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NUCLEAR POWER AND THE ENVIRONMENT

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FOREWORD

At the September 30, 1999, International Nuclear Societies Council (INSC) meeting held in Vienna, Austria, development of a New Issue on Nuclear Power and the Environment was approved and guidelines for the creation of a specific task group were set.

At the beginning of their development, the use of railroads, the tramway, the underground, the automobile, the first airplanes all raised not only skepticism but also fears or even hostility on the part of the general public, the media, and some officials. Contrary to the development of other technologies, in the beginning there was even support and enthusiasm about the possibilities of the wide uses of nuclear energy. However, the voices against the use of nuclear power increased with time. Now the future of nuclear power is dependent on reversing this situation.

The present INSC report addresses the role of nuclear power in the global energy sector in a broader context, that of sustainable social and economic development and the environmental impacts arising from the use of different sources of energy.

The main objective of this report is to provide clear and complete information and to demonstrate that nuclear power is a mature technology that has environmental advantages.

INSC hopes this report will assist the energy community, energy policy and decision makers, environmentalists, and the wider public to understand and accept the benefits of nuclear power as a fundamental energy source toward sustainable development and a better standard of life. The fact that nuclear power is environmentally benign makes it an energy source consistent with the goals of sustainable development and environmental protection that should be taken into consideration in discussing the future energy mix in different countries.

Chang Kun Lee
Chairman, International Nuclear Societies Council

1. INTRODUCTION

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Despite the impressive development of nuclear power over the last four decades, its environmental advantages as compared to practical alternatives for electricity production, and its economic competitiveness in many countries, the general public and the media still question its desirability and the need for it.

The fact that all energy systems of any kind have an impact on the environment is usually unknown or not discussed.

Nuclear power is the only technology used for electricity generation that, from the very beginning of its development, took the environmental impacts into consideration. It is one of the human activities in which research on safety was developed together with its technology. Nuclear power plants are licensed from a safety point of view by independent governmental organizations and are also subject to regional and local site approval procedures. Participation of public and nongovernmental organizations in both licensing and environmental procedures is allowed and encouraged in many countries. Its impacts on the environment are almost nonexistent if well managed: It occupies only small surfaces of land and consumes small amounts of fuel; its waste is small, confined, and isolated from the environment.[1,2]

Despite the Chernobyl accident, there is no industry in the world that can present the same excellent record of safety performance as the nuclear industry.

All these safety (and environmental) features are incorporated in the final costs of nuclear power, including, in many countries, provisions for waste management and for future plant decommissioning. That is, all safety and environmental costs are internalized, which is certainly not the case with conventional thermal power plants. Even so, nuclear power remains competitive in many countries under this unequal condition of comparison.[3]

With a share of 24% in total electricity production, nuclear power was the second most used source for electricity production in the Organization for Economic Cooperation and Development region, in 2000, second only to coal (37%). Worldwide nuclear power is the third most used source of energy for electricity production, after coal and hydropower. Nuclear power supplied 2448 TWh of electricity in 2000, or about 16% of total electricity generation worldwide. If this amount had to be replaced by modern coal-fired power plants having abatement equipment complying with stringent regulations, it would mean the emission of some additional 4 million tons of SO_2, 1.8 million tons of NO_x, and 0.6 million tons of particulates in 2000 alone. In 2000, nuclear power avoided the emission of some 2.5 billion tons of CO_2, the major greenhouse gas, or some 10% of the total emission of CO_2 by fuel combustion in the world (Table 1). Apart from the obvious saving in pollutant emissions by conventional thermal power plants, nuclear power worldwide saved some 1 billion tons of coal in 2000. Based on the average safety record of the coal mining industry, this would represent the sparing of about 600 miners' lives.

Table 1
CO_2 Emissions Worldwide

Emissions by the combustion of fossil fuels: 25 billion tons of CO_2 annually
World electricity production by nuclear power: 2248 TWh (net) 2000 16% of the total electricity generation 6% of total primary energy production
Amount of avoided CO_2 emissions due to the use of nuclear power in 2000: 2.5 billion tons of CO_2 (10% of total CO_2 emissions)
Recommendation from the Toronto conference (1988): Cut total annual emissions by 20% (4 billion tons of CO_2 up to 2005
Power sector: CO_2 emissions: 8.5 billion tons of CO_2 (34% of total emissions) Avoided emissions due to the use of nuclear power: 29% of total emissions of the power sector

Coal, the major fuel used for electricity production today, is responsible for some 40% of total world electricity generation. It discharges combustion gases, a major source of atmospheric pollution. Large amounts of ash and other waste products arise from the combustion. Fly ash, sulfur and nitrogen oxides, toxic metals, organic cancerous and mutational agents, and natural radioactive substances are released to the atmosphere during combustion and may cause severe environmental and health damage even at great distances from the point of discharge (Table 2). The ash from burning coal contains toxic elements such as arsenic, mercury, and lead and radioactive nuclides, including radium-226. If radioactive emissions of coal power plants were to be strictly controlled as in nuclear power plants, many coal-fired plants would not be given license to operate.

Table 2
Toxic Constituents in Coal and Annual Emissions from a Coal-Fired Power Plant

Constituent	Contents in Coal (g/t)	Emissions (t/yr)
Arsenic	30	99
Cadmium	1	3
Copper	12	40
Lead	12	40
Mercury	0.1	0.5
Radium	2.7×10^{-7}	-
Thorium	1.7	6
Uranium	0.78	3
Zinc	86	284
Totals	144	475

Despite the above considerations, the general public perception is that nuclear power is an environmental burden. On the contrary, nuclear power is environmentally one of the most benign sources of energy for electricity production that can make a positive contribution to the quality of life and decrease the present rate of degradation of the environment.[4]

2. MAIN ISSUES

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The main issues that will be emphasized in this report are the following:

- By the first decades of the new century, all forms of primary energy for electricity production will be needed if sustainable development is to be achieved. In this context, we have the moral obligation to utilize those energy resources that lead to the lowest possible environmental impacts.
- Nuclear energy is a form of energy that does not emit any greenhouse gas (carbon dioxide, methane, nitrous oxide, and others) or any gas causing acid rain or photochemical air pollution (sulfur dioxide, nitrogen oxides). It does not emit any carcinogenic, teratogenic, or mutagenic metals (As, Hg, Pb, Cd, etc.). The utilization of nuclear energy also does not release

gases or particles that cause urban smog or depletion of the ozone layer.[5]

- Nuclear power is the only energy technology that treats, manages, and contains its wastes in a way that is complete and segregated from the public and the environment.
- Nuclear power does not require large areas for resettling large populations because it is a highly concentrated form of energy. Hence, its environmental impact on land, forests, and waters is minimal.
- In the span of a single generation, the Earth's life-sustaining environment has changed more rapidly than it has over any comparable period of history. Much of this change is due to anthropogenic emissions. Much of the current concern about the global environment is related to the increased concentration of greenhouse gases and possible effects on the global climate.[6]
- In the entire world, increasing efforts are being devoted to the task of developing greenhouse-responsive global energy systems. Any greenhouse-responsive energy strategy requires curtailing the use of fossil fuels. Fossil fuels currently provide more than 85% of global primary energy supply. To replace fossil fuels, nuclear power has to be a part of the solution because it is one of the few available nonemitting greenhouse gas alternatives capable of producing the large amounts of electricity required for sustainable global development. Today, by generating 16% of global electricity production, nuclear power avoids some 10% of additional CO_2 emissions, considering all economic sectors, and about one-third in the power sector.
- Nuclear power alone cannot solve the environmental load created by the emissions of greenhouse gases. But, without the use of nuclear power, no other solution for this crucial problem exists within a reasonable time span and the state of the art of energy generation technologies.[7]

3. THE NEED FOR NUCLEAR POWER

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Based on projections carried out by the World Energy Council (WEC), International Institute for Applied Systems Analysis, and other international organizations, Table 3 indicates possible trends of major economic and energy parameters. For comparison, the year 1960 is taken as reference.

Table 3
Trends of Major Economic and Energy Parameters

Year	1960	1980	2000	2020	2050
Population	3 billion x 1.0 (*reference*)	4.5 billion x 1.5	6 billion x 2.0	7.5 billion x 2.5	8 to 10 billion x 2.7 to 3.0
Total primary energy demand	100% (~3 Gtoe)[a]	210% (~6 Gtoe)	320% (~10 Gtoe)	450% (~14 Gtoe)	600% (~18 Gtoe)

Table 3 (cont'd.)
Trends of Major Economic and Energy Parameters

Year	1960	1980	2000	2020	2050
Electricity only (TWh)[b]	100% (~2 000)	400% (~8 000)	700% (15 000)	1000% (20 000)	2000% (42 000)

[a] 1 Gtoe = one gigatoe: the equivalent of one billion (10^9) tonnes of oil. (To transform Gtoe to exajoules (EJ), another common energy balance unit, the following relation can be used: 1 EJ = 23.9 Mtoe = 23.9 10^{-3} Gtoe.)
[b] 1 TWh = one terawatt-hour = one billion kilowatt-hours.

Global primary energy needs will grow by a factor of 1.8 between 2000 and 2050. Total electricity supply, some 42 000 TWh or about 9 Gtoe, will correspond to 50% of the total primary energy needs. According to these estimates, the demand for electricity will probably triple from now to 2050 for the following reasons:

1. general increase in the world's population
2. increase in the fraction of the population living in cities (there are already 10 cities with more than 20 million inhabitants)
3. improvement of general well-being (today some 2 billion people have no access to a commercial supply of energy)
4. ease of use, reliability, comfort, and cleanliness of electrical energy compared to other sources of energy
5. explosive increase in the demand for energy in the heavily populated developing countries.[a]

From these figures, it is clear that energy demand, especially the demand for electricity, will increase substantially in developing countries and that all sources of

[a] The consumption per capita in China or India is now one-tenth of that in America and one-fifth of that in France. Today, less than 25% of the world's population consumes more than 75% of the world's energy supply.

energy will be called upon to meet that demand: fossil fuels, hydropower, and nuclear power and renewable sources of energy such as biomass, wind, solar, etc.

In 2000, oil, coal, and gas together supplied 87% of the energy consumed in the world; hydropower and other renewables, 7%; and nuclear power, 6%. Although new gas fields are being discovered and the efficiency of extracting oil is increasing continuously, it is expected that these resources will begin to run out by 2050. Hence, other sources of energy, including renewable energy (hydropower, solar, wind, and biomass) and especially nuclear energy, will have to play a major role.[8]

A probable evolution of the total energy supply during the next 50 years estimated by experts of the oil industry is given in Table 4. It shows the important share nuclear power will have in the next 50 years.[9]

Table 4
Evolution of Total Energy Supply

Year	2000		2020		2050	
Source	Gtoe	%	Gtoe	%	Gtoe	%
Oil	3.7	40	5.0	36	3.5	20
Gas	2.1	22	4.0	29	4.5	25
Coal	2.2	24	3.0	21	4.5	25
Total fossil	8.0	86	12.0	86	12.5	70
Renewables[a]	0.7	7.5	1.0	7	1.5	8
Nuclear	0.6	6.5	1.0	7	4.0	22
Total	9.3	100	14.0	100	18.0	100

[a] Including hydropower.

This energy mix means that by 2050, some 2550 GW of nuclear power capacity would be needed to be in operation to produce about 17 500 TWh of electricity, about the same amount that is produced today by all sources of energy (coal, hydro, nuclear, gas, and renewables). To cope with these requirements by the year 2050, the total nuclear capacity in the world would have to be multiplied by 7 as compared to that in 2000. These results are consistent with previous investigations.[10-12]

The need for nuclear power could be even higher if nuclear energy were used to generate more than just electricity (i.e., chemical fuels, heat district, heat process, desalination, etc.).

4. ENVIRONMENTAL ADVANTAGES OF NUCLEAR POWER

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4.1 Emission Gases

Nuclear power does not produce CO_2 or other greenhouse gases, nor does it produce any SO_2, $NO_{X,}$ or other gases that contribute to acid rain. These characteristics of nuclear power are especially important in comparison to the coal-fired generation of electricity, which contributes with 40% of all electricity, generation in the world. As an example (Fig. 1), in comparison with a modern coal-fired power plant of the same size and with advanced abatement techniques, a 1300-MWe nuclear power plant avoids annual emissions to the air of about 2300 t of particulates; 10 million tons of CO_2, 14 000 t SO_2, and 7000 t NO_x, the precise quantities being dependent on coal quality, power plant design, thermal efficiency, effectiveness of the abatement systems, and operational performance of the plants.

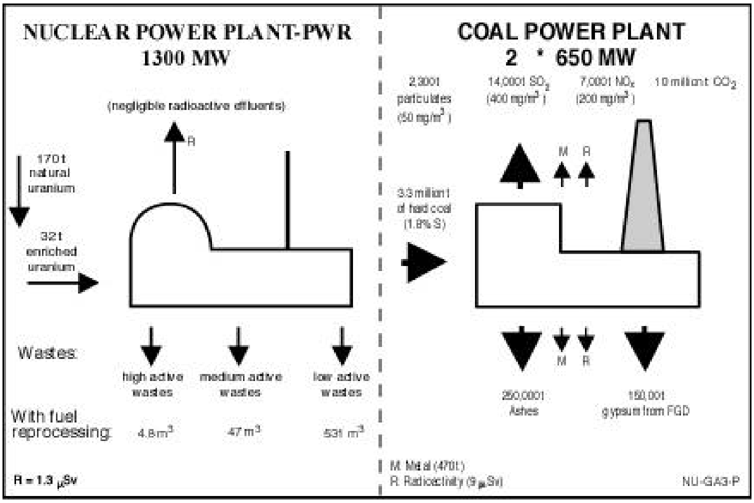


Fig. 1. Annual fuel and waste disposal requirements of a 1300-MW plant (annual production: 10 000 GWh).

A nuclear power plant can avoid the emission of some 10 million tons CO_2 per year. Today, 16% of the world electricity is generated using nuclear power. If this electricity were to have been generated using coal, it would have resulted in about 2.5 billion tons CO_2 annually. As a result, nuclear power is already avoiding 10% of present CO_2 emissions by all sources and 30% by the power sector (Table 1).

It has been argued that, from the environmental point of view, nuclear power should not be compared with coal power plants, but with natural gas, considered to be a cleaner source of electricity production and the fuel of the future. Not considering the issues of gas availability and the assumption that the price of gas will stay low for many years, some aspects need to be discussed when stating that gas is a "clean" technology. Considering power generation, Fig. 2 compares a nuclear power plant with a gas combined-cycle power plant.

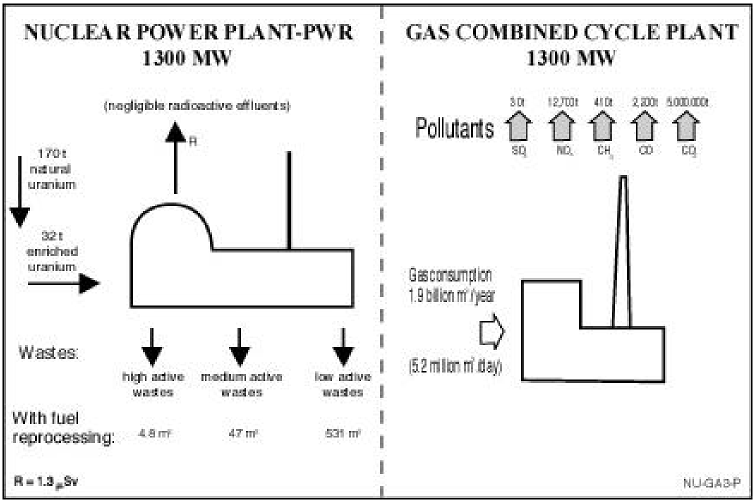


Fig. 2. Annual fuel and waste disposal requirements of a 1300-MW plant.

The combustion of gas emits several air pollutants, such as SO_2, NO_x, CH_4, CO, and CO_2. In particular, the emissions of nitrogen oxides, one of those responsible for acid deposition, and CO_2, the main greenhouse gas, are substantial (Fig. 2). Considering the full energy chain, there are emissions of methane (CH_4) during the extraction and transportation of gas. As methane is a much stronger greenhouse gas than CO_2, transforming the amount of methane in CO_2 equivalent, the emissions of greenhouse gases from the use of gas in electricity production might be of the same order as those of the coal cycle. From these considerations, it can be said that the use of gas cannot be reported as “the” solution of the climate change problem.

Appendix A shows the effects of the use of nuclear power in the last quarter of the 20th century on reducing fossil fuel gas emissions.[13] The operation of more than 430 nuclear power plants in the world contributed to avoid the consumption of large amounts of coal, natural gas, and fuel oil.

4.2 WASTE DISPOSAL

Part of the waste resulting from the burning of coal, namely, toxic heavy metals such as arsenic, cadmium, lead, and mercury, remains dangerously forever in the environment, contrary to the wastes of nuclear power generation, whose radioactivity decays with time. Table 2 gives an idea of the concentrations of toxic constituents in coal and of quantities resulting annually from the operation of a coal power station similar to the one described in Fig. 1.[14,15] (It must be emphasized that there are large differences between coals of different origins, and the data here refer to a "clean" coal.)

The quantity of toxic metals emerging as waste by the combustion of coal is more than 10 times larger than the quantity of spent nuclear fuel, and over 30 times more than the separated high-level waste products if the fuel is reprocessed, resulting from the generation of the same amount of electricity by a nuclear power plant. It must be emphasized that the relatively much smaller amount of nuclear waste is fully isolated from the environment. From coal generation, depending on the stack filtration system, 1 to 10% of the above amounts could be dispersed to the atmosphere together with CO_2, sulfur, and nitrogen oxides. A great part stays in the ashes, Usually, ashes are flushed with water to ash ponds, where elements may be leached and enter the aquatic environment. If the same standards as applied to nuclear power plants were applied to coal power plants, the dangerous wastes from coal generation would need to be removed and isolated. Coal power plants also emit naturally occurring radioactive nuclides to the atmosphere, because most coals contain uranium, thorium, and radium. As a consequence, sludge from coal power plants contains radioactive materials, not controlled as in nuclear power plants. A nuclear power plant normally delivers a smaller radiation dose per unit of energy produced than a coal-fired plant and only slightly more than certain renewable energy technologies.

Owing to the fact that nuclear is a highly concentrated form of energy, 1 t of nuclear fuel in a light water reactor (LWR) nuclear power plant produces the same amount of electricity as 100 000 t of hard coal of good quality, the volumes of radioactive wastes are small (Fig. 1).

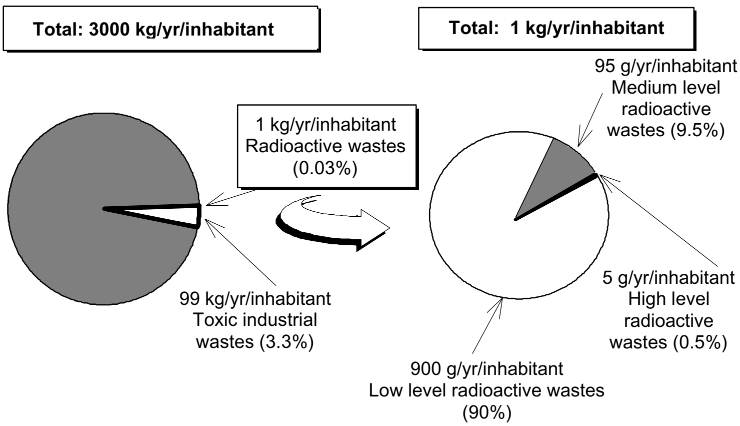
Table 5 shows the energy contents of major primary energy sources for electricity production, indicating the enormous energy content of natural uranium as compared to other alternatives.

Table 5
Energy Content of Major Primary Energy Sources for Electricity Production

Source	Can Produce
1 kg of wood	~2 kWh
1 kg of coal	~3 kWh
1 kg of oil	~4 kWh
1 m^3 of natural gas	~6 kWh
1 kg of natural uranium	~60 000 kWh (PWR[a]) 3 000 000 kWh (FBR[b])

[a]Pressurized water reactor.
[b]Fast breeder reactor.

This important characteristic of the nuclear fuel cycle means that its waste volumes are very small compared with different alternatives as previously described. Hence, they can be adequately handled and treated. As a matter of fact, nuclear power is the only energy technology that treats, manages, contains, and isolates its wastes in a way to fully protect human health and the environment. Solutions for final disposal of low-, medium-, and high-level radioactive wastes are available and in use in several countries. New technologies for waste management and disposal are feasible and some are already under development, including transmutation and fuel recycling. When comparing with the total of manufactured wastes, the issue of radioactive wastes should be put in the right perspective. In France, for example, where nuclear power supplies about 80% of the total electricity generation in the country, the production of wastes of all kinds is 3000 kg per inhabitant and year. Of this, 100 kg per inhabitant and year (3.3%) are toxic industrial wastes (Fig. 3). About 99% of these toxic industrial wastes are chemical wastes, some of which are nondegradable (mercury, lead, cadmium, stable chemical compounds, etc.) and only 1% are radioactive wastes, i.e., 1 kg per inhabitant and year. Summarizing, only about 0.03% of the total production of wastes in France are radioactive wastes, and from these only 9.5% are highly radioactive wastes.



Source: EDF 1996

Fig. 3. Manufactured waste in France. Radioactive waste is only 0.03% of the total waste by weight.

4.3 Fuel, Transport, and Land Requirements

Because nuclear is a highly concentrated form of energy, nuclear power plants and the associated fuel cycle facilities do not require vast land areas for their operation. Hence, the environmental impact of nuclear power on land, forests, and waters is minimal, and there is no requirement for resettlement of large populations. The burden nuclear power facilities provoke in the fuel transportation infrastructure is extremely low when compared with fossil fuel facilities, due to the different order of magnitude of the quantities being transported. Also, for the same reason, nuclear power plants require much less space for fuel storage at site than fossil plants of the same capacity. Table 6 compares the requirements of the whole fuel cycle system for fuel storage, land occupation, and transportation needs for coal-fired and nuclear fuel plants. Note that coal power systems require about eight times more land area than nuclear systems for the same annual production of electricity.

Table 6
Fuel, Land, and Transport Requirements from Coal and Nuclear Power Plant Systems*

1300-MWe Power Plants	Coal	Nuclear
Installed capacity Fuel Fuel annual consumption	2 x 650 MWe Hard coal 3.3 million tons	1300 MWe Enriched uranium 32 t U (170 t nat U)
Land use for plant site, mining, and waste disposal Area requirements for fuel storage	415 ha [a] 25 ha (2 months' reserve)	50 ha A few square metres
Fuel transport requirements	82 500 wagons of 40 t each year [b]	5 trucks each year
CO_2 emissions SO_2 emissions with flue-gas desulfurization NO_x emissions with denitrification Particulate emissions with control [c]	10 000 000 CO_2/yr 14 000 t SO_2/yr 7000 t NO_x/yr 2300 t/yr	0 0 0 0

Table 6 (cont'd.)
Fuel, Land, and Transport Requirements from Coal and Nuclear Power Plant Systems*

1300-MWe Power Plants	Coal	Nuclear
Wastes	250 000 t ashes 140 000 t fly ashes 85 000 t sulfur 150 000 t gypsum	A cube of 1.5 m of size with high radioactive waste

* Annual production: 10 000 GWh.

[a] 1 ha =10 000 m^2 = 0.01 km^2.

[b] 6.5 trains with capacity of 1400 t every day, each train with 35 wagons of 40 t.

[c] The figures shown in this table correspond to emissions during operation. Actually, if the entire fuel cycle for all sources is considered, these emissions should be increased by those provoked by burning fossil fuels during mining and extraction and fuel processing, including uranium mining and milling, conversion, enrichment, fuel fabrication, and reprocessing, as well as for waste disposal (such as fuel used for transportation and operations and maintenance). Also, for all sources, emissions are associated in the production of concrete, steel, and other products used for construction of the fuel cycle and power plants.

Table 7 gives some order of magnitude of land requirements for the site of different types of power plants (fuel cycle requirements are not included). Renewable energies, particularly solar and wind, require substantial land use that in many cases would be needed for other purposes, agriculture for example. It can be observed that renewable energy sources require much more land than thermal ones. Numbers shown in this table are average values; the actual values are site and project specific.

Table 7
Land Area Needs for Power Plant Sites (1000 MWe)

Type of Power Plant	Land Area Requirements (ha)
Oil and coal (including storage for fuel)	100
Nuclear and natural gas	50
Hydropower [a]	25 000
Solar photovoltaic in a sunny place [a]	5 000
Wind in a windy place [a]	10 000
Biomass plantation [a]	400 000

[a] The values are indicative only, as they are substantially site specific.

5. EXTERNAL COSTS

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Different energy sources for electricity production cause different environmental and health impacts (Appendix B). Usually, they are not directly comparable. For instance, hydropower usually requires large population resettlements, whereas conventional thermal and nuclear power plants do not. Conventional thermal power plants emit large amounts of gas polluters, while hydro and nuclear power plants do not. Nuclear power and conventional thermal power plants produce wastes of different kinds, whereas hydropower does not.

Hence, to compare the social and environmental impacts arising from the use of different energy sources for electricity production is a very complex task. The accepted approach today is to try to quantify all impacts in terms of monetary amounts. A reference study on this matter is the one carried out for the European Commission under the ExternE Project.[16] The main results of this methodology as applied to France[16-19] and for average European conditions[19] are given in Table 8 for the power sector and include the impact of the entire fuel chain.

Table 8
External Costs of the Entire Power Fuel Cycle for Major Energy Sources (ECU/MWh)*

Fuel	France	Average European Conditions
Coal	69 to 99	72.7
Oil	84 to 109	44.5
Gas	19 to 31	23.7
Nuclear	2.5[a]	2.5
Hydro (SD)[b]	0.05 to 11.74	0 to 4
Wind (SD)	-	0.5 to 2
Solar (SD)	-	1.3 to 1.9
Biomass (SD)	6 to 7	1 to10
Waste incineration	159 to 216	-

* ECU = European Common Unit of Currency.

[a] For a discount rate of 0%/yr for discounting future damages. If a 3%/yr discount rate is used, the cost of externalities for nuclear power would decrease to 0.098 ECU/MWh (Ref. 18).

[b] Results from renewable sources of energy are extremely site dependent (SD).

It can be seen that the nuclear chain, from mining until waste disposal, compares favorably with all the fossil chains and is of the same order of magnitude with the so-called renewable energy chains. It has to be emphasized that these external costs are not included (internalized) in the prices of electricity. Were they to be internalized, the competitiveness of nuclear power would increase accordingly because the costs for ensuring safety and radioactive waste management and decommissioning of facilities are explicitly included in the price of electricity generated by nuclear power.

6. CONCLUSIONS

6. CONCLUSIONS

The world population is currently increasing by the equivalent of one Brazilian population every 2 years, or one U.S. population every 3 years, or one European population every 5 years. The people of the world will be unwilling to face a future that diminishes lifestyles or expectations much below those enjoyed at present. One-third of the world's current population lives in poverty, without access to commercial energy. The WEC at its 17th World Congress in Houston, Texas, in September 1998 concluded that the number one priority in sustainable energy development today for all decision makers in all countries is to extend access to commercial energy services to the people who do not have it now and to those who will come into the world in the next two decades, largely in developing countries.[7] Hence, world demand for energy will continue to grow as population grows and countries develop and expand their economies. It is essential to provide energy, particularly electricity, to a world population approaching 10 billion people in the next 50 years. Nuclear power is a part of the solution that has the advantage of avoiding the wide variety of environmental problems arising from burning fossil fuels—coal, oil, and gas. Environmental problems that have received the most attention have been "global warming," which is changing the Earth's climate; acid rain, destroying forests and killing fish; air pollution, causing disease and death among thousands of people every year; and the destructive effects of massive coal mining and oil spills on biosystems. In a longer-term perspective, nonelectrical applications of nuclear energy, such as heat, potable water, and hydrogen production, if further developed, would enlarge significantly nuclear energy's contribution to avoid emissions of gas pollutants, particularly greenhouse gases.

Without nuclear power, the long-term future of the global ecosystem is at risk. It is not claimed that an extended use of nuclear power would be the only solution for avoiding global warming or other environmental damages originating from electricity production. It is asserted that nuclear power offers a significant contribution to a global energy balance with low emission of gases that cause climate change and that it should be used in a well-balanced combination with energy conservation and renewable sources so that emissions of greenhouse gases can effectively be reduced.

The existing contribution from nuclear power should be an integral part of greenhouse gas abatement strategy as it meets the tests of sustainable development as defined in the Kyoto Protocol.[b] The development of nuclear as Joint Implementation or Clean Development Mechanism

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[b] Emissions reductions resulting from each project activity shall be certified by operational entities to be designated by the Conference of the Parties serving as the meeting of the Parties to this Protocol, on the basis of

a. voluntary participation approved by each Party involved
b. real, measurable, and long-term benefits related to the mitigation of climate change
c. reductions in emissions that are additional to any that would occur in the absence of the certified project activity.

(CDM) projects should receive credit for action if requested by any country. The CDM is intended to encourage the transfer of technologies to the developing world that control, limit, or avoid carbon emissions and provide for sustainable development.

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APPENDIX A

APPENDIX A

Environmental Effects of the Use of Nuclear Power in the Last Quarter of the 20th Century

In Table A.1, nuclear power units in different regions of the world are shown, including their capacity and their power generation.

Table A.1
Nuclear Power in the World (1995)

Region	Number of Units	Capacity (MW)	1973-1995 Generation (million kWh)
North America	132	115 629	10 646 375
Western Europe	150	121 303	10 583 426
Eastern Europe	68	45 467	3 642 474
Far East	71	56 064	4 122 837
Rest of the World	16	5 223	318 895
TOTAL	437	343 686	29 314 007

Table A.2 shows the amount of fossil fuel saved due to the utilization of nuclear power. Without nuclear power, 25% more coal and oil and 22% more natural gas would have been consumed by electric utilities between 1973 and 1995.

Table A.2
Savings from Using Nuclear Power

Consumption	Coal (ton)	Natural Gas (m^3)	Oil (bbl)[a]
Amount of avoided consumption in 1995	706×10^6	155×10^9	620×10^6
Amount of avoided consumption during 1973-1995	8.9×10^9	1.6×10^{12}	10×10^9

[a] bbl = barrels.

The corresponding reductions in CO_2 emissions, are stated in Table A.3. In 1995 alone, electric utilities worldwide would have emitted 32% more carbon dioxide without nuclear power plants.

Table A.3
Reduction in CO_2 Emissions

Emissions	Carbon (metric ton)	CO_2 (tonne)
CO_2 emissions reduction in 1995	482×10^6	1770×10^6
CO_2 emissions reduction during 1973-1995	6.1×10^9	22.4×10^9

Reductions of emissions of SO_2 and NO_x are given in Table A.4. In the absence of nuclear power, the world's electric utilities sulfur dioxide and nitrogen oxide emissions would have been 35% and 32% greater, respectively, in 1995.

Table A.4
Reduction of SO_2 and NO_X Emissions

Emissions	Sulfur Dioxide (ton)	Nitrogen Oxide (ton)
Reduction in 1995	15×10^6	8×10^6
Reduction during 1973-1995	219×10^6	98×10^6

APPENDIX B

APPENDIX B

Environmental Impacts of Electricity Production

1. Introduction

This Appendix describes the environmental aspects of the major sources of energy for thermal power production. Most of the information used was derived from work carried out by the Brazilian Coordination Committee on Environmental Activities of the Power Sector[1] (COMASE) and expanded to cover international experience. It was then complemented with the associated impacts outside the boundaries of the power sector, such as fuel mining, fuel transportation, and waste disposal.

2. Full Chain Impacts

It is useful to illustrate the range of waste stream types, their basic characteristics, and their production scale that may have to be considered in a comparative assessment framework. Impacts[2] are briefly described for the full chain of major energy technologies and fuel cycles.

Some waste streams considered to be harmless are discharged directly to the air or to surface water bodies. They are herein called *direct emission wastes*. Other wastes are produced in solid form that cannot be directly discharged. In addition, waste streams that are hazardous will require some treatment for their safe disposal. This treatment may result in further discharges to the air or surface water bodies and to the production of other solid wastes. These wastes are herein called *nonemission wastes*.

2.1 Coal

Most electrical energy derived from coal is obtained by direct combustion of coal, including fluidized bed combustion and coal gasification.

The major components of the coal fuel cycle for direct combustion of coal are listed in Table B.1. Also listed in this table are major air and water emissions, other waste streams, and estimates of waste amounts. Quantities of solid wastes were estimated for a coal with a heat content of 8000 kWh/t, 7% ash content, 6600 kg/m^3 density, and sulfur content of about 1%. Because these parameters can vary significantly among various coal deposits, the quantities of waste described are approximate and should be considered indicative. The amounts of solid waste production are also indicative due to uncertainties on the degree of flue gas treatment.

Table B.1
Coal (1 Gwe·yr)

Fuel Cycle Component	Emissions to Air or Water	Nonemission Wastes
Coal mining		
surface	Drainage water containing dissolved solids, suspended soils and acids	10^7 t overburden
underground	Acid/salty drainage water	10^5 t solid wastes

Table B.1 (cont'd.)
Coal (1 Gwe·yr)

Fuel Cycle Component	Emissions to Air or Water	Nonemission Wastes
Coal preparation (cleaning)	Particles to air and "black-water" releases	10^5 t solid wastes
Transportation	Air emissions from trains, barges, and/or trucks	Solid and hazardous wastes associated with the transportation industry
Combustion at power plant	CO_2, NO_2, SO_2, Hg, waste heat, other metals, and organic chemical emissions to air	3 x 10^5 t of bottom and fly ash containing trace metals (arsenic, lead, nickel, etc.) and Gbq quantities of radionuclides such as ^{228}Th, ^{230}Th, ^{232}Th, ^{226}Ra, and ^{228}Ra
	Waste heat and boiler-wash waste emissions to water	Some of the boiler-wash waste may need to be treated as hazardous waste
Combustion at power plant with flue-gas desulfurization	Same as above but with substantially lower sulfur emissions	Same as above plus 4 x 10^5 t of $CaSO_4$ and 5 x 10^4 t of $Ca(OH)_2$
Power plant construction and dismantling		Building rubble, possibility of asbestos-contaminated materials, soil restoration wastes

Regarding fluidized bed reactors and coal gasification combustion processes, a mixture of coal and limestone particles is suspended in a stream of air flowing from below. Use of limestone increases the output of CO_2 relative to that of a conventional coal plant and almost doubles the quantity of solid materials that must be disposed of (500 000 t/yr versus 300 000 t/yr for conventional coal combustion). In addition, the toxic components of the ash (heavy metals, radionuclides, etc.) are incorporated into the solid waste volume, whereas, in a conventional coal plant, the solid wastes from desulfurization processes are mostly free of these components.

2.2 Oil

The major components of the residual oil fuel cycle are listed in Table B.2. Listed in this table are major air and water emissions, other waste streams, and estimates of waste amounts. Quantitative estimates for solid wastes are made for a residual oil plant with 38% conversion efficiency and energy content of crude oil assumed to be 1.4×10^6 kWh/m^3.

Table B.2
Oil (1 GWe·yr)

Fuel Cycle Component	Emissions to Air or Water	Nonemission Wastes
Crude oil extraction continental wells	3×10^3 m^3 oil lost by blowouts or spills at wells	10^7 m^3 of brine Drilling fluids Wastes associated with cleaning up blowout and spilled oil
off-shore wells	10^7 m^3 of brine 7×10^3 m^3 oil lost by blowouts or spills at wells	Brine that cannot be released to water drilling fluids blowout and spilled oil
Transport to refinery		10^4 m^3 oil spills Solid and hazardous wastes associated with the transportation industry

Table B.2 (cont'd.)
Oil (1 GWe·yr)

Fuel Cycle Component	Emissions to Air or Water	Nonemission Wastes
Refining of crude oil to residual oil to power plant	Releases to air including CO_2, NO_2, SO_2, and organic chemicals	10^5 t oily waste solids and sludge 10^8 t water wastes containing 600 t grease, 3 t phenol, 7 t chromium, 3 t lead, and numerous dissolved and suspended organic and inorganic chemicals in lesser amounts
Transportation of residual oil to power plants		600 m^3 of spilled oil. Solid and hazardous wastes associated with the transportation industry
Combustion at power plant	CO_2, NO_2, SO_2, Hg, waste heat, other metals, and organic chemical emissions to air through flue gas Waste heat and boiler-wash waste emissions to water	Solid/ash wastes are less than for coal, unless flue gas de-sulfurization is employed, in which case total mass can be similar
Power plant construction and dismantling		Building rubble, possibility of asbestos-contaminated materials, soil restoration wastes

2.3 Natural Gas

In order to minimize CO_2 emissions, natural gas is very attractive for power generation because its energy ratio is less than half that of coal. So far as the greenhouse effect is concerned, this advantage may be canceled by releases of methane occurring during gas extraction, transportation, and handling. The major components of the natural gas fuel cycle for electricity production are listed in Table B.3. Also listed in this table are major air and water emissions and descriptions of other waste streams.

Table B.3
Gas (1 GWe·yr)

Fuel Cycle Component	Emissions to Air or Water	Nonemission Wastes
Natural gas extraction from gas wells	Methane losses	Brine and well condensate
Raw natural gas processing	Flue gas emissions, including CO_2, NO_2, various organic chemicals, and particulates	Liquid hazardous wastes
Gas transmission to power plant	Methane losses	
Combustion at power plant	Flue gas emissions including CO_2, NO_X, various organic chemicals and particulates Waste heat and boiler-wash waste emissions to water	Some of the boiler-wash wastes may need to be treated as hazardous wastes. Amounts are small compared with coal or oil
Power plant construction and dismantling		Building rubble, possibility of asbestos-contaminated materials, soil restoration wastes

2.4 Nuclear Power

Nuclear power and its fuel cycle produce radioactive wastes in which there are varying degrees of contamination by a range of radioactive isotopes. The problems of managing and disposing of these wastes are most demanding for high-level waste (HLW) made up of spent fuel or the most concentrated waste arising from reprocessing of spent fuel. In addition, a considerable amount of so-called intermediate- and low-level waste (ILW and LLW) is produced. Although the activity levels of these wastes are much lower than for HLW, their volumes are rather higher. Apart from radioactive waste, nuclear power generation also gives rise to a range of other conventional waste materials, common to the running of large industrial plants.

There is enough similarity among the different types of reactors that representative waste streams can be developed for all designs by considering typical LWR, (boiling water reactor and pressurized water reactor) fuel cycles. The major components of a light water once-through fuel cycle are listed in Table B.4. Also listed in this table for each fuel cycle component are the major air and water emissions and descriptions of nonemission waste streams. The magnitude of solid wastes has been estimated assuming a 32% efficiency LWR plant.

Reprocessing results in larger quantities of LLW and ILW but much smaller inventory of uranium and plutonium in HLW. It also reduces the need for uranium mining and milling.

Table B.4
Uranium (1 GWe·yr)

Fuel Cycle Component	Emissions to Air or Water	Nonemission Wastes
Mining of 0.2% U ore		10^6 t overburden
Milling and concentration	Gaseous releases including gigabecquerel amounds of radon and liquid releases including gigabecquerel amounts of U, ^{230}Th, and ^{226}Ra	85 000 t of solid tailings, including quantities of ^{230}Th and ^{226}Ra and heavy metal contaminants
Conversion from U_3O_8 to UF_6	Liquid wastes containing gigabecquerel amounts of ^{230}Th and ^{226}Ra	40 t containing residual U and Th
Isotopic enrichment		145 t depleted uranium
Conversion and fuel fabrication	Liquid wastes contaminated with Th and U	30 t CaF_2
Power plant operation	Gaseous and liquid releases of radionuclides	Spent fuel LLW associated with plant operation
LLW stream management	Depends on choice between reprocessing and once-through fuel cycle: controlled emissions—regulated limits	For the once-through cycle, approximately 20 t HLW, 200 t ILW, and 800 t LLW
Plant decom-missioning	Gaseous and liquid radioactive releases associated with decontamination and dismantling procedures	LLW and ILW associated with dismantling of the plant Conventional wastes from plant dismantling

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