised fluid bed combustion; MCFC = molten carbonate fuel cells; MHD = magneto-hydrodynamic; SOFC = solid oxide fuel cells; O&M = operating and maintenance

[a] MW = megawatt; kWh = kilowatt hour; BTU = British thermal unit; GH = gigajoule; kgC = kilograms of carbon; $_e$ = effective.

for fuel cells (future fuel cells may reach efficiencies above 60 per cent (International Atomic Energy Agency, 1991), which would effectively double the current average efficiency of electricity generation). The current average efficiency of coal power plants in OECD countries is almost 39 per cent, approaching the performance of modern conventional coal power plants. In contrast, the global average efficiency of coal power plants is about 33 per cent or almost 20 per cent lower than the conventional reference plant. As modern power plants increase their market share, the potential for improvement in average efficiencies is large.

28. Some of the designs of advanced coal power plants are approaching commercial maturity. Compared to the current average global efficiency of coal power plants, such advanced designs imply an efficiency improvement potential of almost 40 per cent, and would also emit drastically less particulate matter, sulfur and nitrogen oxides, and almost 40 per cent lower carbon dioxide emissions. Efficiency improvements are a very effective method of decreasing the environmental impacts of energy use at all scales, including emissions of sulphur dioxide, nitrogen oxides and carbon dioxide, without necessarily increasing the cost of electricity.

29. This comparative assessment of advanced fossil electricity generation technologies indicates that the most cost-effective choice today across a range of different local and regional conditions is combined-cycle natural gas power plants. That situation will not change for some time. Most of the other advanced technologies are expected to have higher capital costs, but in some cases these may be a decreasing function of scale. However, natural gas is the preferred energy source, in conjunction with combined-cycle technology, where natural gas is available. On a large scale, i.e., greater than 500 megawatts, a combined system of IGCC and MHD technologies may emerge as a viable option. Furthermore, natural gas has the lowest environmental impacts of all fossil energy sources: its sulfur dioxide emissions are minimal, its nitrogen oxide emissions can be controlled and its carbon dioxide emissions are the lowest of all the fossil fuels. The main problem is the leakage of methane, a potent greenhouse gas. Fortunately, pipeline leaks are kept low if for no other reason than safety, and other sources of methane can be controlled effectively. Clearly, the availability of natural gas is an issue in many parts of the world, either because domestically it is not an abundant or developed source of energy, or there are no acceptable import possibilities, or the appropriate infrastructure for transport and distribution does not exist.

V. Energy distribution and end use

30. The structure of energy end use is of crucial importance for the overall efficiency of fossil energy from source to service. The purpose of conversion of primary energy to final energy forms is indeed to facilitate higher efficiencies and greater convenience and reduce the environmental impacts of energy end use. In fact, the efficiency of final energy use can be more important for the overall efficiency of the full fuel cycle than the upstream efficiencies themselves. Obviously, end-use technologies, such as motor vehicles, are intimately linked to particular fuels. More often than not, such technologies limit the flexibility for switching between different sources of primary energy and fossil fuels. The question is, therefore, which combination of end-use technologies and associated fossil fuel cycles could provide the full range of required energy services in the future with the highest overall efficiencies, economically and with low environmental impacts. Based on an assessment of efficiencies, total cost and carbon dioxide emissions for a number of end-use applications and their fossil fuel cycles, it is evident that electricity is the final energy of choice for combining different fossil fuels with different (stationary) end-use technologies.[8]

31. Since fuel cycles are driven by the demand for energy services, attention must be given to improving the performance of end-use devices. Thus, demand-side management and other measures to improve the efficiency and reduce costs of energy end use are at least as important as upstream improvements. The existence of large opportunities for demand-side management and improved end-use efficiencies raises the question why they have remained substantially unexploited. Evidently, barriers exist, especially in developing countries, involving a variety of market allocation failures, pricing policies, institutional impediments, consumer awareness, incentive structures, access to credit and infrastructural constraints. Current approaches do not adequately address those issues.

VI. Technological and socio-economic policies

A. Technological change and learning

32. High rates of innovation in the energy sector are a prerequisite to meeting the ambitious requirements for increasing the quantity and quality of energy services and at the same time significantly lowering the costs and adverse impacts of many technology options. However, over the last decade, public-sector support for energy research, development and demonstration has declined by one third in the OECD countries and by half a percentage of GDP (Watson et al., 1996). Fortunately, energy technologies require relatively modest investments in research, development and demonstration. Some advanced fossil technologies are of small scale and modularity, which promise high rates of learning with relatively modest investments.

33. Research, development and demonstration programmes are necessary but not sufficient to establish new technologies in the market place. Commercial demonstration projects and programmes located in realistic economic and organizational contexts to stimulate markets for new technologies are also needed. Both research, development and demonstration efforts and commercial demonstration and deployment, especially in niche markets, require coordinated initiatives from both private and public sectors, and a range of market and regulatory measures and policies.

B. Other fossil energy policies and measures

34. The diffusion of advanced, clean and efficient, fossil energy technologies over and above the technology performance improvements that accompany the natural replacement of depreciated capital stock in the energy system is unlikely to occur without appropriate policy instruments and measures.

35. Capital scarcity, especially in the developing world and some countries undergoing economic transition, is a major barrier to the adoption of advanced energy technologies. In addition, energy supply technologies compete with other development needs for limited capital. However, many energy options could involve endogenous technology production, creating new local infrastructure and employment. Even in the industrialized countries, the capital used for financing energy supply technologies may yield lower returns than other investment opportunities. Measures that make supply and conversion technologies more attractive in the market place would help to resolve some of the financing difficulties by reducing risk, uncertainty, and upfront capital requirements. Other helpful measures include accelerated depreciation, start-up loans and concessional grants.

36. The removal of institutional barriers is also often a crucial step for attracting private-sector interest in advanced technologies. Regulatory reform and deregulation (breaking-up of producer monopolies, transmission and distribution networks) have allowed small and independent power producers access to the grid and improved their competitiveness. Standardization of equipment to facilitate connection to the grid would also improve technology adoption.

VII. Future improvement of fossil energy technologies

A. Improvement potential of fossil technologies

37. Numerous studies indicate that 10 to 30 per cent energy efficiency improvements above present levels are feasible at little or no net costs in many parts of the world through technical change and improved management practices over the next two to three decades (Watson et al., 1996a). An instantaneous replacement of the current energy system by the best available technologies would result in an overall efficiency increase of about 60 per cent, even without taking into account the most advanced technologies that are not yet available commercially. The realization of that potential would take about 70 years at the historical improvement rate of one per cent per year. However, within a period of 50 to 100 years, the entire energy supply system will be replaced at least twice. Thus, it is technically possible to realize substantial performance improvements in step with the normal timing of investments to replace infrastructure and equipment as it wears out or becomes obsolete. Higher improvement rates are certainly possible if appropriate policies are in place to accelerate technological transformation of fossil fuel systems.

B. Environmental performance of fossil technologies

38. Emission reduction potentials are roughly proportional to efficiency improvements. The reduction potential is larger, however, when emissions controls are considered. For improved technologies that use the same fossil fuel, the efficiency gains translate to lower fuel costs, which can often offset the somewhat higher capital needs. Those technology improvements can result in significant secondary benefits, such as reductions of other pollutants (e.g., sulfur dioxide, nitrogen oxides and particulates). For example, emissions declined by some 24 per cent between 1990 and 1994 in western Europe and the economies in transition as a result of continued sulfur reduction policies or economic recession and declines in coal use, respectively (Grübler, 1997). Conversely, emissions have increased in Asia significantly over the same time period, e.g., by about 22 per cent in China (Grübler, 1997).

39. Scenarios of future sulfur dioxide emissions foresee a fivefold increase in emissions in the highest case, while the lowest lead to reductions of a third of current levels. Taken together, the range of future sulfur emissions indicates a strong desulfurization of energy during the next century,

partly due to shifts in the structure of the energy system away from sulfur-rich coals and partly due to overall energy efficiency improvements. Global carbon dioxide emissions projections can also be derived from the range of scenarios documented in the database developed by Morita and Lee (1997). They range from more than a tenfold increase to complete elimination of emissions altogether, which translates into an emissions range of more than 40 GtC by the year 2100 to no emissions at all, with a median of about 15 GtC. Both sulfur and carbon emissions are expected to decrease relative to economic and energy activities.

VIII. Suggestions for further action

40. Appropriate policies should be designed to support research, development and demonstration, and should be complemented by other measures for promoting efficient and clean energy that take into account the widely differing institutional, social, economic, technical and natural resource endowments in individual countries and regions. Such policies should include market instruments, such as subsidies, energy and emissions taxes, and regulatory measures, such as emission or fuel quality standards and codes, as well as voluntary agreements with industry.

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Notes

[1] In the 1990s, economic transition in the Republics of the former USSR and the East European countries

resulted in significant declines in their energy consumption.

[2] Natural gas and electricity have the highest end-use efficiencies compared with the low primary to final conversion rates; the lowest end-use efficiencies can be observed for biomass, with 17 per cent at the global level and only 12 per cent in the economies in transition and the developing countries.

[3] Energy intensities are different if GDP is estimated at market exchange rates rather than on the basis of purchasing power parities. Energy intensities of developing countries are substantially lower when economic activities are measured with purchasing power parities, which increases the value of economic activities since those countries have comparatively low price levels, thus reducing the magnitude of measured energy intensities.

[4] In absolute terms, primary energy requirements are expected to range from a low of 7 Gtoe in the year 2100 (a decline compared to 1990 levels of 9 Gtoe) to almost 80 Gtoe in the year 2100. Most scenarios envisage consumption levels of between 14 and 32 Gtoe, or about 1.5 to 3.5 times 1990 consumption levels.

[5] Fossil energy fuel cycles are the major source of air pollution in general. Both health and environment energy-related impacts can be identified with two main categories of underlying causes (World Energy Council, 1995a; International Institute for Applied Systems Analysis and World Energy Council, 1995). The first might be called "pollution from poverty"; it includes many categories of health risks, such as the high levels of indoor pollution, deforestation and high ambient concentrations of particulate matter in urban areas. The second category might be called "modern pollution"; its source is dense motorized traffic and electricity generation from low-grade coal, resulting in the high urban concentrations of air pollution.

[6] First, it is essential to improve the conversion efficiencies of end-use devices, which would both conserve the limited availability of traditional sources of energy, such as fuelwood, and at the same time reduce air pollution. Second, and equally important, are the structural shifts away from traditional energy end-use patterns and energy forms towards more efficient modern conversion technologies and cleaner energy forms. Third, there needs to be a long-term shift towards energy services provided through clean, grid-dependent fuels.

[7] Currently identified global fossil energy reserves are estimated at more than 1,000 Gtoe. That quantity is theoretically large enough to last more than 130 years at the current level of global energy consumption (9 Gtoe in 1990), or five times larger than total global fossil energy consumption since 1860 (Nakićenović et al., 1996). Coal accounts for more than half of all fossil reserves. Current estimates of fossil resources and additional occurrences are much larger but more uncertain than reserves. The global resources base is almost 4,000 Gtoe, with additional occurrences of more than 20,000 Gtoe, mostly in the form of gas hydrates. Thus, fossil energy is abundantly available in the world and known deposits are likely to last more than a century, and with technological and scientific progress in fossil energy extraction, many centuries again beyond that.

[8] Examples of the efficiencies, total costs and carbon dioxide emissions for a number of representative end-use devices and their alternative fossil fuel cycles are assessed in the full report; examples include space and water heating, cogeneration, electric drives and refrigeration, lighting, automobiles, passenger aircraft and railways.