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Addressing Energy Poverty, Energy Security, and Climate Change in India

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India's Energy Reality—the 'Burning' Issues

India is severely energy deficient—more than half its rural households are resigned to darkness after sundown; cities suffer long and frequent power cuts. Per capita power availability in India at 631 kilo watt hour (kWh) is way below the world average.[1] This compares poorly with global statistics of 17,179 kWh in Canada, 13, 338 kWh in USA, or 5,644 kWh in Italy, and even 1,300 kWh in China.[2] This has both a direct and indirect impact not only on the quality of life but also on the overall economic growth potential and the national development index.

In addressing the challenge of energy poverty, it is imperative for the government to pay adequate attention to the overall picture of sources of energy available to the country and their advantages and limitations. For instance, it would be counter-productive for the nation to solely invest in those energy sources which do not come with the assurance of secure supplies, or those that raise national vulnerability by increasing dependence on unreliable and unstable supplier nations, or cause significant environmental pollution. Therefore, the energy demands need to be met through safe, reliable, secure, and environmentally sustainable fuel sources. This obviously calls for a diversification of energy sources. At the moment, India draws the bulk of its electricity from thermal sources, especially coal. In fact, 55 per cent of the country's total commercial energy need is met by coal-fuelled electricity generation. Hydro power comes a distant second at about 25 per cent, and then renewable sources provide another small share of the electricity at about 15 per cent. Finally, nuclear reactors provide 3 per cent of the total electricity generation. Despite its rather meagre contribution, nuclear energy holds substantive promise from the perspective of meeting India's humungous energy needs in a secure and sustainable low carbon way.

This article examines the role that nuclear power could play in assuring India with a level of energy security, and

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1 Union Power Minister Mr Shinde in a reply to a question in the Rajya Sabha and as reported in 'Per Capita Power Consumption in India', http://www.inrnews.com, 20 August 2007.

2 International Energy Agency (2006).

even energy independence,[3] in an environmentally sustainable manner. It explores the advantages of investing in nuclear expansion, which is today possible with the conclusion of the Indo-US civilian nuclear cooperation agreement that has opened the prospects of India's participation in international nuclear commerce. It highlights the advantages, some of them unique to this country, of adopting nuclear power as a major input to the future energy mix. It also examines the challenges that lie ahead in the expansion of nuclear power.

While the primary focus of the paper is on nuclear energy, it nevertheless is premised in the belief that there is need for growth and development of *all* energy sources, existing and potential, to power India's socio-economic growth and development. The country's energy requirements are so huge that it cannot afford the luxury of banking on only one or two fuel sources to power its future.

Among the challenges facing an emerging India, two could particularly derail the process of its rise to being a significant power in the region and beyond, and they are interconnected. The first is widespread social disharmony as a result of skewed economic development and unmet aspirations of a growing and an increasingly aware population. The resulting discontentment coupled with growth of sub-nationalism, opportunistically exploited by vested interests of domestic and external adversaries could severely strain the country's socio-politico-economic fabric. Hence, it is important to comprehend the criticality of inclusive social and human development along with economic growth to ensure societal peace and national security.

The second challenge arises from the sheer shortage of electricity that drives the economic growth and development. It is widely accepted that electricity has a direct connection with development and per capita energy consumption is a parameter for calculating the human development index. Therefore, it is hardly surprising that energy and the ability of a nation to access it from reliable, secure, sustainable, and safe sources tops national priorities everywhere. Energy poverty is obviously a handicap that a nation aspiring to fast-track development and growth can ill afford. This is even more important for a nation like India that expects a phenomenal growth in its energy demand, estimated to be between 6–10 per cent per annum during the first quarter of the twenty-first century. The power policy of India promises electricity availability to all by 2012.[4] This appears practically impossible given that the present total power generation of about 157 GW is woefully short of the demand that is growing by the day. In fact, India's power generation capacity was calculated to be 68 per cent below the target that had been set for 2009.[5]

For this situation to substantially change, the absolute amount of electricity generated by India would have to at least double by 2020, double again over the next ten years, and be close to ten times the figure today by 2050. According to Dr Kakodkar, Chairman, Atomic Energy Commission, even if India's per capita energy consumption was to rise to 5,000 kWh (which would still be about one-third the current consumption figures in Canada or the USA), the country would suffer an energy deficit of 412 GW by 2050.[6] As is evident, the deficit itself is likely to be close to three times the current total power production!

The Expert Committee on Energy constituted by the Government of India estimated in 2006 that India's power needs would be about 960 GW by 2031–2, assuming a GDP growth rate of 9 per cent.[7] Later developments such as the global financial crisis and the consequent economic downturn have brought down the expected rate of growth of the Indian economy to 7 per cent per annum. Even at 7 per cent the vulnerabilities that will accompany large-scale energy import dependence are clearly evident.[8] A stark contrast in this sector is evident when one compares India with the rapid strides that China is making. It is today the fastest growing generator of electricity in the world. New generation capacity that China will add to its existing capacity in 2010 alone will exceed the total installed capacity of Brazil, Italy, and Britain, and these are nations with fairly large generation capacities themselves.[9]

It is obvious that energy poverty alleviation has to remain a critical priority for India if it is to realize its aspiration of emerging as a major power. Energy security through the expansion of generation capacity not only bolsters national confidence and pride, it also enables further growth and development. Secure and abundant

[3] Former President A.P.J. Abdul Kalam often talked of energy independence as the 'nation's highest priority'. See his address at Kudankulam Nuclear Power Project on 22 September 2006 as reproduced in *Nuclear India* (2006).

[4] Srinivasan (2005).

[5] *livemint.com* (2009).

[6] Kakodkar (2008).

[7] Aiyar (2008).

[8] India's energy imports are discussed in a subsequent section of this paper.

[9] *Economist* (2010). China is in fact slated to produce more power annually than America, the current leader, by 2012.

availability of electricity to run modern economies makes a nation an attractive investment destination. In this regard, it would be useful to cite a statement made in the context of China, 'Cheap, reliable electricity is one reason why China remains the *preferred destination* for manufacturing even as its wages rise above those in such countries as Bangladesh, Indonesia, the Philippines and Vietnam'.[10]

The Government of India, therefore, must urgently focus on meeting the enormous energy requirements of the country. This would call for cultivating a diverse mix of energy sources that pragmatically balance considerations of cost, uninterrupted availability of fuel, and environmental impact. It is important that every potential source of energy be optimally used and the menu of options be as varied as possible so as to minimize risks of disruption arising from shortages, price fluctuations, or political manipulations.

Sources of Energy in India: the Present Scenario

For India, which together with China accounts for 45 per cent of the increase in global primary energy demand, nuclear power holds tremendous promise. Much like the rest of the world (except perhaps France and Japan), the bulk of India's existing power generation capacity exists in the thermal sector. In fact, nearly 65 per cent of the total energy generation of India is met from coal, oil, and gas. The worrisome part is that India imports these traditional fossil fuels in large quantities to meet its energy demand, increasing its vulnerability to global mood swings. For a large and rapidly developing country like India, bulk imports of fuel are neither affordable nor strategically prudent. Moreover, with increasing worldwide competition for non-renewable hydrocarbons, their prices can only be expected to rise and this will remain a cause of concern for the future.

India has reasonable coal reserves, which according to British Petroleum estimates, comprise 8 per cent of the world total. The country is the fourth largest producer of coal and lignite in the world (after the United States, China, and Australia).[11] However, India's coal reserves are of low quality (with high ash content and low calorific value) concentrated in select pockets of the country. This necessitates haulage of coal over long distances, which not only raises cost but also ties down the transportation network. In fact, transport costs raise the cost of coal three times from when it comes out of the mine. Nevertheless, at present, coal remains the dominant fuel. This, however, entails the large-scale imports of coal annually. In fact, the Sankar Committee set up to recommend measures to meet the demand-supply gap had estimated import of 30–40 million tonnes of high-grade coal by 2011–12.[12] However, coal imports have far exceeded that figure in 2010 itself. According to the chairman of Coal India Ltd., in 2009, India's coal imports stood at 59 million tonnes and 'should be around 100 million tonnes' for the year ending 2011.[13] If the time horizon is stretched to 2050, *without adding nuclear energy to the Indian energy basket*, then coal imports would have to be to the tune of 1.6 billion tonnes.[14] The enormity of these figures and the gravity of the situation are self-evident.

India's oil consumption in 2009 was about 2.67 million barrels per day, having doubled from the figure in 1992.[15] As the Indian economy continues to grow even modestly at 7 per cent per annum, the oil requirement of the country is expected to double again from the present consumption figures by 2030.[16] In 2006, India was the seventh largest net importer of oil in the world. With 2007 net imports of 1.8 million bbl/d, India is currently dependent on imports for 68 per cent of its oil consumption. The EIA expects India to become the fourth largest net importer of oil in the world by 2025, behind the United States, China, and Japan.[17] Crude oil prices are unlikely to fall below $50 per barrel in the coming few years even though they have come down from the high peak of $135 per barrel earlier in 2008. This has enormous implications not only for the strain it causes on the Indian exchequer, but also on the strategic autonomy of the nation. It may be recalled that France and Japan realized their vulnerabilities during the oil shock of 1973 and thereafter pursued strategies to secure their energy supplies on a war footing.

[10] Ibid. Emphasis added.

[11] Tata Energy Research Institute (TERI) (2003), http://www.teriin.org/energy/Indian energy sector.htm

[12] *Hindu* (2007).

[13] Lomax (2010). India is presently importing its coal from Australia, Indonesia, South Africa, and more recently Colombia.

[14] As estimated by Kakodkar (2008), footnote 6.

[15] At 2.67 million barrels per day, India's oil consumption was actually less than in 2008 which had peaked at 3 million barrels a day but fell due to the economic slowdown. For more on this see India Energy data provided by US Energy Information Administration at http://www.eia.doe.gov/cabs/India/Oil.html

[16] EIA (2007).

[17] Ibid.

Fast track expansion of nuclear power generation emerged as the solution for them.

The third source of thermal power generation is natural gas. The use of this fuel for energy generation is expected to increase substantially in the coming years. But, given the limited domestic availability of natural gas vis-à-vis the demand, it will have to be sourced from outside through elaborate and long-distance pipelines and LNG shipments. These will bring their own risks of terrorism, piracy, and environmental spills. While 'peace pipelines' is politically a laudable concept, it has enormous economic and security implications, especially for India since the pipelines will have to pass through politically unstable nations that harbour open hostility towards India.

Efforts to harness viable renewable energy resources continue to increase the share from such sources, as wind, biomass, solar, hydro, in the total energy generation portfolio. Research and development efforts are being encouraged in renewable energy technologies, which include such sources as tidal and geothermal energy. However, except for hydro power in the few places where it is plentiful, none of these has presented itself as being suitable, intrinsically or economically, for large-scale power generation where continuous, reliable power supply is needed and it is well known that reliability and evenness of electricity supply is even more critical for an increasingly digitized information society. Development of energy efficient technologies and measures has to continue. But, these efforts cannot be expected to be able to meet the enormous energy demand and can only be complementary to the addition of new generation capacities.

In a scenario where the domestic deficit on fuel sources exists, nuclear energy emerges as a promising energy source. Nuclear power can significantly supplement electricity availability and hence ease the heavy dependence on hydrocarbons. As has been stated earlier, the cases of France and Japan amply prove this. France today generates 80 per cent of its electricity from nuclear energy. Meanwhile, Japan had managed to reduce its oil imports from 80 per cent in 1970s to 56 per cent by 1990s and today sources 30 per cent of its electricity from nuclear power, though it has no indigenous uranium sources.[18]

Nuclear Energy and Increasing Environmental Consciousness

If the growing Indian economy continues to rely on traditional thermal energy sources, carbon emissions would significantly rise and environmental consequences like greenhouse effect, global warming, and climate change would progressively become a serious cause for concern. Thermal power plants pose the problem of GHG emissions that cannot be wished away despite technology improvements and implementation of stringent environmental measures. Rather, pollution is sure to increase with the upsurge in energy production from thermal plants. Table 14.1 estimates CO_2 emissions from different energy sources in order to illustrate that coal, oil, and gas remain major sources of carbon emissions, while nuclear and other renewable energy sources figure around the lowest.

As is evident, nuclear power emits the least amount of greenhouse gases bettered only by wind energy. Given these figures, it is obvious that the strategies and technologies adopted by countries with large energy requirements will have critical implications for local and global environment. Illustratively, France, which meets 42 per cent of its primary energy consumption from nuclear energy has the lowest per capita carbon dioxide emission in Europe.

At present, India's per capita carbon emissions stand at 1–1.2 tonnes[19] compared to 20 tonnes per capita in the US.[20] This is not in the least due to exceptionally good energy policies and practices but due to the fact that a large proportion of the Indian population is denied access to power. This is about to change and should too, if India expects to grow and emerge as a power to reckon with globally. The least it can do is provide energy access to its people. With continued urbanization, a shift from non-commercial to commercial fuels, increased use of motorized vehicles, and prolonged use of older and inefficient coal-fired power plants, India's emissions are expected to

Table 14.1 Carbon Dioxide Emissions from Power Technologies in g/kWh

Coal	*Advanced Coal*	*Oil*	*Gas*	*Nuclear*	*Biomass*	*Hydro*	*Wind*
960–1,300	800–860	690–870	460–1230	9–100	37–166	2–410	11–75

Source: Banerjee (2001).

[18] Singh (1999).
[19] Ministry of Finance (2010).
[20] A report by Hinkle Charitable Foundation.

increase and nearly triple by 2030.[21] In fact, according to the US Department of Energy, between 2001 and 2025, India's carbon emissions will grow by 3 per cent annually, twice the predicted emissions growth in the US, making India the third largest air polluter after the US and China by 2015 itself.[22] If India is to avoid this dubious distinction, then a conscious decision must be taken to switch to more environmentally sustainable energy technologies, such as nuclear power.

Global Interest in Nuclear Energy

Nuclear power today accounts for 15 per cent of global electricity generation[23] and the world now has more than half a century's experience in handling this technology which is equivalent to over 14,000 reactor years; expertise and confidence in the area has steadily grown.[24] Furthermore, rising oil prices and growing environmental concerns over the last decade have led to a reconsideration of sustainable energy fuels. In this milieu, nuclear power has resurfaced as a keen contender for large-scale energy generation. Thus, even in the US, after a period of low interest in new nuclear construction, studies such as the one conducted by the Massachusetts Institute of Technology, indicated the need for renewed emphasis on the role of nuclear power for energy security.[25] After nearly three decades of no new nuclear plants (though upgrades of existing plants continued), the US Nuclear Regulatory Commission (NRC) today has licence applications for 20 new plants pending before it. Even as the NRC hires more people to help cope with the application rush, new factories are being set up to fabricate parts and components of nuclear plants.

Likewise, in Europe too, a report prepared for the European Economic & Social Committee, which advises the European Commission, emphasized that Europe needed nuclear power.[26] Consequently, some of the EU members, such as Italy and Germany that were not in favour of nuclear energy, are reconsidering their phase-out policies. The UK plans to build four more nuclear plants with help from France, with the first one likely to be operational in 2017.

Meanwhile, China has emerged as the fastest growing nuclear power generator and if its ambitious plans are realized, then it will be the largest producer of nuclear energy at 130 GW by 2030.[27] In fact, of the 55 GW of additional installed nuclear generating capacity projected for Asia, 24 GW is projected for China, 12 for India, and 12 for South Korea.[28] China currently has 21 nuclear power plants simultaneously under construction, more than in any other nation at any point in time in the past. As they attain criticality over the next ten years, China would have spent $150 billion to increase its nuclear capacity nine-fold.[29] According to OECD estimates, if the nuclear activity planned over the coming decades remains on track, nuclear reactors would supply a fifth of the total electricity generated worldwide by 2050.[30]

Nuclear Energy in India: Dispelling the Myths and Misconceptions

Several analysts have argued that given India's limited and low-grade uranium reserves, the development of the nuclear programme beyond 10,000 MWe would imply increasing dependence on uranium imports. However, this viewpoint tends to overlook the logic of India's three-stage nuclear power programme that envisages large-scale utilization of India's significant thorium reserves. It is in order to tide over the transition from fast breeder reactors to the thorium cycle that India needs uranium. Therefore, unlike the case of coal or oil or gas, where imports appear to be a permanent reality, uranium dependency would be for a limited period of time till India graduates to the thorium cycle.[31]

What is the contemporary Indian situation on the nuclear energy front? At present, India produces 4,340

[21] Ministry of Finance (2010).

[22] Figures as cited by Condoleezza Rice, Remarks at the Senate Foreign Relations Committee on the US India Civil Nuclear Cooperation Initiative, 5 April 2006. Available at US State Department website.

[23] This has dropped from 16 per cent in 2005 as a result of six of Japan's nuclear power plants remaining shut as a consequence of the earthquake early in 2008 and several of France's reactors going in for simultaneous repairs.

[24] World Nuclear Association (2009a).

[25] MIT Study (2004).

[26] 'EU Report Supports Nuclear Role', *Nucleonics Week,* 2004.

[27] At present, the US is the largest producer of nuclear power at 98 GW. At present, China has 11 operational nuclear power plants that provide 1.3 per cent of its total generating capacity.

[28] World Nuclear Association (2009b).

[29] Slater (2010).

[30] Patel (2008).

[31] For a detailed techno-scientific explanation of the three stages of the programme, see http://www.dae.gov.in

MWe from its 17 operational nuclear power plants. This amounts to about 2.9 per cent of the total generation capacity of the country. With the recent opening of India to international nuclear commerce, it is expected that there may be a surge in nuclear generation capacity in the coming decades.

It is worthwhile to examine the much debated issue of the economics of nuclear energy. Traditionally, nuclear power has been considered an expensive energy source given the high capital cost and long gestation periods required for building power plants. But recent empirical data indicates otherwise. Nuclear power has long been proven a viable economic option in terms of Long Range Marginal Cost (LRMC), or for power supply at locations far away from coal reserves, particularly if hydel sources are also not available in these areas.[32] In fact, a comparative techno-economic analysis that accounts for location of coal mines, transportation of fuel, availability of railroads, ash content, and associated environmental impact and necessary mitigation measures, etc., skews the cost benefit in favour of nuclear energy. Even if the cost of uranium has doubled in the last few years, yet given that fuel costs for nuclear plants are a minor proportion of total generating costs, in contrast to coal or gas-fired plants, the long-term economics of nuclear plants work out better. Also, the fuel's contribution to the overall cost of the electricity produced is relatively small, so that even a large fuel price escalation has relatively little effect. For instance, typically a doubling of the uranium market price would increase the fuel cost for a light water reactor by 26 per cent and the electricity cost about 7 per cent (whereas doubling the gas price would typically add 70 per cent to the price of electricity from that source).[33]

In fact, contemporary trends such as low interest rates, high oil prices, improvements in nuclear plant capacity factors,[34] reduction in construction time, etc., have further rationalized the per unit cost of nuclear electricity. In fact, the construction and cost experience of Tarapur Atomic Power Plant (TAPP) 3 and 4, among India's latest nuclear plants is illustrative of this. Not only have these plants been constructed in record time but also at a cost lower than expected. According to the Chairman of the Nuclear Power Corporation of India Ltd. (NPCIL),[35] the two units were built in five years at a cost of Rs 6,100 crore against an approval of Rs 6,525 crore. Modern systems of construction and resource management have indeed contributed to the economics of nuclear power.

At the same time, newer methods of cost calculation that include 'external costs' of health and environment tilt the balance further in favour of nuclear energy. Unlike thermal plants where the waste generated is so much more, nuclear power internalizes the cost of spent fuel management, plant decommissioning, and waste disposal. An EU study estimated that inclusion of health and environment costs would double the EU price of electricity from coal and increase that from gas by 30 per cent.[36] The cost of nuclear power is further enhanced once carbon dioxide emissions begin to carry a significant 'price'. Emission trading provides incentives for investment in carbon-free electricity technologies, and this improves the economics of nuclear power considerably.

Nuclear Energy for India's Energy Security

With experience of over half a decade in the field of nuclear technology, India, in the words of Dr Chidambaram, former Chairman, AEC, is 'the only developing country that has demonstrated its capability to design, build, operate and maintain nuclear power plants, manufacture all associated equipment and components, and produce the required nuclear fuel and special materials'. Indeed, India can claim to have experience in construction, operation, and maintenance of a varied range of nuclear power plants—Light Water Reactors (LWR), Pressurized Heavy Water Reactors (PHWR), Fast Breeder Reactors (FBR), and Advanced Heavy Water Reactors (AHWR). Having gathered several years of reactor experience in PHWR operations, India has now entered the commercial demonstration stage of the FBR programme with installation of the first prototype FBR of 500 MWe at Kalpakkam. Further, India is an emerging leader in the development of reactor and associated fuel cycle technologies for thorium utilization. A 30 kW (Th) research reactor, KAMINI, has

[32] Alagh (1997).

[33] World Nuclear Association (2010).

[34] Power plant reliability is measured by capacity factor, or the percentage of electricity actually produced compared to the total potential electricity that the plant is capable of producing. On this parameter, nuclear power plants have shown out as the most reliable sources of electricity production, with average capacity factors exceeding even 90 per cent in many countries, compared to only 68 per cent for coal, 35 per cent for natural gas, and 34 per cent for oil. Capacity factors for renewable energy sources are also low at about 30 per cent.

[35] A public sector undertaking of the Department of Atomic Energy (DAE) that is tasked with the designing, construction, and operation of nuclear power reactors.

[36] For more on this see section 'External Costs', in WNA, footnote 30.

been operational since 1996 and is one of a kind globally operating with uranium-233 based nuclear fuel along with thorium.

Indian nuclear plants have also achieved many international benchmarks. For instance, in 2002, the average capacity factor of Indian PHWRs was more than any reactor in the US. At the end of September 2002, Kaiga Atomic Power Station (KAPS) recorded a capacity factor of 98.4 per cent during the preceding 12 months and became the best performing PHWR among 32 reactors worldwide.[37] In 2009, the Nuclear Fuel Complex at Hyderabad made history of sorts by supplying 11,016 fuel rods from the imported natural uranium to NPCIL in a record time of six months. This fuel was meant for the three reactors at Rajasthan which are now under IAEA safeguards.[38]

While the Indian uranium reserves at about 0.8 per cent of the world are considered to be insufficient for a power programme more than 10,000 MWe if the uranium is used on once-through basis and then disposed of as waste, India has planned for spent fuel reprocessing to complement its nuclear fuel resources. The first stage of this programme involves using the indigenous uranium in PHWRs. The second stage utilizes the spent fuel of PHWRs after reprocessing to extract Pu 239. This is then used in FBRs to breed additional fissile nuclear fuel, plutonium, and uranium-233. In the third stage, thorium and uranium-233 based AHWRs will be able to meet the long-term Indian energy requirements. Thus, the available uranium will eventually be used to harness the energy contained in non-fissile thorium, of which India possesses about 32 per cent of the world's reserves or 360,000 tonnes of high-quality thorium, but which needs plutonium to kick-start fission.

Envisaging the crucial role that rapid addition of nuclear power generation could play in easing the overall energy deficit in the coming years, the government has been able to achieve exceptionalization for India from NSG guidelines that had long prohibited any transfer of nuclear material or technology to India until it accepted NPT membership as a non-nuclear weapon state and opened all its nuclear facilities to full scope safeguards. An opportunity to bypass this requirement presented itself in 2005 when President Bush offered to abandon the long-standing US nuclear policy towards India in favour of a constructive engagement in civilian nuclear cooperation. Intense and unprecedented negotiations between India and US over 2005–08 that traversed many steps and crossed several hurdles finally culminated when President Bush signed HR 7081 US-India Nuclear Cooperation Approval and Non-proliferation Enhancement Act in October 2008. This has opened a range of opportunities for the Indian nuclear power programme that had been the hamstring for international cooperation since May 1974. The opportunities, particularly in four dimensions of the Indian programme, are worth examining.

Fuel Availability

Lack of uranium to power the Indian nuclear reactors stood out as the most serious constraint that had begun to hamper the functioning of Indian reactors over the last few years. It is common knowledge today that through most of 2008, the Indian power plants had to run at half their capacity levels owing to inadequate availability of nuclear fuel. In fact, the Nuclear Fuel Complex itself that manufactures the fuel rods for the Indian nuclear reactors operated at less than 50 per cent of its capacity due to the shortage of uranium in 2008. This situation arose out of two factors: firstly, though the country's uranium reserves estimated at 61,000 tonnes had been calculated by the DAE to be enough for 10,000 MW power generation for 40 years, the uranium prospecting, mining, and milling had been relatively ignored over the last few decades. Since 1968, the Uranium Corporation of India Ltd. (UCIL) has been commercially producing and processing uranium ore mainly from the mines at Jaduguda, Bhatin, Narwapahar, and Turamdih, all located in Singbhum district of Jharkhand. This was sufficient for the operating power plants and research reactors until fast-track power plant construction started from the mid-1990s onwards. Thereafter, a mismatch developed between uranium demand and supply. Secondly, over the decades, the uranium reserves have depleted and the ore at Jaduguda mines is presently being obtained at much deeper levels than earlier. This pushes up the cost of recovery of uranium, which in the case of India is always high because of low concentration of uranium in the ore. Indian ore has low uranium content of about 0.6 per cent as compared to some Australian, Canadian, and Kazakh ores containing up to 15 per cent of uranium.

To meet the projected demand of the nuclear power programme, UCIL is exploring uranium deposits in Andhra Pradesh and Meghalaya, besides other areas of Jharkhand. Progress in this direction, however, has suffered due to opposition from the local populace and non-governmental activists in the regions. Therefore, in order to tide over the domestic uranium crunch, one of the relatively immediate

[37] Parthasarthy (2008).

[38] Article in *Business Standard* (2009).

benefits of the recent nuclear cooperation agreement is to access uranium from the international market at competitive prices for a programme that has planned at least five more indigenous power plants in the near future. It is interesting to note that uranium prices that had peaked in 2007 at $ 136 per lb U_3O_8 had fallen to $ 44.50 per lb U_3O_8 in 2009.[39] India has already procured uranium from France, Russia, and Canada, leading to a 15 per cent increase in reactor capacity factors.[40] UCIL would also be able to bid for uranium prospecting or mining in other resource-rich regions of the world. It has already concluded an agreement with Mongolia for capacity creation in Ulan Bator's nuclear sector and uranium mining. With Namibia, Gabon, Kazakhstan, and Russia too, India has arrived at uranium mining or supply arrangements.

Import of Larger Reactors and Export of Smaller Ones

The Tarapur Atomic Power Plant (TAPP 3), India's sixteenth nuclear reactor, went critical on 14 May 2006. With this, India's indigenous nuclear programme demonstrated the capability to construct and operate PHWR of capacity size 540 MWe. TAPP 3 and 4 are today India's largest capacity reactors, with all the other indigenously built plants being of capacity 220 MWe. In the future, NPCIL has plans to standardize 700 MWe plants that it has the capability to build. Larger reactors obviously offer economies of scale and having developed a mature expertise and technological and industrial base, India has felt the need to move on to larger capacity generations.

The Koodankulam plants being acquired from Russia are of 1,000 MW. The predominant reactor capacities in many of the countries that are advanced in nuclear technologies average at least 1,000 MW; majority of the reactors in France have a capacity of 1,300 MW. With the opening of international cooperation, India has the opportunity to import larger reactors to augment its generating capacities.

Meanwhile, given the interest in nuclear energy for peaceful purposes in many smaller countries, particularly in South-east Asia, India has an opportunity to export its 220 MWe reactors that would be ideally suited for their smaller electricity grids. These reactors have proved their competitiveness in capital as well as unit energy costs and have a demonstrated record of safe operations. India also has the capability to emerge as a low-cost manufacturing hub for nuclear component supplies to the resurgent nuclear industry worldwide. For instance, companies like L&T can export nuclear reactor building skills and/or operation and maintenance services. The firm has already formed alliances with many of the leading nuclear technology providers, such as Atomstroyexport, Atomic Energy of Canada Ltd, US-based Westinghouse Electric Co, which is owned by Japan's Toshiba Corp, and GE-Hitachi Nuclear Energy, with the aim of producing components and equipment for their reactors. It has also set up a $ 463 m joint venture with NPCIL to provide heavy forgings and generators for nuclear reactors.[41] GE Hitachi Nuclear Energy Ltd. and Westinghouse Electric Co. also plan to use India as a low-cost supplier of nuclear parts for exports to the US and Europe. Other Indian companies such as Reliance Power, NPCIL, and BHEL announced plans to invest $ 50 bn in the next five years to expand their nuclear manufacturing base. In particular, BHEL is looking to spend $ 7.5 bn in just two years to build the factories needed to supply 1,600 MW reactors.[42]

Participation in International Projects

It is in recognition of India's nuclear expertise that India was invited to participate in the multinational International Thermonuclear Experimental Reactor (ITER) being built in Cadarache, France to harness energy from nuclear fusion. Indian research in fusion had in any case been underway for the past two decades at the Institute for Plasma Research at Gandhinagar. India had planned to build an ITER scale reactor by 2030.[43] Participation in the global project will enable it to leapfrog in technology, while making a value addition to the multinational effort. India is also member of the IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) activity and is participating in eight of the 12 collaborative projects under INPRO's phase II programme. This programme seeks to build innovative energy systems which are not only more proliferation resistant but have better safety, economics, and waste management; these are crucial for the sustained growth of nuclear power. Interestingly, research on such reactors is exploring closed fuel cycles and seriously considering reprocessing technologies as a means of extracting greater energy and reducing waste. India is among the handful of countries that have

[39] 'Uranium Mining Issues: 2009 Review'. Available at http://www.wise-uranium.org/uissr09.html, updated February 2010.

[40] Balaji (2010).

[41] Fenwick (2010).

[42] Ibid.

[43] *Hindu* (2006).

mastered the plutonium reprocessing technology and has lots to offer from its experience. Meanwhile, Indian nuclear scientists have a chance to interact with the best of their fraternity elsewhere, an exchange that has been denied to them since the late 1970s.

Tiding over Delays in Moving to Thorium Cycle

India's development of the thorium cycle has now completed nearly 40 years of work on the concept and demonstrated feasibility through the successful operation of a research reactor since 1996. Of course, problems of high cost and technical complications in fuel fabrication because of high radioactivity of U-233 and reprocessing required to move to the thorium fuel cycle still persist. But then, India is among the very few countries pursuing this technology. Even the World Nuclear Association, which is dedicated to the promotion of nuclear technology, sees little scope of development of this technology as long as abundant uranium is available. However, given the peculiarities of the Indian resource base, Dr Homi Bhabha had prescribed a three-stage programme for the country that would culminate with the exploitation of India's large thorium reserves. There is, nevertheless, a logical technical progression that is required of the PHWR and FBR stages in order to reach an optimal level of fissile material build-up that would then make the use of thorium feasible and effective. While R&D continues to reach the thorium utilization stage from multiple directions, including the use of Accelerator Driven Systems (ADS), these are pioneering technologies that India is struggling with alone. Therefore, there can be no pre-determined dates for the advent of the third stage. Estimates vary from 2020 to 2040. In the meantime, the import of reactors from abroad would not only help India in quicker accumulation of requisite fissile material but also help narrow the widening demand-supply gap in an environmentally friendly way.

Grappling with Challenges

Even though it makes eminent sense for India to not only keep the option of nuclear power expansion open, but to press for it urgently, there are certain limiting factors that must be grappled with.

The (DAE) is estimated to have a work force of 70,000 experts today. Given the additions planned to nuclear generation capacity, it is understood that the need for more nuclear scientists, engineers, craftsmen, construction managers, plant operators, and maintenance personnel would significantly swell in the coming years. The AEC has a Nuclear Training School that has until now been in charge of manpower development. However, with the need for rapid and increased numbers, it would be a challenge to recruit, educate, train, and retain technical personnel especially at a time when the private nuclear industry is also expected to be expanding worldwide. To strengthen research at universities, the DAE provides grants for projects through the Board for Research in Nuclear Sciences. A DAE Graduate Fellowship Scheme for IITs has existed since 2002 to promote collaborative research. IIT Kanpur already offers a course in nuclear engineering and technology, and so does Chennai since 2009. Concerted efforts towards creation of a trained manpower pool will be required from academic institutions and the DAE to have sufficient number of nuclear experts available for future expansion plans.

Given the high technology content, and the sensitive and precise nature of materials, equipment, and processes involved in nuclear power generation, it is imperative for the Indian manufacturing industry to keep pace with advancing nuclear science and technology. In fact, this challenge could be turned into an opportunity by the industry, given that the global nuclear renaissance is exposing the inability of manufacturers worldwide to meet the growing demand for reactor components and systems. For instance, the US does not have the capability to domestically manufacture ultra large forgings that exceed 350 tonnes. These are necessary for making reactor vessels and its global suppliers are the Japan Steel Works that has the capacity to make five to six such forgings every year. Given the small number of suppliers for such high-end products, it is natural for their manufacturing capacities to be booked years in advance.

Given India's cost-competitiveness, reasonably high engineering and technological skills supplemented by innovative techniques, the country could emerge as a hub of nuclear components and graduate slowly to more complex and high-end products over the years. With the opening of international nuclear trade with India, Indian companies have the possibility to enter into joint ventures or technical collaborations with global nuclear manufacturing majors. This could not only support the Indian nuclear expansion but also enable exports. The government could help build an enabling environment for the Indian industry by drafting necessary policies to this effect. For instance, just as there are offsets in the defence industry, a similar provision may be worked into the commercial contracts for import of nuclear reactors, making it mandatory for the seller to enhance the capability of Indian companies active in the field. It would also be of great value if the indigenous component of every new power plant is kept at a high level by sourcing equipment, components, and labour from the domestic market.

This would not only enable cost benefits but also provide a fillip to the domestic industry and help provide employment to large numbers.

The existing Atomic Energy Act, 1962 does not allow private players into the field of nuclear power generation. Until now, this has been the exclusive preserve of state-owned companies. With the opening of the sector to international markets, it is now necessary to amend the Act in order to allow listed public sector and private companies to set up and operate nuclear reactors.[44] The National Thermal Power Corporation (NTPC), the largest Indian power company, has already proposed a joint venture with imported technology to set up and make operational a 2000 MWe nuclear power plant by 2017.[45] Besides, many private companies such as Jindal Steel and Power Ltd., Tata Power Ltd., Reliance Power Ltd. have expressed a desire to step into the field. Also, several multinational companies would be encouraged to bid for the multi-billion nuclear reactors market in India.

However, in order to enable this, India would also have to enact nuclear liability laws to safeguard against the eventuality of an accident. This is certainly a concern for American private companies more than for the state-owned enterprises of France or Russia who have sovereign immunity. Nevertheless, India will be required to sign the international legal framework for nuclear accidents, namely the Convention on Supplementary Compensation that covers claims through a global fund to pay victims.[46] Moreover, government support will also be necessary to provide risk insurance for companies building nuclear reactors, which would cover events beyond the control of the owner, including regulatory and litigation delays.

Given the sensitive nature of the technology and materials in use at a nuclear power plant, these have existed in a heavily regulated environment to guard against possible threats, natural and man-made, to their safety and security. For a sustainable and safe expansion of the nuclear power programme, ample attention must therefore be devoted to the correct and quick implementation of necessary regulatory and environmental procedures. These are extremely essential because any accident at a nuclear site would have repercussions on the growth of the global nuclear industry. Therefore, safety of operating nuclear power plants (NPPs) and periodic and stringent rule-based evaluation are of vital importance in order to minimize and possibly obviate any danger to plant workers or the public. In fact, for every nuclear plant that is built and operated, the society needs assurance that the facility:

- Will not suffer an accident leading to large radioactive radiation.
- Will not pollute the environment during its routine operations.
- Will ensure and account for long-term storage and safe disposal of radioactive waste.

The guarantee of these assurances requires deployment of effective measures at all stages—design, site selection, operation, and decommissioning—of the development and operation of the nuclear plant. At the same time, relevant regulatory bodies need to be instituted to oversee and assess the implementation of safety measures against different parameters so that the individual, society, and the environment can be protected against radiation hazards. From the moment of site selection to the actual construction of the plant, a number of other mandatory requirements of seeking environmental clearances, rehabilitation of displaced populations from exclusion zones, development of infrastructure etc. are required to be undertaken. While India's AERB has performed this task well in the past, as the pace of nuclear activity rises, it might be necessary to expand the regulatory organization through additional induction of trained manpower so as not to develop bottlenecks on issues of requisite licensing, while simultaneously ensuring that the most stringent standards of safety and security are maintained.

Yet another significant obstacle to rapid and large-scale nuclear power expansion is public perception of this source. Unfortunately, there is very little awareness of the stringent safety regulations enforced and followed in the design, construction, and operation of power plants, or of the safety record of India's power plants of nearly three and a half decades. Neither is there adequate knowledge of the fact that natural radiation in some cases exists at scales that are several times that in the vicinity of a power plant ordinarily. Fortunately, the nuclear industry is extremely conscious of the dangers involved in its activities and

[44] Interestingly, the US Atomic Energy Act, 1946 was revised in 1954 to permit private sector involvement in reactor development, though the Congress retained ownership over nuclear fuel. The 1954 Act also established the AEC as the agency to oversee reactor construction and use. This distinguishes the manner in which the nuclear power generation is regulated as compared to conventional electricity production.

[45] World Nuclear News Overview (2008).

[46] This convention will come into force once five or more nations that collectively have 400,000 MWe of installed capacity ratify it with the IAEA. Four have already done so—US, Morocco, Argentina, and Romania totalling a capacity of 319,256 MWe.

hence takes sufficient precautions to obviate chances of an accident.[47] It is well aware of the fact that any accident anywhere in the world would have an adverse impact on the global nuclear programme. Hence, complacency in the nuclear power plant operations cannot be tolerated and India must keep its safety record unblemished if it is to reap the true potential of nuclear energy.

The other major aspect of nuclear energy that causes public concern is that of waste management and disposal of spent nuclear fuel. Fortunately for India, this is not such a big challenge since it follows a closed fuel cycle in which the nuclear fuel after being used once is not immediately disposed of as waste. Rather, the spent fuel is reprocessed to extract plutonium for the second stage of the reactors and the products left only after reprocessing constitute waste. High level waste is then vitrified and stored underwater. The US has been following a once through fuel cycle since the 1970s when President Carter had put a stop to reprocessing due to proliferation concerns. However, now grappling with the issue of spent fuel management, the US is showing an interest in returning to the closed cycle. Meanwhile, on the domestic front the public relations department of the DAE must step up its efforts to better educate the public on the advantages and risk mitigation endeavours of the atomic establishment in order to develop the ground for greater exploitation of nuclear energy.

Conclusion

Nuclear technology in India has reached a state of self-reliance. India today has nearly 300 reactor years of safe nuclear power generation. Kaiga 2 set a record by registering 529 days of uninterrupted run during August 2006–January 2008; 17 operating reactors and six more under construction indicate a high level of nuclear activity that will only pick up in the coming years as more fuel and technology is inducted into the domestic programme. The Indian nuclear power programme has also moved into the second stage of development wherein a Prototype FBR is now under construction, and research and development for AHWRs is under way. India today has the capacity, technology, and the will to expand its nuclear power programme. International cooperation would facilitate the availability of environmentally sustainable energy to India well in time to avoid stagnation of human development.

We are witnessing a moment in history that has opened new vistas for the country's energy scenario. It is the bounden duty of the nation to use this to its own advantage after a careful consideration of risks and vulnerabilities. As has been indicated earlier in the paper, the energy choices before India from indigenous sources are severely limited. Large-scale imports of coal, oil, and gas raise dependence and hence the vulnerabilities of the nation. This is particularly uncomfortable for a country that is economically on the ascendant and cannot afford to be choked on energy. Renewable energy offers an attractive alternative and the country has exploited its hydel potential. However, both the hydroelectric plants and wind farms also come with the problems of environmental displacement and rehabilitation, besides being poor sources of base load electricity. Solar energy, of course, is plentiful in India but its commercial viability for large-scale electricity generation and storage are issues that still demand more R&D. The government needs to invest in this in order to find a long-term energy solution in solar power. In the meantime, nuclear energy presents itself as a commercially proven and environmentally sustainable, large-scale electricity source. With the opening of the international market to India, this is an opportune moment to undertake its rapid expansion through import of nuclear fuel as well as large capacity reactors. However, as India embarks down this road, three caveats are in order:

- Nuclear safety and security must remain topmost priority for the nuclear establishment. It cannot afford an accident of any sort.
- Investment in R&D in the third stage of the nuclear programme that will enable the utilization of indigenous thorium should be accelerated so that uranium dependency can be obviated in the future.
- Greater public awareness on the merits of nuclear energy in India's energy mix must be generated. While none can deny the risks involved in nuclear fission, the investments made in the safety processes and regulatory procedures to minimize these must be adequately brought out. The government must also encourage transparency in calculating the costs of nuclear electricity generation, which ample studies have proven is cost competitive in many scenarios.

If human development, economic growth, and environmental sustainability are taken as essential parameters for these decisions, then there is a case for nuclear expansion for electricity generation, especially as part of the

[47] For more on the safety aspects of the Indian power programme, see Sethi (2006).

strategic imperative to develop as wide a diversification of the Indian energy basket as possible.

India, today, adds about 30–35 GW of power capacity every five years, which is half the planned amount. In order to add 60 GW every five years for the next 25 years, the right choices must be made now. For sustained progress to usher in a resurgence in civil nuclear power, realistic action will be necessary on several fronts: a supportive policy environment, including legislative changes, commensurate industrial investments, linkages with university, and training institutes for manpower requirements and support from the academic and strategic community to monitor trends and identify limitations to forewarn against possible dangers. A comprehensive policy on its expansion must be urgently drafted and implemented if India is not to let unavailability of power stand in the way of its economic growth and development.

The IAEA Director General, El Baradei, once rightly pointed out, 'Disparity in energy supply, and the corresponding disparity in standards of living, in turn, creates a disparity of opportunity, and gives rise to the insecurity and tensions . . . .' India cannot afford such fissures.

Therefore, the imperative of nuclear energy for addressing the current and projected energy deficit and ensuring long-term energy security, while simultaneously addressing environmental issues, can afford to be dismissed only at India's own peril. Energy poverty and its concomitant implications stare the nation in the face. Nuclear energy, if produced safely, offers promise. The requirement hence is to fast-track civilian nuclear expansion while maintaining the highest standards of nuclear safety and security. Today's India has to carefully make the right choices to assure the future generations of a brighter and secure tomorrow.

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