E3 Journal of Environmental Research and Management Vol. 3(4). pp. 088-098, June, 2012
Available online http://www.e3journals.org
ISSN 2141-7466 © E3 Journals 2012

Full Length Research Paper

Sustainable development and impact of nuclear energy: security concern and policies of asian developing countries

Km. Saroj Gupta

Nehru Gram Bharati University Kotwa-jamunipur, Allahabad, Uttar Pradesh, India; Administrative office-12, park street, New Delhi; Telefax: 011-23094091; Professor"s colony, Gyanpur, S.R.N. (Bhadohi); Pin no.-221304; Phone no. 09936895570; Email. sarojgupta _0@yahoo.com; Sarojgupta1886@gmail.com.

Accepted 10 April, 2012

The problem of global climate change will be solved by meeting stringent, long-term policy targets that are much more ambitious than the short-term, greenhouse gas emission reductions that some countries currently attempt to reach. The large-scale implementation of carbon-free technologies constitutes one of the measures essential to realize the mitigation of global warming. Nuclear power generation involves no carbon dioxide emissions, but the current use of nuclear energy cannot be considered sustainable. However, in attempting to achieve sustainable development - and to establish transition paths towards sustainable energy systems in particular - nuclear energy might, for the moment, need to remain a component of the global energy mix.Asian developing countries, aspiring to embark upon paths of rapid economic growth and to increase levels of welfare, should carefully consider the relatively high costs involved in the development of nuclear power when designing long-term, sustainable, and affordable energy infrastructure. This paper argues that if countries such as China and India continue to expand the use of nuclear energy, they would do better not to choose a nuclear fuel cycle based on reprocessing, but to adopt a once-through fuel cycle instead.

Keywords: nuclear energy, sustainability, global climate, fossil fuel.

INTRODUCTION

Nuclear energy remains a controversial issue for policy-making on energy and environment because of arguments concerning radioactive waste, reactor accidents, nuclear proliferation, economic competitiveness, and public opinion. The issues of climate change and supply security have provided a new rationale for its reappearance on the international political agenda. Recent national policy directions in some countries show that such a potential comeback of nuclear energy is not just wishful thinking of the nuclear establishment. Because nuclear energy currently faces stagnation, it is unrealistic to consider it a serious option for significantly reducing carbon emissions in the short run. On the other hand, it seems a mistake to exclude at this time any of the available options - including nuclear power -that could possibly contribute to mitigating emissions of GHGs (greenhouse gases) in the longer run. Whether or not nuclear energy will play a role of significance in the long term, all energy technologies - including nuclear ones -ought to be considered in terms of their potential to contribute to goals of sustainable development, including aspects related to environmental, economic, and social risks, particularly climate change prevention and supply security support.

It is widely recognized that, in addition to other factors, the availability and use of electricity can improve the standard of living in developing countries and, in fact, may be an indispensable driver of economic and social progress (IEA 2002). Economic growth towards higher levels of wealth in these countries is intimately linked to increases in per capita utilization of energy. However, in attempting to establish effective, efficient, affordable, and sustainable energy production and consumption in the developing world, one must be careful not to automatically transpose to developing countries existing energy technologies, infrastructures, and modi operandi as currently employed in developed countries. The resource-related, technological, cultural, legal, and societal differences between developing and developed countries should be carefully contemplated and integrated into the design of energy systems in the developing world. Many consider the lack of proper energy facilities in the developing world as one of the world's prime development problems, to be tackled on priority. The solution lies in an intelligent, regional - probably decentralized - approach, which takes into account local needs, capabilities, and customs.

In this context, the question is what the future role of nuclear energy may be in addressing the energy challenges of the 21st century in developing countries, particularly in Asia. This article provides an overview of some of the main issues concerning the prospects for nuclear energy in Asian developing countries, and presents some perspectives of nuclear development in China and India—however different these two countries may be from a nuclear point of view. In these countries, the expertise required for nuclear expansion is available; their governments too are firm in their efforts to enlarge the deployment of nuclear power capacity. This paper discusses whether it is wise to let nuclear energy increasingly contribute to domestic power generation in China and India, and how the share of national nuclear power production is likely to develop. Some recommendations are given on how potential nuclear development, if deemed necessary, could best be pursued.

After providing this outlook on the global future use of energy and the role of fossil fuels and energy supply security therein, the chapter puts nuclear energy into the perspective of sustainable development and presents the results of a simple scenario analysis, through which the merits of nuclear energy can be assessed in terms of climate change control. It goes on to describe some elements relevant for the economics of nuclear energy and, in particular, of reprocessing of spent nuclear fuel. It then analyses the potential role of nuclear power in Asia, takes up two detailed cases of China and India, and concludes.

Data And Methodology

The present study is analytical study based on secondary sources of data and information. the data And information have been compiled from Economic survey of India, report on trend and progress of Natural resource management commission ,basic statistical returns relating to energy consumption in india.for the preparation of present study various journals,magazines and newspapers like Indian journal of energy and environment ,economic and political weekly,financial express,economic times etc.have also been used .the period has been chosen considering the availability and consistency of data.

Global Fossil Energy Outlook

The global fossil resource base is abundant and estimated at approximately 5000 Gtoe (gigatonnes of oil equivalent) (Rogner 1997). Given that the current global primary energy use amounts to approximately 10 Gtoe per year, this amount is largely sufficient to fuel the world economy throughout the 21st century, even if demand rises significantly. Of course, the geological existence of large hydrocarbon resources does not necessarily guarantee energy supply stability or security. Energy supply uncertainties exist for many reasons. First, these uncertainties concern the costs of resource recovery and conversion to usable fuels. Second, hydrocarbon development and production decisions often lie with public sector agencies and are therefore not driven by market considerations alone, but by international political arguments as well. Temporary energy supply shortages and volatile market prices will thus continue to mark the development of the energy system, and it is unlikely that the development of that system will be less volatile in the future than it has been in the past.

Most important, however, the largest source of energy supply uncertainty seems to be the environment. The CO_2 (carbon dioxide) emissions from the combustion of fossil fuels constitute the main reason for the increase of the atmospheric GHG concentration. This increase results in a higher global average temperature of the earth's surface, leading to regional and local effects of climate change. The combustion of fossil fuels - especially coal - is also the cause of various forms of air pollution, with detrimental effects for both human health and the natural environment. The environment is likely to constrain the use of fossil fuels long before global resource scarcity comes into play, so that resource availability limitations are unlikely to drive the global energy system away from a continued reliance on fossil resources. If humankind wants to avoid destabilizing the global climate and preserve local air quality, it will need to operationalize environmental policies, such as the implementation of full-cost pricing, that is, the internalization of the external costs of energy production.

Resource constraints are unlikely to drive down hydrocarbon production during the 21st century, if technological progress continues to improve productivity—a phenomenon incessantly observed in the past. Oil production from existing, recoverable oil reserves is expected to peak within a few decades, but this will at some point spur the development of alternatives, such as the transformation of currently uncertain conventional oil or marginal unconventional oil into the conventional oil of the future. The oil era is thus likely to last well beyond the time frame suggested by the currently known, recoverable, conventional crude oil reserves. With global demand for oil rising, pressure on oil prices can be expected in the long run. At times, volatile fluctuations of oil prices may well be encountered, with alternating periods of rapidly increasing and decreasing price movements, around an otherwise long-term trend of gradually rising production costs. However, the volatility fluctuations are unlikely to be caused by resource scarcity, rather by the time lags between market signals such as prices and the point in time when new exploration investments become production-effective.

In addition to conventional and unconventional oil, there are large amounts of natural gas and coal recoverable from the earth's crust. From an aggregate carbon quantity-cost curve for the total global fossil resource base, one can deduct that for a maximum of 40 dollars (1990) per barrel of oil equivalent, most of the global fossil resource base is recoverable from the earth when some (modest) level of technological progress over a 100-year period is anticipated (Rogner 1997). This underlines the likelihood that fossil fuels remain the predominant form of energy use throughout the 21st century. Until 2100, however, humankind may have emitted an amount nearing 2000 GtC (gigatonnes of carbon) into the atmosphere, which pushes the atmospheric CO2 concentration to a level well above the 700 ppmv (parts per million by volume)—more than double the pre-industrial concentrations. Such an increase will almost undoubtedly imply considerable impacts on living conditions and the environment as a result of climate change.

The industrialized world is today responsible for the majority of CO2 emissions. If humankind is to stabilize atmospheric CO2 concentrations at a level that prevents a dangerous human interference with the climate system, then the developing countries need to be engaged in efforts to limit and reduce GHG emissions. These emissions are growing much faster in developing countries than in industrialized countries, more as a result of economic growth than population growth. To help maintain stability in the world's climate system, (especially) Asian countries such as China and India must, as their economies and populations grow, fuel their development with not only economically competitive but also clean energy technologies (Wirth, Boyden, and Podesta 2003). Asia will experience the most rapid energy demand increase among all world regions because of its expected robust economic growth over the coming decades. The most important environmental issues for the Asian region are local. To control local environmental pollution, as well as CO2 emissions, the best strategies for Asia focus on rapid technological progress and the use of energy resources other than coal (IIASA and WEC 1998).

In 2030, the world energy system will probably continue to be dominated by fossil fuels, with a continued proportion of 80%-90% of total energy supply. Oil will probably remain the main source of energy (with an expected 34%), followed by coal (28%), while natural gas is projected to represent some 25% of global energy supply by then (EC, IEPE, BFP, et al. 2003). Coal is fuelling the largest share of power generation worldwide and will most likely supply an increasing percentage of the growth in demand in the future, particularly in the developing world. Over the coming 30 years, about two-thirds of the increase in coal supply will, in all probability, come from China and India. Because of the abundant coal resources in Asia, the share of its coal usage remains high (42%) and will not change significantly. In contrast, the shares of oil and gas increase rapidly at the expense of biomass that is almost phased out (probably dipping to around 6% of primary energy consumption in 2030, compared to 30% in 1990). By 2010, Asia will be the world's largest consumer of primary energy. By 2020, China and India are expected to produce more carbon emissions than the US and the European Union combined. Asia already imports around 60% of its oil from the Middle East, and Asian dependence on this volatile region is increasing (Manning 2000). This dependence is a growing concern for Asian governments, which view energy largely in strategic terms as a matter of fundamental national security.

In the Asian region, over the past 25 years, there has been a general decrease in the energy intensity of the gross domestic product, driven both by structural and technological factors (Datt, Kacker, Mehra, et al. 2002). This decrease has been beneficial for the development of a sustainable energy sector in Asia. In the areas of improving access to modern energy forms and arresting adverse environmental impacts of energy development, progress has been less impressive. The trend towards the use of economic instruments to support environmental legislation needs to be strengthened, while the role of governments in improving access to energy needs to be enhanced. Still, in the coming decades, countries like China and India are not likely to realize a share of commercial energy production from renewable energy resources much beyond the 1% level. This brings up the question of the extent to which nuclear energy could contribute to establishing transition paths towards sustainable energy infrastructures in Asia - China and India in particular - over the decades to come.

Nuclear Energy And Sustainability

Only recently has nuclear energy been subjected to detailed studies in terms of its potential contribution to establishing sustainable development (see, for example, NEA 2000; Rogner 2001). Most analysts confirm that nuclear energy currently does not meet some essential requirements for representing a sustainable energy resource (see, for example, Bruggink and van der Zwaan

2002) and that, in particular, the current use of LWR (light water reactor) technology cannot be qualified as sustainable (Rothwell and van der Zwaan 2003). Arguments concerning radioactive waste, reactor accidents, nuclear proliferation and terrorism, and economic competitiveness all feature in the discussion on the sustainability of nuclear energy. Likewise, however, it has been pointed out that it is hard to claim that any of the existing, so-called ‘renewables’ meet all the criteria of a sustainable energy resource (Bruggink and van der Zwaan 2002). One of the major reasons is that renewables have so far not been applied on a large (global) scale, so that the risks involved in their usage cannot yet be apparent. Fundamental issues determining the (un)sustainability of renewables relate to land usage, materials usage, waste production, and environmental impact.

While it is not recognized as a sustainable energy resource today, nuclear energy - along with other currently available energy options -could play a transitional role towards establishing sustainable energy systems. Whereas changes in energy infrastructures, particularly nuclear ones, generally occur relatively slowly, nuclear energy should still be viewed in a dynamic way. During a transitional phase with some role for nuclear power, some of the more problematic aspects of nuclear energy might be rendered more sustainable through, for instance, waste minimization, accident reduction, proliferation control, resource use optimization, and enhancement of economic competitiveness (Rothwell and van der Zwaan 2003). Over the past few decades, technological developments in the nuclear field have been considerable, demonstrated, for instance, by the substantially declining likelihood - since the 1986 Chernobyl catastrophe - of experiencing another serious reactor accident with significant consequences for the external environment. These technological advancements are likely to continue, for instance with respect to increasing reactor safety, reducing radioactive waste lifetime and toxicity, or building more proliferation-resistant reactors.

This could give nuclear energy a potential role beyond the aforementioned transition period. To some extent, depending on perspectives of both time and location, nuclear energy could contribute to establishing paths towards sustainable energy systems and thereby to achieving sustainable development.

In the past, an important reason for developing domestic nuclear energy capacity was its potential to greatly enhance national energy independence, mainly since nuclear fuel (uranium) is widely available and can be cheaply acquired and easily stored. Arguments of energy supply security will continue to motivate countries, including those in the developing world with currently modest or absent shares of nuclear energy in electricity production, to develop domestic nuclear power facilities. Since the subject of climate change mitigation has been recognized as one of the most significant existing global challenges, nuclear energy has received renewed consideration. As will be pointed out later, whereas even a massive global expansion of nuclear energy would not be a panacea for the problem of global warming, its potential share in controlling atmospheric temperature increases could be significant (Sailor, Bodansky, Braun, et al. 2000; van der Zwaan 2002). Given the size of the global change challenge, nuclear energy might indeed deserve increased attention. Nuclear power might need to be expanded on a global scale, or at least should not be left out of the current energy mix. Developing countries could, in principle, play roles in continued and, perhaps, intensified employment of nuclear fission.

Nuclear Energy And Climate Change

Through a simple scenario analysis, one can readily estimate the global potential of nuclear energy in reducing carbon emissions and, hence, in mitigating global warming. In other words, if for ease of analysis, one momentarily discards (still important) questions regarding the feasibility and desirability of a large increase in nuclear energy use, what then are the climate-change-related merits of nuclear power when it is expanded massively? Since today, about one-third of total global commercial primary energy is supplied in the form of electricity, an answer in first approximation to this question would be that for the moment nuclear energy would not readily be able to reduce carbon emissions by much more than one-third (since nuclear energy is today primarily available through power generation). Suppose, in a slightly more detailed analysis, that the current ‘400 EJ (exajoules) world’ is expanded over the coming 75 years to one that consumes 1200 EJ per year. Currently, three fossil fuels together fulfil the major portion of commercial primary energy supply (approximately 86%, responsible today for around 6 GtC per year of emissions), while hydropower, nuclear fission, and renewables account for shares of about 7%, 6%, and 1%, respectively. Let us make the stylized assumptions that the use of fossil fuels is decarbonized, by 2075, to the level of the current carbon intensity of natural gas power generation, and that global energy consumption (total, and specified by resource) increases, in two scenarios (I and II), according to the factors stated in Table 1. (For a more extensive description of the corresponding analysis, see van der Zwaan [2002]).1 The main features of the scenario analysis according to Table 1 are that hydropower retains its relative share of energy supply, over the 2000-75 period, while the use of renewables is ambitiously assumed to increase by a factor of 100 over this time frame. Nuclear energy is supposed to stagnate at its current absolute level in Scenario I, while it is expanded by the hypothetical factor of 10 in Scenario II.
Table 2 shows the results of a corresponding exercise in

Table 1. Expansion factors of total energy demand and of the non-carbon emitting hydropower, renewables, and nuclear energy supplies, in Scenarios I and II

	Energy expansion factors	
	Scenario I	**Scenario II**
Total energy demand	3	3
Hydropower	3	3
Renewables	100	100
Nuclear energy	1	10

Table 2. Annual and cumulative carbon emissions in a simple energy scenario analysis Economics of reprocessing and recycling in LWRs (light water reactors) and FBRs (fast breeder reactors) compared to that of the once-through cycle (directdisposal of spentfuel) in LWRs

	Scenario I	**Scenario II**	**Difference**
Annual emissions in 2075	7.7GtC[a] per year	5.3 GtC per year	31%
Cumulative emissions over 2000-75	549 GtC	440 GtC	20%

	Break-even price uranium ($/kgU)	**Increase electricity costs (mills/kWh)**
Reprocessing in LWR	360	1.3
Reprocessing in FBR	340	7
Source Bunn, Fetter, Holdren, *et al.* (2003)		

[a]gigatonnes of carbon

terms of annual and cumulative carbon emissions over the period considered, in a comparison between Scenarios I and II.

One concludes that if nuclear energy were expanded ten-fold, it could contribute significantly to reducing carbon emissions. Such an expansion could avoid about 20% of cumulative CO2 emissions over the period 2000-75, while annual emissions in 2075 would be reduced by about 30%. Still, it is evident from this calculation that nuclear energy can be no panacea for global warming. Even with massive expansion, nuclear energy should be complemented by drastic fossil fuel decarbonization and massive renewables development, preferably in combination with far-reaching efficiency and savings measures, to attain an emission profile involving a carbon reduction down to one-third of the current level during the latter half of the 21st century (and to lower values after that).Figure 1 demonstrates, through a comparison of the two scenarios, the potential significance of a huge expansion of nuclear power in terms of total energy-related (annual and cumulative) carbon emissions.

Nuclear Economics

The costs and capital intensity of electricity generation alternatives are essential determinants for energy policy decisions, more so for developing countries than for countries in the industrialized world. Whereas nuclear energy has proven its ability to compete with other (fossil) alternatives in a few cases, on a global level it has never done so in a convincing manner. In the current context of liberalizing electricity markets, the capital intensity of nuclear power constitutes an increasing economic disadvantage. Also the intrinsic uncertainties and liabilities of nuclear power generation (related, for instance, to radioactive waste, decommissioning, and reactor safety) render nuclear energy economically unattractive. On the other hand, once nuclear power plants are fully depreciated - typically after 30 years of operation - their low fuel costs imply that reactors become competitive on a marginal-cost basis, even in a deregulated environment. Another aspect in favour of nuclear energy is that its negative environmental

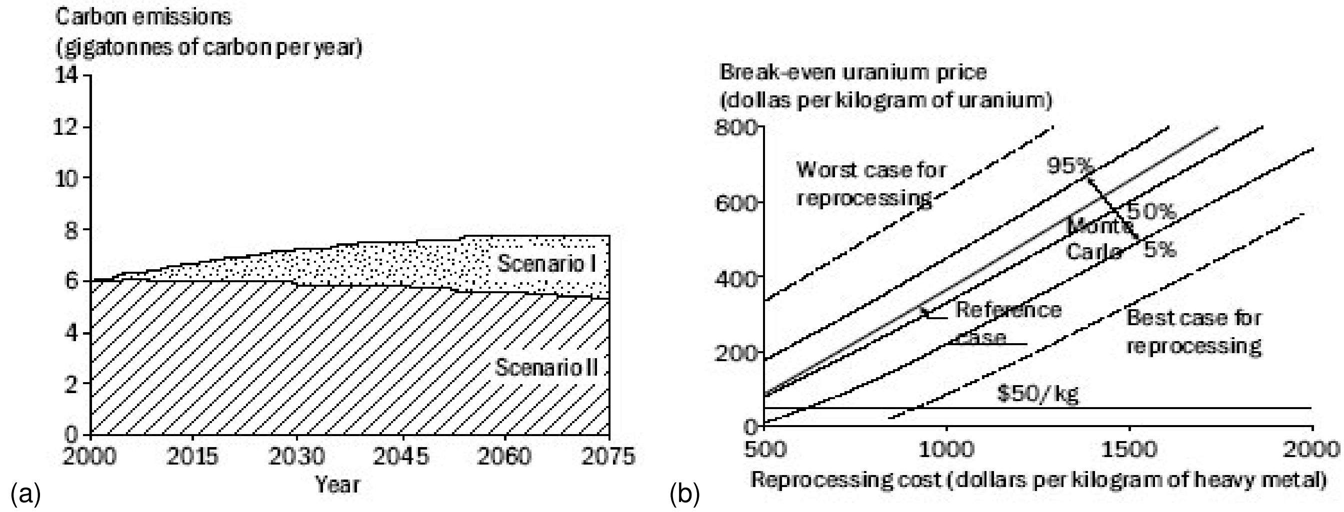

Figure 1. a. Energy-related carbon emissions (gigatonnes per year), from 2000 to 2075. **b.** Monte Carlo analysis of the break-even uranium price as a function of the cost of reprocessing, for various sets of assumptions about the cost of other fuel-cycle services **Source** Bunn, Fetter, Holdren, *et al.* (2003)

externalities have been more extensively included in electricity costs than in the case of its fossil-based counterparts. Like for most renewable energy resources, and unlike for fossil fuel energy systems, the external costs of nuclear energy are expected to be small (Rabl 2001).3 Proper internalization of negative externalities for all energy resources would thus probably reinforce the competitiveness of nuclear energy. Two possible caveats in this respect, for nuclear energy, are perhaps reactor accidents and nuclear proliferation.

As for large reactor accidents with major external radioactivity pollution, a justified argument can be made that the environmental costs corresponding to the resulting radioactive contamination damage can be very substantial. In the external cost calculations of Rabl (2001), reactor accidents and their effects have been included. Only, their contribution to total costs proves small, as a result of their relatively low occurrence. Since the earliest days of the nuclear era, another aspect unfavourable to nuclear power has been the prevention of nuclear (military) proliferation.

The related costs are not accounted for in externality calculations, partly because it appears difficult to do so, and partly because it appears controversial how to do so. For example, the costs required for maintaining international institutions such as the International Atomic Energy Agency, designed to warrant the civil use only of nuclear energy, are not included in external costs. But since these are small in comparison to other (external) costs, this omission probably does not affect the end result of external cost calculations. How does one go about dealing with the expenditures of the (nuclear) military build-up of one country in response to the acquisition of nuclear weapons by another? The corresponding costs are surely not accounted for in electricity prices or external costs, however much the civil use of nuclear energy opens the door to its military use. Since the 9/11 attacks in 2001 on New York and Washington, DC, public and political fear has been expressed regarding the use of nuclear fission or radiological devices by terrorists. Among potential radiological threats are those involving material or facilities related to the civil nuclear power industry. Terrorist risks to nuclear power plants and spent fuel cooling ponds may be considered especially high (Alvarez, Beyea, Janberg, et al. 2003; van der Zwaan 2003), and costs to enhance security against terrorist attacks (supposing that through heightened security measures such attacks, and their potential results in terms of costs incurred, can be avoided) should be taken into account in - and are unfavourable for - the economics of nuclear energy.4

If a country decides to develop a civil nuclear power programme - that is, if it chooses to do so after having thoroughly weighed the costs against the benefits of starting off and maintaining such a programme - it still needs to make a careful cost-benefit analysis of the various nuclear options available, especially with regard to the adoption of an open or closed nuclear fuel cycle. There is general agreement on the fact that with today's low uranium and enrichment prices, the reprocessing and recycling option (allowing to close the nuclear fuel cycle) is more expensive than the alternative of direct disposal of spent fuel (implying an open fuel cycle). Arguments exist, however, over the magnitude of the difference, and how long this difference is likely to hold. Advocates of reprocessing often argue that the extra cost of reprocessing is small today, and might soon disappear, as uranium supplies become scarce and their prices rise. In some recent studies, by contrast, it is demonstrated that the margin between the cost of the closed fuel cycle and that of the direct disposal option is wide, and is likely to persist for many decades to come, if not longer (MIT 2003; Bunn, Fetter, Holdren, et al. 2003).For example, with central estimates for key fuel-cycle parameters, reprocessing and recycling plutonium in existing LWRs will be more expensive than direct disposal of spent fuel until the uranium price reaches over 360 dollars per kgU (per kilogram of uranium). This price is not likely to be seen for many decades, as current uranium prices are about an order of magnitude smaller (typically 40 dollars per kgU or lower). With reprocessing and recycling of plutonium, the electricity cost would be increased by some 0.13 dollar-cents (1.3 mills) per kWh (kilowatt-hour), compared to a total back-end cost for direct disposal of about 1.5 mills per kWh. With central estimates for key fuel-cycle parameters, reprocessing, and recycling plutonium in FBRs (fast breeder reactors) (involving an additional capital cost, compared to new LWRs, of 200 dollars per kWe (kilowatt-electric) will not be economically competitive with a once-through cycle in LWRs until the price of uranium reaches around 340 dollars per kgU. Electricity from a plutonium-recycling FBR would cost over 7 mills per kWh more than electricity produced with a once-through LWR (Table 3).

The findings of Table 3 are obtained through detailed calculations that include assumptions on all parameters determining the costs of nuclear power through either of the two types of fuel cycle. By how much would the costs of the various parameters have to change in order to significantly modify the results on the economics of reprocessing and recycling in LWRs and FBRs in comparison to that of the once-through cycle in LWRs? Figure 2 provides the answer through an illustration of the results of a Monte Carlo analysis of the break-even uranium price as a function of the cost of reprocessing, for various sets of assumptions about the cost of all main fuel-cycle services. It is evident that even when optimistic assumptions are made regarding the costs of all elements of the entire reprocessing cycle, it remains difficult to reach values of the uranium break-even price that approximate prices at which uranium can today be purchased on commercial markets.

The economics of reprocessing is an increasingly important issue, since some countries in both the industrialized and developing worlds need to take major decisions on the future management of their spent fuel. For developing countries like China and India, particularly, the high costs involved in reprocessing and recycling must be given careful consideration, now that important decisions regarding the possible construction of large commercial reprocessing facilities in these countries are soon to be taken. Of course, economics is not the only factor determining whether or not a country should close the fuel cycle through the establishment of a reprocessing industry. Other arguments matter, such as the property of reprocessing to enhance (uranium) resource efficiency. More pertinently, reprocessing may lead to substantial reductions in the overall volume of waste production (for example, per unit of electricity generated) and may contribute, in principle, to ascertaining long-term energy supply security. In both China and India, however, vast opportunities exist for underground geologic waste storage, so that waste volume reduction is probably not a very important issue. Arguments can be made for creating a reprocessing economy since it could enhance energy security but, as will be pointed out next, such reasoning does not appear very strong here. Therefore, in decisions regarding whether to reprocess or not, economics probably plays a fundamental role in these countries.

Nuclear power in Asia

Today, only eight developing countries (excluding those with economies under transition in Central and Eastern Europe and the former Soviet Union) possess nuclear power or are in the process of building one or more nuclear reactors: Argentina, Brazil, China (including Taiwan), India, Iran, North Korea, Pakistan, and South Africa (IAEA 2002). Of these, five are in Asia. Almost the entire current expansion of nuclear power capacity in developing countries today takes place in Asia, with Argentina being the only non-Asian developing country that has currently a reactor under construction (South Africa will probably build one or more again in the near future), and Pakistan being the only Asian developing country (of the ones that already possess some nuclear capacity) that currently has no additional power plant under construction (the other four Asian developing countries with nuclear capacity or aspirations have at least one unit under construction).

Even seen from a global perspective, nearly all nuclear power expansion currently takes place in Asia. Today, the two countries in the world pursuing an expansion of their nuclear power capacities most actively (with the largest numbers of reactors under construction) are China (with three units under construction, totalling a net capacity of about 2.5 GWe (gigawatt-electric) and India (with eight units under construction, totalling a net capacity of over 2.5 GWe (IAEA 2002). Having tested a range of different reactor types, largely from Canadian, French, Russian, as well as domestic designs, China is now moving to standardization and self-reliance in design, manufacturing, construction, and operation. India has already occupied for some time a leading place among Asian nations in indigenous design, development, construction, and operation of nuclear power reactors. Because of their leading roles in the nuclear field in developing Asia, their ambitious nuclear expansion plans, and their potential to become major exporters of nuclear technologies, the decisions of China and India regarding nuclear energy will determine its development in Asia and may have a sizeable effect on its evolution worldwide.

China

In 1997, electricity generation in China was 1163 TWh (terawatt-hours), about three-quarters of it coming from coal-fired plants (IEA 2000). Over the coming two decades, it is expected to grow by about 5% per year, so that by 2020 electricity generation will amount to some 3691 TWh. In 1997, electricity generation through the combustion of coal, oil, and natural gas amounted to 863 TWh, 83 TWh, and 7 TWh, respectively. By 2020, these values are projected to increase to 2568 TWh, 197 TWh, and 149 TWh, respectively. Hydropower is estimated to generate around 622 TWh in 2020 (196 TWh today), while renewables remain negligible over the two decades. Due to its large population and its heavy reliance on coal, China's contribution to global GHG emissions stands high. In 1997, its CO2 emissions were 14% of the world total; by 2020, they are expected to climb to nearly 6.5 Gt (gigatonnes)—roughly 18% of the world total.

Today, China has eight large nuclear reactors in operation, representing a net capacity of over 6 GWe. Five of these started operating only during the past two years. Within the next few years, three reactors currently under construction should be in operation too, taking the total available net nuclear power capacity to nearly 9 GWe. China's official plans for further expansion of nuclear capacity are ambitious and, until recently, reached as high as an installed capacity of 20 GWe by 2010 and 40 GWe by 2020.5 It is probable, however, that these official goals will not be met. Still, China may well have installed a nuclear power capacity of about 20 GWe by 2020. Nuclear energy's contribution to electricity generation in China is currently a little over 1%, and will most likely remain below 3% for decades.

To realize and support the long-term expansion of its nuclear power programme, China plans to reprocess its spent nuclear fuel produced, and to recycle the resulting plutonium in mixed oxide, or MOX, fuel for both LWRs and FBRs. China already possesses a small - more or less operational - civilian pilot reprocessing plant with a capacity of 50 tonnes of spent fuel per year, and has started the construction of an experimental FBR with a capacity of 25 MWe (megawatt-electric). Decisions are pending on whether or not to build a large commercial reprocessing plant with an annual capacity of 800 tonnes of spent fuel as well as a 300-MWe FBR. Energy security is a major reason for China's desire to operate a closed nuclear fuel cycle, rather than an open cycle in which spent fuel once discharged from the reactor is considered as waste and stored as such. Indeed, under China's existing nuclear programme, based on a once-through fuel cycle, the currently proven domestic uranium reserves would probably be used up within a few decades (Zhang 2001).

India

In 1997, electricity generation in India was 463 TWh, about three-quarters of it coming from coal-fired plants (IEA 2000). Over the coming two decades, it is expected to grow by about 5% per year, so that by 2020 electricity generation will amount to some 1483 TWh. In 1997, electricity generation through the combustion of coal, oil, and natural gas amounted to 339 TWh, 12 TWh, and 28 TWh, respectively. By 2020, these values are projected to increase to 1008 TWh, 32 TWh, and 216 TWh, respectively. Hydropower is estimated to generate around 171 TWh in 2020 (75 TWh today), while the contribution of renewables will probably increase to the 1% level over the two decades. Whereas India's population will soon surpass China's, India's level of GHG emissions will remain significantly lower over the decades to come. In 1997, its CO2 emissions were 0.9 Gt; by 2020, they are expected to climb to nearly 2.25 Gt—a factor of three smaller than that of China.

India currently possesses a rather large number of (small) reactors. Today, it has 14 reactors in operation (with a cumulative capacity lower than the eight in China) representing a net capacity of around 2.5 GWe. By the second half of this decade, the eight reactors now under construction should all be in operation, taking the total available net nuclear power capacity to over 5 GWe. The Indian government's official plans for further expansion of its nuclear power capacity are ambitious. Like with other countries, the main rationale for India to embark upon an expansion of its nuclear power programme is its desire to create domestic energy security (Iyengar 1999). It is realistic to assume that India will have installed a nuclear capacity of around 15 GWe by 2020. The current contribution of nuclear energy to electricity generation in India is close to 4%. With the domestic nuclear capacity increase as projected, this contribution could amount to 8% by 2020.

Like China, India has chosen the closed fuel cycle for realizing a long-term expansion of its nuclear power programme, and thus plans to reprocess the spent fuel generated by its nuclear power plants. India's programme is based on a three-stage plan, to eventually exploit its abundant domestic resources of thorium through the use of FBRs. In this plan, the first stage involves the construction of mainly PHWRs (pressurized heavy water reactors) for electricity generation with the production of plutonium as a by-product. In the second stage, FBRs are built, to be fuelled with this plutonium and depleted uranium, to produce uranium-233 in their thorium-loaded blankets. In the third stage, FBRs are fuelled with thorium and the uranium-233 initially produced from the second stage. A small 14-MWth (megawatt-thermal) test FBR has been successfully operated for over a decade now, while a detailed design of a 500-MWe prototype FBR has been completed and a construction site approved. If current construction plans are realized, India's first large FBR could be commissioned by the end of this decade. As for China, a major reason for India to choose the closed nuclear fuel cycle is energy security. Indeed, under India's first-stage, largely PHWR nuclear power programme, domestic uranium reserves are expected to represent some 400 GWe-years worth of electricity, which would be consumed within a few decades under current nuclear power expansion plans (Gopalakrishnan 2002).Is reprocessing the right choice for Asia?

A recent study by the Massachusetts Institute of Technology concludes that, over at least the next 50 years, the best choice to meet nuclear energy's challenges is the open, once-through fuel cycle (MIT 2003). It judges that there are adequate uranium resources available at reasonable cost to support this choice under a global growth scenario of nuclear power. China and India have arrived at the critical point of deciding whether or not to develop large-scale reprocessing and breeder programmes. For both countries, energy security is one of the main arguments not to opt for the once-through nuclear fuel cycle that obviates the need to reprocess and recycle spent nuclear fuel. Below, through at least six arguments, it is pointed out that energy security in China and India constitutes insufficient ground for justifying the elevated costs that the establishment of a closed nuclear fuel cycle would entail.6

First, advocates of a large nuclear energy programme - including a plutonium recycling economy - claim that it would reduce national dependence on foreign energy resources such as oil. This is true, since through nuclear energy one can decrease dependence on oil for electricity production. However, it is true only to a limited extent: nuclear energy and oil are today largely complementary energy resources, rather than substitutes. Oil's largest application is currently in the domain of transport, for which nuclear energy is for the moment still unsuitable. Only in the longer term could nuclear energy be used for the production of hydrogen, which is fit - in principle - for large-scale employment in the transport sector.

Second, in the two scenarios depicted for China and India, 3% and 8%, respectively, are possible (and probable) electricity shares for nuclear energy in 2020. (Much higher shares by that time are deemed unlikely.) These shares correspond to a share in the national demand for energy (rather than for electricity) of a few percentage points at most. In view of the larger scheme of energy security, these numbers are too small to make any significant difference for the energy dependence of either of these countries. How the projected nuclear energy is produced - for instance, whether it is through a reprocessing cycle or not - matters little. Third, if China's and India's energy infrastructures become more dependent on nuclear energy beyond the forthcoming two decades, while domestic fissile resources are rapidly used up, energy security could become a concern. However, a depletion of global uranium reserves is unlikely for a long time to come, due to the existence of large global reserves of uranium, the possibility of enlarging these by factors when exploration at higher costs is allowed, the likely presence of large and yet undiscovered uranium resources, and the availability in oceans of vast amounts of uranium, presumably recoverable at competitive prices. With a continued existence of well-established, commercial world markets for uranium, the supply of nuclear fuel does not seem in danger for many decades, if not centuries.7

Fourth, several countries including South Korea have shown that a large nuclear power programme can be easily realized, operated, and maintained without possession of large domestic uranium resources, extensive local enrichment facilities, and national nuclear fuel production. The reason is that the existing global market for uranium products is hardly subject to fluctuations in supply or price, and has - so far - not displayed the volatility that industries relying on the supply of petrol experience in global oil markets.

Fifth, uranium suppliers in the world are diverse, both geographically and politically, and are unlikely - quite contrary to common practice in the global oil market - to collude to raise prices dramatically or limit supplies substantially. Also, in this respect, the differences are large in comparison to the behaviour of global oil markets, where even private consumers dependent on petrol for transportation regularly experience the fluctuations occurring in crude oil prices.

Sixth, even if domestic uranium supply security were to become a matter of concern at some point in the future, a strategic reserve of uranium fuel could be realized easily - surely more easily than in the case of strategic oil reserves - since uranium is inexpensive to buy, simple to handle, and easy to store.

Furthermore, the separation of plutonium increases the risk of illicit purchase by states or non-state/sub-national entities wishing to acquire nuclear weapons, as well as the risk of theft by terrorist groups attempting to develop nuclear fission devices. This implies increased costs and enhanced burden of safeguards and physical protection. The policies of China and India regarding reprocessing could significantly influence the attitude of the international community and the posture of powerful nuclear and economic actors in particular. Indeed, the civil use of plutonium in these countries could serve as an encouragement or excuse for its use by other nations, especially when the latter have interests in using plutonium for military purposes. If China and India were to decide not to develop civilian reprocessing, a good example could be set for other countries in the region contemplating the reprocessing and recycling of plutonium. Also, it seems that China and India currently need to worry little about issues of public opinion (concerning safety, waste, and costs, for instance). The Japanese case, however, may be indicative of how sensitive the matter of maintaining a reprocessing industry can become in these countries as well. The evolution of the reprocessing industry in Japan will probably also influence its potential development in other Asian countries, including China and India.

With these arguments - unfavourable to the development of a reprocessing industry - an obvious question arises. Why do some countries still choose this fuel cycle option, rather than considering spent fuel as waste once it leaves the nuclear reactor? Indeed, China and India currently seem to continue to push for expanding reprocessing technology, and probably not merely for the aforementioned ‘standard reasons’—enhancing uranium resource efficiency and reducing radioactive waste volumes.8 In the way India's nuclear tests have been driven, partly by domestic policy and psychological factors, including the authority of the nuclear establishment (perhaps more than by geopolitical factors [Perkovich 1999]), both in China and India the desire to possess the ability to reprocess may be associated with the virility of the nuclear research elite and thus with the prestige of the country. The Chinese and Indian push for reprocessing technology may partly be explained by elements like the domestic political need to show prowess and also the desire of scientists for continued access to research money and personal fame. Clearly, one should look for arguments beyond economics to understand why countries like China and India push for reprocessing, but it goes beyond the scope of this paper to go into these matters more extensively.

CONCLUSION

As summarized in the beginning of this paper, the fossil resource scarcity perception of the late 20th century was probably unjustified, that is, if one takes a long-term perspective. As the experience of western nations in the 1970s demonstrated, however, threats to energy security remain in terms of the possibility for the world community to need to face short-term energy disruptions. Energy cooperation, increased energy efficiency, and 90-day strategic petroleum reserves were the western response to these disruptions in the late 1970s (Manning 2000). In this, there maybe important lessons for Asia. The US remains a resource- and energy-fuel-rich country, compared to most of the rest of the world, particularly East and South Asia. China and India are generally richer in energy fuels than the rest of East and South Asia, but for most of these fuels not as rich as the US (May 1998).Thus, for Asian countries, nuclear power is partially an insurance policy, the only long-term, internally sustainable energy resource now in sight that can generate electricity at affordable prices. Holding back on nuclear power, including reprocessing, is therefore a more serious gamble for these countries than it is for the US. They are, therefore, unlikely to abstain from developing nuclear energy.

A major challenge facing humankind during the 21st century will be to ascertain adequate, affordable, and reliable energy services in a sustainable manner. Energy is a critical input for social and economic development. With energy use in many developing economies in Asia still at a low level, with about 60% of the world's 2 billion people without access to modern energy services living in this part of the world, and with the global increase in energy demand concurrent with expected economic growth for a large part taking place in this region, it is important that the right (sustainable) energy choices are made (Saha 2003). In developing countries, supply of energy should not become a constraint to their economic growth. Security of supply does not seem to become a major issue for decades to come at least, if not longer, not in developing countries or elsewhere in the world. Rather, the question is whether we can afford the current patterns of energy production and consumption to continue in the rapidly deteriorating health of our common environment. Efforts to control climate change are becoming increasingly important, as well as the role that should be played herein by the implementation of carbon-free energy resources. For the time being, it seems safest to adopt a hedging strategy, in which all non-fossil energy technologies have a share in an energy mix as diversified as possible, including nuclear energy. Still, however large an expansion of nuclear energy may once be realized, it will never contribute by more than a significant part to mitigating global warming, and cannot ever constitute the panacea to the challenge of climatic change. Irrespective of what energy technology blueprint humankind finally deems most appropriate, and adopts, taking a transition path away from the current unsustainable patterns of energy use is one of the main challenges for both developed and developing countries. In attempting to establish sustainable energy systems worldwide, whether in the nuclear field or elsewhere, it is important not to simply impose the model in use in developed nations to countries in the developing world, given the latter's distinct (past) societal and economic evolution and different (current) social and cultural characteristics.

China and India have a vast potential over the 2 ist century to affect regional and global energy markets, linked inextricably to an interdependent world energy sector (see, for the Chinese case, Ogiitcii 1998). Meeting their energy needs in a secure, efficient, and sustainable manner remains one of the most significant challenges China and India face. The developments in the energy field in these two countries will not only determine (to a large extent) domestic economic prosperity and security but also affect the global economy and environment. Therefore, it is no longer useful to think purely in discrete European, American, or Asian policy terms when analysing regional energy futures. In the increasingly interlinked world energy system, more integrated geo-strategic policies and international cooperation are essential to sustain economic growth; to carry out multinational energy projects between China, India, and the industrialized world; and to protect the global environment. Regional and international cooperation will remain important not only for harnessing and trading cleaner forms of energy, but also for addressing transboundary environmental concerns (Datt, Kacker, Mehra, et al. 2002).

Nuclear energy is an option that probably should (and will) be pursued by China and India, as well as other Asian countries, and perhaps by the developing world at large. Nuclear energy can complement other options on the path to realizing clean and affordable energy production and consumption, and possesses intrinsic value in terms of the diversification of energy supply. It is important, however, that the right choices are made in the development of nuclear energy, if a decision is taken to include this option in national energy programmes. China and India, or other developing countries for that matter, do not need to pursue a reprocessing programme in the foreseeable future, based on the arguments made in this paper. It is cheaper to choose the option of direct disposal of spent fuel, rather than to opt for the alternative of reprocessing and recycling. Substantial savings can be realized by going in for direct disposal. The resulting financial means, especially needed in developing countries, can be usefully employed in other domains, for example in the development of other clean energy options. The decision to eventually adopt a nuclear reprocessing economy or not should therefore be postponed, for at least a couple of decades to come, but probably longer. Meanwhile, as new and more advanced nuclear technologies might emerge, the interim storage of spent nuclear fuel from a once-through cycle can be effectively and safely employed. Since the expert discussion about reprocessing is likely to continue for years, countries like China and India could, for the time being, best employ the once-through nuclear cycle, until the reprocessing conundrum has been fully resolved and more technological clarity has been achieved on the nuclear technology to be employed in the future.

REFERENCES

Alvarez R, Beyea J (2003). Reducing the hazards from stored spent power-reactor fuel in the United StatesScience and Global Security11(1): 1-51

Bruggink JJC, C (2002). The role of nuclear energy in establishing sustainable energy pathsInternational Journal of Global Energy Issues18(2, 3, 4): 151-180

Bunn M (2003). The economics of reprocessing vs direct disposal of spent nuclear fuel: managing the Atom ProjectCambridge, USA: Belfer Center for Science and International Affairs and Kennedy School of Government, Harvard University.

Datt D (2002).Sustainable energy: trends and perspectives for AsiaPacific and Asian Journal of Energy12(2): 129-149

EC, IEPE (Institute of Energy Policy and Economics), BFP (Belgian Federal Planning Bureau), IPTS (Institute for Prospective Technological Studies).(2003) World energy, technology and climate policy outlook 2030Brussels: European Commission

Gopalakrishnan A (2002). Evolution of the Indian nuclear power programmeAnnual Review of Energy and the Environment27: 369-395

IAEA (International Atomic Energy Agency) .(2002)Nuclear power status around the worldIAEA Bulletin IEA (2000).World Energy Outlook Paris: International Energy Agency, Organisation for Economic Co-operation and Development

IEA (2002).Energy and Poverty (Special issue in the World Energy Outlook (2002)Paris: International Energy Agency, Organisation for Economic Co-operation and Development

IIASA (International Institute for Applied Systems Analysis) and WEC (World Energy Council) . 1998Global Energy Perspectives, edited by Nakicenovic N, Griibler A, McDonald A Cambridge, UK: Cambridge University Press

IPCC (Intergovernmental Panel on Climate Change) . 2001Climate Change 2001: the scientific basis[Contribution of Working Group I to the Third Assessment Report of the IPCC, edited by J T Houghton, Y Ding, D J Griggs, M Noguer, P van der Linden, X Dai, K Maskell, C I Johnson]Cambridge, UK: Cambridge University Press

Iyengar PK (1999). Problems and prospects for nuclear power in India In Nuclear Energy: promise or peril?, edited by van der Zwaan B C C, Hill C, Mechelynck A L, Ripka G Singapore: World Scientific. 288 pp.

Manning RA (2000). The Asian energy predicamentSurvival

Perkovich G (1999). India's nuclear bomb: the impact on global proliferationBerkeley: University of California Press. 597 pp.

Rabl A (2001).The importance of external costs for the competitiveness of renewable energiesInternational Journal of Global Energy Issues15(1/2)

Rogner HH (1997).An assessment of world hydrocarbon resourcesAnnual Review of Energy and the Environment

Footnotes

[1]All energy consumption patterns from 2000 to 2075 are assumed to increase linearly.

[2]Such a carbon emission profile would preclude reaching over a doubling of the CO2 concentration in the atmosphere. A doubling of this concentration corresponds to an increase of the average atmospheric temperature on earth by around 1.5-4.5 °C (referred to as the 'climate sensitivity'; see IPCC 2001).

[3]The data on nuclear energy in Rabl (2001) comes from the French nuclear power programme. This does not necessarily correspond with that from nuclear programmes in other countries because, for example, safety measures may not have been implemented as strictly in China as they have been in France.

[4]Also, if in some country or by some terrorist group, civil separated plutonium will one day be diverted into an atomic explosive, this may well provoke military and/or anti-terrorist expenditures the world over, and is also likely to adversely affect civil reprocessing programmes in all countries practicing the closed fuel cycle. These consequences are not accounted for in external cost calculations. Similar arguments can be made regarding the possibility to construct radiological devices (dirty bombs) from spent nuclear fuel material.

[5]Meanwhile, it seems that this impressive aim is currently being adjusted downwards.

[7]Admittedly, arguments three through six hold less for India than they do for China, given the embargo and isolation it has experienced from most western and other nuclear suppliers since its underground nuclear tests in 1974. Still, if after further exploration of potential land and ocean resources, uranium proves to be insufficiently abundant domestically, uranium could in principle be imported from countries that are not members of the Nuclear Suppliers Group (for instance Nigeria in Africa). Also, at some point, a solution may be found for the current political international impasse regarding India's nuclear programme.8By engaging on the reprocessing path, China and India are apparently prepared to spend more for those other reasons; how much more has been calculated by Bunn, Fetter, Holdren, et al. (2003).