NUCLEAR POWER FOR SUSTAINABLE ENERGY DEVELOPMENT

IAEA Background Paper for the Second Session of the Ad Hoc Open-ended Intergovernmental Group of Experts on Energy and Sustainable Development
26 February-2 March 2001

Contents

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BACKGROUND

1. No energy source and associated energy conversion technologies is without adverse effects on the environment, is completely risk-free, safe, reliable, and secure, and at the same time maximizes socio-economic welfare. Nuclear power, like all other electricity generating technologies, has its advantages and disadvantages. Assessing the nuclear power option in the context of sustainable energy development, therefore, requires recognising the technology's particular risks and benefits, and comparing these with the risks and benefits of the various alternative energy technologies.

2. On the one hand, nuclear power is a mature technology presently providing some 16 percent of global electricity supply. Generating base load electricity for more than 35 years, nuclear power has also accounted for most of the reduction in the carbon intensity per unit of delivered energy in OECD countries, and has avoided the emission of significant amounts of particulate matter, sulfur dioxide, nitrous oxide and volatile organic compounds. On a full energy chain basis from uranium mining to waste disposal and decommissioning, nuclear power emits little environmental pollution. Currently nuclear power avoids some 520 million tonnes of carbon (8% of total emissions) compared to an equivalent amount of electricity generated from fossil fuels. Its low annual fuel requirements, low share of fuel costs in total generating costs and vast uranium resource base help meet supply security concerns and guard against potentially escalating fossil fuel prices.

3. On the other hand, there is a nuclear power stalemate in many regions in part because the technology is much more costly than was originally projected—a problem exacerbated by low fossil fuel prices and increasingly competitive market conditions arising from the ongoing worldwide restructuring of the electric power industry. Lower than expected electricity demand and excess generating capacity in much of Europe and in North America have led to the need for smaller capacity increments which further challenges the competitive position of nuclear power in these regions. As a consequence, in Europe and in North America nuclear power appears too high an economic risk today for private and public sector investors and the trend is not towards nuclear power in these countries.

4. High costs also put nuclear power beyond the reach of many developing countries, at least absent vendor or government support. Still, nuclear power continues to be of strong interest in a number of Asian countries and countries undergoing economic reform, even where financial resources are limited. This is especially true for countries with notorious shortages in generating capacity, without appreciable domestic energy sources or lacking transportation infrastructures, with

long distances between resource location and consumption centers, or high electricity demand expectations.

5. Economics and security of supply remain the prime consideration in the choice of nuclear power, along with an awareness of its environmental benefits, particularly reduced air pollution emissions. However, other factors tend to cloud future prospects for nuclear power, namely, public concerns relating to the operating safety, radioactive-waste management, and proliferation of nuclear capabilities for non-peaceful purposes. In many cases these concerns overshadow the environmental and supply security benefits of nuclear power to the point that some groups of civil society perceive nuclear power as unsustainable.

6. If nuclear power continues to contribute to global energy supply as the world moves towards more sustainable development, then it is important to deal with the concerns - whether perceived or real - that surround this contribution, and to explore options and policies that would permit nuclear power to play a more significant role in a sustainable energy future. Indeed, it is difficult to envisage a future for nuclear power unless the technology is at least tolerated in the general public. At its root is the fact that these issues cannot be resolved in narrow technical and economic terms. Perceptions about costs, safety, proliferation/diversion impacts and risks in waste management, for example, matter as much as detailed engineering calculations and expert consent.

7. The following sections address issues and perceptions revolving around the use of nuclear power and its potential contribution to sustainable development. As per suggestion of UNDESA, the following sections are structured to first identify the "Challenges facing nuclear energy technologies", then to offer "Options and strategies to improve nuclear energy technologies", to "Actions relevant to overarching issues for nuclear energy technologies" and finally touch upon "Proposals for international and regional cooperation for nuclear energy technologies".

NUCLEAR SAFETY

Challenges facing nuclear energy technologies

8. Countries operating nuclear power plants maintain a legislative and regulatory framework governing the safety of nuclear installations. The national systems are complemented by a broad spectrum of mechanisms for international co-operation, which encompass exchange of experience between countries in the siting, design, construction and operation of reactors, a set of non-binding international safety standards prepared by IAEA, which serve as an international reference, peer reviews by international teams of experts of the safety of installations based on these standards, and finally legally binding instruments such as the Conventions on Nuclear Safety. The challenge is to ensure the safe operation of the existing reactors, in many countries under the pressure of economic competitiveness. As regards new facilities, progressive improvements in safety need to materialize through innovative technologies. In addition, regulatory authorities have to streamline licensing processes for new designs and still enable a high degree of transparency for public scrutiny.

Options and strategies to improve nuclear energy technologies

9. New evolutionary designs have been developed where improved safety results from making use of modern control technology, simplifying safety systems, and from introducing passive safety features requiring less human interaction. 'Risk informed decision making' focuses on priority safety issues. The industry is also pursuing revolutionary designs that would meet the objective of a practical

elimination of accident sequences leading to a significant release of radioactivity and limit accident impacts to the plant site. Innovative designs based on passive safety features aim at demonstrating that certain safety systems required for today's reactors are no longer needed for protecting public health and safety.

Actions relevant to overarching issues for nuclear energy technologies

10. Efforts are underway in many countries to improve the effectiveness and efficiency of the Regulatory Bodies by streamlining standards and regulations and licensing processes, exploring modern tools like "risk informed " regulations and "safety indicators", prioritising inspection and enforcement activities, and enhancing the quality assurance process in the regulatory bodies themselves. A clear separation of the Regulatory Bodies from bodies responsible for "promoting" nuclear energy improves transparency and credibility. Stagnating nuclear power risks the loss of both institutional and corporate knowledge.

11. At the international level the IAEA is the organisation with the mandate to establish safety standards and to provide for their application including providing expert advice and peer (safety) review services. Strengthened international co-operation in technology RD&D could lead to consensus on safety requirements, agreements on technical solutions, and sharing of research results. At the industrial level, the World Association of Nuclear Operators (WANO) fosters safety self-assessments and peer reviews.

Proposals for international and regional cooperation for nuclear energy technologies

12. Intensifying international co-operation can economise national efforts, harmonise safety requirements across countries thus easing licensing, promote a similar high level of nuclear safety world-wide, and add to transparency in nuclear safety related decisions. Other measures include strengthening the international peer safety review mechanism, promoting self-assessments and learning from international experience, e.g. through the Incident Reporting System jointly operated by IAEA and NEA, the development of an internationally adopted set of safety indicators and increased transparency in nuclear safety.

EFFECTS OF IONIZING RADIATION ON HUMAN HEALTH

Challenges facing nuclear energy technologies

13. Radiation effects are caused by damage in cells, resulting in cell death or modifications that can affect normal functioning organs and tissues. Cells are able to repair and recover from the damage imparted by radiation. However, unrepaired or misrepaired damage leaves a potential for subsequent changes; in particular, cancerous growth may develop in the tissue, or hereditary effects may occur in offspring. For high radiation doses, there is clear evidence of biological effects, ranging from an increased risk of cancer and skin necrosis to human death. For the low doses that typically result from routine operation of nuclear facilities, where cancer induction is the main concern, the situation is more complex. Existing national and international radiation protection policies and standards are based on the assumption that, even at low doses, radiation may act as an initiator of cancer. The simplest representation of the relation between the dose and the effect is a linear relationship, which is consistent with most of the available data. The dose limits set by the standards ensure that the

possible health effects will be very small. Still some of the public perceive the radiation from nuclear power as a large, unknown hazard to be avoided at any cost.

Options, strategies to improve nuclear technology

14. The nuclear industry manages existing radiation protection confidently – radiation doses to workers and the public are generally below the prescribed limits. The deviations, which inevitably occur, are of the same nature and frequency as are observed from non-nuclear industrial incidents or accidents. Strengthening the existing high level of radiation protection is still the primary strategy. Continuing studies of the effects of low radiation doses might help to cope with public concerns about nuclear power.

Overarching issues

15. The risk to the individual of getting cancer depends on many factors, such as lifestyle, profession, age, and gender. The risk of radiation induced cancer should be assessed in relation to non-radiation cancers and other health risks. Comparisons of health risks from various industrial activities, social habits, and natural phenomena exist. The very small impact of nuclear activities shown in these comparisons do not lead to corresponding changes in environmental regulations for non-nuclear technologies. This reflects the absence of equal footing for different technological hazards. Ensuring such a footing and managing the hazards on that basis, preferably using economic instruments such as the internalization of the associated external costs, is an extremely important overarching issue.

Proposals for international, regional co-operation

16. Two principal issues call for international co-operation: the management of radiation hazards in a uniform framework with other technological hazards, possibly using the internalization of external costs, and the quantification of the effects of very small radiation doses. The two issues are extremely complex, both scientifically and organisationally; that is why international co-operation is desirable and beneficial for all counterparts.

SPENT FUEL AND WASTE MANAGEMENT

Challenges facing nuclear energy technologies

17. Although volumes are small compared to other forms of electricity generation, spent fuels and radioactive wastes from nuclear power plants need to be managed safely. About 25 tonnes of spent fuel are discharged annually per 1,000 MW(e) generated. By the year 2010 the IAEA estimates the cumulative amount of spent fuel produced will be 340,000 tonnes, with 110,000 tonnes reprocessed and 230,000 tonnes stored. Spent fuel can be safely stored for long times in water filled pools or dry facilities, some of which have been in operation for 30 years. While spent fuel storage capacity globally is considered adequate over the next few decades, facilities at some specific sites are nearing capacity. High-level radioactive waste is produced when spent fuel is reprocessed to recover uranium and plutonium for recycle as reactor fuel. Some countries do not reprocess spent fuel but plan to directly dispose of it. The scientific and technically communities generally agree that geologic disposal, using a system of engineered and natural barriers, can be carried out safely in stable geologic formations. However, site selection is a major public acceptance issue in all countries

developing such facilities and no such facility has yet been authorized. For now most high-level waste from commercial nuclear power is either stored on-site or transported to interim storage sites.

Options and strategies to improve nuclear energy technologies

18. Several countries are currently engaged in studies of deep geologic disposal, preparatory to construction of repositories (Belgium, Canada, Finland, France, Germany, Japan, Sweden, Switzerland and United States) by developing and testing underground research facilities for demonstrating the technologies to dispose safely of high level waste and spent nuclear fuel. Potential radiation exposures have been calculated to be close to zero for periods of 100,000 years for all scenarios/sites considered; for longer periods the risks are so small as to impose very small additional externality costs, even if there is no discounting for these uncertain remote future events. Licensing and opening of disposal facilities will be the convincing demonstration that it can be done. National efforts supplemented by IAEA activities such as facilitating early entry into force of the legally binding Joint Convention on the Safe Management of Spent Fuel and the Safe Management of Radioactive Waste or by fostering co-operative research on scientific issues related to the engineered and natural barriers for waste isolation.

Actions relevant to overarching issues for nuclear energy technologies

19. Countries with small nuclear programmes (one or a few reactors), or having fragile economies, often lack the resources to develop geologic repositories. The IAEA provides a forum for technology transfer from the larger industrialized countries to such countries by sponsoring co-ordinating research, preparing documents on state-of-the-art technologies, and organizing international co-operative projects. The Agency is also scrutinizing factors that would need to be addressed in developing multi-national repositories and the scenarios that could lead to development of such facilities.

Proposals for international and regional cooperation for nuclear energy technologies.

20. A technology being considered for the future management of high-level waste is the partitioning of the long-lived radionuclides and their transmutation to shorter half-life radionuclides in accelerators or specially designed reactors. This technology has yet to be developed and costs are likely to be high, but it is of interest to countries planning to reprocess spent fuel to recover the maximum energy from uranium fuel by recycle of the recovered plutonium. The Agency, as well as the OECD/NEA and the CEC have programmes in place to transfer technology and provide fora for international information exchange.

PROLIFERATION OF FISSILE MATERIAL

Challenges facing nuclear energy technologies

21. Nuclear fission is central to both nuclear power production and nuclear weapons. Proliferation concerns stems from the possibility of diverting nuclear material from peaceful uses, and the potential misuse of nuclear facilities to produce weapon-grade nuclear material. At present, some 900 nuclear related facilities including locations outside facilities are under Agency safeguards, including power reactor facilities, fuel fabrication plants, reprocessing and enrichment plants. With such a large and

likely growing number of nuclear power-related facilities, the challenge is to curb the potential nuclear power link to weapons proliferation by implementing effective and efficient safeguards.

Options and strategies to improve nuclear energy technologies:

22. The Treaty on the Non-Proliferation of Nuclear Weapons (NPT), signed in 1970 and extended indefinitely in 1995, is at the centre of the international non-proliferation regime. At present, 187 States have signed the NPT, including 182 States which do not possess nuclear weapons and the five States which had tested nuclear weapons before the NPT came into force. The international community has entrusted the IAEA with the authority to safeguard nuclear facilities. The 1997 Model Additional to Safeguards agreements extend the IAEA safeguards authority and allows access to locations not previously subject to IAEA inspection. Treaties other than the NPT focus on preventing the misuse of nuclear materials as well as the establishment of new nuclear weapon free zone treaties in many parts of the world. Technology strategies to complement IAEA safeguards that are considered include the development of proliferation resistant nuclear power technologies and fuel cycles. Safeguards implementation effectiveness and efficiency would greatly benefit from fuel cycles that better take into account the verification requirements of IAEA safeguards.

Actions relevant to overarching issues for nuclear energy technologies

23. Nuclear weapons are above all a matter of politics and may not have so much to do with nuclear power. Consequently, the response to weapons proliferation has to be a political one. IAEA safeguards provide one of the most crucial answers. The international community must ensure the continuous improvement of the effectiveness and efficiency of IAEA safeguards, provide the resources required for the expansion of the safeguards technical verification goals to include both declared and undeclared nuclear material and activities and the implementation of state-of-the-art verification technologies and address the conceptual issues related to these new developments.

Proposals for international and regional cooperation for nuclear energy technologies

24. International co-operation is critical for an effective barrier against proliferation. IAEA safeguards activities have to complement and interact with other components of the international non-proliferation regime such as export control of nuclear and nuclear-related material and equipment, nuclear non-proliferation and disarmament treaties including nuclear weapons free zones, control of nuclear material illicit trafficking, physical protection of nuclear material and assessment of existing and innovative fuel cycle developments including the utilised technologies and nuclear material.

ECONOMIC COMPETITIVENESS

Challenges facing nuclear energy technologies

25. Given low nuclear fuel costs and being partially or fully depreciated, many existing reactors operate efficiently, safely and profitably even in the most competitive markets. There are often strong economic incentives to extend the life of profitable existing nuclear power plants. The investment requirements of such extensions are generally considerably less than the costs of new fossil fuelled or renewable plants. However, new nuclear power plants can cost 2–4 times more to build than fossil-fuelled plants with pay back times well over twenty years, take longer to build than other conventional power generating facilities, and face lengthy and costly regulatory and licensing

procedures. Investors, especially in competitive capital markets, are aware that nuclear facilities have been at risk for both completion and operation and tend to demand higher returns to justify the higher economic risk. The result is that nuclear power is now seldom the "least-cost" option for new power generation. In addition, there are concerns that certain cost factors that are incurred after plant closure such as decommissioning and waste disposal costs are not adequately reflected in present cost assessments.

Options and strategies to improve nuclear energy technologies

26. Based on utility requirement documents the nuclear industry expends considerable efforts to meet the challenge to cut costs to allow for competitiveness and to improve safety at the same time to ambitious levels. Simultaneously improving operating safety and economic performance of technology has always been one of the fundamental drivers of engineering ingenuity and innovation. Evolutionary design improvements explore avenues to lower costs and increase safety using modern control technology, simplifying safety systems, making use of passive design features and capitalizing on economies of scale. Several such advanced reactors are commercially available. Evolutionary improvements alone may not revive the nuclear option globally. Therefore, revolutionary designs that turn from large to smaller units with much shorter construction periods, with significantly lower capital costs and load following capability are under development. In addition to lower generating costs and even greater use of passive safety features, these designs may also include proliferation resistance features. These smaller and thus easier to finance systems could also operate in countries with modest electricity grids or areas without grid connections or non-electric applications such as district heating and desalination. Decommissioning costs vary greatly with the scope of decommissioning and waste disposal efforts required by national regulation. The electricity generating cost estimates published by OECD/IEA and OECD/NEA include decommissioning costs based on current regulation. Waste management and disposal comprise a small share of total nuclear fuel cycle costs and amount to 2-3% of generation cost.

Actions relevant to overarching issues for nuclear energy technologies

27. All energy supply options, directly or indirectly, produce some form of pollution and thereby result in some form of health and environmental impacts. The impacts associated with pollution are deemed to be externalities, i.e., costs that are not generally factored into the market price of energy. Society arrives at a socially and politically acceptable level of external costs by imposing pollution limits, environmental and health standards, and taxes on pollution assuring that, in the end, "the polluter pays" for damages caused. Valuating externalities is not simple and requires consideration of occupational as well as public effects for the entire fuel chain - from fuel recovery to decommissioning - not only on a local scale, but also regionally and globally. Recent studies such as the joint EU/USA study ExterneE indicate that external costs of nuclear power and renewables are significantly lower than those for coal and oil-fired electricity which would bear the brunt of a cost placed on health and environmental impacts due to releases of noxious gases, toxic pollutants and particularly greenhouse emissions. If internalised this would definitely improve the economic competitiveness of nuclear power and renewables. As well, the addition of a carbon value of 30 USD per tonne to today's roughly 50 USD coal price would increase the comparative cost of coal electricity by 20%. Clearly, carbon values would not change the generating costs of nuclear, hydroelectric and most renewable systems at all.

Proposals for international and regional cooperation for nuclear energy technologies

28. Prototype or demonstration plants would be needed for most innovative reactor designs. Under current circumstances with limited government support of nuclear research and development, there is a need for close co-ordination of RD&D activities to avoid duplication while pooling resources could generate the critical momentum for the successful development and demonstration of new and innovative reactors and fuel cycle concepts. It could be facilitated by international co-operation among governmental research centres, international organizations (such as the IAEA, OECD/NEA, IEA) and particularly the nuclear industry. The nuclear industry will need to be a key player in this process and recent international industry mergers may lead to a more focused look at the issue. Early certification by governments, perhaps the issuing of international licenses, would help avert the unpredictable delays that have driven up capital costs in the past.

TECHNOLOGY TRANSFER

Challenges facing nuclear energy technologies

29. Technology transfer has been an important element for the diffusion of nuclear power technology. Given the unique nature of nuclear power, technology transfer necessarily involves governments, the nuclear industry and financial institutions. Most countries with nuclear power programmes benefited from technology transfer, meanwhile some have developed a domestic industry to a measure of self-sufficiency. The stagnation of nuclear power in countries with technology export capacity may limit the transfer of innovative technologies as recipient countries often wish to adopt commercially proven technology. As well, enrolment in nuclear science and engineering programmes has dropped below long-term replacement levels possibly limiting the export capacity for nuclear technologies in the longer run, as well as creating near term difficulties in maintaining qualified staffs for existing plants. Multilateral financial institutions usually do not consider the finance of nuclear projects in developing countries.

Options and strategies to improve nuclear energy technologies

30. Private sector-driven technology transfer remains crucial for the diffusion of nuclear power. Governments, however, have to create enabling policies and ensure the timely establishment of the necessary infrastructures and independent regulatory institutions. Smaller and less capital-intensive units may improve the finance of technology transfer. The use of the mechanisms under the Kyoto Protocol (clean development mechanisms and joint implementation) can accelerate nuclear technology transfer. These mechanisms intensify co-operation between sponsor and host countries involving governments, private sector entities and community organizations – traditionally a prerequisite for successful nuclear technology transfer.

Actions relevant to overarching issues for nuclear energy technologies

31. Will there be a ratified Kyoto Protocol, and if so, will nuclear be considered as an eligible technology for use with the flexible mechanisms? An equally important question concerns the willingness of government to introduce and enforce environmental protection standards. In one way or another, these questions influence technology choice and can provide additional financial incentives for technology transfer.

Proposals for international and regional cooperation for nuclear energy technologies.

32. Building human and institutional capacity must be an integral part of technology transfer. Capacity building has been one of the IAEA's main methods for implementing technology transfer to developing countries. Member States wishing to embark on a nuclear power programme can request assistance on all relevant technical, safety, legal and regulatory aspects through national or regional projects. Technology transfer will be through expert advice and missions, training courses, fellowships, scientific visits, workshops and, in support of a project, a limited supply of equipment.

10URANIUM MINING AND AVAILABILITY OF FISSILE MATERIAL

Challenges facing nuclear energy technologies

33. Stable, economically accessible and environmentally benign fuel supply contributes to sustainable energy development. Naturally occurring uranium is a finite resource with long-term availability depending on demand and advances in geosciences and mining technology. Presently known uranium reserves are sufficient to fuel the world's existing reactors well through the first half of the 21^{st} century. Stepped-up use of nuclear power might accelerate the depletion process. Like mining operations in general uranium mining has been a source of environmental concern, particularly because mining and milling results in wastes and releases of radioactivity (primarily from naturally occurring by-products such as radon and radium).

Options and strategies to improve nuclear energy technologies

34. Lower than expected demand and the availability of fissile material from military stocks have resulted in a uranium market glut for quite some time and exploration is at a historical low. Like with any natural resources, higher demand would raise prices and stimulate exploration and expand the resources base. In addition to conventional uranium reserves, there exist enormous amounts of unconventional low concentration natural uranium in the earth's crust and oceans. Thorium is another fuel candidate for nuclear power. Appropriate technologies to tap into these resources have been investigated but development has been low priority given the plentiful reserve base of conventional uranium. Current once-through fuel cycles utilize only some 5 percent of the energy content of the fuel. Reprocessing and recycling of spent fuel as is already practised by several countries extend the fuel availability considerably. In combination with breeder reactors, plutonium recycling would effectively decouple nuclear power from fuel resource considerations. A similar effect could be achieved in the longer run through the development and commercialisation of fusion technology. Continuous improvements in mining practices, especially post-operation, have already improved safety and reduced potential environmental impacts significantly.

Actions relevant to overarching issues for nuclear energy technologies

35. Nuclear power offers a unique venue to reduce the existing stocks of highly enriched uranium and plutonium from dismantled weapons programmes.

Proposals for international and regional cooperation for nuclear energy technologies

36. International co-operation could expedite the utilization of military stocks of fissile material for peaceful purposes. Regional (multi-national) reprocessing and fuel recycling centres would allow for easier safeguards.

Attachment: Five Case Studies

INTRODUCTION

The attached five case studies were contributed as input to the February 2001 second session of the Ad Hoc Open-ended Intergovernmental Group of Experts. One item on the agenda of the second session pertains to "lessons learned." In connection with this agenda item, the Group has invited "case studies describing lessons learned and experiences gained at the national levels in translating sustainable energy policies into concrete actions." The attached case studies were contributed in response to that invitation. A review committee concluded:

> *"These are plans and projections and are therefore speculative rather than descriptive, which is evident from the fact that they do not follow the prescribed format. As a result, there are no lessons learned, which was the goal of the exercise. In a way, this is a shame, because at least in the cases of China and Korea, there is enough experience with nuclear energy to have carried out a real case study to determine the effectiveness of nuclear energy in reducing GHG and noxious pollutant emissions and in providing real figures for the costs involved. But, of course, this would have taken considerable time and money to carry out. We encourage them to include the documents as examples of projections in the background document on nuclear energy they are preparing for the second session of the Ad Hoc Group of Experts."*

In accordance with that suggestion, we include the case studies here. The review committee is absolutely right that as case studies that assess future options rather than past actions, these can yield no "lessons learned." In the cases of China and Korea that the committee cites, however, the data are taken from specific recent projects and can therefore be assumed to be very close to what would have been the result had this assessment been applied to those recent projects.

The case studies are written by authors from five non-Annex I countries (China, India, Pakistan, Republic of Korea, and Viet Nam) and address possible CDM projects in those countries based on nuclear power. They were developed in response to a resolution of the IAEA's 1999 General Conference that asked the Agency to help developing country members explore and prepare such projects. The authors have presented the case studies at side events at the IAEA's 2000 General Conference and at the Sixth Conference of the Parties to the UNFCCC (CoP-6) in The Hague in November 2000.

The case studies follow a somewhat different format than that suggested in the guidelines circulated in Ms. Abdalla's April 11, 2000 e-mail. However, they cover most of the points in the guidelines and are all limited to four pages. They are therefore presented as written by their original authors, with this cover note added to address the specific items listed in the guidelines.

SUGGESTED FORMAT FOR THE CASE STUDY

Abstract: National authors in China, India, Pakistan, Republic of Korea, and Viet Nam present initial assessments of nuclear power projects as prospective CDM projects under the Kyoto Protocol, including estimated carbon emission reduction costs. Nuclear power projects appear the

most cost-effective new capacity alternative for reducing power sector GHG emissions in all five countries. The one exception is in India for new capacity to be sited at least 1200 km from the nearest useful coal mine. In this case, a nuclear power plant is the overall least-cost option and thus ineligible as a CDM project. The case studies estimate carbon reduction costs to be within the range other studies indicate might be profitable.

Key issue addressed: The key issue addressed by all five case studies is that of limiting future greenhouse gas emissions. All, however, also address issues such as energy supply security, reductions in local air pollution, and sustainable economic development.

Objectives: The case studies provide initial assessments of whether nuclear power projects in the five countries might meet the prospective eligibility criteria for CDM projects under the UNFCCC and the Kyoto Protocol. They also estimate the cost of carbon emission reductions that would be associated with such nuclear power CDM projects. The assessment of CDM eligibility is uncertain because, with the suspension of CoP-6 on November 25, 2000, the eligibility criteria remain undefined. In particular, one proposal discussed at CoP-6 was an explicit exclusion of nuclear projects from the CDM. Such a provision would obviously vitiate all five case studies.

Implementation: As these are analytic case studies, implementation in the sense of carrying out the studies was not a major issue. The challenges were getting good cost estimates and good assessments of national energy plans and projections. The authors were well placed to get that information. The steps that would be needed to actually implement a specific nuclear power CDM project are much more substantial. They will depend, first, on the final formulation of the CDM rules. Second, they will depend on how much it costs to reduce carbon in other ways. That is, while each of the case studies finds nuclear power to be the most cost-effective *power plant* choice for reducing carbon emissions in the baseload electricity generating sector, there may be cheaper non-power carbon reductions that would attract away CDM investment dollars. And third, depending on how the CDM rules are negotiated, financing may be an important obstacle. The Kyoto Protocol only applies to 2008-2012. If buyers only want to buy carbon emission reductions that occur in those five years, the selling price for each tonne of carbon will have to increase relative to that for a buyer who – believing that limits will be extended beyond Kyoto – is interested in buying emission reductions covering the entire plant lifetime. Financing may also depend on the level set for the CDM administrative payments and adaptation fund contributions provided for in the Kyoto Protocol. The higher the overall price of carbon reductions, of course, the more difficult it will be to attract buyers.

Outcome and impacts: The outcome is the case studies that are attached. If the CDM rules are written to exclude nuclear power, these case studies will have little impact. Otherwise, their impact will depend on how the market for Certified Emission Reductions (CERs) develops. If Annex I countries are required to accomplish half of their reductions at home, for example, if a glut of forestry projects or Russian hot air keeps CER prices low, and if it appears that limits after 2012 will be relatively relaxed, nuclear power CDM projects may prove too expensive to have much of an impact. If the price and timing are right, however, the initial expertise promoted by these case studies may develop into more complete, and ultimately successful, proposals.

Project/program status: The case studies are complete. Next steps await developments at particularly the resumed CoP-6 in 2001.

Replicability: Such case studies would not be difficult to replicate in most countries. However, even under the same assumptions on CER rules (n.b., no nuclear exclusion), other countries may generate different results concerning the eligibility of nuclear power for CDM projects and the associated CER costs. But extending the analysis, if not the conclusions, to other countries would be relatively straightforward.

Lessons Learned: The principal lesson is that – absent prejudicial CDM rules – nuclear power projects appear to be the most cost-effective new capacity alternative for reducing future GHG emissions in the baseload electricity generating sector in the five countries studied. The only exception is the case of new capacity in India that would be sited at least 1200 km from the nearest useful coal mine. In that case, a nuclear power plant is estimated to be the overall least-cost alternative and thus ineligible as a CDM project. Second, all five case studies estimated carbon reduction costs to be within the range that other studies indicate might be profitable. As we are not aware that anyone has yet taken the next step that would be needed to turn these analytic conclusions into concrete projects, we cannot comment on the implementation lessons that might be learned in that process.

Further Information: The individual case studies list the authors and their affiliations. Overall coordination was provided by:

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BACKGROUND ON THE KYOTO PROTOCOL AND FLEXIBLE MECHANISMS

The possibility of global climate change resulting from an increase in greenhouse gas (GHG) concentrations in the atmosphere is a major global concern. At the Third Conference of the Parties (CoP 3) to the United Nations Framework Convention on Climate Change (UNFCCC) held at Kyoto, in December 1997, industrialized countries (i.e. Annex I countries[1]) agreed to accept binding commitments that would reduce their collective GHG emissions, in the 2008–2012 commitment period, by at least 5% below 1990 levels[2]. These Annex I countries also agreed to make demonstrable progress towards reducing GHG emissions by 2005.

Because climate change is a global problem, i.e. it does not matter where on the globe GHGs are emitted — they all end up in the same atmosphere, many market economists maintain that mitigation should first occur wherever it is cheapest. Thus Article 12 of the Kyoto Protocol makes provisions by which those signatories who are required to limit emissions can gain credit for financing cost-effective mitigation projects in developing countries, while at the same time promoting sustainable development through the provision of financial and technical assistance. This option is known as the Clean Development Mechanism (CDM).

The CDM could be of particular interest to developing countries, which are not subject to emission limitations in the Kyoto Protocol. For example, the use of capital-intensive nuclear power instead of less costly coal-fired electricity generation would result in a significant reduction in GHG emissions. Because many developing countries may not be able to afford the higher investments associated with a nuclear power project, or because nuclear may simply not be the least-cost generation option for a given country, CDM offers an opportunity for (incremental) capital and technology transfer sponsored by an Annex I country in exchange for GHG emission credits. The benefit to the sponsor would be compliance with the emission limits set out in the Protocol, at a lower cost than if mitigation occurred at home.

[1] Annex I includes the OECD (membership of 1990) plus Belarus, Bulgaria, Croatia, Czech Rep. Estonia, Hungary, Latvia, Lithuania, Poland, Romania, the Russian Federation, the Slovak Rep., Slovenia, and Ukraine.

[2] The individual national emission allowances relative to 1990 are (in percent):

Australia	108		Greece	92	(125)	Norway	101	
Austria	92	(87)	Hungary	94		Poland	94	
Belgium	92	(92.5)	Iceland	110		Portugal	92	(127)
Bulgaria	92		Ireland	92	(113)	Romania	92	
Canada	94		Italy	92	(93.5)	Russian Federation	100	
Croatia	95		Japan	94		Slovakia	92	
Czech Republic	92		Latvia	92		Slovenia	92	
Denmark	92	(79)	Liechtenstein	92		Spain	92	(115)
Estonia	92		Lithuania	92		Sweden	92	(104)
European Community	92		Luxembourg	92	(72)	Switzerland	92	
Finland	92	(100)	Monaco	92		Ukraine	100	
France	92	(100)	Netherlands	92	(94)	United Kingdom	92	(88.5)
Germany	92	(79)	New Zealand	100		United States of America	93	

The figures in parentheses reflect the EU internal reduction agreements (the "EU bubble"). Annex I members that are also Economies in Transition are allowed to propose base years other than 1990 for calculating their own reductions.

Interpretation of Article 12 of the Kyoto Protocol

CDM is one of three "flexibility" mechanisms for emission reductions that were adopted as part of the Kyoto Protocol[3]. However, CDM is the only mechanism involving non-Annex I[4] countries (i.e. those that are not subject to emission reduction commitments). The other two can only be used among Annex I countries. CDM differs in a second important way from the other two flexibility mechanisms – under CDM, certified emission reductions (CERs) prior to 2008 can be applied toward Annex I country reduction requirements in the 2008–2012 commitment period. Finally, a third difference between CDM and the other mechanisms is that CDM is open to private sector involvement.

There are several important aspects of CDM beyond its contribution to the ultimate objective of the Convention, i.e. stabilization of the atmospheric GHG concentration at a "safe" level consistent with sustainable development. For a project to qualify under the CDM, it must provide more than just lower GHG emissions. Specifically, a CDM project should

- provide real, measurable and certifiable emission reductions that are additional to any that would occur in the absence of the project (additionality);
- assist Annex I countries in complying with their quantified emission limitation and reduction commitments;
- supplement domestic action in Annex I countries; and
- benefit non-Annex I countries in terms of technology, capital and know-how transfer.

The CDM will be under the authority and guidance of the Parties to the Kyoto Protocol and supervised by an Executive Board, the structure of which has yet to be defined. The certification of emission reductions will be organized by operational entities (also still to be defined) under the Board's supervision. All CER units will be registered with the Executive Board.

Implementation Criteria of Article 12 of the Kyoto Protocol

There are several prerequisites associated with the determination of a CDM project's emission reduction levels. These include

- an unambiguous definition of project boundaries;
- the definition of a baseline project against which the CDM project can be evaluated;
- the definition of the CDM project;
- mechanisms to ensure the measurement, verification and certification of actual emission reductions after project implementation; and
- the establishment of an adaptation fund.

Project boundaries delineate the physical and temporal boundaries of the current or planned GHG emitting facility (the baseline facility) and should be set to minimize the potential for emission leakage[5].

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[3] The other two mechanisms are (a) Emission trading (ET), including trade in "Hot Air" (HA) and (b) Joint Implementation (JI). ET results from the adoption of the least-cost mitigation principle in that a firm or country with relatively low mitigation costs may reduce emissions by more than its committed amount and sell the slack to firms and countries with higher specific mitigation costs. HA refers to a particular form of emission trading involving Annex I countries that have experienced a dramatic decrease in GHG emissions due to the institutional collapse of their formerly planned economies. These countries may have emissions well below their limits mandated in the Kyoto Protocol. This creates emission reduction credits ("hot air" or "paper tonnes") that can be traded at a profit. Yet another mechanism is the approach of the EU – labelled "Bubbles (BU) where the cumulative GHG emissions of the region are reduced (the bubble) in compliance with the Protocol. Individual member states, however, have been allocated differing reduction target by the EU such that some may even increase their GHG emissions while others must make reductions beyond the 8% assigned in the Protocol to the EU as a whole. JI, roughly speaking, is CDM among Annex I countries.

[4] All other countries (essentially developing countries) not belonging to Annex I countries and hence not subject to emission reduction commitments.

[5] Leakage occurs when the emission reductions from a particular project directly or indirectly cause an increase in emissions at another location or time. This reduces the emission reduction benefits of the project due to factors beyond the project scope.

The emission baseline is then the estimate of emissions that would occur in the absence of the CDM project, i.e. under business-as-usual practices within the defined boundaries. The emission reductions under a CDM project then are the difference between the baseline emissions and the (actual) emissions of the CDM project after implementation.

The baseline is an important factor for the additionality criterion because the CDM project must demonstrate that it generates real and incremental emission reductions that would not occur otherwise. If the proposed project would have occurred anyway for other reasons — e.g. profitable private sector investments, legal requirements, foreign aid, etc. — it would not satisfy the CDM additionality criterion. Four further "additionalities" have also been discussed in connection with CDM — financial, regulatory, investment and technology additionality — although these are not set out as formal requirements in the Kyoto Protocol. Financial additionality means that project funding would be additional to existing financial commitments of Annex I countries including official development assistance and other systems of cooperation. Regulatory additionality means that the emission reductions exceed existing standards, i.e. they would not have been mandated directly or indirectly by policy or regulation. Investment additionality means that the value of the CERs significantly improves the financial/commercial viability of the project. Technology additionality means that the CDM project involves the best available technology for the host country given local conditions.

There is also a movement within the UNFCCC process to restrict eligible CDM projects to those minimizing the possibility of "leakage" and "hot air" projects, and to establish strict criteria that projects are supplementary to domestic action.

The adaptation fund is used, first, to cover administrative expenses associated with the CDM verification, monitoring and certification process and, second, to assist developing countries that are particularly vulnerable to the adverse impacts of climate change to meet the costs of adaptation. The fund would be financed by a share of the proceeds from the certified CDM projects — i.e. by a quasi-tax on CDM projects.

Key issues related to the possible role of nuclear power as a CDM

1. Industrialized countries view CDM as an additional mechanism for emission reductions based on the concept of Joint Implementation (JI), i.e. the accomplishment of emission reductions elsewhere at lower costs than through domestic action; while developing countries view CDM as a new venue for financial assistance, investments towards sustainable development, technology transfer, and the promotion of equity.
2. As Annex I countries are expected to make demonstrable progress towards reducing GHG emissions by 2005, now is the time to investigate the viability of CDMs in developing countries, particularly in light of the almost eight percent increase in global carbon emissions since 1990 (see Table 1 — although total CO_2 emissions of Annex I countries have declined by two to three percent since 1990, this is primarily due to the economic collapse of the Annex I members of the Economies in Transition (EITs) and not a result of determined greenhouse gas mitigation efforts). In most OECD countries, CO_2 emissions have gone up since 1990, not down, and economic recovery in other Annex I countries will boost their emissions as well.
3. The CDM is more contentious than the other flexibility mechanisms as it involves the transfer of credits from countries not subject to emission limitations.
4. To date there has been no formal debate at CoPs on the role of nuclear power as an eligible technology under the flexible mechanism scheme. However, many environmental NGOs are keen to see the nuclear option ruled out, and an earlier submission to UNFCCC by the Alliance of Small Island States (AOSIS) proposed explicitly that nuclear projects be ineligible for CDM status.

5. Outstanding details of the Kyoto Protocol, including a decision on which GHG mitigation technologies will qualify under CDM, need to be finalized at CoP 6 to be held in The Hague, 13–24 November 2000.

6. The overall concept and relevance of the CDM is not clearly understood by many developing countries and several have strong reservations about the CDM. There appears to be a lack of awareness and understanding of the opportunities and issues related to the CDM. The need for capacity building around the CDM has been demanded by G77 and China.

Table 1. Regional and global CO_2 emissions from fuel combustion, million tonnes of carbon (Mt C)[6]

	1990	1995	1999	
OECD	**3,013**	**3,164**	**3,338**	**10.8%**
USA and Canada	1,618	1,691	1,822	12.6%
EU-15	928	914	932	0.4%
Japan and Australia	395	440	451	14.2%
Economies in Transition (EIT)	1,311	925	841	-35.9%
Developing Countries	**1,774**	**225**	**2,383**	**34.3%**
World	**6,098**	**4,314**	**6,562**	**7.6%**

Note: OECD excludes Mexico and Republic of Korea (both included under Developing Countries) and Hungary and Poland (both included under EIT).

The Role of IAEA in the Debate on CDM

- At the 43rd regular session of the IAEA General Conference, Member States requested the IAEA to help countries in assessing nuclear power's role in light of global environmental challenges and energy needs (GC(43)/RES/14). Such assistance should include support for implementing national case studies, and facilitating access to relevant information about nuclear power's role in achieving sustainable development in developing countries and in mitigating GHG emissions.
- The dissemination of information on CDM is of particular importance to developing countries, so as to enable Member States interested in the mechanism to take an active and informed role in the debate regarding the Kyoto Protocol and eligible CDM technologies.
- Therefore, the Secretariat organized a series of information seminars, workshops and training courses for Member States on the Kyoto Protocol, the Clean Development Mechanism, Joint Implementation and Emissions Trading with particular emphasis on the potential role of nuclear power for GHG mitigation.
- On request, the Secretariat also provided training and assistance to several Member States in the preparation of national case studies that explore the potential role of nuclear power as a CDM technology. These case studies are summarized in this annex and have been presented by the respective national study teams during side events at the 44th IAEA General Conference and the Sixth Conference of the Parties (CoP 6) to the UNFCCC.
- Within the general criteria included in the Kyoto Protocol, the decision on which technologies are eligible for GHG mitigation under the flexibility mechanisms is a sovereign decision of each country.

[6] Source: "Carbon Dioxide Emissions in the 1990s". ECoal 2000, Vol. 35. World Coal Institute, London, UK, September 2000.

CHINA — NUCLEAR POWER FOR GHG MITIGATION AND SUSTAINABLE ENERGY DEVELOPMENT

Liu Deshun, Zhao Xiusheng, Zheng Jiantao[7]

Introduction: Coal-fired power plants are the major source of electricity in China, accounting in 1998 for 73% of total installed capacity. However coal-fired plants create serious air pollution problems, and their fuel transport requirements place a heavy burden on the transportation system. Nuclear power plants (NPPs) are therefore a potentially attractive option for China, particularly in the coastal regions, which are both more economically developed and far from the main coal mines in northern and western China.

Currently, China has no capability to build large-scale nuclear power plants. Nor would nuclear power plants in China be financially competitive with coal-fired plants under fair market conditions. China does have three NPPs currently in operation, built partly with French and British expertise and assistance, and eight more under construction. These have all benefited from a number of favourable government policies — i.e. exemptions from taxes on imported equipment and from value-added taxes, and an electricity purchase agreement at an artificially high price.

The Electric Power System in China and the Potential for Nuclear Energy

Current status: From 1980 to 1998 China's electric power industry grew rapidly. Installed capacity grew at an average of 8.15% annually and electricity generation at an average of 7.83%. In 1997 and 1998, however, there was a drop in electricity demand growth to 4.8% and 2.8% respectively87, due to energy efficiency improvements, economic restructuring associated with market reforms, and the Asian financial crisis. At the end of 1998, total installed electricity capacity was 277 GW. Annual electricity generation was 1,158 TWh.

China's electricity generation mix is dominated by coal, which accounts for 73% of total installed capacity. Nuclear capacity is only 2.1 GW, or 0.9% of total power capacity.

Future plans: The long-term planning targets for China's electric power sector for 2010 are 500–550 GW of total installed capacity, with around 20 GW of new capacity added annually. For electricity generation, the 2010 target is 2,500 TWh, with 6% annual growth. For 2020 the target for total installed capacity is 750–800 GW, with around 25 GW of new capacity each year. For electricity generation, the target is 3,200 TWh, with 4% annual growth.

These targets may yet be adjusted downwards. Electricity shortfalls due to tight supplies have declined remarkably in the past few years, given the recent slowdown in electricity demand growth. But even with lower targets, there would remain large opportunities for investors and suppliers in the power sector to provide financing and equipment.

Need for nuclear power: China's existing subsidies for nuclear are motivated by several national interests that would not be reflected in a private economic assessment of nuclear power. These include energy supply security, a cleaner and more efficient energy mix, the promotion of high technology innovation, and stimulating growth and demand in industries related to NPP construction and operation. In addition there are now several environmental concerns that might justify further subsidies, including international subsidies, for nuclear power.

1. Global environmental concerns: The electric power sector in China is a growing significant source of CO_2 emissions.

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[8] Source: the State Statistics Bureau, 1999.

2. Local environmental concerns: It was estimated by World Bank[9] that China's economic losses due to air pollution and acid rain were about 37 billion US$ in 1995, over 5% of overall GDP.

3. National transportation concerns: Long distance transportation of coal from northern and western China, where the principal coal mines are, to eastern and southern coastal areas, where electricity demand is growing fastest, imposes a heavy burden on the national transportation system. This, in turn, exerts upward pressure on the coal price, which reduces the competitiveness of domestic coal against imported coal. In contrast, the burden of nuclear fuel transportation for new NPPs would be almost negligible.

However, even with its environmental and transportation advantages, nuclear power remains a very capital- and technology-intensive electricity supply option. As is the case in many other developing countries, these financial and technological barriers still hold back the pace of nuclear power development in China.

Current developments are therefore limited to three operating reactors (with a total installed capacity of about 2.1 GW), plus eight NPPs under construction (Table 2). Looking further into the future, China has formulated nuclear power targets for 2010 of 20 GW(e) of total installed capacity, rising to 40 GW(e) by 2020. Whether or not these targets can be met will depend on financing, market liberalization, and the evolution of electricity rate structures.

Table 2. Nuclear Power Plants in China

Nuclear Power Plant		Project Phase	Capacity MW(e)	Type	Operation Time
A.	**Qinshan**	Phase-I	300×1	PWR	1991
B.	**Daya Bay**	Phase-I	900×2	PWR	1994
C.	**Qinshan**	Phase-II	600×2	PWR	2001 and 2002
D.	**Qinshan**	Phase-III	700×2	CANDU	
E.	**Ling'Ao**	Phase-I	900×2	PWR	
F.	**Lian Yungang**	Phase-I	900×2	PWR	
G.	**Total**		8.3 GW(e)		

The need for sustainable development in China: China is a large developing country with a very low national income (769 US$ GDP per capita in 1998) and low energy consumption (1.09 tce, or 0.763 toe, per capita in 1998[10]). Despite rapid economic growth over the past two decades, China still ranks among the low and middle income countries in the world. As indicated in the UNFCCC, the top priorities for non-Annex I, low-income, developing countries such as China are economic and social development and poverty eradication. In full recognition of these priorities, the UNFCCC and Kyoto Protocol do not impose any GHG mitigation commitments upon developing country Parties.

Nonetheless China has devoted substantial attention to the mitigation of GHG emissions and has adopted domestic policies and measures that are compatible with the national sustainable development plan. "The Agenda for 21 Century Development in China" is one principal example of China's national strategies to abate GHG emissions and climate change. It puts forward preferential action plans and development projects in various priority areas.

However, China has been constrained by barriers that hinder further development, such as the country's huge population and limited natural resources per capita, its poor ecological environment and its vulnerable capability for mitigating and adapting to climate change. As a result, China very much needs assistance, including the CDM, in pursuing sustainable development options. There is a large potential in

[9] World Bank : " China in 2020", Sept. 1997.

[10] Source: The State Statistics Yearbook by State Statistics Bureau, 1998. Exchange rate: 1 US$: 8.29 Yuan RMB.

China for CDM projects, including nuclear power, and such assistance is vital for China achieving sustainable development.

Baseline Project – Coal: Coal-fired power is the preferred option for the next generation of investments in China. The capital investment ratio for a nuclear power plant in China relative to a coal-fired power plant of the same capacity is about 2.5 to 1, rather high by the standards of industrialized countries. The fuel costs of nuclear power are also high, due to the high price of domestic nuclear fuel. Table 3 calculates the incremental costs of emission reduction for Ling'Ao's two 900 MW(e) nuclear units relative to a comparable coal-fired power plant. The coal-fired plant is assumed to be located in Guangdong Province, a region of high expected electricity demand growth. This is where the Ling'Ao nuclear power plant is located, so that the comparison provides a fair reflection of the incremental cost of emission reduction associated with shifting from a baseline coal-fired alternative to a CDM nuclear power plant of the same size and serving the same market.

Additionality: Table 3 shows that a nuclear power plant would lead to long-term measurable GHG reductions of 2.85 MtC/yr relative to the baseline coal project, thus satisfying the CDM criterion of environmental additionality.

Table 3 shows that the nuclear plant also meets the criterion of financial additionality as it is more expensive than the coal-fired baseline project and thus would not be built under fair market conditions. Indeed without subsidies, tax breaks, or other financial support, the nuclear power plants necessary to meet China's future targets will not be built. This is partly because electricity pricing in China incorporates social goals as well as purely financial considerations. But it will also be true in an increasingly liberalized electricity market in the future, with coal-fired power plants remaining the most attractive alternative to nuclear.

Nuclear power further satisfies the criterion of technology additionality given, first, China's current domestic inability to develop large-scale nuclear technology and, second, the reality that electricity generation costs using imported technologies would, in the absence of CDM, be too high relative to coal-fired plants to be justified.

Table 3 shows the resulting mitigation costs, based on the difference in levelized generating costs between the nuclear and coal-fired alternatives. For a CDM nuclear power project to compare favourably economically to the coal-fired baseline, payments from an Annex I partner to cover the difference between nuclear and coal generating costs would be on the order of US $45/tC (about US $12/t$CO_2$).

Concluding Remarks: Because nuclear power is not financially competitive with coal-fired power plants in China, the government has subsidized the initial stages of nuclear development due to national concerns about secure energy supplies, a cleaner and more efficient energy mix, the promotion of high technology innovation, and stimulating growth and demand in industries related to NPP construction and operation. These, plus concerns about the environment and a transportation system overburdened by coal in the absence of imports, have led China to set targets for the expansion of installed nuclear capacity to at least 40 GW by 2020, which would avoid 63 MtC of CO_2 emissions annually.

To meet such targets, however, China will need financial support through the CDM or some other mechanism to cover the difference between nuclear power plants costs and coal-fired power. Assistance through the CDM would assist in meeting the goals of the UNFCCC, would contribute to cost-effective GHG reductions on the part of Annex I countries, would reduce air pollution from coal-fired electricity generation in China, and by increasing the technological and financial resources available to China, would contribute significantly to sustainable development in China.

Table 3. Comparison of baseline and CDM project technologies — China

Characteristics	Units	Baseline Coal	CDM Nuclear
Technical			
Plant lifetime	year	30	30
Net capacity	MW(e)	1,800	1,800
Load factor	%	75	75
Net efficiency	% (LHV)	37	35
Sulfur abatement (SO_2)	%	70	—
Nitrogen oxide abatement (NO_x)	%	0	—
Particulate abatement	%	99.5	—
Economics			
Investment costs	US$/kW(e)	734	1,800
Interest during construction	US$/kW(e)	197	644
Total capital investment[1])	Million US $	1,676	4,400
Localization rate	%	100	15
Real discount rate	%	10	10
Fix O&M costs	US$/kW(e).yr	34.24	55.27
Variable O&M	US$/MWh		
Fuel purchase costs	$/GJ	2.16	0.416
Total levelized generating costs	mills/kWh	41.26	52.16
Emissions & Wastes			
Ash	g/kWh	50.66	
Sludge from abatement	g/kWh	n.a.	
I & L level radioactive waste[2])	m^3/MWh		$1.735 * 10^{-5}$
High level radioactive waste	g/kWh		n.a.
Heavy metals	g/kWh	n.a.	
Particulates	g/kWh	0.49	
Sulfur dioxide SO_2	g/kWh	4.79	
Nitrogen oxides NOx	g/kWh	3.92	
Carbon monoxide CO	g/kWh	n.a.	
Methane	g/kWh	n.a.	
Nitrous oxide N_2O	g/kWh	0.02	
Carbon dioxide CO_2	g/kWh	241	0
Total GHG emissions	g C/kWh equiv.	n.a.	
GHG abated	g C/kWh equiv.	0	241
Total GHG emissions	Mt C / year	2.85	0.00
Total annual GHG reductions	Mt C / year		2.85
Mitigation costs based on levelized generating costs			
Incremental generating costs	mills/kWh		10.84
Mitigation costs (generation)	US$/t C		45
Mitigation costs (generation)	US$/t CO_2		12.3
Mitigation costs based on levelized capital costs			
Incremental capital costs	Million US $		2,724
Mitigation costs (capital)	US$/t C		101.4
Mitigation costs (capital)	US$/t CO_2		27.7

1) *Total plant capital investment including interest during construction*

2) *Intermediate and low level radioactive waste data based on Daya Bay nuclear power station operation report.*

INDIA — NUCLEAR POWER FOR GHG MITIGATION AND SUSTAINABLE ENERGY DEVELOPMENT

A.K. Nema[11], B.K. Pathak[12] and R.B. Grover[13]

Introduction: The increasing use of the earth's resources to improve our quality of life has led to certain deleterious effects on the environment. The increased concentration of greenhouse gases (GHGs) is one such important effect. GHG emissions have come primarily from industrialized countries. Currently industrialized countries emit 11.4[14] tonnes of carbon per year per capita. For India the corresponding figure is 1.0[15], and for China it is 2.7[16]. We recognize the necessity of both meeting the development needs of all the countries in the South, and ensuring that such development is sustainable. The CDM may have an important role to play, although the positions of a number of countries, including India, with respect to the CDM appear to be still evolving. In any event, nuclear energy should be an important energy option under the CDM, if and when the CDM is ready to be implemented. The present study is an attempt to understand the implications of setting up a nuclear power plant (NPP) in India as a CDM project.

Future Electricity Demand and Baseline Capacity Mix: Table 4 presents India's prospective electricity expansion plans through 2012. The country's total installed capacity in 1997 (excluding Andman, Nicobar and Lakshadweep islands) was 84.5 GW(e), excluding 900 MW(e) from wind power. The projected energy requirements in Table 4 also exclude Andman, Nicobar and Lakshadweep islands.

Table 4. Electricity Expansion Plan for India, installed Capacity, in MW(e)

Year	1997	2002	2007	2012
Hydro[17]	21,658	31,474	52,534	75,534
Thermal[18]	60,977	91,384	119,974	150,974
Nuclear[19]	1,840	2,720	3,720	7,600
Total installed capacity	84,475	125,578	176,228	234,108
Total energy requirement[20] **in TWh**	395	570	782	1,058

India's planning is done in terms of five-year blocks. The current five-year plan (April 1997 – March 2002) is the ninth such plan, and is referred to hereafter simply as the "9th Plan". Nuclear capacity additions included in the 9th Plan, and in Table 4 through 2007, represent firm commitments. They are planned for locations that are significantly far away from coal pit-heads where nuclear power is an economical option, a point we return to later. In addition, the targets in Table 4 could be revised to increase the share of nuclear in the event that appropriate technologies and funding mechanisms become available, including subsidies under CDM.

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[11] Nuclear Power Corporation of India Ltd., Department of Atomic Energy, Mumbai 400094, India.

[12] Bhabha Atomic Research Centre, Department of Atomic Energy, Mumbai 400085, India.

[13] Technical Advisor to Chairman, Atomic Energy Commission, Anushakti Bhavan, Mumbai 400001, India.

[14] Human Development Report 1998, UNDP, p202.

[15] Human Development Report 1998, UNDP, p181.

[16] Human Development Report 1998, UNDP, pp180.

[17] As per Central Electricity Authority's report on Generating Capacity Planning Studies-1998.

[18] Ibid.

[19] As per tentative plan of Nuclear Power Corporation of India Ltd.

[20] 1996–97 generation figure is for public utilities taken from CEA Annual report-1998–99 issue. The other figures are demand projections as per 15th Electric Power Survey report.

Energy Resources and the Rationale for Nuclear Power: All forms of energy have their merits and their constraints. India has reasonable coal reserves — more than 200 billion tonnes, of which about 75 billion tonnes are considered mineable reserves. Coal based power stations will therefore continue to play a major role in the energy system for many years to come. However, the difficulty of transporting large quantities of coal across the country and the environmental problems associated with ash disposal and emissions of both greenhouse gases and acid gases are likely to impose future additional constraints on coal use, beyond concerns about resource depletion. The "Fuel Map of India", published by the Central Electricity Authority in August 1998 recognizes that fuel handling and transportation facilities will have to be expanded to optimize the use of indigenous resources. The report further concludes that indigenous production will not be sufficient to meet projected requirements, and 14–15 million tonnes of coal may have to be imported during the 9th Plan. Estimates of how long India's coal deposits will last differ, depending on the patterns of usage and postulated growth rates that are assumed, but it appears unlikely that the country's coal resources will be sufficient even for this century.

Oil is mainly used in the transport, industrial and domestic sectors. Oil and natural gas can only be considered as short-term supplements as India is not endowed with adequate resources, and any substantial long-term oil and gas use will have to be based on imports. India's hydropower potential should be exploited to the maximum extent possible, taking into account potential population displacements and ecological impacts. Renewables like solar, wind, and the sustainable use of biomass will all play useful roles, although all of these need further technological development before they can be deployed on a commercial scale. Nuclear energy has significant potential and in the long run, the rapid depletion of India's fossil resources makes the country's nuclear fuel resources (natural uranium plus large thorium reserves) an important future energy source. In the short term, nuclear power already enjoys a locational advantage in regions that are far from India's coal-bearing areas.

Economics of Nuclear Power: The comparative economics of nuclear power plants depend on local conditions, discount rates and the cost of other fuels like coal and gas. Wherever fossil fuels are available at reasonable prices, thermal power plants are obvious options for consideration. The issues to be addressed in a comparative techno-economic analysis include the location of coal mines relative to load centres, coal transportation, the availability of railroads for transportation, the sulphur and ash content of the fuel and associated environmental impacts. Among the alternatives that should be considered, hydropower provides low-cost electricity generation associated with large capacities, but the sites available for new large projects are limited and the social costs of submerging large areas are very high. In the case of natural gas, gas prices, which constitute a sizeable fraction of the electricity cost for gas-fired plants, are subject to fluctuations due to market forces. The cost of electricity generated from gas-fired plants can therefore vary substantially depending on market conditions.

An internal study done by the Nuclear Power Corporation of India Ltd. (NPCIL), "Long-Term Cost Effectiveness of Nuclear Energy – 1998"[21], indicates that the competitiveness of nuclear power relative to coal-fired power varies depending on how far away the coal-fired plant is from the mine that supplies its coal. If the coal-fired plant can be located close enough to the pit-head, it will be cheaper than nuclear power. But if, in order to be close to the load centre it serves, the coal-fired plant were more than about 1200 km away from the coal pit-head, then nuclear power is competitive. There are several regions in the country where such distances exist between prospective power plant sites and the mines that would supply coal, should a coal-fired plant be chosen. As shown in Table 5, for sites 1200 km from the pit-head, the "Cost-effectiveness update-2000"[22] of the above study estimates unit energy costs for nuclear and coal-fired power at 49.07 mills/kWh and 50.7 mills/kWh respectively at a 5% discount rate (assuming constant prices). Given that inflation in India is currently about 6% and that the prevailing interest rate is about 12%, the 5% discount rate is appropriate. For a coal-fired plant located at the pit-head, the unit energy cost is only 31.16 mills/kWh, also shown in Table 5. In addition to the discount rate,

[21] A.K. Nema, "Nuclear Generation Cost in India", Nu-Power, Vol.13, No.1 (1999).

[22] A.K. Nema, Unpublished Internal Report.

many other factors influence the cost of electricity. A sensitivity analysis indicates that the levelised cost is most sensitive to the capacity factor in the case of nuclear power, and to fuel prices in the case of thermal power. Higher capacity factors and higher coal prices would improve the competitiveness of nuclear power.

Baseline Project – Coal: For India the baseline project against which nuclear power should be compared depends on the location of the proposed power plant. Thus the top part of Table 5 compares the technical data for a nuclear power plant against two alternative baselines. First is a coal-fired plant 1200 km away from the pit-head to represent cases where the load centre location requires siting a power plant at least that far from coal mines. Second is a coal-fired plant located at the pit-head to represent cases where the load centre is relatively close to coal mines. As can be seen from Table 5, if a power plant must be at least 1200 km from a pit-head, given the location of the demand center it is meant to serve, nuclear power is economically competitive. But if the coal-fired project can be located near the pit-head, its generation costs drop below those of the nuclear plant. In this case the coal-fired plant becomes the lowest-cost option, and thus the baseline project for CDM purposes against which to compare nuclear power.

Additionality: Additional nuclear capacity is currently foreseen in India's energy development plans because power plant expansion sites exist that are sufficiently far from coal mines to make nuclear power competitive. However, there are also sites closer to coal mines, and in these cases nuclear power plants are economically uncompetitive and would not be built in the absence of CDM. Thus in these cases nuclear power meets the CDM criterion of financial additionality. As shown in the bottom half of Table 5, replacing a coal-fired plant with a nuclear plant reduces GHG emissions by 1.87 million tonnes of carbon (MtC) each year, thus also meeting the criterion of environmental additionality. The total emission offset over the lifetime of the nuclear power plant is 56 MtC. As shown in the table, the mitigation costs, based on levelised generating cost differences, are 57 US$/tC based on a baseline coal-fired plant located at the pit-head. As one considers sites that are progressively further away from the pit-head, the mitigation costs of nuclear power relative to a coal-fired baseline project decline.

Concluding Remarks: Substantial environmental damage has already been caused by the profligate use of energy by the industrialized countries. In the effort to limit further damage most cost-effectively, it is possible to calculate mitigation costs associated with clean technologies using a mutually agreed framework along the lines of that above. But it must be remembered that any benefits in the form of mitigation cost payments to developing countries that did not cause the damage in the first place, would amount to only token payments falling far short of any plausible level of just compensation.

In that context, any assessment of possible CDM options for India must recognize that while coal-based power plants will continue to play a major role in India for many years to come, research, development and demonstration (RD&D) is needed to solve environmental problems related to the disposal of ash and emissions of greenhouse gases and acid gases. RD&D is also needed to increase the share of non-conventional sources like solar, biomass and wind in the energy mix. Nuclear power is of importance to India because it has a large, well-qualified and potentially unlimited resource base (based on a closed fuel cycle approach), does not emit GHGs, and, depending on location, has potentially favourable economics versus coal. In the long term, if we are to preserve the environment, it will be necessary to tap this source to the maximum extent feasible.

Table 5. Comparison of baseline and CDM project technologies — India

Characteristics	Units	Coal 1200 km from pit head	Coal at pit head	CDM Nuclear at pit head
Technical				
Plant lifetime	year	30	30	30
Net capacity	MW(e)	1,000	1,000	1,000
Load factor[1]	%	68.5	68.5	68.5
Net efficiency	% (LHV)	30	30	29
Sulfur abatement (SO_2)	%			—
Nitrogen oxide abatement (NO_x)	%			—
Particulate abatement	%	99.5	99.5	—
Economics				
Investment costs[2]	US$/kW(e)	1,107	1,107	1,577
Interest during construction	US$/kW(e)	134	134	352
Total capital investment[3]	Million US $	1,241	1,241	1,929
Localization rate	%	~100	~100	~100
Real discount rate	%	5	5	5
Fix O&M costs	US$/kW(e)yr	27.7	27.7	93.5
Variable O&M	US$/MWh	0.00	0.00	0.00
Fuel purchase costs[4]	$/GJ	2.41	0.94	0.87
Total levelized generating costs	mills/kWh	50.70	31.17	49.07
Emissions & Wastes				
Ash[5]	g/kWh	n.a	n.a.	
Sludge from abatement	g/kWh	n.a.	n.a.	
Intermediate level rad. waste[6]	g/kWh			0.032
High level radioactive waste	g/kWh			0.0036
Heavy metals	g/kWh	n.a.	n.a.	
Particulates	g/kWh	0.99	0.99	
Sulfur dioxide SO_2	g/kWh	7.8	7.8	
Nitrogen oxides NO_x	g/kWh	3.35	3.35	
Carbon dioxide CO_2	g/kWh	312	312	
Total GHG emissions	g C/kWh equiv.	312	312	0
GHG abated	g C/kWh equiv.	0	0	312
Total GHG emissions	Mt C / year	1.87	1.87	0.00
Total annual GHG reductions	Mt C / year		0.00	1.87
Mitigation costs based on levelized generating costs				
Incremental generating costs	mills/kWh			17.90
Mitigation costs (generation)	US$/t C			57.3
Mitigation costs (generation)	US$/t CO_2			15.6
Mitigation costs based on levelized capital costs				
Incremental capital costs	Million US $		0	687
Mitigation costs (capital)	US$/t C			23.9
Mitigation costs (capital)	US$/t CO_2			6.5

[1] *Does not account for decrease of availability during the period of plant refurbishment.*
[2] *Including discounted cost of refurbishment, working capital and its pay back at the end of plant life.*
[3] *Total plant capital investment including interest during construction.*
[4] *Based on gross generation.*
[5] *While exact data are not available, Indian coals have very high ash content.*

VIET NAM — NUCLEAR POWER FOR GHG MITIGATION AND SUSTAINABLE ENERGY DEVELOPMENT

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Introduction: The Government of Viet Nam has recently formulated a national energy programme entitled Strategy and Policy of Sustainable Energy Development. Its aim is to define a development policy for the country for the period from 2000 to 2020. The main objectives of the national energy programme are:

1. Increasing energy efficiency and demand side management (DSM)
2. Expanding rural electrification
3. Defining an energy price policy (e.g. pricing such that revenues cover costs)
4. Minimizing environmental impacts
5. Encouraging private investment in the energy and electricity sectors
6. Energy supply security
7. Diversifying energy sources, and
8. Exploring the potential role of nuclear power in Viet Nam

In formulating this programme, one of the objectives has been to minimize environmental impacts, as noted in Item 4, including those caused by the electricity sector. Nevertheless, the shortage of investment capital in Viet Nam and the difficulty of securing favourable financial arrangements are crucial obstacles to the introduction of new technology options to mitigate GHG emissions.

Viet Nam views CDM as an opportunity to find ways to overcome such problems and expects that all GHG mitigating technologies will be considered equally under the CDM.

Current Economic and Electricity Situation: As a result of economic reforms launched in 1986, GDP growth from 1989 to 1997 averaged 7.0% per year. However, because of Asia's financial crisis in late 1997, GDP growth in 1998 and 1999 remained below target. Commercial energy consumption increased about two-fold between 1990 and 1997, but actually decreased in 1998 and 1999 because of the Asian crisis, especially in terms of industrial coal and electricity demands. While Viet Nam is a net energy exporter, it imports refined oil products in order to meet final energy demand. In 1998, energy exports were 2.9 million tons of coal and 12.4 million tons of crude oil, while imports were 6 million tons of oil products.

In 1999, the total installed electric capacity reached 5,765 MW, corresponding to an available capacity of 5,384 MW. Installed capacity was composed of 53% hydropower, 22% coal-fired power, and 25% diesel and gas turbine. Total electricity generation reached 23,739 GWh, of which hydropower, coal-fired, and diesel and gas turbine shares were 58.7%, 22.7%, and 18.6% respectively.

Over the period 1991-1999, electricity generation has increased 2.7 times with an average growth rate of 12% per annum. In the three years 1994-1996 electricity growth reached 17% per year, compared to annual GDP growth of 9% in the same period. Although the GDP growth rate decreased to 4.8% in 1999, electricity generation continued to grow at 9.6%. The share of hydropower in the national electricity supply mix declined from 70.5% in 1996 to 58.7% in 1999 as a result of several new thermal plants coming into operation. In the interests of electricity supply security, the Government of Viet Nam plans to reduce the hydro share to below 50% by 2003.

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[23] Viet Nam Atomic Energy Commission (VAEC).

[24] Institute of Energy (IE) Viet Nam.

Projected Electricity Demand through 2020: Three scenarios of future electricity demand through 2020 have been developed based on past demand growth, indigenous fuel supplies, and electricity import potentials from neighbouring countries. The three demand scenarios reflect three different economic development scenarios. Electricity demand increases by average annual growth rates of 9.5%, 10.2% and 11.0% corresponding to average GDP growth rates of 6.4%, 6.8% and 7.4% respectively.

Base Scenario: The middle scenario of these three is labelled the base scenario. Electricity demand rises to 167 TWh in 2020, requiring total capacity additions on the order of 30 GW, including more than 10 GW hydro, 10 GW gas-fired, 4 GW coal-fired, 100 MW geothermal, 4 GW of imported electricity, and 1.2 GW of nuclear power. The total primary energy demand for electricity generation is estimated to be approximately 20 Mtoe. Table 6 shows the evolution of the electricity supply mix in the base scenario.

Table 6. Installed Capacity by Fuel Types in the Base Scenario (MW)

Year	2000	2005	2007	2009	2010	2015	2020
Hydro	3,234	4,508	5,371	6,141	6,461	10,606	13,794
Coal	640	1,890	2,190	2,640	2,940	3,340	4,840
Gas + Oil	2,252	4,777	5,497	6,217	6,517	8,737	10,857
Geothermal		50	100	100	100	100	200
Nuclear							1,200
Elec. imports			300	600	1,000	2,000	4,000
Total	6,126	11,225	13,458	15,698	17,018	24,783	34,791

CDM – A Mechanism to Assist in Achieving Sustainable Development in the Electric Power Sector: Viet Nam is a country with a low level of economic development. Shortages of both new technologies and capital investment create problems for the implementation of electric power projects.

For reasons of economics, financing and technology availability, Viet Nam's energy policy must give top priority to the use of indigenous primary energy sources. Only when indigenous energy options cannot meet the electricity demand should imports and nuclear power be considered. According to the base scenario of Table 6, this situation could arise as early as 2007, and through 2015 imported electricity and imported coal are the principal supplements to domestic options. In the base scenario nuclear power remains uncompetitive, and beginning around 2010 Viet Nam imports increasing amounts of coal for electricity production. Such imports are expected to create a number of problems. In addition to their implications for energy supply security, they will place increasing burdens both on the environment and on Viet Nam's poor technical infrastructure for coal handling and transportation. By 2020, in the baseline scenario, these burdens are sufficiently costly that nuclear power becomes a small part of the least-cost energy mix. However if, through the CDM, nuclear power could displace enough of the projected expansion in coal-fired capacity to eliminate the need for coal imports through 2020, it would reduce Viet Nam's annual coal demand by up to 13 Mtce, and the country's annual GHG emissions by up to 6.5 million tonnes of carbon (MtC) (24 $MtCO_2$), as well as reducing local air pollution and regional acidification.

Nuclear power could thus play an active role in sustainable development in Viet Nam and contribute to the mitigation of global GHG emissions. Viet Nam, like other developing countries, expects that nuclear power will be eligible as a CDM technology, and hopes that through the CDM we will find a way, in cooperation with developed countries, to overcome the barriers currently hindering nuclear power development in Viet Nam.

Baseline Project – Coal FGD: In this section we compare nuclear power and other potential CDM options to a baseline coal-fired power plant. For the baseline power plant we use the technology representing the next investment cycle in Viet Nam, i.e. advanced coal flue gas desulfurization (FGD) technology with the following combustion characteristics: 0.52% sulfur, 28% ash, and 10.5% moisture (all by weight) and a heating value of 21.14 GJ/tonne. As alternatives to this baseline, five potential CDM options are analyzed: a coal-fired integrated gasification combined cycle plant (IGCC), a CANDU-6 nuclear power plant, a fuel oil-fired power plant (FO), a wind generator, and a flat plate solar photovoltaic facility (PV). To facilitate the comparison, all the CDM options have been scaled so that their maximum electricity generation levels are equal.

The data assumptions and results are given in Table 7. The upper portion of the table presents the essential technical data on all six technologies. After adjustments to equate the maximum electricity generation levels of all six, the bottom half of the table calculates GHG mitigation costs, first, based solely on levelized generation cost differences and, second, based on levelized capital cost differences.

Additionality: The results in Table 7 indicate that the nuclear power would reduce GHG emissions by 1.22 MtC/yr compared with the coal baseline project. Because nuclear power is more expensive than coal, the coal baseline project would be the preferred choice on economic grounds alone. Thus nuclear power satisfies the CDM financial additionality criterion. Among the CDM alternatives in Table 7, nuclear power is also the least expensive. Its associated mitigation costs are US \$33.38/tC (US \$9.1/tCO_2). The next closest alternative (wind) is 1.7 times as expensive. Both wind and solar power are intermittent energy sources, however, and are expected to account for only a very small percentage of Viet Nam's main electricity grid in 2020. Their principal niche is expected to be off-grid, for electric power supplies for islands, remote villages, and other small-scale or remote applications.

Thus nuclear technology appears an attractive CDM option for Viet Nam.

- It would contribute to Viet Nam's sustainable development, first, by directly eliminating both the local air pollution and GHG emissions that would be associated with the least-cost baseline alternative, additional coal-fired capacity, and, second, by providing new technology and financial assistance that would help the country proceed more quickly toward its overall development and strategic goals.
- It would help Annex-I investor countries achieve cost-effective compliance with the quantified emission limitations and reduction commitments under Article 3 of the Kyoto Protocol.
- It would contribute directly to global GHG emission reductions.
- It would satisfy the CDM additionality requirement, given its unattractive economics relative to coal in the absence of the CDM.

Concluding Remarks: Viet Nam recognizes the ongoing controversies in a number of developed countries about their own use of nuclear power. We also recognize that some of those opposed to nuclear power in their own countries have extended their opposition to include nuclear power in developing countries if it is proposed as part of a CDM project. Viet Nam believes that such controversies are for nations to deal with domestically. The issue of nuclear power development is one that each country should decide on its own. No country should try to impose its internal choice on other countries, particularly under the guise of the CDM, with its otherwise substantial potential for technology transfer, cost-effective GHG mitigation, and sustainable development. In the common effort of all countries in the world to protect the Earth's atmosphere, each party has the right to choose its preferred clean technologies within the sustainability, development, and efficiency objectives of the CDM.

Table 7. Comparison of baseline and CDM project technologies — Viet Nam

Characteristics	Units	Baseline Coal	CDM Coal	CDM Fuel Oil	CDM Nuclear	CDM Wind	CDM Solar PV
Technical							
Plant lifetime	year	30	30	25	30	15	15
Net capacity	MW(e)	300	300	600	672	0.5	10
Load factor	%	70	70	70	75	32	20
Net efficiency	% (LHV)	34	44	34	33	100	100
Sulfur abatement (SO_2)	%	0	80		—	—	—
Nitrogen oxide abatement (NO_x)	%	0	90		—	—	—
Particulate abatement	%	99.5	99.5		—	—	—
Economics							
Investment costs	US$/kW(e)	973	1,577	771	1,562	1,200	6,000
Interest during construction	US$/kW(e)	99	253	79	482		
Total capital investment[1)]	Million US $	772	1,318	612	1,374	1,890	15,120
Localization rate	%	50	40	50	15	15	15
Real discount rate	%	10	10	10	10	10	10
Fix O&M costs	US$/kW(e)yr	31.36	35.2	11.5	52.56	20.4	10
Variable O&M	US$/MWh	2.40	3.60	1.75	1.29	4.05	0
Fuel purchase costs	$/GJ	1.23	1.23	3.02	0.55		
Total levelized generating costs	mills/kWh	39.08	51.06	50.87	48.29	67.61	455.96
Emissions & Wastes							
Ash	g/kWh	96.3	74.4				
Sludge from abatement	g/kWh				0.016		
I & L level radioactive waste[2)]	m^3/GWh				0.074		
High level radioactive waste	g/kWh				n.a.		
Heavy metals	g/kWh	0.038	0.027				
Particulates	g/kWh	0.693	0.433	0.1			
Sulfur dioxide SO_2	g/kWh	5.08	1.106	0.021			
Nitrogen oxides NO_x	g/kWh	2.99	0.299	0.003			
Carbon monoxide CO	g/kWh	0.13	0.09	0.15			
Methane	g/kWh	0.01	0.0077	0.01			
Nitrous oxide N_2O	g/kWh	0.0075	0.0058	0.0039			
Carbon dioxide CO_2	g C/kWh	275	213	237			
Total GHG emissions	g C/kWh equiv.	276	213	237	0	0	0
GHG abated	g C/kWh equiv.		63	38	276	276	276
Total GHG emissions	Mt C / year	1.22	0.94	1.05	0.00		
Total annual GHG reductions	Mt C / year		0.28	0.17	1.22	1.22	1.22
Mitigation costs based on levelized generating costs							
Incremental generating costs	mills/kWh		11.98	11.79	9.21	28.53	416.88
Mitigation costs (generation)	US$/t C		191.0	306.5	33.4	103.4	1,511.3
Mitigation costs (generation)	US$/t CO_2		52.1	83.6	9.1	28.2	412.2
Mitigation costs based on levelized capital costs							
Incremental capital costs	Million US $		546	-160	602	1,118	14,348
Mitigation costs (capital)	US$/t C		209.1	0.0	52.4	120.7	1549.0
Mitigation costs (capital)	US$/t CO_2		57.0	0.0	14.3	32.9	422.4

[1)] *Total plant capital investment including interest during construction.*
[2)] *Intermediate and low level radioactive waste.*

PAKISTAN — NUCLEAR POWER FOR GHG MITIGATION AND SUSTAINABLE ENERGY DEVELOPMENT

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Introduction: Although Pakistan's contribution to global GHG emissions is very small (currently only 0.3% of world-wide emissions), it shares with the world community the concerns of climate change due to the build-up of GHGs. Pakistan is committed to co-operating with global efforts to avert the potential threat of global warming and is already working towards its own socio-economic development in a sustainable manner. However, due to the country's limited technical and financial capabilities, its efforts are diluted and limited to only high priority areas of national interest. There is a large potential for expanding these efforts, if the necessary technical and financial support can be made available, and such an expansion would contribute significantly to the collective global objective of sustainable development. One such step is the reduction of GHG emissions from Pakistan's power sector by introducing advanced cleaner technologies. Nuclear power is one such technology.

Current Energy and Electricity Situation: The present level of commercial energy and electricity consumption in Pakistan is 0.3 toe/capita and 492 kWh/capita, respectively. These values are about one-fifth of the world average and only one-twentieth of the OECD average. During 1998–99 the total primary energy supply was 41.7 million tons oil equivalent (Mtoe), of which oil represented 42.8%, gas 38.6%, coal 5.2%, LPG 0.4%, hydroelectricity 12.8% and nuclear electricity 0.2%. In addition, about 25 Mtoe of traditional fuels, firewood, crop and animal wastes were used. Pakistan plans to gradually replace these with commercial fuels, which would provide significant social and environmental benefits to the rural population.

The total electricity generation capacity in Pakistan is about 16,916 MW, approximately two thirds of which is based on oil and gas. Hydro capacity is 4,884 MW while coal and nuclear are 162 MW and 137 MW respectively. Over the last five years, thermal capacity has almost doubled including about 4,000 MW from private sector IPPs. An additional 2,285 MW of private power generation capacity will become operational by 2003. These plants will be using furnace oil and gas.

At present, there is a surplus of power generation capacity of about 2,000 MW due to the recent slowdown in economic growth. Nevertheless, this trend will not continue for long. The ongoing efforts to revive the economy will lead to increased economic growth, which will require a rapid expansion of the electricity supply system.

Future Electrical Demand and Capacity Requirements: The average economic growth rate in Pakistan over the last few years (1993–1998) has been 4.5% per year, much lower than the historical average of 6%. This lower economic growth has slowed growth in electricity demand to some 5.0% per year, in contrast to the long-term historical growth rate of about 9-10%. In view of this reality, the Working Group on Energy for the Ninth Five Year Plan (1998–2003) and Perspective Plan (1998–2013) has projected that electricity demand will grow at about 7% per year up to the year 2003, and at 8–9% thereafter. To match these growth rates, very large capacity additions of some 55,000 MW will have to be made over the next 25 years.

Indigenous Energy Resources: At present Pakistan imports about 80% of the oil it consumes. These imports amount to one third of the country's total commercial energy use. This energy import dependence of Pakistan, in spite of its very low level of per capita energy consumption, is a result of its relatively poor fossil fuel reserves. Total proven fossil fuel reserves are 2086 Mtoe, comprising 363 Mtoe of gas, 34 Mtoe of oil and 1689 Mtoe of coal.

[25] Applied Systems Analysis Group Pakistan Atomic Energy Commission

Natural gas at present supports about 25% of the power generation capacity. Additional gas commitments for power generation can only be made if new large gas fields are discovered. The largest fossil fuel resource is the Thar coalfield in Sind province, with estimated measured, indicated, inferred and hypothetical resources of over 175,000 million tonnes. Although, these resources have yet to be investigated in detail for their reserve estimates, mineability and quality of coal, they offer a large potential for future power generation. There is also some 30,000-40,000 MW of hydropower potential, but only 15% of this potential has been exploited so far, while another 1,634 MW of hydro capacity (Ghazi, Barotha and Chashma) is under construction. Future development of hydropower is, however, constrained by a combination of techno-economic, environmental and socio-political factors.

Nuclear power technology was introduced in Pakistan by building a 137 MW CANDU-type plant in 1971. The second nuclear power plant, a 325 MW PWR unit at Chashma, has recently been completed and connected to the national grid, and will shortly start commercial operation. Nuclear power has always had a great potential in Pakistan, but this potential has remained largely untapped due to financial difficulties and a lack of adequate technical capabilities. If technical and financial support is available, nuclear power can play a more significant role in the coming decades.

Policy Guidelines for the Medium to Long Term Development of the Power Sector: The power sector in Pakistan, like other countries, is undergoing restructuring. Independent power producers were introduced in the early 1990s, and the public utility is being unbundled. It has been decided that all future plants will be built by the private sector, with two exceptions: large hydropower plants and, although they have not been specifically mentioned in government policies, nuclear power plants. For the medium term all capacity additions will be based on indigenous coal and hydropower. Imports of natural gas are also being planned, a portion of which will be allocated to the power sector, partly for fuel-switching at existing oil-fired power plants and partly for new combined cycle gas-fired plants. A modest nuclear power programme will also be pursued in the public sector.

Baseline Electricity Scenario: Consistent with formal policy guidelines, the principal possible supply options are hydropower, indigenous coal, imported gas and nuclear. Because all these options have fuel supply or capacity addition limits, oil-fired power plants are also included as a possible option to fill future gaps between demand and supply.

The baseline electricity projection in Table 8 includes the introduction of advanced high-efficiency technologies. Specifically, an advanced steam cycle technology for coal-based plants with a 40% efficiency (compared to 37% for conventional coal plants) is assumed to be available in Pakistan after 2010, as are high-efficiency (55%) combined cycle plants.

Fuel prices for oil, gas, coal and uranium are assumed to remain constant in real terms over the planning horizon. The capital cost assumptions for various technologies are derived from historical experience in the country and the latest information available on experience in other countries. An interest/discount rate of 10% has been used for this analysis. All technological options considered for future expansion are assumed to satisfy Pakistan's current National Environmental Quality Standards (NEQS) for particulates, SO_2 and NO_x emissions.

Using these assumptions and the government's policy guidelines, a least-cost expansion plan for electricity generation was developed using WASP-IV. The total power capacity additions required over the next 25 years are on the order of 55,000 MW. The capacity additions of various technologies are shown in Table 8.

Table 8. Baseline Electricity Generation Capacity Mix (MW)

Year	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**
Hydro	4,884	6,518	8,518	12,878	15,662	16,502
Coal	162	150	1,350	3,150	12,150	16,150
Oil	6,400	6,356	6,356	8,270	12,534	27,464
Gas	5,333	7,140	10,161	13,148	11,704	11,494
Nuclear	137	462	462	325	325	325

Under conservative cost assumptions for nuclear power plants (US $2000/kW capital cost, seven-year construction period and no increases in the prices of alternative fuels) they are not part of the least-cost expansion plan. However, for an overnight capital cost of about US $1800/kW, and a construction period of six years, nuclear units would become part of the least-cost solution.

Baseline Project – Coal: A large amount of coal-fired capacity is part of the least-cost expansion plan that is shown in Table 8. In assessing nuclear power as a CDM option, we therefore use as a baseline alternative a 600 MW coal-fired unit with the characteristics shown in Table 9.

Additionality – Nuclear: Nuclear power technology offers long-term measurable GHG reductions if it can replace technologies, like coal, that emit GHGs. As shown in Table 9, assuming a discount rate of 10% and a capacity factor of 70%, replacing a 600 MW coal-fired unit with a nuclear power plant avoids about 0.9 million tonnes of carbon (MtC) annually (3.6 $MtCO_2$) at a cost of US $26.4/tC. GHG mitigation based on an alternative option, wind, would cost US $89.3/tC equivalent.

Nuclear power satisfies financial additionality given that, absent CDM, the coal baseline project shown in Table 9 would be the economically preferred alternative. A simplified financial analysis shows that to recoup the cost differential between nuclear power and the coal baseline in only 15 years, instead of 30, would require selling CO_2 credits at US $33/tC, instead of the US $26.4/tC shown above and in Table 9. This price compares very favourably with the estimated marginal costs of GHG emission reductions in many Annex I countries, which range from about US $120 to 580/tC assuming only domestic measures are available for meeting Kyoto commitments.

Concluding Remarks: This case study has shown that nuclear power is a cost-effective CDM option for Pakistan. Nuclear power satisfies the CDM's additionality criterion, as new coal-fired plants will be built instead of nuclear power in the absence of CDM, and a nuclear plant would reduce GHG emissions 0.89 MtC/yr relative to a 600 MW coal-fired baseline alternative. Nuclear power would provide additional tangible environmental benefits through reductions in SO_2, NO_x, particulates, and other emissions. Further benefits of using this technology in Pakistan include securing a reliable supply of electricity and enhancing the technological capabilities of the country. All these will add to Pakistan's sustainable socio-economic development.

Table 9. Comparison of baseline and CDM project technologies — Pakistan

Characteristics	Units	Baseline Coal	CDM Nuclear	CDM Wind
Technical				
Plant lifetime	years	30	30	20
Net capacity	MW(e)	600	600	14
Load factor	%	70	70	26
Net efficiency	% (LHV)	37	33	100
Sulfur abatement (SO_2)	%	60	—	—
Nitrogen oxide abatement (NO_x)	%	40	—	—
Particulate abatement	%	99.5	—	—
Economics				
Investment costs	US$/kW(e)	1,250	2,000	1,100
Interest during construction	US$/kW(e)	232	703	97
Total capital investment[1)]	Million US$	889	1,622	1,934
Localization rate	%	25	20	20
Real discount rate	%	10	10	10
Fix O&M costs	US$/kW(e)yr	24	33.96	25.92
Variable O&M	US$/MWh	3.50	0.56	—
Fuel purchase costs	US$/GJ	1.89	0.458	0
Total levelized generation costs	mills/kWh	51.48	57.85	73.11
Emissions & Wastes				
Ash	g/kWh	69.3	—	—
Sludge from abatement	g/kWh	n.e.	—	—
I & L level radioactive waste[2)]	g/kWh	—	0.0652	—
High level radioactive waste	g/kWh	—	0.0046	—
Heavy metals	g/kWh	n.a.	—	—
Particulates	g/kWh	0.4		
Sulfur dioxide SO_2	g/kWh	7.6	—	—
Nitrogen oxides NO_x	g/kWh	3.7	—	—
Carbon monoxide CO	g/kWh	n.a.	—	—
Methane	g/kWh	0.01	—	—
Nitrous oxide N_2O	g/kWh	0.014	—	—
Carbon dioxide CO_2	g/kWh	237	—	—
Total GHG emissions	g C/kWh equiv.	242	0	0
GHG abated	g C/kWh equiv.		242	242
Total GHG emissions	Mt C / year	0.89	0.00	0.00
Total annual GHG reductions	Mt C / year		0.89	0.89
Mitigation costs based on levelized generating costs				
Incremental generating costs	mills/kWh	0	6.38	21.63
Mitigation costs (generation)	US$/tC		26.3	89.4
Mitigation costs (generation)	US$/t$CO_2$		7.2	24.4
Mitigation costs based on levelized capital costs				
Incremental capital costs	million US$	0	733	1,044
Mitigation costs (capital)	US$/tC		87.3	137.8
Mitigation costs (capital)	US$/t$CO_2$		23.8	37.6

1) *Total plant capital investment including interest during construction.*
2) *Intermediate and low-level radioactive waste.*

KOREA — NUCLEAR POWER FOR GHG MITIGATION AND SUSTAINABLE ENERGY DEVELOPMENT

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Introduction – national overview: The Republic of Korea occupies the southern half of the Korean Peninsula. Korea's population in 2000 is 47.3 million, and the population density is over 450 persons per km^2, the third highest in the world. However, the effective implementation of family planning policies has slowed population growth from 3.0% in 1960 to less than 1% currently. Korea's economy has changed markedly in every respect since the government launched a series of economic development plans in the early 1970's. Average economic growth over the last decade was above 8% per year, excluding the financial crisis period.[28] High economic growth has inevitably led to rapid growth in energy consumption. Due to a lack of domestic energy resources, the overseas dependence rate of energy consumption has continuously increased from 47.5% in 1970 to 97.5% in 1997. Especially fossil fuels, such as oil, coal, and gas, accounted for 88.2% of total energy consumption in 1997. These also caused a rapid increase in greenhouse gas emissions including CO_2. In 1997, 140 million tonnes of carbon (MtC) was emitted – 1.8% of total world greenhouse gas (GHG) emissions.

Projection of energy demand and CO_2 emissions: Since the 1980s, chemical and heavy industries have grown rapidly, with their share of GDP rising to 76.2% of the total manufacturing sector in 1996. The increase of industrial activities boosted energy consumption and greenhouse gas (GHG) emissions. To fuel rapid economic growth, primary energy consumption also increased from 43.9 million tonnes oil equivalent (Mtoe) in 1980 to 165.2 Mtoe in 1996, a growth rate of 7.8% per year from 1980-1990 and 10.0% from 1991-1996. The combination of stable population growth and rapid economic growth brought an increase in per capita energy consumption that reached 3.63 toe in 1996. Nevertheless, that value is still lower than the average among other OECD countries.

Table 10. Energy demand projection and the CO_2 emission projection

	1985	1990	1995	2000	2005	2010	AAGR(%) 86-95	AAGR(%) 96-2010
Primary energy Demand (Mtoe)	56.3	93.2	150.4	213.4	272.9	328.1	10.3	5.3
Energy/GDP (toe/90yr Mwon)	0.51	0.52	0.58	0.60	0.58	0.54	1.5	-0.6
Per capita energy Consumption (toe)	1.4	2.2	3.4	4.6	5.7	6.6	9.3	4.6
CO_2 emissions (MtC)	44.0	65.2	101.2	148.5	187.4	217.0	8.7	5.2
Per capita CO_2 Emission (tC)	1.1	1.5	2.3	3.2	3.9	4.4	7.7	4.5
CO_2/GDP (tC/90yr Mwon)	0.39	0.36	0.39	0.42	0.40	0.36	-0.1	-0.7

Economic growth is an important factor determining future energy demand. The energy demand projection used in this case study is based on the assumptions of the economic growth forecast in the Long-term Economic Management Plan of 1992, with the actual energy consumption data for 1996 as a starting point. Table 10 shows the energy demand projection and CO_2 emission projection given in the National Communication of 1998.

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[28] The financial crisis began in the 4th quarter of 1997. For 1997 as a whole, economic growth was 5.0%. In 1998, it was –6.7%. In 1999, it rebounded to 10.7%.

GHG mitigation policies and measures: After Korea ratified the United Nations Framework Convention on Climate Change (UNFCCC) in December 1993, environmental considerations became an important factor in policy-making. In this respect, Korea has intensified its efforts to reduce GHG emissions to combat global warming. Given its heavy dependence on foreign imports for energy resources, the Korean Government has undertaken a variety of measures to promote rational energy use. In the energy sector, those efforts include energy conservation, inter-fuel substitution with nuclear and LNG, energy technology development, and demand side management.

The 5th Long-Term Power Development Plan: The government of Korea, in consultation with the Korea Electric Power Corporation (KEPCO), revises the Long-term Power Development Plan every two years and released the fifth Long-term Power Development Plan on January 13, 2000. The new plan covers a planning period of 17 years from 1999 to 2015. Its fundamental objective is to achieve a stable power supply while maintaining minimum costs and an optimum combination of energy resources. To meet future electricity demand, the Long-term Power Development Plan requires new generating facilities with a capacity of 45,130 MW. The total capacity of all generation facilities in 2015 will be 79,055 MW, of which nuclear power plants will contribute 33.0%, coal-fired plants 26.8%, LNG combined cycle plants 23.8, oil-fired plants 7.6%, and hydro and other plants 8.8%.

Table 11. Composition by Plant Capacity (MW(e))

Item	1999	2000	2005	2010	2015	Ave. growth 1999-2015
Nuclear	13,716	13,716	17,716	22,529	26,050	4.01%
Coal	13,031	14,031	18,165	20,565	21,220	3.05%
L N G	12,368	13,289	16,464	18,387	18,850	2.63%
Oil	4,716	4,866	4,866	6,806	6,001	1.51%
Hydro	3,148	3,148	4,404	6,324	6,934	4.94%
Total	46,978	49,050	61,614	74,611	79,055	3.25%

The 5th Long-term Power Development Plan will be affected by on-going restructuring and privatisation in the electricity sector. After privatisation, the Long-term Power Development Plan will serve only as a guideline. It will no longer effectively guarantee the construction of scheduled power plants.

Restructuring and privatisation in the electricity sector: KEPCO (Korea Electric Power Corporation) is an integrated electric utility company and the only company engaged in the transmission and distribution of electricity in Korea. KEPCO owns approximately 94% of the total electricity generating capacity in Korea, excluding plants generating electricity primarily for private or emergency use. On January 21, 1999, MOCIE (Ministry of Commerce, Industry and Energy) published a Plan for Restructuring the Electricity Industry in Korea. The overall objectives of the Restructuring Plan are to introduce competition and thereby increase efficiency in the Korean electricity industry. The Restructuring Plan sets forth the Government's broad policy directions and calls for flexible implementation over the next 10 years or more. As the 1st phase of restructuring, KEPCO will separate its non-nuclear generating capacity into 5 wholly-owned generation subsidiaries, each with its own management structure, assets and liabilities. KEPCO will also separate its nuclear generating capacity into a single separate generation subsidiary which will remain wholly-owned by KEPCO for the foreseeable future. KEPCO will retain its monopoly position with respect to transmission and distribution. In the 2nd phase, which is expected to run through December 31, 2002, KEPCO intends to sell its non-nuclear generation subsidiaries.

Baseline Project – Bituminous Coal: The objective of this case study is to estimate the costs and benefits of possible CDM projects for electricity generation. For that purpose, we assume that Korea, as a non-Annex I country, is able to host CDM projects and wants to substitute for a planned new bituminous coal-fired power plant (with costs and characteristics identical to the most recent such plants) either a gas-fired combined cycle plant or a nuclear power plant. Coal-fired power plants in Korea can be divided into two types. One type uses indigenous anthracite coal, while the other uses bituminous coal imported from abroad. In the case of anthracite coal-fired plants, because the coal is of low quality and produced in deep underground mines, generation costs are much higher than for bituminous coal-fired plants. A new prospective bituminous coal-fired power plant is thus the least-cost baseline against which the nuclear and gas-fired options need to be compared. All are considered as base-load power supply options.

CO_2 emissions were calculated using emission factors from the IPCC. Most of the data used in this case study are very close to the input data in the actual national long-term expansion plan. Some values are changed for simplicity. Specifically, a uniform lifetime of 30 years was assumed for all three options and plant sizes were adjusted to 500 or 1000 MW(e) to facilitate comparison.

Additionality: Table 12 shows that, compared to the baseline bituminous coal-fired power plant, nuclear power would be the more economic carbon reduction option, assuming a load factor of 70% and a discount rate of 8%. The cost of carbon reduction for nuclear power is 4.22 $/t C, which is quite small compared to that for the gas combined cycle plant, about 71.70 $/t C.

Because the carbon reduction costs of the two CDM technologies depend on several crucial input variables such as the discount rate and load factor, we conducted sensitivity analyses with respect to these two input variables. Varying first just the discount rate, we found that the carbon reduction cost for nuclear power becomes negative for discount rates below 6.57%. Thus, if the appropriate discount rate were below this value, nuclear would be the least-cost option and ineligible as a CDM technology. At a discount rate of 15.0%, the carbon reduction cost for nuclear power would equal that for the gas combined cycle plant, and if the discount rate were higher than 15.0%, the gas combined cycle plant would be a more economic CDM project than nuclear power. For discount rates over 19.0%, the gas combined cycle plant becomes the least-cost option and thus the appropriate new baseline against which a possible nuclear power CDM project should be compared.

A similar situation is found in the case of the load factor. If the load factors for all three technologies are above 78.1%, then nuclear power becomes the least-cost option and thus ineligible as a CDM project. For load factors from 78.1% down to 45.0%, the least-cost baseline is the coal-fired plant and nuclear power is the most economic CDM option. For load factors from 45.0% down to 37.1%, the coal-fired plant remains the least-cost baseline, but the gas-fired combined cycle plant works out to be the most economic CDM option. And finally, for load factors below 37.1%, the gas-fired combined cycle plant becomes the least-cost baseline against which a possible nuclear power CDM project should be compared.

Concluding remarks: The reference data used in this case study show that, compared to the baseline bituminous coal-fired power plant, nuclear power is a more economic option than gas combined cycle options for mitigating carbon emissions. The cost of carbon reduction for nuclear power is 4.22 $/t C, which is quite small compared to that for the gas combined cycle plant, about 71.70 $/t C. The cost of carbon reductions for nuclear and gas power would be equal if the investment costs for nuclear were to rise to US$2,569/kW(e), or the load factor to decrease to 45.0% or the discount rate to reach 15.0%.

Korea must also keep in mind nuclear power's contribution to improving the security of the country's energy supplies. Nuclear power will give Korea more diversity in an energy supply system that is heavily dependent on conventional fossil fuels. Moreover, it is also suitable for storage against contingencies, because of its higher energy intensity.

Table 12. Comparison of baseline and CDM project technologies — Korea

Characteristics	Units	Baseline Coal	CDM Nuclear	CDM Gas Combined
Technical				
Plant lifetime	year	30	30	30
Net capacity	MW(e)	1,000 (500x2)	1,000	1,000 (500x2)
Load factor	%	70	70	70
Net efficiency	% (LHV)	39	35	53
Sulfur abatement (SO_2)	%			
Nitrogen oxide abatement (NO_x)	%			
Particulate abatement	%			
Economics				
Investment costs[1)]	US$/kW(e)	1,043	1,535	520
Interest during construction	US$/kW(e)			
Total capital investment	Million US $			
Localization rate	%	~100	~100	~40
Real discount rate	%	8	8	8
Fix O&M costs	US$/kW(e)yr	44.93	56.67	31.52
Variable O&M	US$/MWh	—	—	—
Fuel purchase costs	US$/GJ	1.31	0.39	4.51
Total levelized generating costs	mills/kWh	34.48	35.41	43.15
Emissions & Wastes				
Ash	g/kWh			
Sludge from abatement	g/kWh			
I & L level radioactive waste[2)]	g/kWh			
High level radioactive waste	g/kWh			
Heavy metals	g/kWh			
Particulates	g/kWh			
Sulfur dioxide SO_2	g/kWh			
Nitrogen oxides NO_x	g/kWh			
Carbon monoxide CO	g/kWh			
Methane	g/kWh			
Nitrous oxide N_2O	g/kWh			
Carbon dioxide CO_2	g C/kWh equiv.	222	0	101
Total GHG emissions	g C/kWh equiv.			
GHG abated	g C/kWh equiv.			
Total GHG emissions	Mt C / year	1.36	0.0	0.62
Total annual GHG reductions	Mt C / year		1.36	0.74
Mitigation costs based on levelized generating costs				
Incremental generating costs	mills/kWh	—	0.94	8.68
Mitigation costs (generation)	US$/t C	—	4.22	71.70
Mitigation costs (generation)	US$/t CO_2		1.15	19.55
Mitigation costs based on levelized capital costs				
Incremental capital costs	Million US $	—		
Mitigation costs (capital)	US$/t C	—	32.12	-62.58
Mitigation costs (capital)	US$/t CO_2	—	8.76	-17.07

[1)] *The investment cost including interest during construction*
[2)] *Intermediate and low-level radioactive waste.*