Nuclear Energy and Electricity

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ABSTRACT

It is well known that electrical power generation is the key factor for advances in industry, agriculture, technology, and standards of living. Also, a strong power industry with diverse energy sources is very important for a nation's independence. In general, electrical energy can be generated from (1) burning mined and refined energy sources such as coal, natural gas, oil, and nuclear; and (2) harnessing energy sources such as hydro, biomass, wind, geothermal, solar, and wave power. Today, the main sources for electrical energy generation are (1) thermal power, primarily using coal and secondarily natural gas; (2) "large" hydraulic power from dams and rivers; and (3) nuclear power from various reactor designs. The balance of the energy sources is from using oil, biomass, wind, geothermal, and solar, which have a visible impact just in some countries. This paper presents the current status and role of the nuclear energy in producing electricity.

Keywords: Electricity, nuclear energy, nuclear reactors, fossil fuels, waste management

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Introduction

Energy availability is vital for human development and is the prime mover of economic growth. As population increases and economic growth continues, the demand for energy will further rise. Since agriculture, services and industrial sectors are all driven by power, there is an ever increasing need to generate more power. India is the seventh largest country in the world with an area of 3.3 million sq. km. and population of about 1.2 billion. As of today, a significant segment of this population does not have access to electricity and other clean fuels, and those who have electricity available to them face shortages of it regularly. According to the Central Electricity Authority estimates, the peaking shortage prevails in various regions of the country from 1.3% up to 26.1%. As the economy grows and more people are provided access to electricity, this gap between demand and supply will further increase. India's primary energy consumption more than doubled between 1990 and 2011 to nearly 25,000 PJ. India's dependence on imported energy resources and the inconsistent reform of the energy sector are challenges to satisfying rising demand.

Need of Nuclear Power

The main resources being used for producing electricity in India include coal, oil and natural gas. Coal is the main resource being used at present and coal-fired plants will continue to be the primary source of electricity production in the country for quite some time to come. The Integrated Energy Policy indicates that at a growth rate of 5% in domestic production, currently extractable coal resources will be exhausted in about 45 years. Vigorous efforts are required to survey and to identify additional potential coal bearing areas. Coal provides more than two-thirds of the electricity at present, but reserves are effectively limited. In 2013, 159 million tons was imported, and 533 million tons produced domestically. The per capita electricity consumption figure is expected to double by 2020, with 6.3% annual growth, and reach 5000-6000 Kwh by 2050, requiring about 8000 Kwh/yr then. The second main source oil is nearly 80 per cent imported in the country, which is an area of concern for the Government with regard to energy security in the near future. These fuels have other limitation of global warming related with them. The generation of electricity from fossil fuels, notably natural gas and coal, is a major and growing contributor to the emission of carbon dioxide – a greenhouse gas that contributes significantly to global warming. Climate change arising out of Green House Gas Emissions is among the most important challenges facing the world today. The effects of climate change are expected to be catastrophic, with crop losses, sea-level rise, extreme weather events and other losses predicted by various models. Although India's per capita emissions are among the lowest in the world, in absolute

terms, the emissions are sizeable (at 4.8% of global emissions) on account of the large population. Emissions in future are projected to grow rapidly in India and China. The power sector contributes significantly to Green House Gas emissions, estimates of which vary from 40 to 50% of total emissions of Green House Gases. De-carbonization of the energy/power sector is one of the key recommendations made by various reports like the recent Intergovernmental Panel on Climate Change (IPCC) report in this regard.
Other energy sources have their own limitations like hydro potential has the limitation which is determined by rainfall and topography of the location of water sources. Other renewable energy sources like wind have similar limitations of growth and energy supply. Renewable energy source like solar energy also holds a promise as a possible inexhaustible energy source for a tropical country like India. Use of extensive solar energy may call for change in pattern of energy consumption and urbanization. But this source is very expensive and less efficient. In comparison, Nuclear energy theoretically offers India the most potent means for long term energy security. Nuclear power is environmentally benign and the life cycle Greenhouse Gas emissions of nuclear power are comparable to that of wind and solar photovoltaic power. Currently, the nuclear energy share in electricity generation is about 3%. In 2002, nuclear power supplied 20% of United States and 17% of world electricity consumption. The nuclear share in total primary energy mix is expected to grow, as the installed nuclear power capacity grows. The Integrated Energy Policy of India estimates the share of nuclear power in the total primary energy mix to be between 4.0 and 6.4% in various scenarios in the year 2031–32.

Nuclear Power Development in India

Nuclear power for civil use is well established in India. Since building the two small boiling water reactors at Tarapur in the 1960s, its civil nuclear strategy has been directed towards complete independence in the nuclear fuel cycle. India's nuclear power program has proceeded largely without fuel or technological assistance from other countries. The pressurized heavy-water reactor (PHWR) design was adopted in 1964, since it required less natural uranium than the BWRs, needed no enrichment, and could be built with the country’s engineering capacity at that time – pressure tubes rather than a heavy pressure vessel being involved. Its power reactors to the mid-1990s had some of the world's lowest capacity factors, reflecting the technical difficulties of the country's isolation, but rose impressively from 60% in 1995 to 85% in 2001-02. Then in 2008-10 the load factors dropped due to shortage of uranium fuel. India's nuclear energy self-sufficiency has extended from uranium exploration and mining through fuel fabrication, heavy water production, reactor design and construction, to reprocessing and waste management. It has a small fast breeder reactor and is building a much larger one. It is also developing technology to utilize its abundant resources of thorium as a nuclear fuel.
The Atomic Energy Establishment was set up at Trombay, near Mumbai, in 1957 and renamed as Bhabha Atomic Research Centre (BARC) ten years later. Plans for building the first Pressurized Heavy Water Reactor (PHWR) were finalized in 1964, and this prototype Rajasthan 1, which had Canada's Douglas Point reactor as a reference unit, was built as a collaborative venture between Atomic Energy of Canada Ltd (AECL) and NPCIL.

Modern Nuclear Power Plants

Although nuclear power is often considered to be a nonrenewable-energy source as the fossil fuels, like coal and gas, nuclear resources can be used for significantly longer or even indefinite time than some fossil fuels, especially, if recycling of unused uranium fuel, and thoria-fuel resources and fast reactors are to used. Major advantages of nuclear power are as follows:

1. High-capacity factors are achievable, often in excess of 90% with long operating cycles, making the units suitable for semi continuous base-load operation, alongside intermittent windmills backed by gas peaking plants.

2. Essentially negligible operating emissions of carbon dioxide into atmosphere compared to alternate thermal plants.

3. Relatively small amount of fuel required (e.g., a 500-MWel coal-fired supercritical-pressure power plant requires 1.8 million ton of coal annually, but a fuel load into 1300-MWel PWR is 115 ton (3.2% enrichment) or 1330-MWel BWR at 170 ton (1.9% enrichment)). Therefore, this source of energy is considered as the most viable one for electrical generation for the next 50–100 years.

Nuclear reactors deployed in India

The two Tarapur150 MWe Boiling Water Reactors (BWRs) built by GE on a turnkey contract before the advent of the Nuclear Non-Proliferation Treaty were originally 200 MWe. They were down-rated due to recurrent problems but have run well since. They have been using imported enriched uranium (from France and China in 1980-90s and Russia since 2001) and are under International Atomic Energy Agency (IAEA) safeguards. However, late in 2004 Russia deferred to the Nuclear Suppliers' Group and declined to supply further uranium for them. They underwent six months refurbishment over 2005-06, and in March 2006 Russia agreed to resume fuel supply. In December 2008 a $700 million contract with Rosatom was announced for continued uranium supply to them. In 2015 a further contract was signed with TVEL for pellets which will be incorporated into fuel assemblies at the Nuclear Fuel Complex in Hyderabad. The Tarapur 3&4 reactors of 540 MWe gross (490 MWe net) were developed indigenously from the 220 MWe (gross) model PHWR and were built by NPCIL.

Tarapur 4 was connected to the grid in June 2005 and started commercial operation in September. Tarapur 4's criticality came five years after pouring first concrete and seven months ahead of schedule. Tarapur 3 was about a year behind it and was connected to the grid in June

2006 with commercial operation in August, five months ahead of schedule. Tarapur 3 & 4 cost about $1200/kW, and are competitive with imported coal. The two small Canadian (Candu) PHWRs at Rajasthan nuclear power plant started up in 1972 & 1980, and are also under safeguards. Rajasthan 1 was down-rated early in its life and has operated very little since 2002 due to ongoing problems and has been shut down since 2004 as the government considers its future. Rajasthan 2 was down-rated in 1990. It had major refurbishment 2007-09 and has been running on imported uranium at full capacity. The 220 MWe PHWRs were indigenously designed and constructed by NPCIL, based on a Canadian design. The only accident to an Indian nuclear plant was due to a turbine hall fire in 1993 at Narora, which resulted in a 17-hour total station blackout.

There was no core damage or radiological impact. Rajasthan 5 started up in November 2009, using imported Russian fuel, and in December it was connected to the northern grid. Kakrapar unit 1 was fully refurbished and upgraded in 2009-10, after 16 years operation with cooling channel (calandria tube) replacement. The Madras (MAPS) reactors were refurbished in 2002-03 and 2004-05 and their capacity restored to 220 MWe gross (from 170). Much of the core of each reactor was replaced, and the lifespans extended to 2033/36. Madras needs enhanced flood defences in case of tsunamis higher than that in 2004. The prototype fast breeder reactor (PFR) under construction next door at Kalpakkam has defences which are already sufficiently high, following some flooding of the sitein 2004.

Kudankulam 1&2 are the country's first large nuclear power plant, under a Russian-financed US$ 3 billion contract. A long-term credit facility covers about half the cost of the plant. The AES-92 units at Kudankulam in Tamil Nadu state have been built by NPCIL and also commissioned and operated by NPCIL under IAEA safeguards. The turbines were made by Silmash in St Petersburg and have evidently given some trouble during commissioning. Russia is supplying all the enriched fuel through the life of the plant, though India will reprocess it and keep the plutonium. The first unit was due to start supplying power in March 2008 and go into commercial operation late in 2008, but this schedule slipped by six years.

In the latter part of 2011 and into 2012 completion and fuel loading was delayed by public protests, but in March 2012 the state government approved the plant's commissioning and said it would deal with any obstruction. Unit 1 started up in mid- July 2013, was connected to the grid in October 2013 and entered commercial operation at the end of December 2014. Unit 2 constructions were declared complete in July 2015 and it is expected to start up in late 2015. While the first core load of fuel was delivered early in 2008 there have been delays in supply of some equipment and documentation. Control system documentation was delivered late, and when reviewed by NPCIL it showed up the need for significant refining and even reworking some aspects. Kaiga 3 started up in February, was connected to the grid in April and went into commercial operation in May 2007. Unit 4 started up in November 2010 and was grid-connected in January 2011, but is about 30 months behind original schedule due to shortage of uranium. The Kaiga units are not under UN safeguards, so cannot use imported uranium.

Next Generation NPPs

The three key challenges to new nuclear energy today are

1. Competing with low-cost generating options, especially, natural gas and subsidized wind power;

2. Improving safety, so that even the threat of uncontrolled releases and consequent public fear and evacuation is avoided; and

3. Ensuring more sustainable fuel cycles, to make better use of existing natural resources, and reduced waste streams.

This recently developed oil- and gas-production method from the pressurized fracturing and cracking of underground shale formations (called "fracking") has transformed the global-energy scene. The traditional use of energy as a political and financial tool, as shown by Europe's dependency on imported gas, and a high global dependency on oil from the Middle East. This is coupled to the measures being considered, which are designed to place a price on carbon in the EU and to restrict future carbon dioxide and other emissions.

The demand for clean, nonfossil-based electricity is growing. Therefore, the world needs to develop new nuclear reactors with inherent safety and higher thermal efficiencies in order to increase electricity generation per kilogram of fuel and decrease detrimental effects on the environment. The current fleet of NPPs is classified as Generation-II and III (just a limited number of Generation-III+ reactors (mainly, advanced boiling water reactors (ABWRs)) operate in some countries). However, all these designs (here we are talking about only water-cooled power reactors) are not as energy efficient as they should be, because their operating temperatures are relatively low, i.e., below 350°C for a reactor coolant and even lower for steam in the power-conversion cycle.

One development that is being funded by the U.S. and in other countries, such as Russia, is an attempt to adapt current water-reactor technology to smaller units, in so-called small and medium-sized reactors (SMRs) or even having floating units (for example, KLT-40S, ROSATOM, Russia) (the latter are considered small modular reactors (SMRs)). Here, the emphasis is on factory-built "modules" of smaller size and output, with a series built of multiple units. This approach avoids a large initial capital outlay and can fit locations with a smaller grid or which are more remote. Despite decreasing thermal efficiency, and a potentially higher cost per unit output, some designs like the NuScale concept have indefinite cooling capability using natural circulation assuming a leak-tight system. These concepts use conventional once-through fuel cycles and offer the promise of deployment in regions where larger units just do not fit well, or where multiple builds can be spread over time.

Problems Encountered in using Nuclear Power

1. **Cost:** Nuclear power has higher overall lifetime costs compared to natural gas with combined cycle turbine technology (CCGT) and coal, at least in the absence of a carbon tax or an equivalent "cap and trade" mechanism for reducing carbon emissions. Heavy Water the third key element of nuclear power has also had problem though Heavy Water reactors had been India's most favorite from the very beginning. All this has led to reactors working on low capacity and facing shut downs. Expensive plutonium separation from used fuel rods continues to be justified for its 'tremendous potential' for treating hazardous radioactive waste and for unlocking the huge energy reserves of low-grade uranium and thorium resources through breeder reactors to unfold India's nuclear renaissance.
2. **Safety:** Nuclear power has perceived adverse safety, environmental, and health effects, heightened by the 1979 Three Mile Island and 1986 Chernobyl reactor accidents, but also by accidents at fuel cycle facilities in the United States, Russia, and Japan. There is also growing concern about the safe and secure transportation of nuclear materials and the security of nuclear facilities from terrorist attack. To overcome these risks, many regulations and safety efforts are done. The Atomic Energy Commission (AEC) was established in 1948 under the Atomic Energy Act as a policy body. Then in 1954 the Department of Atomic Energy (DAE) was set up to encompass research, technology development and commercial reactor operation. The current Atomic Energy Act is 1962, and it permits only government-owned enterprises to be involved in nuclear power. The DAE includes NPCIL, Uranium Corporation of India Ltd (UCIL, mining and processing), Atomic Minerals Directorate for Exploration and Research (AMD, exploration), Electronics Corporation of India Ltd (reactor control and instrumentation) and BHAVINI (for setting up fast reactors). The DAE also controls the Heavy Water Board for production of heavy water and the Nuclear Fuel Complex for fuel and component manufacture.
3. **Proliferation:** Nuclear power entails potential security risks, notably the possible misuse of commercial or associated nuclear facilities and operations to acquire technology or materials as a precursor to the acquisition of a nuclear weapons capability. Fuel cycles that involve the chemical reprocessing of spent

fuel to separate weapons-usable plutonium and uranium enrichment technologies are of special concern, especially as nuclear power spreads around the world.

4. **Waste:** The management and disposal of high-level radioactive spent fuel from the nuclear fuel cycle is one of the most intractable problems facing the nuclear power industry throughout the world. No country has yet successfully implemented a system for disposing of this waste. The United States and other countries have yet to implement final disposition of spent fuel or high level radioactive waste streams created at various stages of the nuclear fuel cycle. Successful operation of the planned disposal facility at Yucca Mountain would ease, but not solve, the waste issue for the U.S. and other countries if nuclear power expands substantially Since these radioactive wastes present some danger to present and future generations, the public and its elected representatives, as well as prospective investors in nuclear power plants, properly expect continuing and substantial progress towards solution to the waste disposal problem.

Efforts are done for Radioactive Waste Management like In October 2013 BARC stressed the role of accelerator-driven subcritical molten salt reactor systems (ADS) burning minor actinides arising from partitioning of PHWR and LWR Purex output. These working in tandem would address waste issues more effectively and safely than using critical fast reactors to burn minor actinides. Pyroprocessing would treat these wastes. Radioactive wastes from the nuclear reactors and reprocessing plants are treated and stored at each site. Waste immobilization plants (WIP) are in operation at Tarapur and Trombay and another vitrification plant was commissioned by BARC in 2013 at Kalpakkam for wastes from reprocessing Madras (MAPS) used fuel. The WIPs use borosilicate glass, as in Europe. Research on final disposal of high-level and long-lived wastes in a geological repository is in progress at BARC.

Conclusions

Nuclear energy, in view of its huge potential and techno commercial viability, will play an increasingly important role in the future. The rate of growth of nuclear share at the primary level is expected to be rapid as conventional fossil fuel sources, particularly coal, approach exhaustion, or their extraction tends to become uneconomical. Large number of reactors has been setup in India and many other reactors are under construction. To insure safety from these radioactive materials, many protective measures and methods of waste management are being developed.

The basis for nuclear energy for future electric power generation must take into account the key influences of the global, political, financial, and social pressures in the evolving energy marketplace. The competitive pressures and political factors are likely to dominate the future usage and deployment, including national attitudes too, and international issues arising from energy security and climate change.

1. The major advantages of nuclear power are well known, including cheap reliable base-load power, high capacity factor, and low emissions and minor environmental impact. But these factors are offset today by a competitive disadvantage with natural gas, and the occurrence of three significant nuclear accidents, which caused significant social disruption and the high capital costs.

2. Major sources for electrical energy production in the world today are

   - Thermal, primarily coal (41%) and secondarily natural gas (21%) (also, oil is used (5.5%));
   - "Large" hydro (16%); and
   - Nuclear (14%).

   Other energy sources have visible impact just in some countries, especially where there are government incentives for wind- and solar-power portfolios with electricity prices guaranteed by legislation and power-purchase contracts.

3. The attractive renewable-energy sources, such as wind, solar, and tidal, are not really reliable as full time 24/7/365 sources for industrial power generation. Therefore, a grid must also include "fast-response" power plants such as gas- and coal-fired and/or large hydropower plants.

4. In general, the major driving force for all advances in thermal and NPPs is thermal efficiency and generating costs. Ranges of gross thermal efficiencies of modern power plants are as the following: (1) combined-cycle thermal power plants—up to 62%; (2) supercritical-pressure coal-fired thermal power plants—up to 55%; (3) carbon dioxide-cooled reactor NPPs—up to 42%; (4) sodium-cooled fast reactor NPP—up to 40%;

(5) subcritical-pressure coal-fired thermal power plants—up to 40%; and (6) modern water-cooled reactors—30–36%.

5. In spite of advances in the design and operation of coal-fired thermal power plants worldwide, they are still considered as not particularly environmentally friendly due to producing gaseous carbon dioxide emissions as a result of combustion process, plus significant tailings of slag and ash. Recently, legislated measures have been proposed to limit such emissions, going beyond voluntary and regional emission credits and allowable portfolios.

6. Combined-cycle thermal power plants with natural-gas fuel are considered as relatively clean fossil-fuel-fired plants compared to coal and oil power plants, and are dominating new capacity additions, because of lower gas-production costs using "fracking" technology, but still emit carbon dioxide due to the combustion process.

7. Nuclear power is, in general, a nonrenewable energy source as the fossil fuels unless fuel recycling is adopted, which means that nuclear resources can be used significantly longer than some fossil fuels, plus nuclear power does not emit carbon dioxide into atmosphere. Currently, this source of energy is considered as the most viable one for base-load electrical generation for the next 50–100 years.

8. However, all current and oncoming Generation-III+ NPPs are not very competitive with modern thermal power plants in terms of thermal efficiency; the difference in values of thermal efficiencies between thermal and NPPs can be up to 20–25% with NPPs having higher generating cost and construction times than natural-gas turbines.

9. Therefore, enhancements are needed beyond the current builds, which are now mainly in Asia, to compete in the future marketplace, especially without government subsidies or power price guarantees. New generation (Generation-IV) NPPs must have thermal efficiencies close to those of modern thermal power plants, i.e., within a range of at least 40–50%, and improved safety measures and designs in order to be built in the nearest future.

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