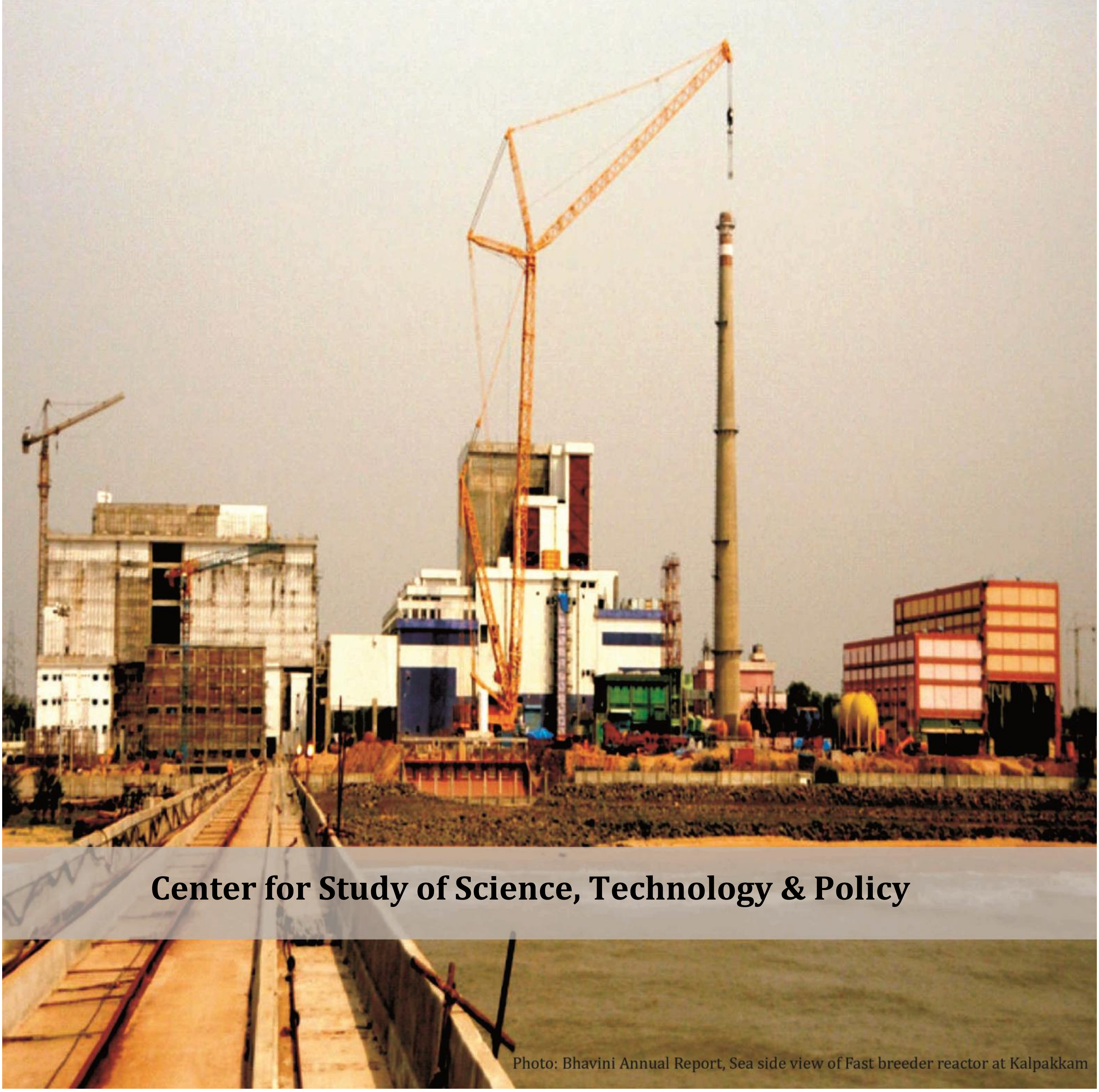
GROWTH OF NUCLEAR ENERGY IN INDIA: INDUSTRIAL CHALLENGES AND PROSPECTS



Center for Study of Science, Technology & Policy

Photo: Bhavini Annual Report, Sea side view of Fast breeder reactor at Kalpakkam

GROWTH OF NUCLEAR ENERGY IN INDIA: INDUSTRIAL CHALLENGES AND PROSPECTS

Aditi Verma

Graduate Student, Massachusetts Institute of Technology, Intern, CSTEP

S. Rajagopal

Advisor, CSTEP

Designing and Editing by: CSTEP

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Center for Study of Science, Technology and Policy
10th Cross, Papanna Layout, Mayura Street
Nagashettyhalli, RMV II Stage, Bengaluru-560094
Karnataka, INDIA
Tel: +91 (80) 6690-2500
Email: communications@cstep.in
Website: www.cstep.in

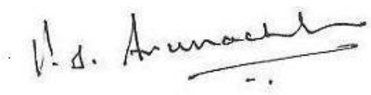
PREFACE

India's commitment to nuclear power continues to be ambivalent. It is surprising considering the India was one of the earliest countries to embrace nuclear power and built up the necessary infrastructure, starting from uranium mining to nuclear waste management. In spite of the initial enthusiasm and commitment, progress in building nuclear power stations slowed and a few years back almost stood still. The reasons are many including reactor accidents such as Chernobyl and also the embargoes imposed by Nuclear Suppliers Group (NSG) because of India's decisions not to sign NPT. Only recently these embargoes were lifted and the supply of uranium has begun. There are also local agitations against building reactors in their vicinities. Fukushima Daiichi accidents have not helped either in public accepting nuclear power as safe.

Both the Planning Commission of India and the Atomic Energy Commission are committed to building more nuclear power stations in the coming years. According to them, by 2020 India would have 20 GW of nuclear power and by 2050 the capacity should be as high as 208 GW. The planners do not see any other option if India wants to stand by its commitment to reduce its emissions intensity by 20-25% by 2020 . These projections may entail building over 4-7 nuclear power stations, approximately 3000 megawatts every year for the coming decade. Where are the manufacturers for these ambitious projections? For building pressurized heavy water reactors (PHWR), India encouraged a number of indigenous engineering companies to build up the necessary competence in engineering and training of human resource for precision metal forming operations. A few engineering corporations have taken up this challenge and have built up the expertise. For a developing country like India these are precious assets that helped to overcome the embargoes the NSG imposed and also helped to overcome the monopolies of a few corporations. But these assets are fragile and would wither away if there are no orders that can keep the workforce fully engaged. Companies also require a steady stream of orders to keep them interested in precision manufacturing. It will be prudent for India to continue to nurture indigenous manufacturing even when it is importing the bulk fraction of the reactor from abroad.

Aditi Verma, a graduate student in nuclear engineering from Massachusetts Institute of Technology spent a couple of months as an intern at CSTEP working on a study of India's indigenous manufacturing base. Prof. S. Rajagopal provided the necessary support and guidance. Her stay and work in India was enabled by supported by MIT Energy Initiative's Energy Education Task Force and MIT International Science and Technology Initiative's India program. CSTEP provided the necessary base in Bangalore for her studies. This study involved extensive travels and discussions with policy makers and engineers. While readily agreeing to meet and discuss with her many of them of them preferred to be anonymous. Aditi undertook these travels for the meetings and spent considerable time interviewing many senior policy makers for preparing this report.

CSTEP commends Aditi Verma for authoring the report and for the useful discussions she inspired while spending a few months working at CSTEP.



Dr. V.S. Arunachalam

Founder and Chairman, CSTEP

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GROWTH OF NUCLEAR ENERGY IN INDIA: INDUSTRIAL CHALLENGES AND PROSPECTS

Abstract

The Indian nuclear energy program is at crossroads, with several alternative pathways of industrial development potentially open to it. These possibilities include options for technology selection and development, as well as for organising the efforts of the state owned entities and private companies. The nuclear energy program also sets and aspires to target installed capacity through mid-century. This paper traces the development of the Indian nuclear industry and the role that key entities – international vendors, private companies and domestic decision-makers – have played in its development, diagnoses and proposes solutions to the challenges the nuclear energy program faces as it plans an expansion to several hundred gigawatts by 2050. Through 2020, uninterrupted construction of nuclear plants is essential for increasing the productivity of companies in the manufacturing sector and preventing the atrophy of skills and attrition of the workforce. In the medium term (i.e. through 2030), the key challenge to development will be to clarify the liability framework, which has slowed industrial development. Finally, achieving the mid-century expansion goal will call for a rapid deployment of technologies that are in the conceptual or prototype phases today, and may also require the rethinking of the nuclear industry. Thus, the challenges to the development of nuclear energy in India arise not only from the development of new technologies but also from technology management and the need for a re-evaluation of institutional frameworks.

Keywords: Planning commission, Nuclear power, Infrastructure, atomic energy commission industry

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INTRODUCTION

In 2012, 3.62% of electricity generated in India was from nuclear energy (IAEA PRIS, 2013). 20 nuclear power reactors provide 4870 MW of installed capacity. To put this in context, the total electric capacity in India in 2013 was 225,793.10 MWe (CEA, 2013). One stated goal for the future of nuclear energy in India is to increase the total installed capacity to 470 GWe by 2050.[1] This amounts to nearly a hundred-fold increase in installed capacity by mid-century. Another set of projections, shown in Table 1, were defined by the Planning Commission in its Integrated Energy Policy Report in 2006. These projections or scenarios called for a dramatic expansion of the program. Can the Indian nuclear industry grow rapidly to meet these targets? And what challenges will it face as it plans for expansion?

Table 1: Projections for nuclear installed capacity [2]

Year	Optimistic Target	Pessimistic Target
2020	29 GWe	21 GWe
2032	63 GWe	48 GWe
2050	275 GWe	208 GWe

There are many dimensions along which these questions might be answered. Researchers have analysed the Indian closed fuel cycle strategy form an economic and fuel supply perspective. [3] However, measures of cost and material inventories alone are pieces – fixed in time -- of a larger puzzle of industrial development, and especially at a time when the rules of the game are changing, these metrics are insufficient to assess the challenges facing the development of the nuclear industry. Another approach to assess the potential for industrial growth is to study the supply chain of an industry. [4]

[1] See (Kakodkar,2008)
[2] These data are from Table 3.4 of Planning Commission (2006).
[3] See (Bhardwaj 2012) and (Woddi, Charlton, & Nelson, 2009)
[4] By focusing on the development of the nuclear industry's supply chain, our intent is not to undermine the importance of the safe and secure use of nuclear energy. The importance of these factors cannot be overstated. But because we are concerned with a question of industry-building, we limit this inquiry to the development of the supply chain.

The empirical question of industrial development raised here is viewed chiefly through the lens of three sets of key stakeholders – international vendors, private Indian companies and Indian policy-makers. But there is also a broader question at stake: what are the appropriate roles of the state and of private entities in the development of strategic but often 'slow' industries, like nuclear. This report tackles this question and here the Indian nuclear industry becomes a case study for a broader inquiry.

MOTIVATION FROM PRACTICETHREE-STAGE NUCLEAR PROGRAM

A nuclear energy program requires the development of a vast array of capabilities, including research , technology design and development, manufacturing, construction, project management, operations and maintenance, and nuclear policy development, to name a few. The extent of indigenous development and the level of localisation of each of these capabilities may depend on the size of the program as well as its goals. For a program like India's that plans a massive and rapid expansion, each of these functions will be critically important and will also probably have to be scaled up.

A three-stage nuclear program was initiated in the 1950s with the aim to transition to a closed fuel cycle to exploit domestic thorium reserves. [5]

The three stages of the nuclear energy program in India, originally conceived, are as follows:

First Stage: Natural Uranium-fueled Pressurized Heavy Water Reactors (PHWRs)

Second Stage: Fast Breeder Reactors (FBRs)[6]

Third Stage: Reactors for utilising thorium, in particular Advanced Heavy Water Reactors (AHWRs).

Figure 1 illustrates the three-stage nuclear program. The addition of Light Water Reactors (LWRS) to the first stage, not shown in this figure, is a relatively recent development.

[5] Thorium reserves in India are about three times larger than domestic uranium reserves, thus supply security was instrumental in fostering an emphasis on thorium usage in the Indian nuclear energy program.
[6] There are likely to be at least two variations on the FBRs based on the fuel type: oxide fuel and metallic fuel (Bharadwaj, 2012).

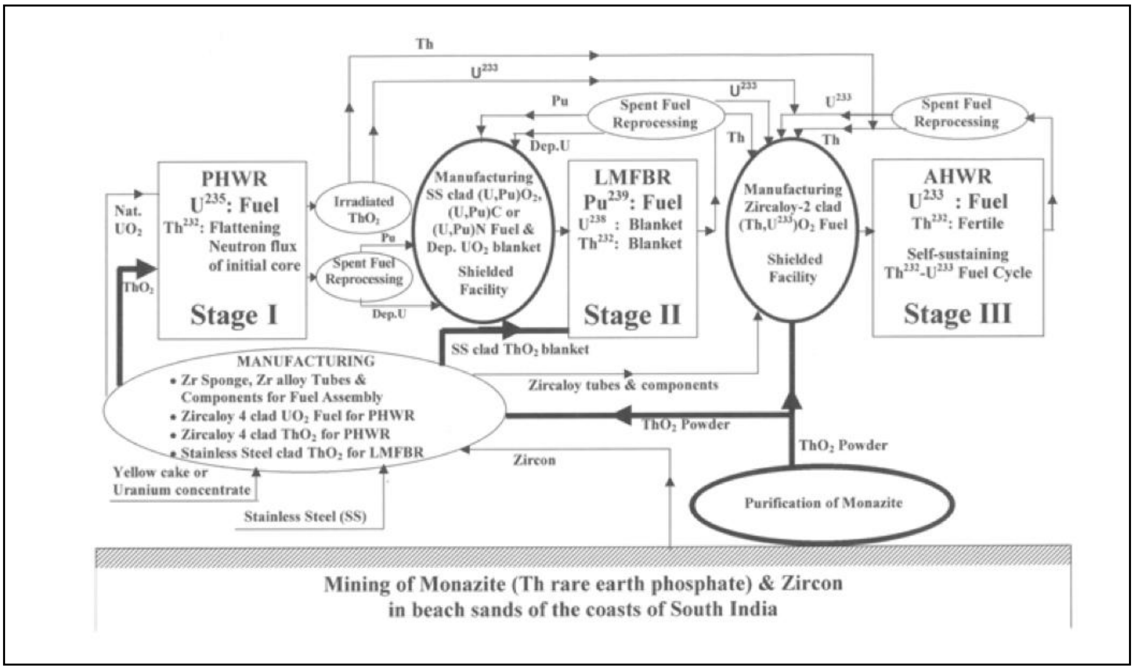

Figure 1: The three-stage Indian nuclear program. Source: IAEA (2005)

Source: IAEA (2005)

The reactors that are in operation and under construction today are based on a variety of designs. Experience gained from constructing and operating the early Canadian Deuterium Natural Uranium Reactor (CANDU) designs allowed the development of the PHWRs in construction and operation. Two Boiling Water Reactors (BWRs) in operation are General Electric designs. The development of the Fast Breeder Test Reactor (FBTR) and its scaled-up version, the Prototype Fast Breeder Reactor (PFBR) was aided by knowledge from French sodium fast reactor designs such as Rapsodie and Phénix . The Advanced Heavy Water Reactor (AHWR) is, the first conceptual design of indigenous origin.

Kakodkar (2008), former chairman of the Atomic Energy Commission (AEC), estimated that there will be a shortfall in installed electric capacity of ~400 GWe by 2050. He noted that such a shortfall could be avoided if 40GWe of LWRs were imported and if the spent fuel from these reactors was reprocessed and used to fuel the breeder reactors. If the reactor contracts with AREVA (6 EPRs), Westinghouse (4 AP1000s) and GE (4 ESBWRs) are completed, and if these reactors are constructed, ~20 GWe of installed capacity will be added. Additionally, 6 more Russian VVER type reactors may be built. More broadly, the Nuclear Power Corporation of India Limited (NPCIL) plans to construct 5

"Nuclear Energy Parks" with 10 GWe of installed capacity at each location. Sites for these parks have been earmarked (WNA, 2012).

Can the existing technological and institutional infrastructure support this growth of nuclear energy? What roles have public and private organisations played in the development of the nuclear industry as it exists today? How and when are public-private partnerships established and how do they affect industrial development? In answering these questions, theories of industrial development provide a useful lens through which to view the empirical findings.

MOTIVATION FROM THEORY

Late development theories originated by Gerschenkron (1962) and later Amsden (1989) posit that the timing of industrial development affects the pathways through which development occurs. Development orchestrated by long-term funding and planning, is largely state led. State involvement in this form results in the creation of large vertically integrated enterprises. However, in order for developmental efforts to be successful, late-developing industries first have to 'catch up' through a process of technology transfer and imitation.

This model of industrial development appears to be descriptive of the development of national nuclear industries that have been characterised by cycles of technology transfer followed by the development of indigenous innovation capabilities when the future ambitions of the national industry have justified the creation of domestic suppliers. US, UK and Russia continue to use domestically developed nuclear energy technologies and can be thought of as the 'early-developers'. France, Japan and Korea acquired LWR technology from the US and later developed domestic vendor capabilities. The Chinese and Indian nuclear industries, which can perhaps be thought of as a third generation of nuclear industries are attempting to follow a slightly different path today – one of localisation of technologies from several different nuclear reactor vendors while simultaneously developing indigenous technologies.

The path of state-led industrial development is often fraught with risk and uncertainty. Sometimes the bets made by the State on technology trajectories fail. Wong (2011) uses the case of the development of biotech industries in South Korea, Taiwan and Singapore as examples of 'failed bets'. Wong concludes that bets made by states are likely to have payoffs when made on industries that do not face technological uncertainty and when final products are driven by market pull rather than technology push forces. How wise is it then for the planners of the Indian nuclear industry to place bets on thorium-fuelled reactors as the future of the nuclear industry? Why, when the option of international trade has been reopened, following the Indo-US agreement in 2008, do these planners resist adopting well-understood LWR technologies in favour of riskier ones?

More recently, through his study of Rapid-Innovation Based industries (RIB), Breznitz (2005) proposes that late-developers can grow domestic industries not by state-led imitation efforts but by a state-coordinated leapfrogging to the forefront of innovation. In this model of development, the state, after initially creating strong organizations, connects them and gradually cedes the leading role. One reason for a divergence from the traditional late-development path could be, as Breznitz (2011) notes, the global fragmentation of production and value chains, which create opportunities for new entrants to become adept at process and organizational innovations and leapfrog to the forefront.

We conjecture that the Indian nuclear program started down the late development path. Technology transfer and imitation led to the development of the pressurised heavy water designs. However, disruption of technology transfer following the nuclear test in 1974 (and again in 1998) eliminated the late development and imitation option for the Indian nuclear industry which then embarked on what was expected to be a leap-frogging to the forefront of innovation in nuclear energy technologies through the indigenous development of thorium-fuelled reactors.

The Indian nuclear industry, which began as a state-led, owned and controlled enterprise has been marked by the gradual entry of private firms such as Tata, L&T and Godrej. However, the State continues to play the leading role – selecting and implementing technology trajectories and designing key technologies.

Does the strategy of the Indian nuclear industry lie somewhere between the imitation and leap-frogging paths? And has a simultaneous pursuit of trajectories of localisation and indigenous development retarded the expansion of the Indian nuclear industry? Is it possible to pursue both imitation and innovation simultaneously as the Indian nuclear industry plans to go through its three-stage program? To what extent does access to international supply chains affect the process of industrial development? How do technological trajectories change when access to these supply chains is created or cut off?

The development of the Indian nuclear industry is a critical case study in finding answers to these questions.

METHODOLOGY

The data for this study were gathered through over 30 interviews and consultations with respondents from key stakeholders –international suppliers, Indian companies and policy-makers in India. The conversations with the international suppliers focused on the opportunities they perceive in the Indian reactor market, how they intend to select suppliers in India, how they plan to transfer technology, and what they view as some of the biggest bottlenecks for an expansion of the nuclear installed capacity.

The interviews with the private companies focused on how each company became a nuclear supplier, how production was scaled up and where each company fits in the project management structure of a nuclear plant construction project, and more broadly in the supply chain of the nuclear industry as a whole.

The interviews with the Indian policy-makers focused on how various reactor technologies were developed, guided from the concept, prototype to deployment stages, how private companies were chosen as partners, and where the Indian nuclear industry sits in the global nuclear supply chain.

DEVELOPING A NUCLEAR INDUSTRY

TECHNOLOGY TRANSFER

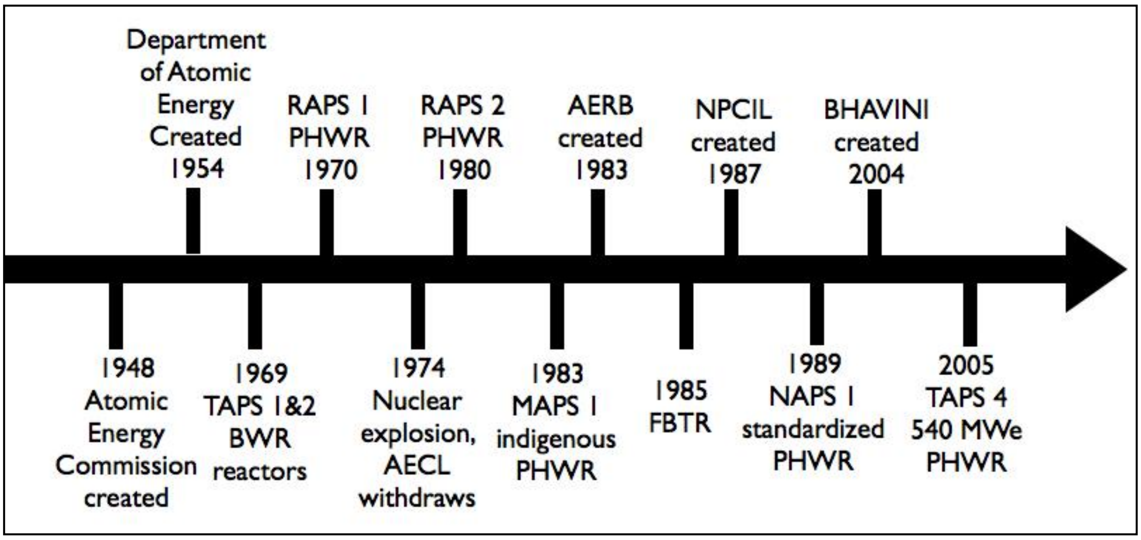

Figure 2: A timeline of industrial development up to 2005

Two boiling water reactors[7] supplied on a turnkey basis were the first power reactors to be built in India, to gain an early experience in reactor construction and operation. But when the time came to choose a reactor technology to localise, the CANDU was chosen over LWR. To a significant extent this decision was determined by the industrial capabilities available in India at the time of technology selection. Two key technologies needed for the development of a light water reactor - enrichment and the fabrication of large pressure vessels - were not available. The CANDU design, a PHWR made up of pressure tubes instead of a single large pressure vessel which uses natural rather than enriched uranium was a technology more amenable to localisation and offered greater prospect of technological independence. Further, the choice of a light water reactor would have necessitated reliance on the enrichment services of another country, in this case the US.

The contract with AECL (Atomic Energy of Canada Limited) was for the construction of two 220 MWe reactors. The reactors would be built on a site in Rajasthan.

[7] Both reactors are from the first generation of GE BWR-1 designs.

Simultaneously, technology transfer and development for the subsequent stages of the three-stage program was underway. A Fast Breeder Test Reactor (FBTR) would be built before the breeder reactors of the second stage. France and India shared a technological vision for closing the fuel cycle. For selecting a design for the FBTR, a team of nearly 30 people (of which half were draftsmen) was sent to France. The French reactor Rapsodie was the reference design for the FBTR in India. But Rapsodie was not a power reactor and the FBTR was designed to be a smaller version of one. Modifications were made to the Rapsodie design. An intermediate heat exchanger (that brought the sodium out of the reactor building for the heat exchange with water) and steam generator were added to the original Rapsodie design. The designs of the core, sodium pumps and grid plate (to hold in place the seed and the blanket assemblies) were based on the original Rapsodie. The reactor vessel, steam generator and turbine generator were designed and manufactured in India.

INDIGENOUS DEVELOPMENT

The first power reactor at the Rajasthan Atomic Power Station (RAPS1), a 200 MWe CANDU design was complete and most of the equipment for a second unit of the same design had been ordered when India tested a nuclear explosive in 1974.

After the tests in 1974, AECL ceased cooperation with its Indian counterparts. The Indian nuclear establishment began a program of developing reactor technologies indigenously. This program of development created a demand for technology design, development, deployment, and operation – and the Department of Atomic Energy (DAE), a state owned entity, needed private partners.

In the 1970s Indian companies produced sugar, fertilisers, cement and some chemicals. Nuclear, an advanced technology that demanded strict tolerances, quality and precision, required an upgrading of the standards of production. [8] The DAE assessed the capabilities of Indian companies and selected suppliers. Critical technologies were retained in-house and developed within daughter organisations of the Department. The Electronic Corporation of India (ECIL)

[8] See (Sundaramam et al, 1998)

manufactured instrumentation and control equipment for nuclear plants. The Nuclear Fuel Complex (NFC) manufactured fuel and the Heavy Water Board supplied heavy water to the plants. The DAE also collaborated with private companies, by sharing funds and transferring expertise. Except for the primary coolant pumps for the PHWR, which were manufactured by KSB (a German company that created an Indian subsidiary), two or more suppliers were sought for each key equipment for the PHWR plant, to create competition on the supply side. WIL and GR engineering manufactured the calandria vessel, L&T and BHEL manufactured the end shields and steam generators, Jyoti Ltd. and later Kirloskar supplied the moderator pumps, the moderator heat exchangers were from L&T and AUDCO valves[9].

DAE engineers stationed at suppliers of PHWR equipment such as steam generators, heat exchangers, end shields, turbines and pumps worked with engineers at the supplier companies to design or re-engineer equipment using engineering drawings or equipment from the RAPS1 reactor. As an example, one technology that proved to be especially challenging to re-engineer was the moderator pump. Engineering design documents for the pumps were not available but operating pumps from the RAPS unit that had already been built were taken apart and studied during reactor outages, and re-engineered.

Throughout this time of technology development by a combination of re-engineering and indigenous development, the interface between the public and private entities, by flows of people and information, remained porous.
Today NPCIL, owner and operator of all operational nuclear power reactors selects its suppliers through a tendering process. The tendering process has two parts: technical and cost. In the first part, the technological capabilities of the bidding companies are ascertained by NPCIL inspectors, and companies are down-selected. In the second part, based on the cost at which each prospective supplier is willing to supply equipment, the lowest bidder, or the L1 supplier, is awarded the contract. NPCIL tenders also have a pre-qualifying clause, stipulating that suppliers of safety critical equipment must already have

[9] Later subsumed by L&T Valves.

experience with manufacturing equipment for operation in high radiation dose environments.

Some orders are designed by the purchaser, others by the supplier. Even for orders that are designed by the purchaser (NPCIL, DAE or BHAVINI), the process of generating the engineering design is often iterative. Specifications for the ordered equipment are generated by the designers and converted into engineering drawings that are handed over to the manufacturers, who frequently suggest changes to the design to improve its manufacturability. Although the PHWR plants have largely been standardised, incremental improvements to the design of individual components continue to be made. An example is a recent change made to the design of the air lock for the PHWR. Because the designs of individual components of the reactor evolve from project to project, mass production is believed not to make sense.

The incremental process of design evolution is viewed as adding to the perceived complexity of manufacturing for a nuclear project, making new suppliers reluctant to break into this sector.

But design evolutions are not the only factor that makes manufacturing equipment for nuclear plants challenging. Safety requirements necessitate regular inspections for the process of production. Safety requirements are codified as standards developed by professional organizations such as the American Society of Mechanical Engineers (ASME). An important qualification for a manufacturer of nuclear plant equipment is the N-stamp, which enables a company to supply reactor equipment to international markets and select its own sub-suppliers without external oversight.

A supplier might either views the process of obtaining qualification as intrusive, expensive or time consuming, and be reluctant to make such an investment absent certainties of contracts for supplying equipment to international markets. On the other hand a larger company may view these qualifications as a source of competitive advantage over smaller suppliers, and invest early in obtaining qualifications to be able to win contracts for supply of equipment for reactor projects from international vendors, or to become a part of an international vendor's global supply chain.

For PHWR projects, NPCIL quality assurance inspectors oversee the process of production. These include inspections of the workers' abilities to produce standards of quality demanded by the safety requirements of nuclear systems. Qualified workers have to demonstrate their skills on a 'coupon' (a smaller sample of the material or a piece of the full equipment being produced). The coupon is then subjected to destructive and non-destructive testing to verify quality of work. Not only are the workers' skills tested and inspected periodically, but also the processes by which to qualify and test the workers.

Workers on the shop floor are drawn from two-year vocational courses and trained through programmes of learning on the shop floors. Some students, in the second year of such two-year courses, are trained at facilities of future employers through apprenticeships with senior, experienced workers. The skills of the new trainees, once developed, are a critical asset and easily lost by attrition to competing companies.

Qualified workers are trained to produce equipment demanding high precision and tolerances. In India, no supplier of nuclear equipment is a 'pure-play' supplier, and between nuclear projects technicians and craftsmen qualified to produce equipment for nuclear plants are assigned to work on equipment for other sectors demanding low tolerances and precision.

The better qualified workers bring their upgraded skills to the process of production, improving the quality of the final product. One manager explains how becoming a manufacturer for nuclear plants improved the quality of production for other sectors, such as space and also. Projects requiring strict tolerances, which the company rarely received earlier, are now completed to the purchasers' specifications.

However, using nuclear craftsmen on non-nuclear projects incurs costs. The nuclear work culture of discipline, willingness to question, and to suggest improvements for future design iterations begins on the shop floor. Several managers have expressed the sentiment that those who work on the nuclear projects take pride in their work, and discontinuities in projects disrupt morale.

In one company there were over 400 workers qualified to work on nuclear plant equipment. At the time of the interview only 60 were involved in working for a nuclear project. Interruptions or slowdown in the nuclear power program will have an adverse effect on incentives to produce to high standards of quality and safety, satisfaction in work and work culture nurtured over several decades. A continuity of nuclear plant construction projects is needed for these supplier companies to stay interested in the nuclear sector and make investments for upgrading their workforce and equipment to support the planned expansion of nuclear installed capacity.

The process of oversight and inspection by the purchaser begins before raw materials reach the factory. Suppliers to the suppliers, the sub-suppliers, are also inspected and raw materials sourced from them are subjected to destructive and non-destructive testing at National Accreditation Board for Testing and Calibration Laboratories (NABL). Companies may set up their own laboratories for testing materials but NABL tests are mandatory and carried out before the metal plates reach the factories.

Finally, at least one component from each batch is also tested by destructive and non-destructive means. One example of a destructive test is a microstructure study; non-destructive methods on the other hand, employ electromagnetic radiation or sound waves to interrogate material imperfections. For example, for a batch of nozzles from a single melt having the same dimensions, at least one is tested destructively and discarded. If component dimensions vary, at least one of each dimension is tested.

Because manufacturing for nuclear plants creates new, and unfamiliar demands on the process of production, companies have to *learn* how to become nuclear suppliers. At the inception of the nuclear program, this learning was imparted by the DAE and its constituent organisations that sought private partners. Today, companies attempting to manufacture for nuclear plants can learn about documentation, inspection and training requirements by entering the nuclear sector as sub-suppliers, for class 3 or class 2 systems, to an established supplier, graduating eventually to become suppliers of safety-critical class 1 systems.[10]

This strategy introduces some challenges: The supplier receives the contract for the finished piece of equipment or sub-system and produces it at a certain margin of profit. Invariably, margins are smaller for sub-suppliers and uncertainties greater. Just as a supplier may be the lowest bidder for one project but not the next, similarly the same supplier may choose to use different sub-suppliers for different projects. Thus uncertainty is compounded downstream in the supply chain. Fine (1999) calls this the 'bullwhip effect'. Suppliers downstream, in an attempt to reduce these uncertainties may attempt to integrate upwards and upstream in the supply chain or a large supplier, desirous of further increasing margins and increasing reliability of supply and quality of components or raw materials, might integrate backwards. But these moves forward and backward in the supply chain are risky because of the discontinuous nature of nuclear projects, and especially difficult strategies for companies without a diversified portfolio of activities.

Few suppliers to nuclear plants rely to a large extent on the nuclear side of their business to generate a large fraction of revenues. For many suppliers of equipment to the nuclear island, in any given year, the nuclear side of the business generates less than 10% of the total revenues for the company, and for many others less than 5%. If margins can be small and uncertain, projects infrequent and demands on production high, why do these suppliers continue to stay in the nuclear business? One reason could be prestige and another expectation of future growth.

AFTER THE DEAL (S)

Until the late 2000s, nuclear reactors in India were operating at capacity factors of around 50%. One reason for the low capacity factors was a shortage of fuel. The Indo-US nuclear 'deal' and agreements of cooperation for the development

[10] These are ASME classifications found in Section III, Division 1 of the ASME Boiler and Pressure Vessel Code. Class 1 components are part of the primary core cooling system or components used at elevated temperatures. Class 2 components are important for the operation of safety systems and these components may be part of the emergency core cooling system. Class 3 components are needed for plant operation but are not safety critical.

of civilian nuclear energy ended the technological quarantine of the Indian nuclear program. A waiver from the Nuclear Supplier's Group (NSG) enabled fuel supply and made previously verboten contracts for the supply of reactor technologies also permissible.

International vendors -- Westinghouse, General Electric, Areva, Rosatom -are prospective suppliers of technology to the Indian reactor market that is estimated to be close to $150 billion over the next three decades. Sites for reactors from each of the vendors have been identified. Reactor contracts between these vendors and the Nuclear Power Corporation of India (NPCIL) will be negotiated not on the basis of the reactor vendors competing with each other, but on their ability to offer a contract price at which the final levelised cost of electricity from the reactors will be competitive with other sources of electricity near the selected reactor site.

Where do opportunities for reducing costs and making nuclear competitive with other sources of electricity arise? Financing and localization of reactor technologies are thought to be key determinants of cost. While the rate at which financial institutions from the vendor country can offer loans are determined by existing financial and legal frameworks of that country[11], the question of localization will be settled by negotiation between the buyer and seller. But whether localisation of technology will truly reduce costs remains an open question.

There are many risks associated with a large construction project such as a nuclear plant. Some of these risks arise in manufacturing as a result of reliance on vendors in new locations. Presence of foreign materials in parts, defects in steam generator tubing, or weld material not meeting specifications are all examples of things that could go wrong in the process of production. To mitigate these risks, reliable partners – established players in the domestic supply chain are desired by reactor vendors seeking to break into local markets.[12] There are

[11] For example, lending rates in OECD countries are determined by OECD regulations.
[12] Although, it may be the case that a willingness to localize technologies and line up local partners may provide a greater competitive advantage in a reactor market in which reactor vendors are competing with each other, and not, as appears to be the case in India, in the ability of the vendors to offer reactor contracts at prices that would make electricity from these reactors competitive with alternate sources of energy at the same site.

objective ways to ascertain risks of working with new suppliers: are suppliers able to comply with international quality and safety codes and standards and supply equipment that meets the specifications of the reactor vendor? There are also subjective perceptions of risk determined by the geographical, organisational, ideological and cultural proximity of the vendor and potential new suppliers.[13]

Thus localising, and a corresponding willingness to rely on an untested vs. established supply chain, is a potential source of competitive advantage and cost reduction, but it may also lead to delays in execution of the overall project and cost overruns. This is a complex optimisation, the success of which can only be truly ascertained after the fact. The key is to find reliable suppliers in new markets, test and qualify them early, so that estimates of the cost at which the package of reactor technologies are supplied are based on the estimates of integrating equipment from all suppliers – old and new.

To this end, reactor vendors like GE, Westinghouse, and Areva have, with the help of trade organizations in India, scoped out the domestic supply chain. The search for suppliers begins at trade fairs and exhibitions to which local suppliers are invited. This provides a forum for reactor vendors to interact with companies. This is followed by company visits and tours of the shops, which can be thought of as the first round of auditing new suppliers. After such an inspection of the capabilities of the local companies, Memoranda of Understanding (MoUs) may be signed. These MoUs are not binding on either party but to the extent that they reflect the division and scope of work to be shared between a vendor and a prospective supplier –in other words, a first iteration of the terms of a future, binding contract – they are instruments for mitigating risks that both parties bear by working with each other. Some domestic suppliers could be sub-contractors but for technologies that have to be adapted to local conditions, the relationship between the vendor and the domestic supplier may be in the form of a partnership – a joint venture in which both parties share risks and returns. One example of such an arrangement is the MoU signed by Areva and Bharat Forge in early 2009, a precursor for a future

[13] For a discussion see Fine (1999)

joint venture for manufacturing heavy forgings in India. Similarly L&T and Westinghouse signed an MoU for the supply of valves, electrical instrumentation, and modules for Westinghouse's AP1000 plants.

Materials that are needed in large volumes, especially for construction – concrete and rebar, are sourced locally. The construction workforce is also generally from the buyer country (but frequently overseen by employees of the vendor company). The difficult decisions on whether to localise or not arise on getting closer to the heart of the nuclear power plant, the nuclear island. How might such a decision finally be made?

Tariffs on the import of equipment increase the cost of the overall contract, as do the costs of transportation, and make localisation desirable. As mentioned earlier, there are risks and potential corresponding costs associated with working with new suppliers. While the Indian nuclear supply chain has mastered PHWR technologies, the 1000 MWe LWR is a technological system of unfamiliar complexity. Pressure vessels, pressurisers, reactor internals such as core support structures and control rod drive mechanisms, as well as the reactor coolant pumps and steam generators of the kind used by large LWR systems are relatively new to the Indian supply chain. Key specifications – temperature and pressure requirements, materials and manufacturing techniques, as well as the codes and standards to which LWR equipment are manufactured, are markedly different. Local suppliers of these key components will have to be trained by the vendor and the vendor's suppliers, through programs of learning by watching and then doing, under tight deadlines for the completion of the overall project on time and on budget.

Further, the technological sub-systems on the nuclear island – steam generators, coolant pumps, passive safety systems, spacers of fuel assemblies -- are all proprietary technologies developed iteratively over reactor generations and projects. Having absorbed these technologies, new suppliers could become competitors of the reactor vendors.

On the other hand, the lower cost of labour in India, knowledge of the material supply chain downstream and the prospects of 'frugal engineering' could confer cost advantages to the vendor, making his bid more competitive both in India and in potential reactor markets in South Asia. These are all factors that render localization desirable.

Viewed from the perspective of Indian suppliers, the entry of international vendors in India represents both a threat and an opportunity. Capabilities of the Indian suppliers were developed over nearly four decades of collaboration with the DAE and its daughter organisations. [14] To the extent that that these vendors seek to use their established suppliers for Indian reactor projects, and minimise the transfer of technologies, the import of LWR technologies presents a threat to the Indian companies of displacement from the nuclear program. But if LWR reactor technologies are transferred localised and an indigenous LWR developed, the entry of international vendors presents an opportunity to master a new generation of reactor designs, cement the foothold in the Indian nuclear supply chain and perhaps gain one in the international supply chain. MoUs for joint ventures and tests of capabilities of Indian companies by initial supplies of non-key pieces of equipment for the vendors' projects elsewhere signal a potential cohabitation of the Indian nuclear industry by domestic and international suppliers.

These partnerships create a possibility for continuity in reactor construction projects, domestically and internationally, and a departure from the fitful trajectory of development. Collaborations with international vendors also offer opportunities for the upgrading of the skills of the Indian companies, and a potential boost for the development of technologies of domestic lineage.

The Civil Liability for Nuclear Damage Act, passed into law in 2010, is likely to have an impact on the Indian nuclear industry and its linkages to the global nuclear supply chain. Until 2010, when the Civil Liability for Nuclear Damage Act was passed into law, India did not have a legal framework for civil liability for nuclear damage and for the compensation of victims in the event of a nuclear accident. The Liability Law allows a re-course to the supplier[15]. Although this

[14] The private companies which have shared in the fortunes of the Indian nuclear program – just as the Indian nuclear establishment was isolated following the nuclear tests in 1974 and 1998, so too did the private companies face restrictions on the imports and exports.

[15] The Paris Convention (Article 6f and 6g), Vienna Convention (Article 10) and the Convention on Supplementary Compensation (Article 10) allow the operator a recourse to other parties. Clauses 17a and 17c of the Indian Act are almost identical to allowances for recourse in the Paris

recourse to suppliers is consistent with liability laws in non-nuclear industries, it marks a departure from international conventions and national laws on nuclear liability in other countries operating nuclear power reactors. Interpreted through the legal frameworks in the vendor countries, the law allows for unlimited liability of the supplier.[16] Ambiguities in the interpretation of the law have impacted the development of the Indian nuclear industry in several ways.

The law caps the operator's liability at Rs.1500 crores. Although it allows operators recourse to the suppliers, the law appears to be silent on how far down the supply chain liability goes. The General Conditions of Contract (GCC), which the Liability Law supersedes, held suppliers liable up to the price of the equipment supplied. It isn't inconceivable that the operator's liability if channelled to smaller companies in the nuclear supply is likely to exceed their balance sheets. Is it meaningful to channel liability to suppliers, who, in the event of an accident, would not be able to pay claims arising as a result of damages? Further, would these companies be willing to 'bet' their businesses by supplying equipment to nuclear plant projects if these projects make up but a modest fraction of their annual revenues? One option is to contractually shield small local suppliers from the full operator's liability and limit their liability to the price of the equipment (as GCC did).

But this too creates a problem. There are risks associated with relying on untested supply chains, especially for complex projects. By allowing the operator's liability to be channelled to the suppliers – one of them being the reactor vendor, the law increases the risks of supplying technology to the Indian reactor markets and inhibits technology localisation via the use of local supply chains. Confronted by a greater liability burden, and the choice between established and untested supply chains, would a reactor vendor choose the latter?

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and Vienna convention. Clause 17b however allows a recourse to the supplier if? "*the nuclear incident has resulted in a willful act or gross negligence on the part of the supplier of the material, equipment or services, or of his employee*"

[16] This concern stems from clause 46 which states that " *The provisions of this Act shall be in addition to, and not in derogation of, any other law for the time being in force, and nothing contained herein shall exempt the operator from any proceeding which might, apart from this Act, be instituted against such operator*".

FUTURE OF THE INDIAN NUCLEAR INDUSTRY

Critics of the nuclear industry in India point to the slow growth of installed capacity, largely ignoring the extent to which the reactor technologies have been indigenised. But realising projections for future installed capacity, at least by 2050, depend to a significant extent on the deployment of technologies that are still in the conceptual or prototype stages of development.

The three-stage strategy continues to be the technological vision for the nuclear energy program in India. Given the targets for installed capacity discussed earlier, what set of policies or incentives might result in a set of decisions that would lead to the development of the industry as a whole?

For the international vendors there are two dimensions along which to make decisions: (1) How should these vendors view the risks associated with exporting reactor technology to India under the current liability framework? Should nuclear commerce be put on hold until a new framework is established or the current one elucidated? And what might the impact of capitulating to this framework be for sales of reactors to other countries? (2) To what extent should these vendors localize reactor technologies?

Traditionally, private firms in India that manufacture for the Indian nuclear plants, have entered the sector as suppliers to the DAE, NPCIL, and more recently Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI). For these companies, a key concern is reducing uncertainties and the costs of doing business in a sector in which projects have been discontinuous. How should the trained workforce be retained in anticipation of future new build? And how should these companies organise their own supply chains to increase margins?

For companies that do not manufacture for nuclear plants, several paths for becoming nuclear suppliers present themselves: becoming sub-suppliers to established suppliers, as suppliers to international vendors and two paths that have not yet been attempted – as suppliers and operators for a reactor project managed entirely privately.

For the policy-makers, the question of the development of the overall program is one of channelling resources for the deployment of standardized technologies; the development and deployment of technologies in the concept or prototype phases of development; localizing, absorbing and perhaps standardizing imported LWR technologies[17]; and planning for export.

Thus the question of the development of nuclear energy is one of aligning the larger technological vision with decisions of each of these key players.

21 GWE BY 2020: EFFECTIVE PROJECT MANAGEMENT

Commissioning of two 1000 MWe VVER reactors, four 700 MWe PHWRs and the 500 MWe PFBR will increase the nuclear installed capacity by 5.3 GWe to a total of ~10 GWe. The additional ~10.3 GWe of the 2020 projection will likely come from a combination of PHWRs, and FBRs. A 700 MWe PHWR reactor project is estimated to take close to 4 years. Information gathered for this work indicates that private companies, in manufacturing and construction, can support work on up to 6 reactor sites or ~4200 MWe. Thus meeting the 2020 target will require that the manufacturing and construction capabilities of the private companies be exploited fully. Keeping manufacturing productivity high and effective project management of reactor construction to commission new reactors on time and on budget will be the challenges for this phase of development.

48 GWE BY 2030: TECHNOLOGY LOCALISATION

For the 2032 projection of 48 GWe now 17 years away, effectively a 27 GWe increase over the 2020 capacity projection will almost certainly necessitate the addition of a large fraction of the proposed 40 GWe of imported LWR capacity, with a continued addition of PHWRs, and the construction of FBRs at a more rapid pace.

This phase of expansion, if realised, will require that the capabilities of private companies be augmented. Here, one bottleneck could be the availability of a well trained and qualified workforce, able to rapidly build known technology, absorb

[17] The development of PWRs for powering submarines makes the question of localizing PWR technologies more interesting. Will the localization of PWR technologies be driven by commercial considerations or is there a strategic dimension also?

new ones, and develop and deploy the FBRs and AHWRs -- reactor technologies that are in the prototype and conceptual phases today. But the most serious obstacle for this phase of development could be institutional. Since meeting this target hinges on the construction of the LWRs, a solution to the current stalemate – the reluctance of international vendors to supply reactors under the current liability framework and the seemingly impossible task of creating a new one will have to be found.

Negotiations with AREVA for supply of 6 EPRs began in 2009 is ongoing, as are negotiations with Westinghouse. Levelised costs of electricity from EPR, AP1000, and VVER are expected to be significantly higher than the cost of electricity generated by PHWRs. Have the negotiations with the international vendors been prolonged on the question of liability and technology localisation alone, or does the cost of electricity from these reactors make a contract untenable?

Finally, the development of reactor technologies that are in the conceptual stages today ought to factor into negotiating the localisation of vendor technologies. Would systems or equipment of the LWR designs, if localised, aid the development of nascent indigenous reactor technologies?

208 GWE BY 2050: INNOVATION AND INDUSTRIAL REORGANISATION

The realisation of the 2050 projection – 208 GWe will require that technologies such as the AHWR are today in the conceptual stages, approach and readiness for deployment.. At least two pathways of industrial development present themselves. One option is a state-led trajectory which will make state-owned players – the AEC, DAE, NPCIL, BHAVINI strong. These larger players will have deeper reserves of capital on which to draw.   Consequently one might expect the reactors they deploy to grow in size and capacity and a lock-in of the existing industrial structure and product architectures.

Alternately, an expansion of the nuclear installed capacity could be achieved by the industrial reorganization of the nuclear program: not by making the large players and technical systems larger but by making reactors smaller and within financial reach of smaller private players (an option being explored actively elsewhere[18]).

Finally, should India become an exporter of nuclear plant technologies, as it hopes to, the demands on the domestic industrial system for the supply of reactor components, will be greater still.

For the Indian nuclear program, not only did the timing of industrial development matter but strategic considerations did too. The choice of PHWRs may not have been driven by industrial considerations alone. Had LWRs been chosen and enrichment services of another country been relied on, the opportunity costs of the nuclear tests to the civilian (and military) program would have been greater.

For a high-technology industry with strategic significance, like nuclear, technology selection, development and deployment is likely to be led by the state. The strategic and dual use nature of a technology leads to a pursuit of both multiple and riskier trajectories of technological development via the development and deployment of new-to-the-world technologies.

If the larger technological system is made up of a number of technologies, key technologies at the heart of the larger system – in the case of nuclear energy, the fuel, control and instrumentation equipment – will be developed by state-owned entities, at least at the inception of the industry. Another key role the State plays is its search for private partners and the creation of institutions that welcome private participation. Private firms, by participating in the process of production of a high technology, upgrade their own capabilities with positive, but not easily quantifiable, externalities to other sectors of production. A key tradeoff in this phase of development is between indigenous development and the transfer and localisation of technologies developed elsewhere. A further quandary, should the path of technology transfer be chosen, is finding ways to continue research and development for a future when technologies transferred today, will become obsolete.

[18] Most notably in the US through various programs of development of small modular reactors.

The Indian nuclear program, largely technologically isolated from the international nuclear supply chain, developed indigenously or reverse-engineered fuel cycle technologies. Thus the path of indigenous development allowed technical 'independence', but not a scale-up of the magnitude that was forecasted by the pioneers of the program. Today, the solitary development of nuclear energy technologies is no longer the only option open to the Indian program and it falls to the policy-makers to select a future path of Industrial development.

During a time of control on the transfer of technologies, the regulatory and financial certainty provided by the DAE spurred government and private partnerships for the development of nuclear energy technologies by a domestic supply chain. But now, access to international reactor markets and nuclear supply chains could upgrade the skills and safety standards of the local suppliers.

Thus, today the challenge facing the program is not just technology development, but its deployment at scale. Rather than developing targets alone, an industry-level roadmap, developed iteratively and jointly through conversations among the public and private stakeholders is needed, and perhaps in the process of doing this, new projections and targets and new technological trajectories to the closed fuel cycle vision will emerge.

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About the Authors

Prof. S. Rajgopal is a graduate of the College of Engineering, Guindy and Post Graduate Diploma in Systems Management from Jamnalal Institute of Management, Mumbai. He started his career with the Neyveli Lignite Corporation and subsequently moved to the Department of Atomic Energy. He was the Secretary, Atomic Energy Commission and Controller, Bhabha Atomic Research Centre. He headed the technical liaison mission in Paris after being a fellow of IAEA at South West Research Institute, US. He was a visiting professor and Dean at the National Institute of Advanced Studies (NIAS), Bangalore.

Aditi is a PhD candidate in the Department of Nuclear Science and Engineering (NSE) at the Massachusetts Institute of Technology, where she is developing curriculum for NSE's International Nuclear Leadership Education Program. Aditi worked as an intern in the Nuclear Power Technology Development Section at the IAEA, in the Reactors and Services Business Unit at AREVA NP, and most recently at CSTEP. Her undergraduate thesis explored how countries about to embark on new nuclear energy programs can build workforces for them. Aditi's doctoral research aims to draw on tools from the engineering and the social sciences to probe and find solutions to the challenges nuclear energy faces in industrial development, safety and regulation. additive@mit.edu

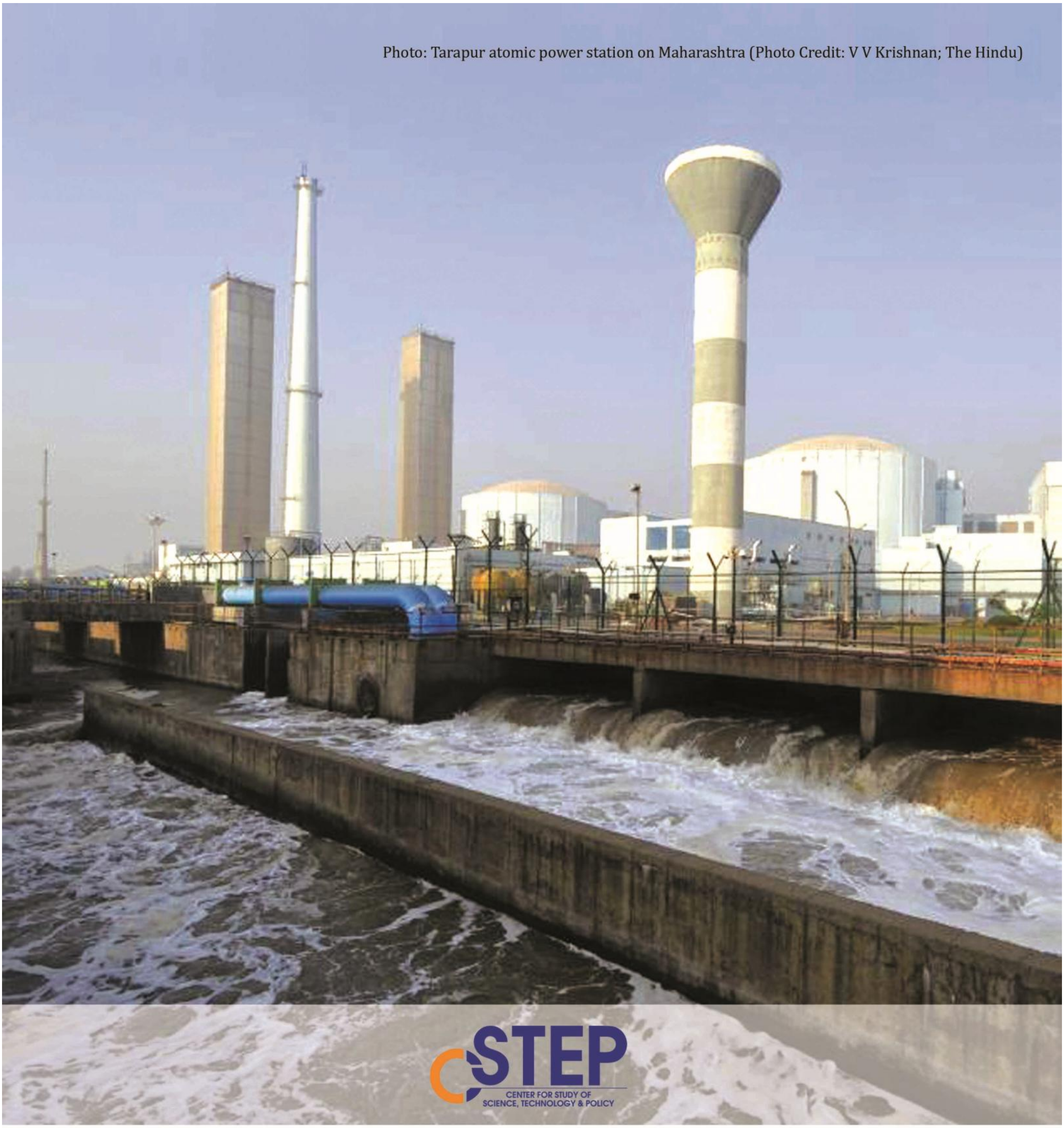

Photo: Tarapur atomic power station on Maharashtra (Photo Credit: V V Krishnan; The Hindu)

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18, 10th Cross, Mayura street, Papanna Layout
Nagashettyhalli, RMV II Stage, Bangalore-560094
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