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Comparative Assessment of Different Energy Sources and Their potential Role in Long-term Sustainable Mix

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1. INTRODUCTION

Economic development, social development and environmental protection are interdependent and mutually reinforcing components of sustainable development. Sustainable development requires that the current generation should meet their needs without compromising the ability of future generations to meet their own. In this context policies to combat climate change are viewed as an integral part of sustainable development.

Energy has played and will continue to play a principal role in promoting economic growth and improved human well-being. However, there are also environmental implications associated with energy supply. The challenge is to develop strategies that foster sustainable patterns of energy use, which do not irreversibly degrade the environment.

There is a general understanding that the present pattern of energy supply, based mainly on the use of fossil fuels, is not sustainable with its significant contribution to local and regional environmental degradation and potential climate change. Another factor that needs to be addressed when assessing the sustainability of a continued global dependence on fossil fuels is the limitation of its resource base.

The alternatives to fossil fuels most often proposed by advocates of the sustainability concept are renewable energy sources: solar, wind power and biomass. Renewables are believed to have neither health and environmental impacts, nor any limitation from the point of view of their resource base. However, their low energy density places a limitation on their use for large scale commercial, industrial purposes.

In the debate on sustainable energy future, the role of nuclear power is a contentious issue. Many, who are outside of the nuclear community, do not even consider nuclear, because of public concerns on nuclear safety, radioactive waste and non-proliferation issues. For example, the United Nations Development Program, in its document Energy After Rio does not suggest a specific role for nuclear power except in the most doubtful of terms. On the contrary, most nuclear organisations and related industries see nuclear power as the only mature carbon-free electricity generating option that can be deployed even on a much larger scale than today.

This paper analyses the potential role of nuclear power in the context of the global sustainable energy future. The fundamental features of sustainable energy development are examined in terms of the following compatibility constraints:

- Demand driven compatibility;
- Natural resource compatibility;
- Environmental compatibility;
- Geopolitical compatibility; and
- Economic compatibility.

2. DEMAND DRIVEN COMPATIBILITY

Provision of energy services is essential for economic development and human welfare. The amount of energy necessary to keep a human being alive and fully operational is approximately 0.07 toe per year. As civilization progressed, energy demands increased extraordinarily. Industrial countries today use one hundred times much energy per capita as primitive man in the form of fossil fuels, hydroelectricity, nuclear energy, biomass, wind and solar energies. Access to and use of such large amounts of energy is unevenly distributed both among countries and among the richer and the poorer within each country.

For the four billion people who live in the poor countries of Africa, Latin America, the Middle East, and Southeast Asia, energy is an essential ingredient for future growth and development. The importance of commercial energy for development is illustrated in Figure1 (See end of the paper), which shows two social indicators – infant mortality and life expectancy, for a number of countries versus per capita commercial energy consumption. Table 1 shows the same demographic indicators in relation to traditional biomass use.

Table 1:Demographic indicators in relation to biomass use

	Percent Biomass (of total fuel use)				
	0-20	20-40	40-60	60-80	80+
Number of Countries	70	12	14	10	16
Life Expectancy	71.5	66.5	59.9	54.5	47.0
Infant Mortality Rate	22.5	46.6	64.7	82.6	116.8

Source: World Bank. World Development Indicators 1998

In the majority of developing countries, where commercial energy consumption per capita is below 1 toe per year, infant mortality is high, while life expectancy is low. Surpassing the 1 toe/capita barrier seems to be an important instrument for development and social change. As commercial energy consumption per capita increases to values of 2 toe (or higher), social conditions improve considerably. Average consumption per capita in OECD countries was about 5 toe per year in 1990.

Primary energy is an essential ingredient of socio-economic development and economic growth (See table 2). The objective of the energy system is to provide energy services, for instance, lighting, comfortable indoor temperature, refrigerated storage, transportation, and appropriate temperatures for cooking.

Table 2: Per capita incomes and consumption of commercial energy

Country	Income, $1995/Capita	Consumption, Toe/Capita (1994)
India	340	0.25
China	620	0.66
Brazil	3,640	0.72
Korea, Rep.	9,700	2.98
Germany	27,510	4.13
United States	26,980	7.82

Source: World Development Report, 1997 World Bank

Today the nuclear power contribution to global energy consumption is around 7%, almost entirely in electricity sector, with 434 nuclear power plants operating in 32 countries. Hydro power contributes another 6% to global energy supply, by generating also only electricity. Practically all the rest - more then 87% comes from fossil fuels: coal, oil and natural gas. Fossil fuels play dominate role in the electricity sector (64 %), and practically have no competing alternatives in other areas of the energy sector, such as, industrial heat generation, transportation, district heating, and so on. Non-hydroelectric renewables - solar, wind, geothermal and biomass- today constitute less than 1 % of the energy supply.

Antinuclear groups argue that the present level of nuclear contribution to global energy is not essential, that nuclear should be phased out and that its share in energy supply may be covered by energy efficiency improvement measures and introduction of renewables.

Conversely, we believe that nuclear power has potential to realize a significant increase of its share in the future global energy mix.

At present, nuclear power provides only some 16% of electricity at the global level. However, some individual countries have reached much higher levels of nuclear contribution. For example, France relies more then 75% on nuclear electricity. In fact, several countries in the world use nuclear power to meet over 40% of their electricity needs, including Belgium, Bulgaria, Lithuania, Korea RP, Slovak Republic, Sweden, Switzerland, Ukraine. Thus, if one considers that nuclear becomes the least cost electricity option everywhere in the world and there are no other constraining factors, its present share in the global electricity sector could double or even triple.

Electricity demand currently constitutes some 33% of global energy consumption and has seen greater growth then overall energy demand. In the coming century the electricity share is likely to increase up to 50%. Demand for more electricity is driven not only by economic development, but also because of the ease of use and cleanliness of electricity at the point of consumption. In this case, if 50% of global electricity supply is generated by nuclear power, then nuclear would meet 25% of the global energy supply, i.e., 4 times higher than the present share.

One can also envision quite large market potential for non-electrical applications of nuclear energy. Today, only some 0.5% of nuclear power generation is used for non-electric applications. Various district heating, industrial process and desalination applications exist in Canada, China, Japan, Kazakhstan, Slovakia and Russian Federation. The most likely new market for nuclear power is supply of heat for industrial, residential, and commercial uses, in particular sea water desalination.

Hydrogen is commonly regarded as the ultimate energy carrier because of its high heat value, transportability, and the absence of polluting combustion products. It is uneconomical today, but it may well become significant, with production at first through the use of high-temperature reactors to reform natural gas and later by using nuclear electricity to electrolyze water. Very large nuclear stations could produce vast quantities of electricity for general use and as hydrogen for transportation.

Fresh water is a vital resource that is becoming increasingly scarce in many parts of the world. Huge urban centers will have to consider very large-scale desalination projects. At this scale of operation, nuclear power will be able to provide fresh water economically and reliably.

The above factors justify that with respect to demand driven compatibility nuclear has significant potential for increasing its present relatively small share in global energy supply. This conclusion was also justified by a recent (March 2000) the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES). The main characteristics of the four marker scenarios are shown in Table 3.

With regard to nuclear energy, the new IPCC emission scenarios show the following:

Most scenarios assume that nuclear energy would retain its important role in the world energy supply (See Fig.2-5 end of the paper). In 2100, the global nuclear capacity for three representative scenarios (of the 4 considered) varies between 3500 and 10600 GW(e), depending on how successfully nuclear energy competes with fossil fuels and renewables. This can be compared with some 350 GW(e) at present.

Table 3. Key characteristics of the 4 marker scenarios.

Scenario family	Family storyline	World population, bln			GDP per capita, 1000 $US 1990			Primary energy, GJ/cap		
		1990	2050	2100	1990	2050	2100	1990	2050	2100
A1	High economic growth, low population growth, rapid introduction of new technologies; convergence to a 'homogeneous world' with a closure of regional differences	5.3	8.7	7.1	4.0	20.8	74.9	66	138	295
A2	Development into a 'heterogeneous world': fertility patters are not converging, population growth is high, economic development remains regionally fragmented	5.3	11.3	15.1	3.8	7.2	16.1	59	86	114
B1	A 'homogeneous world' as in A1, but with economy 'dematerialization' (dominance of services and information); emphasis on global sustainability is modelled	5.3	8.7	7.0	4.0	15.6	46.6	70	93	73
B2	A 'heterogeneous world' as in A2, but with more attention to sustainability; relevant solutions are sought but, in contrast with B1, regionally	5.3	9.4	10.4	4.0	11.7	22.6	67	93	130

At the same time, some scenarios show that rapid improvements in renewable energy options (relative to nuclear technologies) may lead to nuclear stagnation or decline. Under one of such scenarios, the total nuclear capacity decreases from the peak of 5500 GW(e) in the 2050s to 3500 GW(e) by 2100. Some other scenarios indicate the stagnation of nuclear capacities at the present level. Thus, the study confirms that the long-term role of nuclear energy is highly uncertain, in particular because of the uncertainty in the expected competitiveness of different energy technologies, which is illustrated by two extreme "non-marker" cases from the B1 family presented in Table 4.

Table 4. Primary energy mix for two extreme B1 scenarios.

Scenario	Parameter	Shares in primary energy		
		1996	2050	2100
B1	Fossil fuels	83.4%	82.4%	45.1%
	Renewables	14.3%	16.4%	53.9%
	Nuclear (2)	*6.5%*	*3.4%*	*2.8%*
	Nuclear in GW(e)	351	~570	~340
B1	Fossil fuels	83.4%	68.6%	46.9%
	Renewables	14.3%	29.3%	42.0%
	Nuclear (2)	*6.5%*	*6.3%*	*27.5%*
	Nuclear in GW(e)	351	~640	~4200

Regionally, Asia is expected to increase significantly the use of nuclear energy; the nuclear growth rates in the other regions are lower. In contrast with the present situation, by 2050 there may be more nuclear capacities in Asia than in the OECD countries. (See Fig.6-7 end of the paper)

3. NATURAL RESOURCE COMPATIBILITY

Fossil resources. Table 5 puts fossil fuel reserves, resources and additional occurences into perspective to past cumulative consumption and current (1997) fossil fuel use. For an analysis that extends well into the 21st century and eplores the long-term avilability of fossil resources, the relevant yardstick is the fossil resource base. The fossil resource base for conventional and unconventional oil and gas is sufficiently large to last comfortably for another 50 years, possibly much longer than that.

Table 5 Global energy resource base, in Gtoe (IIASA-1998)

	Reserves	Resources	Resources Base	Consumption in	
				1860-1997	1997
Conventional Oil	146	145	291	113	3.2
Unconventional Oil	183	336	519	7	0.2
Conventional Gas	141	279	420	54	1.9
Unconventional Gas	192	258	450	1	0.1
Coal	1004	2399	3402	141	2.4
Total occurrences	1905	3417	5083	315	7.8

Uranium resources.

The known level of uranium resources (4.3 million tonnes) is sufficient to fuel existing thermal reactors for 60 years. In addition taking into account the 11 million tonnes of speculative (undiscovered) uranium resources would allow to sustain the current level of nuclear generation through the year 2200. This time horizon would decrease proportionally with the expansion of nuclear share and global energy demand. So, from the resource compatibility perspective nuclear power based on the use of thermal reactors does not differ significantly from oil and natural gas.

It is a well known fact that thermal reactors use less than 1 % of the energy available from natural uranium. Most of the energy remains unused in depleted uranium. Introduction of fast reactors in future may help to overcome this deficiency. They may recycle plutonium accumulated in spent fuel of thermal reactors, and by this to convert the most part of accumulated depleted uranium into the useful energy. With introduction of fast reactors the resource base for nuclear power may increase up to the several thousand years, making it sustainable. It is worth noting that, although the technical feasibility of this approach is proven, there are concerns related to associated economics and proliferation issues.

Renewables.

Although more evenly distributed and accessible than fossil and nuclear resources, the economic potential of renewables is affected by land use constraints, variation of availability as a function of latitude (solar) and location (wind and hydroelectricity), solar irradiation, water and soil quality (biomass). Still, annual renewable energy flows are three orders of magnitude larger than current global energy use and their utilization will primarily depend on the commercialisation of conversion technologies.

4. ENVIRONMENTAL COMPATIBILITY

Global warming issue. Today the fear of global warming resulting from an increasing concentration of carbon dioxide in the atmosphere is a major global concern. The industrialised countries are responsible for more than two thirds of the current CO_2 emissions. These countries have now agreed in a meeting held at Kyoto in December 1997 to accept binding commitments for reducing their CO_2 emissions, compared to the 1990 level, by at least 5% by the year 2010.

Although at present developing countries have been spared from making any similar commitments, the stabilisation of global CO_2 concentration at some acceptable level will not be possible unless they also make an equal effort to contain the CO_2 emissions. Thus, under increasing international pressure, developing countries are likely to slow down and gradually stabilise their emissions of CO_2, in spite of the need for increased energy services to support their socio-economic development.

All countries will then have to make full use of all the three main options that are now available for reducing CO_2 emissions, namely energy efficiency improvement, shift to low carbon fossil fuels and increased use of non-carbon energy sources.

Improvement of energy efficiency is certainly a very welcome option as it reduces the overall energy requirements and also helps to cut down the emission of all types of pollutants, not just CO_2. But there is a limit to which efficiency may be improved in a cost-effective manner.

Among the fossil fuels, natural gas is the least carbon intensive form of energy. But with all countries seeking to shift more and more to less carbon intensive fossil fuels, countries short of indigenous natural gas resources may well find it difficult to obtain a sufficient share of the limited supplies of gas in the international market. Nuclear power as renewables generates practically no CO_2. (See Fig.8 end of the paper).

Local and regional environmental degradation: Of immediate concern to many countries is the issue of degradation of their local and regional environment. A number of large cities in developing countries are now facing increasing levels of smog. And regional acidification has already become a serious problem in parts of major coal consuming countries, e.g. China and India. This problem is expected to aggravate further and spread to a number of countries in South and East Asia, as the fossil fuel consumption in these densely populated countries increases.

Based on local and regional environmental considerations nuclear power, like renewables, has clear advantages over fossil fuel. It does not release any significant amount of noxious gases or other pollutants. It may be pointed out here that, although some radioactive materials are released to the environment during normal operation of a nuclear power plant and other nuclear fuel cycle facilities, the amounts released are very small and limited strictly by regulations to levels far below those of any health significance, as laid down by international regulations and guides. How small such releases are may be judged from the fact that, in some cases, even the amount of radioactivity released from a coal-fired power plant exceeds that from the normal operation of an equivalent nuclear plant.

Radioactive waste disposal: There is continuous public concern that nuclear waste cannot be safely managed. However, nuclear waste has distinct advantages as quantities involved are quite small - only some 30-40 tonnes per year for a 1000 MWe nuclear capacity operation, as compared to 3-4 hundred thousand tonnes of ash containing several hundreds of tonnes of toxic heavy metals (e.g., arsenic, cadmium, lead, mercury) produced annually by a 1000 MWe coal fired plant. The small quantities permit a confinement strategy with the radioactive material isolated from environment. In sharp contrast, disposal of the large quantities of fossil fuel waste follows an alternative dispersion strategy. Disposal techniques for nuclear waste exist. Deep underground geological formations, which have not been disturbed for many millions of years, are being considered for disposal of high level radioactive waste in some countries.

It is due to public scepticism or opposition coupled with lack of political will that these solutions have not yet been put into practice in these countries. Until some appropriate policy decisions are taken, the present practice of storing such waste above or below ground will have to continue.

The real problem related to waste disposal may arise in countries without adequate geological formation for waste disposal at their national territory. It may also be very costly to have national repository for countries with small nuclear power programmes. For these countries regional co-operation in spent fuel storage and waste disposal may be of particular importance.

The most convincing demonstration to the public that high level waste can be managed will be the construction and operation of a repository. Some also have an opinion that increased role for nuclear requires the development of new fuel cycle concepts with drastically decreased amount and toxicity of radioactive wastes.

Protecting health. Results of the comparative health assessment of the different electricity generation systems indicate that nuclear power and renewable systems tend to be in the lower spectrum of health risks. A significant health and environmental impact from nuclear power arises only from potential abnormal events.

Nuclear safety: Nuclear power plants are generally built to high safety standards. Nevertheless, there have been two serious accidents. Many lessons have been learned from the TMI and Chernobyl accidents. They triggered extensive nuclear safety reviews and modernisation of safety systems of all existing reactors. There has been a large ongoing co-operative effort to improve the safety of all operating Soviet designed plants that has included significant modernization of instrumentation and equipment.

There are already more than 9000 reactor years of accumulate operational experience worldwide, equivalent to an average of 20 years of operation for each nuclear power unit. Building on this large experience base, today's reactors incorporate improved safety measures.

Table 6: Historically based aggregated severe accident risk indicators for full energy chains

Energy Chain	**Number of severe accidents with fatalities world-wide 1969-1996**	**Number of immediate fatalities (per GWe year)**		
		World-wide	**OECD**	**Non-OECD**
Coal	187	3.42 E-01	1.37 E-01	5.14 E-01
Oil	334	4.18 E-01	3.87 E-01	4.58 E-01
Natural Gas	86	8.46 E-02	6.55 E-02	1.09 E-01
Nuclear	1	8.41 E-03	0	5.32 E-02
Hydro	9	8.83 E-01	4.03 E-03	2.19

Advanced nuclear power plants with an even smaller severe accident possibility are designed. Large evolutionary units with power outputs of 1300 MWe and above, which incorporate proven, active engineering systems to accomplish safety functions, and mid-size evolutionary designs which place more emphasis on utilization of passive safety systems are being developed. Designers believe the newest plants would suffer no more than one severe core damage accident in 100 000 reactor- years of operation and this without a subsequent environmental release.

Over the years a global nuclear safety culture has evolved through international collaborative efforts to strengthen safety worldwide. Binding international agreements, codes of practice, non-binding safety standards and guides along with international review and advisory services now exist.

Suffice it to say that, based on the today's experience, an objective comparative assessment of nuclear power and other major options for electricity generation with respect to human health risks associated with the operation of their full energy chains puts nuclear power among the least risky power generation technologies. Still the fear of a nuclear accident and the release of radioactivity weighs heavily on the minds of many. The workable remedy would be prolonged nuclear power operation without any other serious accident or major release of radioactivity into the environment.

Is it enough what was done in safety area to ensure that nuclear power will be an active player in future sustainable energy mix? In our current situation, the answer is still no.

A shift in future to fast reactors would bring new safety risks because of the greatly different design and initial lack of experience with this technology. There is reason to believe that a safe transition would be possible. However, the issue can not be ignored. Taking into account the targeted larger share of nuclear power in future energy supply and the very long-term perspective we should propose fast reactor designs with much better safety features then those that have today's advanced thermal reactors.

5. GEOPOLITICAL COMPATIBILITY

Energy security. Countries which do not have large easily exploitable hydro power potential and are also short of indigenous fossil fuel resources are the most vulnerable group from the point of view of energy security. The oil shocks provided a strong stimulus for the development of nuclear power in 1970s. The risk of an interruption in the supply of natural gas and oil is still not negligible. In the very long run fossil fuel prices are projected to inexorable increase. Since fuel costs account for some 50-80% of fossil plant life-cycle costs, the increased fossil energy prices, will enhance the competitiveness of nuclear power. The consideration of energy security have played a key role in the decision of countries like France, Japan, Republic of Korea and Taiwan China, to go for nuclear power on a large scale. In all likelihood, they will also be major determinants in the decision of other countries placed in similar situation.

By diversifying energy sources, nuclear power can provide a hedge against large increases in the national energy bill. The recent financial crisis in Southeast Asia caused a drastic devaluation of national currencies and corresponding hikes in energy import bills. Countries of the region without domestic energy resources but with a high share nuclear power are less affected by this recent change in the terms of trade

In the long run accumulated depleted uranium and plutonium in spent nuclear fuel of thermal reactors may regarded as indigenous resources for countries planning development fast reactors.

Non-proliferation issues: The risk of nuclear proliferation is a political problem rather than technical one. For years the IAEA has been operating an effective safeguards system to check any possible misuse of nuclear materials from the safeguarded nuclear facilities under its control, to prevent illicit trafficking of nuclear materials and to ensure strict adherence to various treaties related to international non-proliferation regime. With the approval by the Board of Governors last year of the Model Additional Protocol to the safeguards agreements, the Agency has obtained the legal authority to implement a more effective safeguards system. These measures – further strengthened - will minimize the risk of nuclear proliferation while nuclear power expansion based on existing reactor and fuel cycle systems. However, to facilitate large-scale nuclear power development for sustainable energy it would be essential in supplement to the safeguards arrangements to develop more proliferation resistant nuclear fuel cycles than the present ones. The continues accumulation of plutonium in the world may not be tolerated and will become difficult to safeguard. This issue is of particular importance if one take into account the need of transition in future to fast reactors and recycling of plutonium.

There are at present some conceptual proposals how to build the future nuclear power system base on fast reactors with much better proliferation resistance features. They should very carefully analysed by nuclear community in order to find politically acceptable response to the above issue.

6. ECONOMIC COMPATIBILITY

Economics of electricity is an important factor in the choice of electricity generation technologies. As compared to fossil fuel fired plants, nuclear plants are more expensive to build but much less expensive to operate. The specific capital cost in terms of $/kW installed of a nuclear power plant is typically about two to three times that of a oil or gas fired plant and one and a half times that of a coal fired plant. Because of the much longer construction time for nuclear power plants, interest cost accrued during construction aggravates its capital cost disadvantage. The operation and maintenance costs of all the plants are comparable but the fuelling cost of nuclear plant is much lower - only one quarter to one third as much as that of a fossil fuel fired plant. The relative economics of electricity generation from nuclear, coal, gas and oil fired plants in different countries may however vary as the plant construction cost, interest rate, discount rate, O&M cost and fuel cost for each type of plant will depend on specific country situation.

Nuclear power plants already built have generally fared well in restructured markets. The operating costs of nuclear power plants, including fuel costs, are usually lower than for most other major power generation alternatives, with the exception of hydroelectricity. Capital is largely depreciated and a plant with operating and maintenance costs (O&M) below market prices turns in a profit (see Figure 9 end of the paper). Data on nuclear power operating costs are most available in the United States, where electricity prices are publicly known and transparent. In 1998 operating costs averaged around US$ 0.018 per kWh. The most efficient plants saw costs of around US$ 0.012 per kWh. Moreover, the cost trend is still downward leading to optimistic anticipation that even lower operating costs are possible in the near future. Similar low and declining operating costs are experienced in other economies. The result has been that existing nuclear power plants have been quite successful within the new commercial environment. Technological progress and changes in environmental protection and safety regulations will have an impact on the competitiveness of nuclear power as compared to fossil-fuelled power generation.

New Plants

- New NPPs can cost 2–4 times more to build than fossil-fuelled plants (see Table 7).These costs do not include the cost of risks due to non-completion, exchange rate fluctuations or cost over-runs, risks that can affect a power generator's credit rating. OECD investment rules already add a 1% risk premium to lending rates on all OECD export credits to developing countries where nuclear power plants are concerned. Can such risks and costs be reduced or secured sufficiently for nuclear power to compete in capital markets for the financing of new nuclear plants?

- Investment in a nuclear plant would require well over twenty years to repay. Competitive capital markets would require a higher return on investment to justify these longer-term risks. The big question for nuclear power is whether market prices will permit them to afford such premiums and still turn a profit.

- Generating costs have fallen fast. In 1995, US$ 0.043 per kWh was considered the price to beat for a new nuclear power plant to be competitive in the USA. By 1998 estimated costs came in below US$ 0.03 per kWh, absent government intervention, for a plant to be considered a potentially profitable investment. The average is now around US$ 0.02 and likely to fall further.

Table 7: Capital costs (including interest during construction) and construction times for different electricity generating options. Source: OECD, 1998.

	Cost per kWe installed US $	Total cost for 1,000 MW capacity Billion US $	Construction period Years	Typical plant size MW
Nuclear LWR	2,100 – 3,100	2.1 – 3.1	6 - 8	600 – 1,750
Nuclear, best practice	1,700 – 2,100	1.7 – 2.1	4 - 6	800 – 1,000
Coal, pulverized, ESP	1,000 – 1,300	1.0 –1.3	3 – 5	400 – 1,000
Coal, FGD, ESP, SCR	1,300 – 2,500	1.3 –2.5	4 - 5	400 – 1,000
Natural gas combined cycle	450 – 900	0.45 – 0.9	1.5 - 3	250 — 750
Wind	900 – 1,900	0.9 – 1.9	0.4	20 — 100

ESP= Electrostatic precipitator; FGD = Flue gas desulphurization; SCR = Selective catalytic reduction

This decline in generating costs did not just result from competition, but also from low fuel prices and from significant improvements in efficiency in the use of coal and gas. The thermal efficiency of gas use has risen to well over fifty percent with promises of further improvements. Low cost and high efficiency will therefore be essential characteristics of any plants to be built in the future, and non-nuclear technologies are developing rapidly in this direction.

Since investors in new generating plants have no sunk costs and are free to choose at the outset the fuel, technology, site, plant design, financing operations and risk allocation that suits them best, they will tend to opt for the highest return, least risk alternative. Under these circumstances, will new nuclear plants be built? Unless the nuclear industry takes dramatic action to reduce capital costs and financial risks for new nuclear plants, nuclear power could well be priced out of the market, even where it offers other significant advantages.

Nuclear power does have clear advantages including low fuel costs, supply security, minimal environmental impacts, significant potential for greenhouse gas mitigation and low external costs. The challenge for the nuclear sector is to ensure that these advantages are not swamped by high capital and generating costs and their associated high risks. Where governments till choose technologies, nuclear might be chosen to satisfy any number of public policy objectives, but if it fails to do so profitably, then the choice is not sustainable.

Capital Costs and Risks

New nuclear plants are sometimes divided into evolutionary and revolutionary designs. Evolutionary designs, such as the APR-600 and the EPR, bear a certain burden of proof that modifications made will result in commercially competitive reactors. Revolutionary designs offer perhaps a greater potential for competitive advances, primarily because they can be designed explicitly for current and future market conditions. Yet with the exception of the development of the Pebble Bed Modular Reactor (PBMR) in South Africa, and the Advanced Light Water Reactor (ALWR) in the USA, no advanced reactor development has identified as its primary goal a commercially competitive reactor that will meet and beat prevailing market prices, with increased efficiency, profitability and performance. The development of most other advanced reactor designs, prompted by the TMI accident, focus on enhanced safety, but with a cost premium. For the Sizewell-B reactor in the UK, one of the most expensive reactors built to date, up to 20% of the capital cost has been attributed to "enhanced" safety for an "enhanced" reactor (Board, 1999).Right now, new nuclear power plants are not being built in a large part of the world. It is notable that new nuclear plants are being ordered in the Pacific Rim – Japan, Korea, China and Taiwan. In general, these countries do not have access to low cost natural gas or coal, and this offers a better opportunity for nuclear power to be competitive with these alternatives. In China and Korea, the designs currently under construction are "basic" designs which meet acceptable safety standards but do not include all the enhanced safety features proposed in the next generation of "advanced": reactors, or even those incorporated into Sizewell-B.

High capital costs are the largest single barrier to financing and building new nuclear plants, accounting for some 70% of total generating costs of new nuclear plant.

Under current estimates these capital costs would need to be reduced by some 35%-50% before new nuclear plants can compete with new coal and gas fired generating technologies. Certainly such reductions are possible, but would require a number of strategies, reducing the cost of compliance with safety-related regulation, and reducing the uncertainties associated with safety-related regulation and with post-operational liabilities.

Uncertainties, risks and liabilities are economically significant because they carry a cost, sometimes high, that can be reduced or managed more or less. They must all be estimated and accounted for and are every bit as important to investors as the estimated cost of generation. They in fact have tipped the balance in some of the recent decisions to shut down operating plants in the U.S., before their operating licenses have expired. They were also a major factor the privatisation of the electricity sector in Argentina and in delaying the privatization of British Energy. Therefore, reducing financial uncertainties will be just as important as reducing nominal costs.

New nuclear plants have high financial risks that are not necessarily unique to nuclear power. These include completion risk (that the plant will never be finished and never generate revenues to repay the investment), regulatory risk (that approved safety requirements might change in midstream), and political risk (that government policies affecting the profitability or even the desirability of nuclear power may change). Investors will require compensation for these risks. Added to these are commercial risks such as changing markets and changing demand, and the financial uncertainties associated with safety risks and liabilities management.

The implementation of environmental protection measures and policies, including more stringent atmospheric emission limits are likely to increase the costs of fossil fueled power plants that will have to comply with those regulations by adding pollutant abatement technologies and/or relying on higher quality fuels (e.g. low sulfur coal) that are generally more expensive. The cost of nuclear generated electricity will not be affected by such measures.

Financial issues: The high up-front cost of nuclear power plants is a serious deterrent for capital-short countries even in situations where nuclear power has clear economic merit and also looks appealing on energy security and environmental considerations. This has delayed the initiation of nuclear power projects in several countries, prolonged the construction periods of many and, in some cases, even necessitated the abandonment of work on partly completed projects.

With the increasing current trend towards privatisation and deregulation of the electricity sector, the financing of nuclear power plants is becoming even more difficult because of their high up-front costs, long construction times and the higher economic risk associated with investments with long amortisation periods. Private investors are generally more interested in quick financial returns on their investment rather than in long-term economic advantages. And local, regional or global environmental benefits are not an issue of their concern, at least under the current national regulations and policies.

The overall financing environment for nuclear power, even in a deregulated and privatised power sector regime would become more favourable once the new generation of smaller, modularised reactors with reduced capital costs and shortened construction times become available on the market.

The above review of economic and financial issues related to nuclear power shows that in the long run the prospects of competing with fossil fuels is good. However, in near term, economic and financial issues may be the main deterrents for nuclear power growth. It is, therefore, crucial for the nuclear industry to demonstrate the competitiveness of existing reactors and come up with new designs that would compete with all other sources on the basis of investment costs in order to attract financing.

Many of the current activities of the nuclear industry including life extension and improving the management of operations, are aimed at increasing the competitiveness of existing reactors.

New developments relating to advanced reactors, should also contribute to increasing the competitiveness of nuclear power in the near future. The overall financing environment for nuclear power, even in a deregulated and privatized power sector regime, would become more favourable once the new generation reactors with reduced capital costs and shortened construction times become available on the market.

7. CONCLUSION

All three energy options discussed here: fossil fuels, nuclear power and renewables have their advantages and disadvantages with regard to sustainability criteria for energy systems.

Fossil fuels have a big advantage over nuclear and renewables in respect of demand compatibility. Fossil fuels are used in all countries for provision of all types of energy services at competitive costs. The main drawback of this option is its significant contribution to local and regional environmental degradation and potential climate change. Another issue is unequal distribution of the limited fossil fuel resources over the world.

Renewables have clear advantages over fossil fuels from health & environmental compatibility criteria. Although proponents of the sustainability concept believe that renewables would dominate the energy supply in the long run, it is too early to extrapolate from their current share of less than 1% to a significant share in the future energy mix, due to its low energy density.

Nuclear power based on the use of present generation reactors has clear advantages over fossil fuel in respect of health & environmental compatibility criteria . Nuclear does not pollute the air and does not contribute to CO_2 emissions. But there are drawbacks that could impede an active role for nuclear in a sustainable future energy mix. The challenge to the nuclear community is to come up with a new generation of reactors and fuel cycle technologies for the 21st century characterised by greater economic competitiveness including lower investment costs, significantly improved safety parameters, improved proliferation resistant and waste disposal features.

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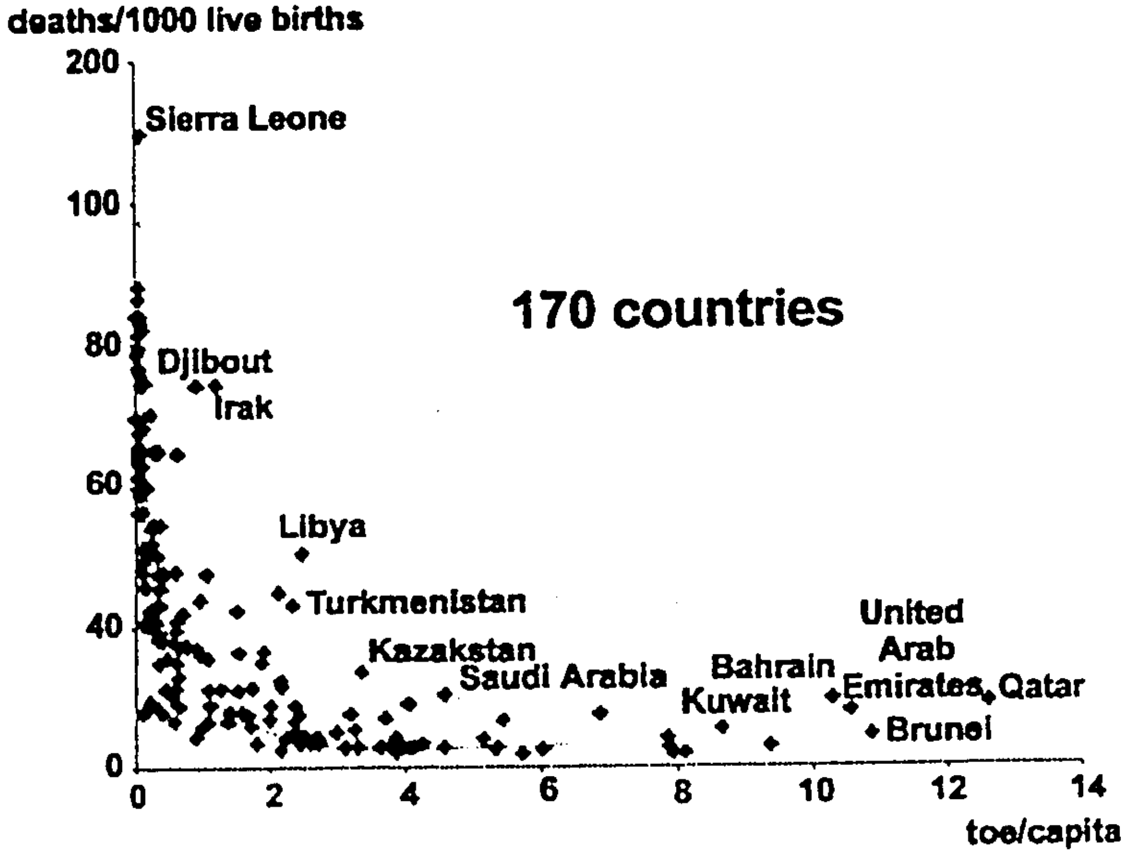
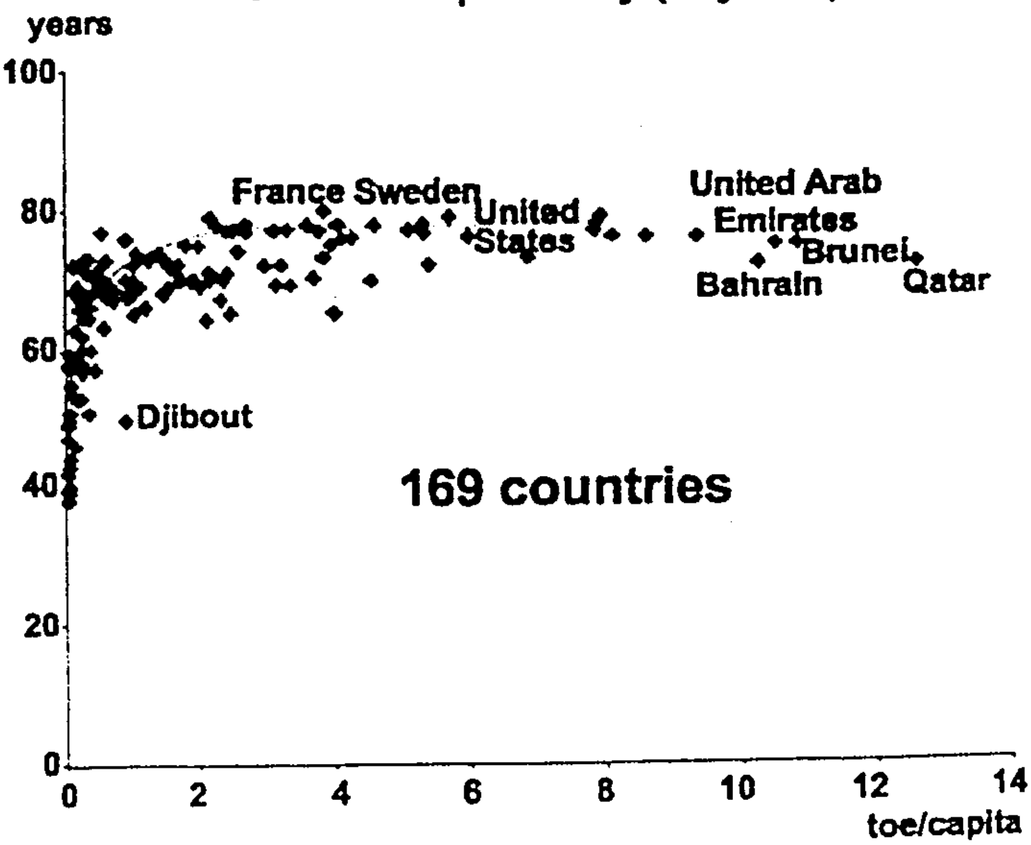
Energy use (in toe/capita) and infant mortality rate (per 1000 live births)



Energy use (in toe per capita) and life expectancy (in years)



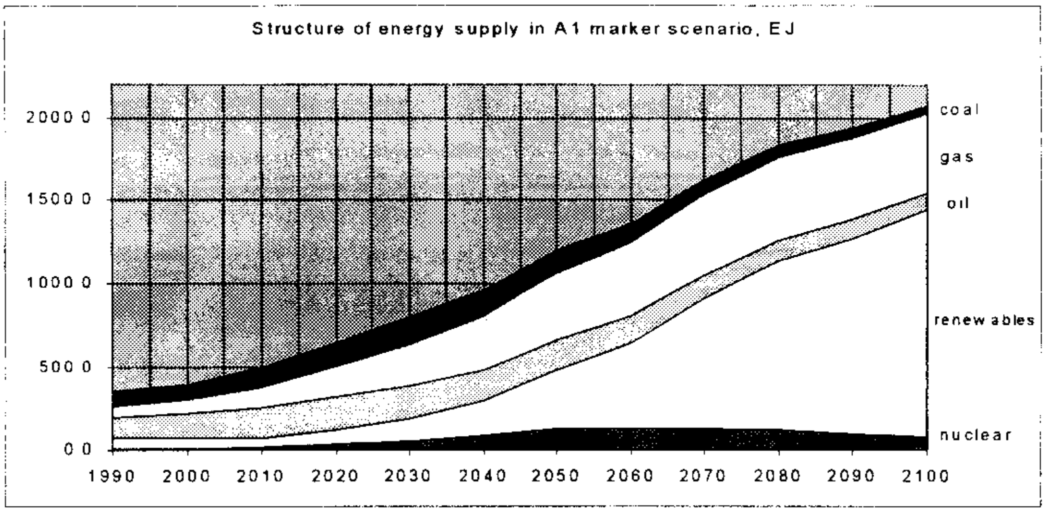


FIG. 2. Primary energy mix in the A1 marker.

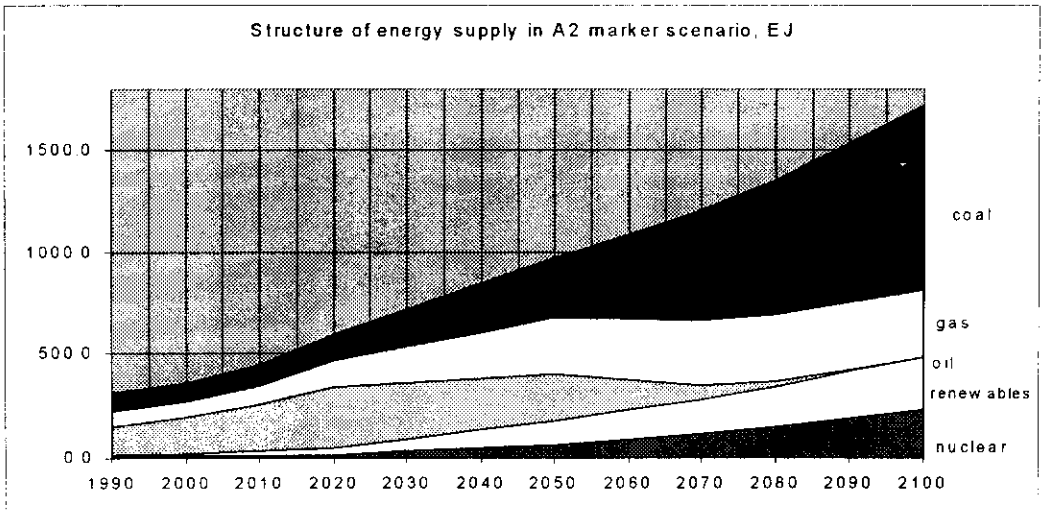


FIG. 3. Primary energy mix in the A2 marker.

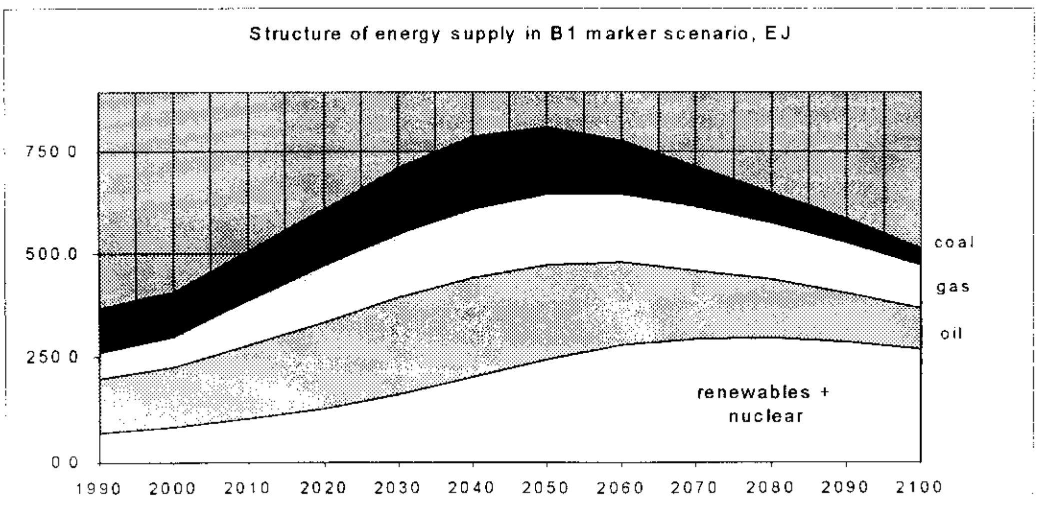


FIG. 4. Primary energy mix in the B1 marker.

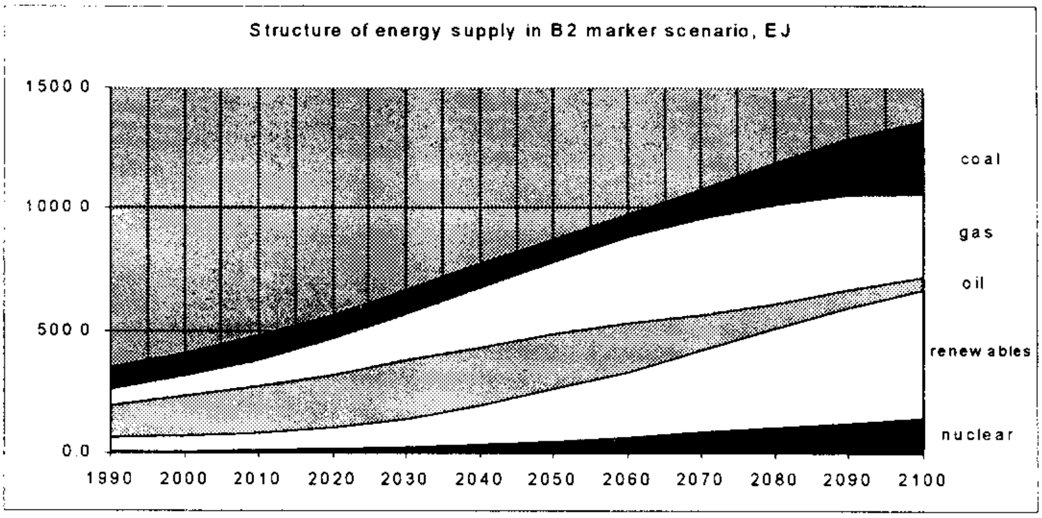


FIG. 5. Primary energy mix in the B2 marker.

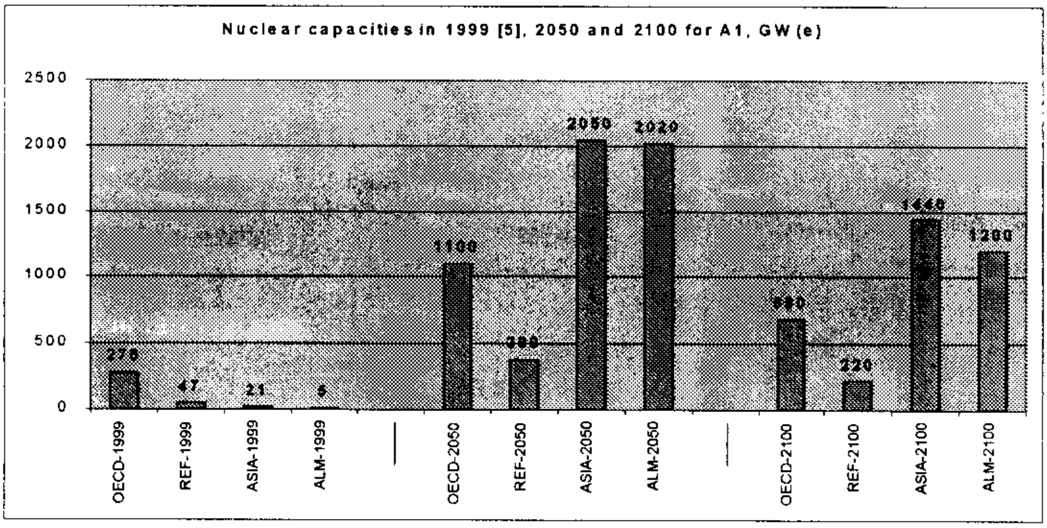


FIG. 6. Nuclear capacities by region for the A1 marker.

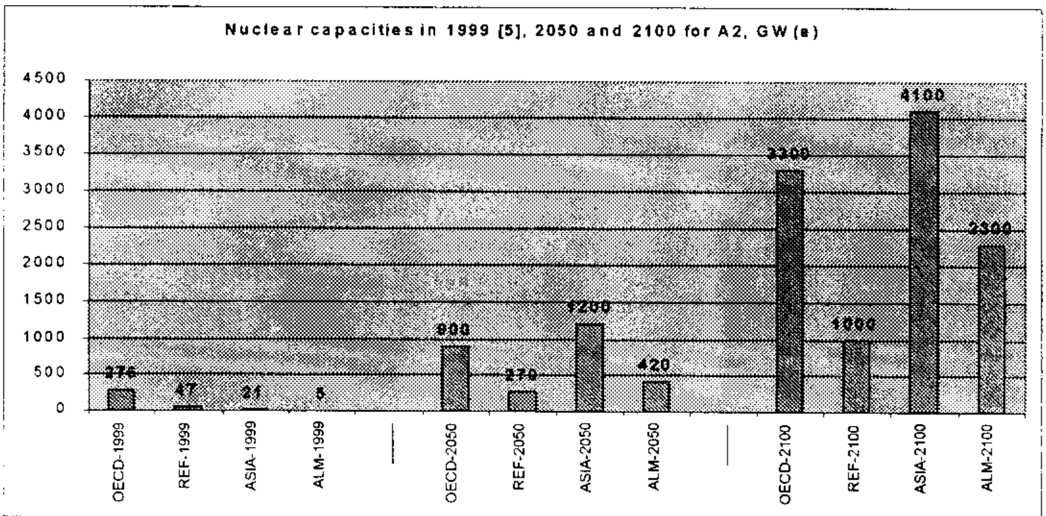


FIG. 7. Nuclear capacities by region for the A2 marker.

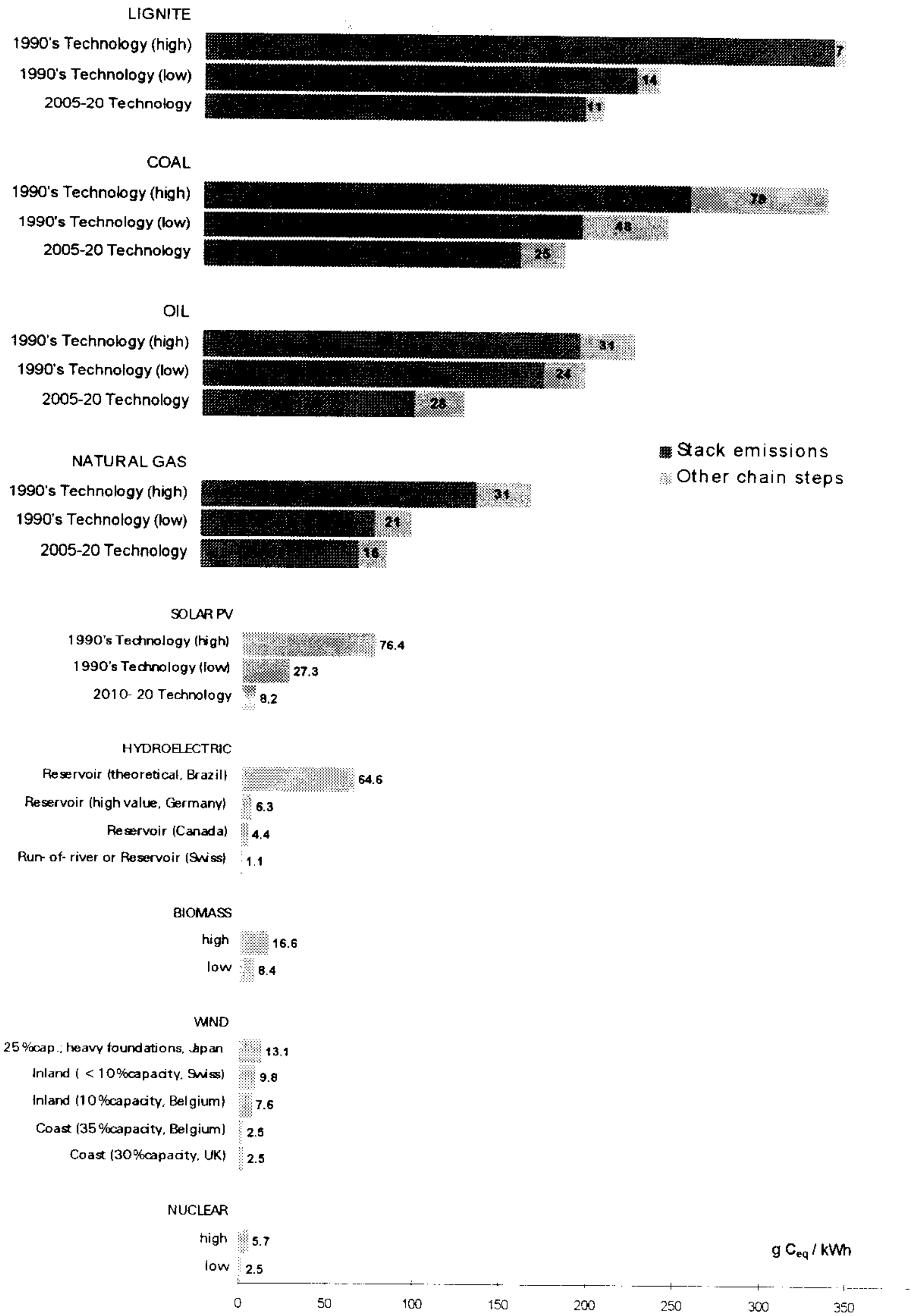


Figure 8: Full energy chain GHG emissions from electricity generation. Source: Spadaro *et al*

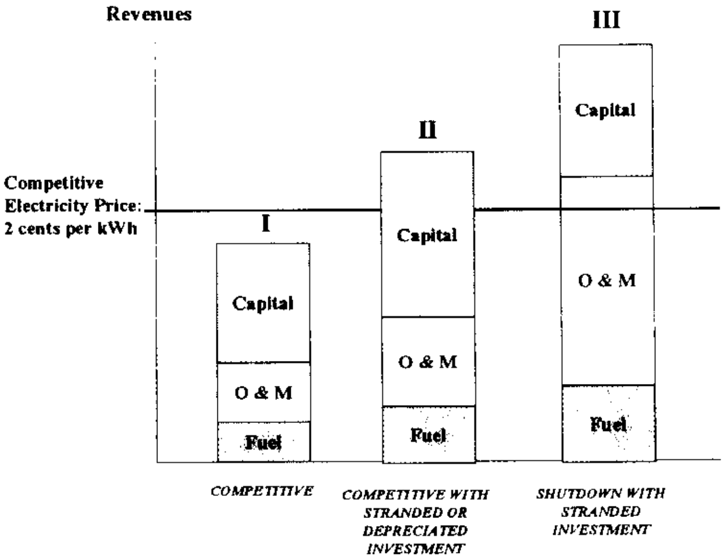


Figure 9: Existing nuclear plants in a competitive market. Source: Gonzales deUmbieta, 1999.

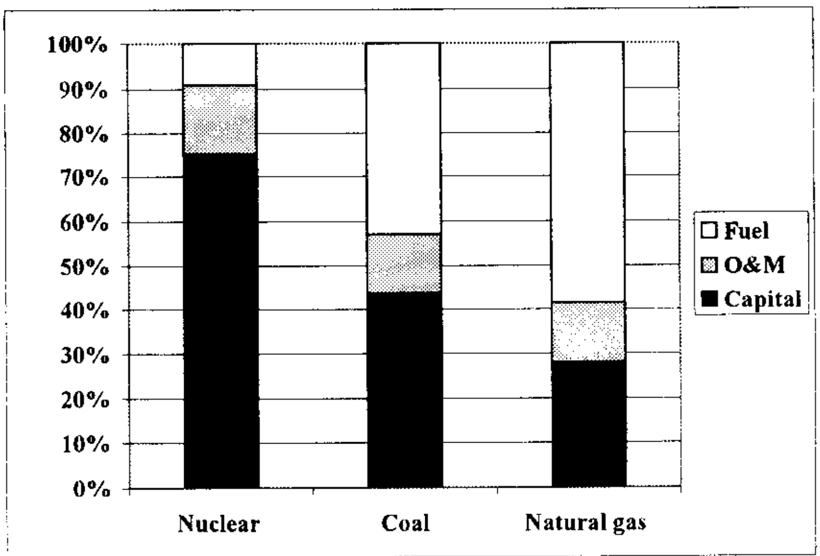


Figure 10: Average electricity generation cost structure for nuclear, coal-fired and natural gas combined cycle plants, 10% discount rate and 25 year planning horizon. Source: Adapted from OECD, 1998.