VIF TASK FORCE REPORT

Nuclear Power:
India's Development Imperative

Vivekananda
International Foundation

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Foreword

Although nuclear power accounts for only about two percent of India's installed power generation capacity, it will continue to play an important role in the overall energy mix of the country. The government has also announced plans to ramp up nuclear power from the present 6.7 GW to 63 GW by 2032. Giving a fillip to nuclear power generation in 2017, the government decided to provide Rs. 3,000 crore per annum as funding for 10 years for building a 10-reactor fleet of indigenously produced Pressurised Heavy Water Reactors (PHWRs). Such an ambitious programme of nuclear power generation has the potential of converting India into a hub of nuclear energy manufacturing, creating high technology jobs and making the country an exporter of nuclear power equipment. As a result of these decisions, India has an opportunity to build an eco-system for nuclear power production in which both the public and the private sectors can participate. However, this will require considerable foresight, planning, financial resources and a rational tariff structure for nuclear power.

India's rise as a global power cannot be imagined without an adequate amount of energy. Its energy sector is undergoing major reform. At the Paris Climate Change Conference in 2015, India committed to increase its share of non-fossil fuel from 30 percent to 40 percent by 2030. The government plans to install 175 GW renewable power capacities by 2022, raising it from the present 70.6 GW. Such a sharp increase in solar and wind power, which is intermittent in nature, will require an adequate base load power capacity which can be supplied by nuclear power. In addition, nuclear energy is clean power with no carbon dioxide emissions. This is a huge plus in favour of its use.

Nuclear power has unique characteristics. It requires heavy capital investment upfront which makes it more expensive to produce in the initial years. But the cost of generation reduces significantly over the long life (40-60 years) of a nuclear reactor. Thus, nuclear power is useful as stable base load, which supplies clean and cheap power over the lifetime of reactors.

India is one of the few countries in the world with long experience of developing peaceful uses of nuclear technologies, including the generation of nuclear power. It has mastered the PHWR and Fast Breeder technologies and has a longstanding programme of building thorium-based nuclear reactors. These advantages need to be preserved and exploited for its growth. Nuclear power must, therefore, be given due encouragement.

Undoubtedly, nuclear power generation is a multifaceted and complex process. A rational tariff structure is essential to make nuclear power generation sustainable and competitive with

other sources of power. The advantages of nuclear power as a clean, stable and eventually cheap source of power must be given due weight while determining the tariff structure.

In 2017, the Vivekananda International Foundation set up a task force of experts to consider the future of nuclear power generation in India and make recommendations. The Task Force was headed by Dr. Anil Kakodkar, Former Chairman of the Atomic Energy Commission, and comprised of experts from the nuclear sector. Ambassador D.P. Srivastava, Senior Fellow, Vivekananda International Foundation, coordinated the work of the task force. The task force examined the global context of nuclear energy, the Indian nuclear energy eco- system, financial aspects of nuclear power generation and other factors. The report of the task force makes several recommendations on how nuclear power generation can be done on a sustainable basis. One of its key recommendations is that a levelised tariff plan for nuclear power should be considered and the nuclear sector be treated at par with the renewable energy sector in terms of incentives etc.

India's ambition to overcome poverty and rise will remain a dream unless it has access to adequate sources of power. The importance of nuclear power for India cannot be overstated despite scepticism in some quarters. Post-Fukushima, public scepticism about nuclear power had increased, but the situation is changing as more and more countries are considering a return to nuclear energy.

I would like to thank Dr. Anil Kakodkar and other task force members for their contributions. My special thanks to Ambassador D.P. Srivastava for the hard work he has put in for organising the work of the task force.

I hope the report will generate awareness about the continued relevance of nuclear power for India and contribute towards an informed debate in the country.

New Delhi
December 2018

Dr Arvind Gupta
Director, VIF

Introductory Comments

Nuclear energy represents a paradigm shift in addressing growing energy needs of mankind as civilisation moves forward. Humans have been deriving energy from motion caused by gravity and other atmospheric phenomena in the form of mechanical energy and from electrons that orbit the nucleus of an atom in the form of chemical as well as electrical energy. Nuclear energy represents the next transition where one derives energy from within the nucleus of an atom. Being most intense, it adds significantly to the capability of earth resources in meeting the growing energy needs of mankind.

Energy being a key factor for meeting human needs, is also a significant multiplier to human capability. This enhanced capability has manifested both constructively and destructively, depending on how the human mind works. Nuclear energy being the most intense has, thus, relatively extreme potential both ways.

India has the unique distinction of addressing the challenge of harnessing nuclear energy potential in the most responsible way. Developing this capability has met with several hurdles on the way. Today, we have reached a stage where we are in a position to leverage nuclear energy to address contemporary energy-related challenges that we as a nation and the world at large are confronted with. The most important among these challenges is to protect the global climate. Global warming arising out of human activities today threatens the very existence of humankind. Several studies have now made it clear that this challenge cannot be met in an affordable manner without nuclear energy playing a significant role. This is a hard reality that the world has to come to terms with despite psychological reluctance in many quarters. With our abundant thorium resources and related capability, I am of the opinion that we have an opportunity to address the twin challenge of meeting concerns related to nuclear energy as well as climate change within the available time frame. We need to put our act together in an effective manner to address this challenge.

Clearly the first step in this direction is to accelerate the deployment of nuclear power in the country to enhance the share of non-fossil base load generating capacity. Improved programme management, higher resource mobilisation, building and sustaining large domestic nuclear manufacturing, construction and engineering capacity base etc., would be a prequisite for this purpose. Leveraging international cooperation in the nuclear area

not only for enhancing domestic nuclear capacity, but also for enhancing domestic value addition and even expanding our export footprint, should be the next step. Going forward, we should also work for exporting full nuclear power plants and systems. Leveraging our thorium capability, we have the possibility of addressing the global climate change challenge on a worldwide basis.

The energy needs of a larger fraction of the world are yet to be adequately addressed and nuclear is destined to play a significant role in addressing this challenge. Further the centre of gravity of global nuclear power development is fast moving closer to India. We cannot afford to remain silent spectators and simply watch the growing presence of other players in the area. India must ensure her significant presence in the international arena. We must prepare ourselves for this important role of leveraging our technological capability as well as our human resource and manufacturing base. This would be consistent with our economic interests as well.

Electricity is only one of the convenient energy carriers whose share is destined to grow. However, fluid energy carriers would remain relevant for the foreseeable future. The challenge then is to produce non-fossil alternatives to fluid energy carriers. Through development of appropriate technologies, nuclear can play an important role here. Technology development for realising our three-stage programme should also incorporate a non-fossil fluid fuel production objective along with a thorium utilisation objective.

Clearly, the long-term scope of nuclear energy development in the country is very large. This report focuses essentially on near-term objectives. These must be met as they are essential for our immediate national development. More importantly, this would also lay down the foundation to move towards a carbon-free energy future for India and the rest of the world. India should not miss on this opportunity. A strong and largescale foundation should, therefore, be quickly and decisively established.

I would like to thank members of the task force and all other contributors for their efforts. Thanks are also due to the Vivekananda International Foundation for entrusting us with this important task.

Mumbai
December 2018

Anil Kakodkar
Chairman,Task Force

List of Abbreviations

ADSS	Accelerator Driven Subcritical Reactor Systems
ASME	American Society of Mechanical Engineers
BARC	Bhabha Atomic Research Centre
BHEL	Bharat Heavy Electricals Limited
BHAVINI	Bharatiya Nabhikiya Vidyut Nigam Limited
BWR	Boiling Water Reactor
C	Celsius
CAG	Comptroller and Auditor General of India
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CARE	Credit Analysis and Research
CO_2	Carbon Dioxide
CEA	Central Electricity Authority
CFD	Contracts for Difference
CGNPC	China Guangdong Nuclear Power Group
CLNDA	Civil Liability for Nuclear Damage Act
CNEC	Consortium for Nonproliferation Enabling
CNNC	China National Nuclear Corporation
CNY	Chinese Yuan
CPSE	Central Public Sector Enterprise
CRISIL	Credit Rating Information Services of India
CSR	Corporate Social Responsibility
CSS	Carbon Dioxide Capture and Storage
CWIP	Capital Work In Progress
DAE	Department of Atomic Energy
DIPP	Department of Industrial Policy and Promotion
DISCOM	Distribution Company
ECIL	Electronics Corporation of Indian Limited
EIL	Engineers India Limited
ENEC	Emirates Nuclear Energy Corporation

EPC	Engineering Procurement Construction
ESCert	Energy Saving Certificates
EV	Electric Vehicles
EXIM	Export-Import
FBR	Fast Breeder Reactor
FBTR	Fast Breeder Test Reactor
FDI	Foreign Direct Investment
FIT	Feed-in Tariff's
FRFCF	Fast Reactor Fuel Cycle Facility
FY	Financial Year
GDP	Gross Domestic Product
GE	General Electric Company
GHAVP	Gorakhpur Haryana Anu-Vidyut Pariyojna
GST	Goods and Service Tax
GW	Gigawatt
GWe	Gigawatt Electrical
H	Hydrogen
HBNI	Homi Bhabha National Institute
HCC	Hindustan Construction Company
HTR	High Temperature Reactor
HTGR-PM	High Temperature Gas-Cooled Reactor Pebble
IAEA	International Atomic Energy Agency
IDC	Interest During Construction
IEX	Indian Energy Exchange
IGST	Integrated Goods and Service Tax
IPO	Initial Public Offering
ITI	Industrial Training Schools
IOCL	Indian Oil Corporation Limited
IPCC	Inter-governmental Panel on Climate Change
IPBG	Integrity Pact Bank Guarantee
JV	Joint Ventures
KAPS	Kakrapar Atomic Power Station
KAPP	Kakrapar Atomic Power Plant

KANUPP	Karachi Nuclear Power Plant
kCal/kg	Kilocalorie per Kilogram
KEPCO	Korea Electric Power Corporation
KGS	Kaiga Generating Station
KKNPP	Kundakulam Nuclear Power Plant
KWhrs	Kilowatt Hour
LCOE	Levelised Cost of Electricity
LNG	Liquefied Natural Gas
LWR	Light Water Reactor's
MAPS	Madras Atomic Power Station
MEA	Ministry of External Affairs
MOU	Memorandum of Understanding
MT	Metric Ton
MW	Megawatt
MWe	Megawatt Electrical
MWd/t	Megawatt Day Per Tonne
MWth	Megawatt Thermal
MIT	Massachusetts Institute of Technology
MOQ	Minimum Order Quantities
NAPS	Narora Atomic Power Station
NDRC	National Development and Reform Commission
NDT	Nondestructive Testing
NIMBY	Not In My Back Yard
NITI	National Institution for Transforming India
NEA	National Environment Agency
NESA	National Employment Services Association
NO2	Nitrogen Dioxide
NPA	Non-Performing Assests
NPCIL	National Power Corporation of India Limited
NPP	Nuclear Power Plant
NPT	Non-Proliferation Treaty
NSCS	National Security Council Secretariat
NSG	Nuclear Supply Group

NSSS	Nuclear Steam Supply System
NTC	Nuclear Training Centre
NTPC	National Thermal Power Corporation Limited
O&M	Operation and Maintenance
OECD	Organisation for Economic Cooperation and Development
ONGC	Oil and Natural Gas Corporation Limited
OVL	ONGC Videsh Limited
PAT	Perform Achieve and Trade
PBG	Performance Bank Guarantee
PFC	Power Finance Corporation Limited
PFBR	Prototype Fast Breeder Reactor
PHWR	Pressurised Heavy Water Reactors
PLF	Plant Load Factor
PPA	Power Purchase Agreement
PPP	Public-Private Partnership
PSU	Public Sector Undertakings
Pu	Plutonium
PV	Price Variation
PWR	Pressurised Water Reactor
QA	Quality Assurance
RAPP	Rajasthan Atomic Power Project
RBI	Reserve Bank of India
RE	Renewable Energy
REC	Rural Electrification Corporation Limited
RLNG	Regasified Liquefied Natural Gas
RPO	Renewable Purchase Obligation
SPA	Special Planning Authority
TAPS	Tarapur Atomic Power Station
TPI	Third Party Inspection
Th	Thorium
U	Uranium
VVER	Water-Water Energetic Reactor

Executive Summary

1. India's energy consumption has been growing at a CAGR of six percent over the last decade. With the completion of the national grid and universal electrification of households, the demand curve will rise more steeply in the future. This trend will be reinforced by a move towards Electric Vehicles (EVs). **The power sector will have to respond to the twin challenges of increased access to electricity and meeting stringent emission norms. Both have to be done at affordable prices.** The environmental pressure is already forcing a change in the composition of India's energy portfolio with a premium on clean energy. The renewables will have a greater share in India's energy mix in the future. The tariff for wind and solar energy has also come down, but does not reflect the cost of balancing power needed when wind or solar are unavailable. Nor does it include the grid cost in terms of backing down dispachable power plants, or operating them at sub-optimal level, when renewable power is available. **In the spectrum of choices available to provide energy for India's growth, the share of nuclear as a key source of stable, non-fossil base load power will have to go up.**

2. In the Paris Conference on Climate Change, India committed to increase its share of non-fossil fuel in total installed power generation capacity from 30 percent in 2015 to 40 percent by 2030. **The renewables currently account for 35.7 percent of India's installed power generation capacity**. The government has announced plans to increase renewables to 175 GW by 2022 **from 70.6 GW as on 30 September 2018**. This will entail dispachable power sources that can rapidly respond like hydro or gas, since wind and solar are intermittent sources of energy and adequate base load power capacity which can only be supplied by coal or nuclear.

3. Being an intermittent source of energy, renewables cannot provide base load power **critical for India's economic growth**. At present, this requirement is essentially met by coal, which accounts for 55 percent of India's commercial primary energy supply[1]. **Its share in India's power generation is 75 percent.** However, rising environmental concerns make it imperative to significantly enlarge the share of a non-fossil source of stable, base load power.

4. Nuclear energy can supplement coal as a source of stable, base load power, not supplant it. At present, it accounts for around two percent of India's installed capacity. However,

the target of ramping up nuclear power from 6.7 GW at present to 63 GW by 2032 will increase its share in India's electricity generation portfolio to around 10 percent. The presently sanctioned capacity is **22.48 GW** to be progressively realised by 2031. There is thus a need to open up additional projects to realise the target of 63 GW and a more efficient project implementation framework for their timely completion.

5. As a source of base load power, nuclear power has to be compared with coal, not renewables. In any comparison with coal, emission costs must be factored in. Broadly speaking, the country's energy mix should be determined on the basis of the availability of different energy resources and their pricing. Left to itself, the market would determine the evolution of this energy mix. This may or may not be consistent with the long-term energy or environment security of the country for which a sizeable contribution from nuclear energy is vital. State policy to steer the energy mix towards long-term national interest is therefore important. **Without factoring grid/system costs of renewables, nuclear tariff may appear high**. We should recognise that energy security can become a bigger challenge in the years to come. A well-designed financing and pricing policy should, therefore, be put in place at the earliest. Thus, as a minimum, measures to create at least a level playing field for nuclear energy recognising its strengths in energy security and absence of CO_2 emission, are necessary.

6. In order to provide a level playing field, nuclear power should also be given incentives as provided to the renewable sector. It needs a '**must run status**', as nuclear plants run on a continuous basis. **Without this facility, there will have to be a steep increase in tariff to recover high capital cost.** There are other incentives given to wind and solar power, which are presently not available to nuclear power in India. Loading for external costs is part of the cost evaluation of tariff from different sources of energy in the United States and the European Union. This is not so in India due to the direct and indirect subsidies given to solar and wind power by both the Central and State governments.

7. After a pause in the post-Fukushima phase, construction of nuclear plants has again picked up in the West. The US (20%), EU (20%) and China (10%) will retain a substantial share of the nuclear sector in their energy mix in the future[2]. Interestingly, Japan, has also decided to retain nuclear power as part of its energy mix. The Fifth Basic Energy Plan approved by the Japanese Cabinet in July 2018, calls for nuclear energy to account for 20-22% of the country's power generation by 2030. This is double the share of nuclear energy in the Indian energy mix (10%) **even** if the nuclear programme is to be ramped up to 63 GW by 2032[3].

8. Germany decided not to expand its nuclear power programme post-Fukushima and rely on gas and wind energy. India does not have the option to depend upon gas; imported LNG is too expensive for the power sector. Reliance on gas has also increased Germany's emission levels and made it difficult for the country to achieve its 2020 greenhouse gas reduction target[4]. Germany could ramp up renewables on a large scale as it can bear the cost, and has access to regional grids to supply balancing power. India does not have the option of a regional grid as most of the neighbouring countries, with the exception of Bhutan, are net importers of electricity. Bhutan exports power to India but does not have the scale to match India's requirements.

9. China entered the civil nuclear power sector later than India. It attempted expansion of its domestic programme and exports simultaneously. There is no conflict between the two. Exports help achieve scale and bring down costs. India should also aim at emerging as a global manufacturing hub for nuclear equipment and material. This task will be facilitated if Indian companies are part of an international supply chain. For this they have to be globally competitive in terms of price and quality.

10. Ramping up the nuclear power sector from 6.7 GW to 63 GW by 2032 will require considerable resources, **financial discipline and reorganisation of the nuclear sector to bring in more players who can invest in expanding capacity**. The government's announcement of funding to the tune of Rs.3,000 crores per annum for building 10 reactors in fleet mode is a welcome step, but falls short of financial requirements.

11. For import of Russian reactors for Kudankulam, 1, 2, 3, 4, 5 & 6, NPCIL has negotiated soft credit. While making financing easier, the foreign credit sometimes limits scope of 'localisation'. For the Indian industry to grow in capacity, progressive indigenisation is essential. This is also needed to bring down costs and tariff.

12. There are other modes of financing. In the case of the UAE and the UK, they have allowed foreign companies not only to construct, but also to operate their nuclear power plants for extended periods. Applying this model to Indian conditions would require an amendment of the Atomic Energy Act. There are intermediate solutions such as encouraging PSUs like NTPC and IOCL to form joint ventures with NPCIL. This can be implemented within the present Act.

13. NPCIL has to bring down the cost of construction to ensure that nuclear power **continues to be affordable in the future**. A key to realising this is to nurture optimum manufacturing capacity where there is not only good competition, but also confidence about continuity of work orders for competitive industries. Continuous orders are necessary for the vendor industry to invest in expansion of

capacity. It also has to evolve procedures for fleet-mode construction. The government has to allow flexibility in procurement procedures. Internally, company procedures must assure quality manufacturing and construction without interruptions. This also needs an increase in trained manpower. This will also generate considerable employment.

14. To propose an increase in the share of nuclear power at a time when the power sector is witnessing a large number of NPAs may seem audacious, but increase in electricity generation capacity cannot be avoided if growth in economy has to take place at a rapid pace. Today, India's per capita energy consumption is a third of the world average. With high emphasis on domestic manufacture in the nuclear sector, the government's target of increasing share of manufacturing in GDP would also be facilitated. Since, this has to be achieved within the constraints of emission norms that are expected to become progressively more stringent, it is clear that nuclear power is not a luxury, but a necessity for India.

15. China's case is instructive. With the same cost constraints, and share of coal in energy profile as India, China is seeking to make nuclear power 10 percent of its total energy requirement by 2030. Its civil nuclear programme started much later than India, nevertheless, it has focused on exports since inception. It also has a multiplicity of reactor types to avoid dependence on a single source. By using economies of scale, it has gone further and faster in indigenising technology and lowering production costs. Till recently, we could not access global markets, but that is possible now. We should now be proactive in exploring the global market not only for our PHWRs (Pressurised Heavy Water Reactors), but also globally explore the much larger market for LWRs (Light Water Reactors). This could be both for equipment and components for LWRs of different designs and also for indigenously designed PWRs for which work is currently in progress.

16. The Inter-governmental Panel on Climate Change (IPCC) released its report in October 2018 in Incheon, South Korea. This is a sequel to the agreement adopted at the Paris Summit on Climate Change in 2015, which called for keeping global warming 'well below' 2°Celsius (C) and above pre-industrial temperature levels. The agreement also urged all countries to 'pursue efforts towards 1.5°C'. The IPCC report brought out the difference between the 2°C target agreed and the more ambitious 1.5°C goal in terms of impact on poverty, agriculture and rise of sea level. It also brought out the cost of different adaptation and mitigation measures. Though the report does not represent an agreement at the government level, it underlines the need for de-carbonisation of the global economy[5].

17. The IPCC report does not suggest specific solutions. However, a recent study by MIT, released on the eve of

the IPCC report, says that nuclear power has to be part of the energy mix in any pathway to a 1.5°C future. The report captioned 'The Future of Nuclear Energy in a Carbon Constrained World' points out that 'as the world seeks deeper reductions in electricity sector carbon emissions, the cost of incremental power from renewables increases dramatically'. The report suggests that 'including nuclear in the mix of capacity options helps to minimise or constrain rising system costs, which makes attaining stringent emission goals more realistic'. The report gives recommendations for policy intervention to ensure that 'public policy to advance low-carbon generation should treat all technologies comparably'. It also calls for a reduction in the cost of producing nuclear power[6].

18. The concept of carbon pricing is at a nascent stage in India. The government has introduced the Energy Efficiency Certificate and a coal cess. However, there is resistance to the idea, as it burdens the down-stream industry. India is far below the world average in electricity consumption and has to use its available coal reserves. However, over a period of time, increase in the share of non-fossil fuels is essential. This is reflected in government policy, but more needs to be done.

19. The current debate on the power sector in India is characterised by concern over low demand, stressed assets and the need to bring down tariff to compete with renewables, which have fallen to Rs. 2.5 per unit. However, the spot power price in September 2018 touched almost a 10-year high of Rs 17.61 per unit on the Indian Energy Exchange (IEX) of spot prices. The spike was attributed to the decline in wind and hydroenergy at this time of the year, coupled with constraints in the movement of coal to thermal power plants. While spot prices do not indicate a long-term trend, they underline the difficulty of relying on renewables, which are an intermittent source of energy. The problem will get worse as the share of renewables in India's energy mix increases with the government's goal of 175 GW of renewables by 2022[7].

20. The coal import bill last year was more than USD 9 billion. There seems to be an increasing trend of coal imports. In comparison to coal, the cost of nuclear fuel is a negligible component of operating cost for a nuclear power plant.

21. India is developing a three-stage nuclear power programme to make full use of its abundant thorium resources. The MIT report brings out the potential of various reactor models, including small modular reactors. India has to maintain its technological perch in the nuclear field. There is an ongoing programme to develop nuclear reactor systems for the second and third stages along with the indigenous PWR. Safety upgrades are also likely to continue to be an ongoing feature. We would also need to develop nuclear reactor systems that can deliver energy at high temperatures for non-electricity purposes such as hydrogen

production or reactor systems that would enable a faster approach to large scale thorium utilisation such as Accelerator Driven Subcritical Reactor Systems (ADSS). The goal of a decarbonised economy will require the greater use of non-fossil hydrogen for mass electrification and the use of heavy transport, heating and industry[8].

22. The rapid ramping up of installed nuclear power capacity from 6.7 GW to 63 GW by 2032 would require the government to provide substantial resources to NPCIL. This cannot be managed through internal accruals alone. There is also a need to look at financing models used by other countries, including the UAE and the UK, where credible international vendors with significant pre-existing domain expertise in nuclear power plant operation are allowed to acquire equity and operate the plant, while the government gives long-term tariff guarantees. This, however, would require amending the existing Atomic Energy Act. NPCIL has to ensure timely completion of projects within the budget. Indian companies should form strategic tie-ups with international majors to be part of the international supply chain.

23. This report is an attempt to look at these and many other questions linked to the nuclear power sector dispassionately. The Vivekananda International Foundation task force was chaired by Dr. Kakodkar and included vendor industry and power sector representatives to present a holistic perspective. While the recommendations are summarised in Chapter 9, some key recommendations are given below:

i. In the spectrum of choices available to provide energy for India's growth, the share of nuclear as a key source of stable, non-fossil base load power will have to go up.

ii. We should recognise that energy security is likely to become a bigger challenge in the years to come. A well-designed financing and pricing policy to steer the required transition in the energy mix should therefore be put in place as early as possible. Thus, as a minimum, measures to create at least a level playing field for nuclear energy, recognising its strengths in energy security and absence of carbon dioxide emissions are necessary.

iii. In order to provide a level playing field, nuclear power should be given incentives as provided to the renewable sector. It needs a 'must run status', as nuclear plants run on a continuous basis. Without this facility, there will have to be a steep increase in tariff to recover high capital costs.

iv. NPCIL must reduce project costs and gestation period to bring down tariff. This requires timely completion of projects to minimise interest during construction.

v. The focus of NPCIL should be on rapid capacity expansion through credit.

vi. NPCIL must ensure adequate competition and continuity of orders for vendors.

vii. Indian companies must be competitive globally in terms of price and quality to get integrated in the international supply chain.

viii. The government must provide additional resources over and above annual support pledged to NPCIL so far. Rs. 3,000 crore per annum would cover only a small fraction of the funds required to reach the target of 63 GW by 2032.

ix. NPCIL's profitability must be maintained, so that it has enough internal resources to finance at least part of the expansion cost of the nuclear power programme.

24. Nuclear power will be an indispensable component of India's national strategy to secure energy self-sufficiency. The expansion of the programme has to be combined with indigenisation to bring down costs. This would in keeping with the Make in India programme. Currently sanctioned programme, which includes 10 PHWRs, and two LWRs would generate employment for 40,000 persons directly or indirectly. The manpower requirement will increase as the programme is ramped-up to 63 GW by 2032. Nuclear power provides an option to harmonise India's developmental needs with increasingly stringent emission norms which are inevitable as global warming worsens.

Chapter 1: Global Context

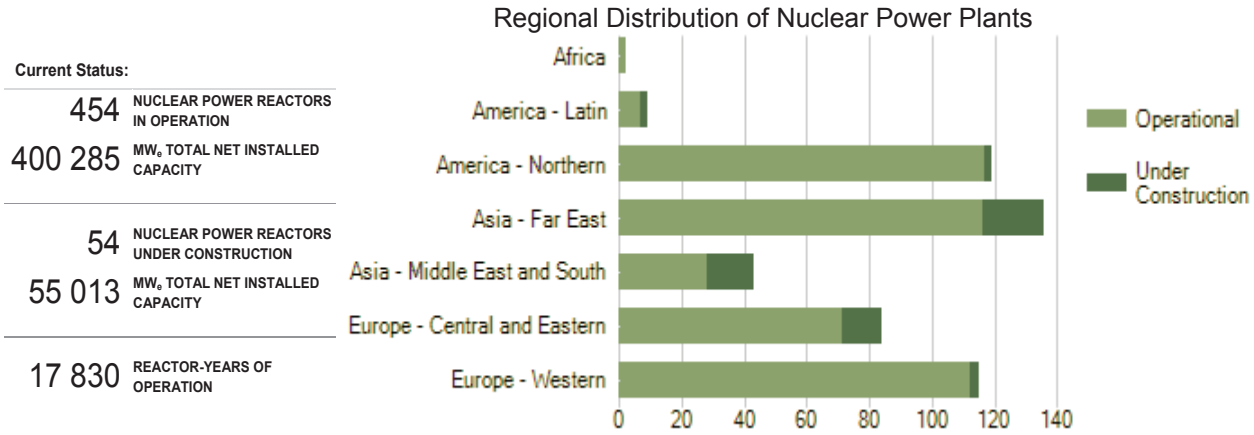
Post-Fukushima, there was a pause in the development of nuclear power. German Chancellor Angela Merkel halted plans for expansion of nuclear power plants and decided to switch to gas and renewable energy. The reliance on gas has increased Germany's emission levels and made it difficult to achieve its 2020 greenhouse gas reduction target. Germany could ramp up renewables on a large scale as it can bear the cost and has access to regional grids to supply balancing power. Interestingly, Japan has after reviewing the safety of its nuclear power plants, re-started some of them as part of its energy mix.

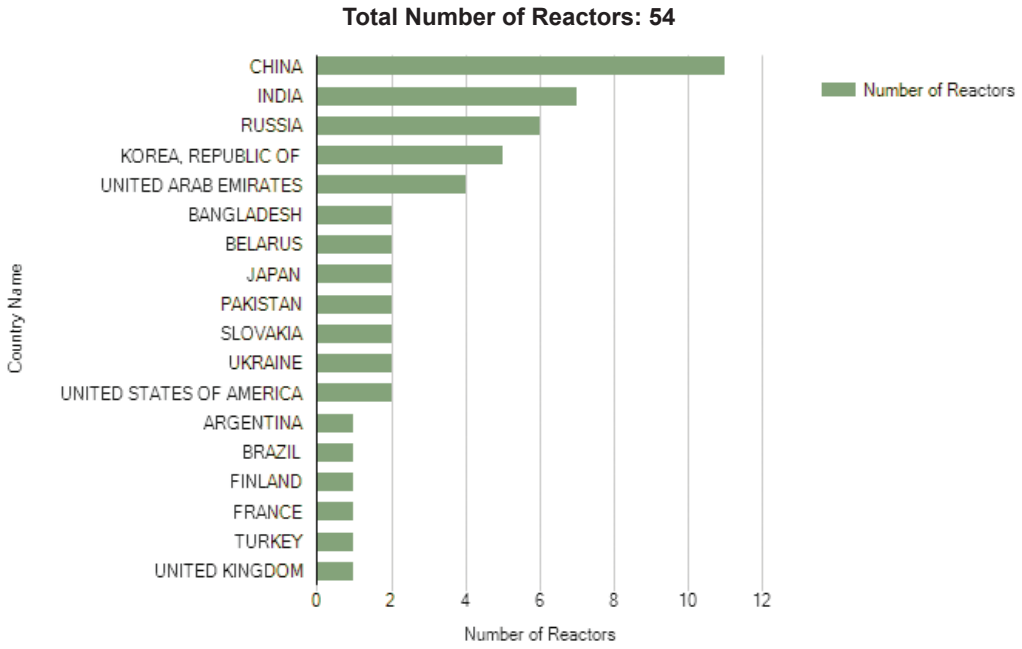
There are 450 nuclear power reactors in operation globally[9]. While industrialised countries still account for a major part of current capacity, most new reactors under construction are in developing countries[10]. This is clearly a manifestation of the fact that net additional capacity growth is expected to be predominant in emerging economies with significant development deficit. The centre of gravity of the market for nuclear power is thus bound to shift to Asia[11].

There are plans or proposals in 17 countries for new nuclear plants. Interestingly, this includes Japan. Also, a Middle East country like the UAE, a traditional hydrocarbon energy provider, is taking up a nuclear power programme.

Saudi Arabia has also announced that it is inviting proposals for 2.9 GWs of nuclear power.

By 2017, Japan had restarted five of its nuclear reactors and 19 more have applied for permission[12]. The Japanese Cabinet has approved the Fifth Basic Energy Plan in July 2018. Under the plan, nuclear will remain a key energy source[13].





The total Number of Reactors includes also 2 reactors in Taiwan, China

Source: IAEA – Reactors under Construction by Country [14]

1.1 Share of nuclear power in the energy mix

According to the IAEA, India ranks 27th in terms of share of nuclear power in total electricity generation. In terms of installed capacity, India (6.7 GW) figures 12th behind the US (99.95 GW), France (63.13 GW), Japan (39.75 GW), China (34.51 GW), Russia (26.14 GW), South Korea (23.07 GW), Canada (13.55 GW), Ukraine (13.11 GW), Germany (10.79 GW), Sweden (9.1 GW) and the UK (8.9 GW). Amongst major economies, the US, Japan, China, Russia and France are planning to retain substantial nuclear capacity in the future as well. The US is the largest producer of nuclear power, providing 20 percent of the nation's electricity needs. The EU currently has 122 GW of nuclear capacity, providing 27 percent of the region's electricity. While in the cases of the US and the EU, there might be a slight decrease by 2030, China actually intends to raise its installed nuclear capacity from 38 GW currently to 160 GW by 2030, providing 10 percent of electricity. In Russia, the share of nuclear power in total electricity supply would be 25-30 percent by 2030.

In India's case, nuclear power provides roughly two percent of installed electricity capacity currently. By 2032, if we achieve the target of 63 GW capacity, the share of nuclear power in India's electricity generation will rise to around 10 percent.

The case of the US and China is relevant, as coal accounts for a major share of their energy portfolio like India. Yet, they have decided to retain a substantial share of nuclear power in their energy mix. Germany has decided to close its existing nuclear units. However, it has the option of using gas (which developing countries like India cannot afford), as well as access to power from neighboring

countries. **Under the Fifth Basic Energy Plan Japan's nuclear energy will account for 20-22 percent of the country's electricity generation by 2030[15].**

1.2 External costs

Tariff structures often don't reflect external costs, including carbon pricing and grid costs. As fossil fuel generators begin to incur real costs associated with their impact on the climate through carbon taxes or emissions trading regimes, the competitiveness of new nuclear plants will improve. This is particularly so where comparison is being made with coal-fired plants, but, it also applies, to a lesser extent to gas-fired equivalents. The studies in the EU and the US have shown that loading external costs could improve the competitiveness of nuclear over other forms of energy.

The European Commission in cooperation with the US Department of Energy launched the ExternE project in 1991 to assess external costs of different forms of energy. It found that nuclear energy had the lowest costs in terms of emission, dispersion and ultimate impact. In case of nuclear energy, the risk of accidents and radiological impacts from mine tailings were factored in. The study found that 'nuclear energy averages 0.4 Euro cents/kWh, much the same as hydro; coal is over 4.0 c/kWh (4.1-7.3), gas ranges 1.3-2.3 c/kWh and only wind shows up better than nuclear, at 0.1-0.2 c/kWh average'. If these external costs were factored in, 'the EU price of electricity from coal would double and that from gas would increase 30 percent. These are without attempting to include the external costs of global warming'[16].

According to a MIT study, nuclear tariff compares favourably with coal and gas, once carbon cost is taken into account.

[12] The capital cost estimates do not take into account any possible prospective change to the cost of capital as a result of the current financial crisis or the recent drop in commodity prices for construction materials. Du, Yangbo and John E. Parsons, Update on the Cost of Nuclear Power, MIT Center for Energy and Environmental Policy Research Working Paper 09-004; http://web.mit.edu/ceepr/www/publications/workingpapers.html

Table 1: Costs of Electric Generation Alternatives

			LCOE		
	Overnight Cost	Fuel Cost	Base Case	w/ carbon charge \$25/ tCO_2	w/ same cost of capital
	\$/kW	\$/mmBtu	¢/kWh	¢/kWh	¢/kWh
	[A]	[B]	[C]	[D]	[E]
MIT (2003)					
\$2002					
[1] Nuclear	2,000	0.47	6.7		5.5
[2] Coal	1,300	1.20	4.3	6.4	
[3] Gas	500	3.50	4.1	5.1	
Update					
\$2007					
[4] Nuclear	4,000	0.67	8.4		6.6
[5] Coal	2,300	2.60	6.2	8.3	
[6] Gas	850	7.00	6.5	7.4	

Source: Update of the MIT 2003, Future of Nuclear Power, An Interdisciplinary Study [17]

1.3 Cost of large scale integration of nuclear energy

Renewables being an intermittent source of electricity, need balancing power. This means creating redundancies – backing down existing thermal power plants when renewable power is available or providing balancing power from other sources when renewable is unavailable. This is also needed to cater to peak demand. This is creating problems even in rich countries like Germany. 'At 40% share of electricity being from renewables, the capital cost component of power from conventional thermal generation sources increases substantially as their capacity factor decreases – the utilisation effect. This has devastated the economics of some gas-fired plants in Germany, for instance'[18].

The Government of India has announced an increase in renewable energy (RE) capacity to 175 GW by March 2022 from the current level of 69 GW. This will increase the share of power generated based on RE from 8% to 19%. With the increase in the salience of renewable energy in total power generation, grid costs will also go up. This includes the cost of standby capacity, flexible generation which can ramp up and down to compensate for variations in RE power generation and the cost of operating coal-based power plants at lower efficiency and Plant Load Factor (PLF). The CEA has estimated that this translates into an additional cost of Rs. 1.57 per kWh of renewable energy in Tamil Nadu and Rs. 1.45 per kWh in Gujarat over and above the tariff. Actual costs are still higher, as the above estimate does not include the cost of remission of inter-state transmission charges of electricity, which has to be loaded on to a conventional source of power[19].

1.4 Climate change and IPCC Report

The Paris Climate Summit of 2015 agreed to keeping global warming 'well below' 2°Celsius (C) above pre-industrial temperature levels. The agreement also urged all countries to 'pursue efforts towards 1.5°C'. This was not a firm commitment; it was included in response to concerns of small island states about the rise in sea levels caused by global warming. The Paris Conference also mandated the Intergovernmental Panel on Climate Change (IPCC) to study the technical feasibility of the more ambitious target of keeping the warming below 1.5°C. This IPCC report was released in Incheon, Republic of Korea, on 6 October 2018. The report has added urgency for the decarbonisation of the economy and put a premium on non-fossil sources of energy, including renewables and nuclear.

At +2°C warming, Karachi (Pakistan) and Kolkata (India) could expect annual conditions equivalent to their deadly 2015 heatwaves (medium confidence). - IPCC Report[20].

The IPCC report has brought out that a 2°C increase in temperature would be reached much before the turn of the century. This has set alarm bells ringing. The report brings out that negative effects of global warming could substantially be reduced if the higher target of limiting the increase in temperature to 1.5 degrees is accepted. This would require more investment to accelerate the pace of decarbonising the economy, and puts a premium on non-fossil fuel, including renewables and nuclear.

The IPCC report examines consequences of climate change as well as a range of adaptation and mitigation measures. It states

that 'the avoided climate change impacts on sustainable development, eradication of poverty and reducing inequalities would be greater if global warming were limited to 1.5°C rather than 2°C, if mitigation and adaptation synergies are maximized while trade-offs are minimized'.

The IPCC report does not recommend a specific energy source, but mentions that most pathways to reach the 1.5°C target require that by mid-century, the majority of primary energy should come from non-fossil fuels i.e., renewables and nuclear energy. Renewables are projected to supply 70-85 percent. In electricity generation, shares of nuclear and fossil fuels with carbon dioxide capture and storage (CCS) are modelled to increase. The use of CCS would allow electricity generation share of gas to be approximately 8% (3-11% inter-quartile range) of global electricity in 2050, while the use of coal shows a steep reduction in all pathways and would be reduced to close to 0% (0-2%) of electricity (high confidence). The report acknowledges that these choices would depend upon the socio-economic conditions of the countries concerned.

Nuclear power increases its share in most 1.5°C pathways, but in some pathways, both the absolute capacity and the share of power from nuclear generators declines. The variation depends upon national preferences. The 2011 Fukushima incident resulted in a confirmation or acceleration of phasing out nuclear energy in five countries; while 30 other countries have continued using nuclear energy, amongst which 13 are building new nuclear capacity, including China, India and the United Kingdom.

The IPCC report represents scientific findings, not the agreed commitments of State parties to the Convention on Climate Change. However, it is bound to increase pressure for reducing or avoiding carbon intensive energy forms. This puts a premium on renewables and nuclear energy.

Independent of the IPCC report's recommendations, the need to do more to achieve a decarbonised economy, cannot be denied. Most experts agree that taking into account the cumulative effect of commitments made by different countries at the Paris Summit, the actual rise of temperature would be 2.7°C. The switch to non-fossil fuel is no longer an option, but an imperative necessity[21].

1.5 MIT report on the Future of Nuclear Energy in a Carbon-Constrained World

The MIT report brings out the role of nuclear power in combating global warming. In a situation that a 1.5°C increase in temperature could be reached by 2030 and the cumulative increase by the end of the century may well be over 2.7°C, climate change is an existential problem for developed and developing countries alike. The report says that without the contribution of nuclear power, 'the cost of achieving deep decarbonisation targets increases significantly'. The report acknowledges that 'the central challenge to realising this contribution is the high cost of new nuclear capacity'[22].

The report suggests several measures for industry to bring down the costs of nuclear energy. It also calls for government help 'in the form of well-designed energy and environmental policies and appropriate assistance'.

Key recommendations of MIT report Future of Nuclear Energy in a Carbon-Constrained World

- Completion of greater portions of the detailed design prior to start of construction.
- Development of a proven supply chain for nuclear steam supply system (NSSS).
- Inclusion of manufacturers and constructors in the design team to ensure that components can be manufactured and structures can be built to relevant standards.
- Modularisation, when used judiciously in nuclear power construction and component fabrication, could be a viable cost-reduction strategy in advanced reactor design.
- Modular construction will also shift some costs to the factory, but financing and building the factory itself will require multiple orders.
- There should be no discrimination against nuclear energy in terms of public policy. Nuclear power's contribution to grid stability should be factored in the pricing mechanism. Similarly, pricing should factor in large investment needed to install additional capacity to provide balancing power for renewables, which are intermittent.
- NPPs also have substantially higher average operating capacity factor.

The report addresses the challenges posed by cheap shale gas and a slowdown in demand in the US. This has been reinforced by fears generated by the Fukushima incident. In Europe, Germany has tapped piped gas from Russia. The challenge in India is cost. Nuclear energy has to compete with coal, which would remain the primary source of base load power. We also cannot accept targets for zero emission or deep decarbonisation in the foreseeable future. India has to catch up for lost centuries of development as the window is closing fast.

1.6 Risk mitigation strategies

Nuclear power plants involve heavy capital expenditure, which makes investment decisions difficult. **Providing incentives for long-term and high capital investment in deregulated markets driven by short-term price signals, presents a challenge in securing a diversified and reliable electricity supply system[23].**

Heavy capital expenditure, high tariff in the initial years and risk perception make it difficult to attract funding from the market for expansion of nuclear power programmes. This has led to many governments adopting risk mitigation strategies. These include

arrangements backed by the host government to buy some or all of the power produced by a plant at a guaranteed fixed price or the host government providing direct sovereign guarantees to lenders. Such arrangements have been central to developing projects such as Akkuyu (Turkey), Hinkley Point C (United Kingdom), and Olkiluoto and Hanhikivi (Finland)[24].

Successful risk mitigation has led to nuclear steam supply system vendors agreeing to take an equity stake in projects. In case of the Barakah project in the UAE, the Korea Electric Power Corporation has taken an 18 percent equity stake, while 'Rosatom' took a 34 percent share in the Hanhikivi Project in Finland[25].

As an OECD study points out, capital-intensive, low-carbon technologies require long-term price stability. Politicians have been willing to accord such stability in the form of guaranteed feed-in tariffs (FITs) to renewables, in particular wind and solar photovoltaic. With two-thirds or more of total lifetime costs spent before the day of commissioning a nuclear power plant (NPP), investors have very little financial flexibility to react to changes in the price environment.

Chapter 2: Indian Scenario – Challenges and Opportunities

The aspirations for a high quality of life comparable to developed countries driven by social mobility and increasing energy needs of the country while the threat of global climate change looms large are the key drivers of the future energy scenario in our country. India will have to expand her power generation capabilities tremendously. Among all available energy sources, the use of solar and nuclear power has to grow even faster since coal alone cannot sustain energy requirements, quite apart from emission concerns. Hydrocarbon prices, on the other hand, are becoming increasingly unstable. Therefore, nuclear power is inevitable as the only available non-fossil and base load source of power. In the long run, nuclear energy along with solar may even be required to support energy usage. This would need energy to be delivered through fluid energy carriers.

India's current grid connected power generation capacity is about 350 GWe. Electricity generation has witnessed CAGR of about six percent over the last decade. Though, the share of coal-based power generation is about 75 percent, India is committed to make more use of renewable and non-fossil energy sources to cut down emission levels. For clean energy generation, besides solar and wind, nuclear power will play an increasingly important role in the current scenario. The present share of about two percent of total installed capacity from nuclear power plants is intended to increase to 10 percent by around 2032.

Nuclear power must be used as a supplement and not as a replacement for coal, when it comes to finding a source of stable, base load power. According to the NITI Ayog Draft National Energy Policy, the share of coal in India's commercial primary energy supply was 55 percent in 2015-16 and is expected to remain high at 48-54 percent in 2040. **Coal's share in India's power generation is 75 percent.** Imports contributed **25 percent** of the supply in 2015-16 and could remain high unless domestic production grows rapidly. The installed coal-based generation capacity is expected to grow to 330- 441 GW by 2040. This is likely to translate into a coal demand of 1.1-1.4 billion tonnes. The known levels of proven coal reserves (138 billion tonnes as of 31.03.2016) may only be able to support an **annual peak production** of 1.2-1.3 billion tonnes **till 2037**, with a **gradual decrease** thereafter[26]. This opens up space for nuclear power to supplement, *not supplant,* coal as a base load source.

India has indicated its intention to ramp up nuclear power capacity 10-fold by 2030 to 63 GW. Currently, the country has an installed nuclear power capacity of 6,780 MW (2016-17), which contributes about three percent of the total electricity generated. Construction of an additional nine reactors is in progress, which will ramp up nuclear capacity to 13,480 MWe of power. In addition, the government has approved an additional 10 PHWR reactors of 700 MWe each, which will give a boost

to the domestic nuclear industry. Two more reactors of 1,000 MWe each have also been approved for construction at Kudankulam, thus taking the total capacity to 22.48 GW by 2031[27].

The financing of nuclear projects is challenging given the highly capital-intensive nature of such projects, their resulting sensitivity to interest rates and construction durations and the nature of uncertainties. The government recently sanctioned fleet mode construction of 10-700 MW PHWR reactors and has announced a provision of Rs. 3,000 crores per annum for the nuclear power sector. This may not be enough for realising 63 GW nuclear power capacity by the year 2032 even after taking into account NPCIL's reserves and a reasonable 70:30 debt: equity ratio. The resource gap will increase, taking into account imported LWRs, which are much costlier. Imported LWRs would broadly need to account for at least half of the 63 GW target by 2032.

Raising money from the market is difficult at a time, when the power sector has large non-performing assets (NPAs) estimated at around 17-18 percent. The cost of money for NPCIL is higher as compared to for example NTPC. NPCIL is listed on the debt market. However, it cannot raise equity, which is a cheaper source of finance. Unlike NTPC, it cannot raise equity from the international market or through FDI route. However, a joint venture with NTPC, IOC or other PSUs could help raise money from the market on easier terms. NPCIL already has MoUs with different PSUs. These haven't been operationalised for want of changes needed in the Atomic Energy Act. The necessary amendments have since been done. The MoUs, however, need to be renegotiated in view of the changed circumstances.

The government does not favour privatisation of the nuclear sector; nor does the Atomic Energy Act allow it. However, the private sector can partner with NPCIL as a minority partner. They can also undertake balance of plant work, while the nuclear island is executed by NPCIL.

While there are challenges, there are also opportunities. There is a slowdown in the construction of nuclear power plants in Western countries, which has affected French and American companies like Areva and Westinghouse. However, the demand in developing countries is continuing. Russia, Korea and China have quickly moved into this market segment. The Russian manufacturing capacity is very high with a well-established supply chain. If India were to become a lead nuclear power country, manufacturing should be made an important element of its national activity. One of the motivations could be to occupy the space vacated by Western nations and take timely action on nuclear manufacturing.

India becoming a nuclear manufacturing hub would also give expression to the government's Make in India policy. For PHWRs, we already have near 100 percent domestic manufacturing capability. We need to promote domestic manufacturing for imported reactor systems as well. This will also bring in economy for the concerned nuclear power projects as domestic manufacture is expected to be cheaper than manufacture in advanced countries. Further, India taking the role of an important nuclear manufacturing hub for the international market would strengthen India's standing as a nuclear supplier and secure

the domestic nuclear programme from the vulnerabilities of international politics.

India may also have an advantage in niche areas. It is clear that nuclear energy would be critical to economic growth in a significant segment of emerging economies. While this trend is already visible, as countries like Bangladesh, UAE, Saudi Arabia and Turkey have started embracing nuclear power; proliferation, safety and used fuel management do remain barriers to the rapid and large-scale growth of the nuclear energy worldwide. India is a pioneer in the utilisation of thorium technology. India's domestic programme on thorium is designed for the specific Indian context characterised by modest uranium resources and vast thorium resources, and hence, large-scale thorium utilisation is envisaged in the third stage of the three stage Indian Nuclear Power Programme. Globally however, the scenario is quite different. There is no scarcity of uranium. Use of thorium along with low enriched uranium in the current generation of nuclear reactors can in fact significantly soften existing barriers to growth of nuclear power. Doing so in PHWRs is, in fact, most attractive. This creates a major opportunity for India to make a major impact through addressing the global challenge of development and climate change through the delivery of non-fossil base load energy. We have time tested strength in PHWR technology and in related fuel manufacturing technology, and have vast resources of thorium. India should proactively move forward to emerge as a major nuclear supplier of PHWRs fueled with a mix of thorium and imported low enriched uranium fuel. It is an area of vast opportunity.

The projects already approved would take the country's nuclear power capacity to 22,480 MWe. This would leave around 40,000 MWe of new capacity to be added to reach the 63,000 MWe target. This would need to be done through imported reactors and indigenous reactors supplementing each other for rapid capacity addition. For this purpose, DAE has identified sites and negotiations are in progress. Imported reactors have higher cost, but will help us ramp up capacity faster. It will also help NPCIL move into operation of LWR, which constitute the bulk of the international market. Without this, integration of Indian companies in the international supply chain and making a breakthrough in the export segment is not possible. Also, India will have to depend upon external suppliers for spare parts for continued operation in the absence of localisation of foreign nuclear technologies.

The import of LWRs with higher cost raises two critical issues. First, the import should not stub the growth of indigenous design and production capacities. With sufficient demand it should be possible to absorb both the indigenous and imported stream. The target of 63 GW offers space for both. Second, higher capital expenditure also results in higher tariff, which has to be absorbed in Indian market conditions.

We need to maintain the PHWR stream, where we have an established product. We also need to move towards the manufacture of the Indian Light Water Reactor. DAE has designed a 900 MW Indian Pressurised Water Reactor. It will be desirable to quickly complete the design, take up its construction and demonstrate its operation. This will also put pressure on foreign vendors to offer better terms for imported reactors. Also, beyond

imported reactor systems that are already planned to be set up through government-to-government negotiations, it may now be time to set up additional units through a competitive bidding process.

2.1 Tariff

The issue of tariff is sensitive, both in the context of the indigenously produced PHWR and imported LWRs, at a time, when power tariffs from alternate sources are falling. High capital expenditure results in high tariff for nuclear power in the initial years, though over the long run, it falls below coal and even renewables. Levelised tariff evens out this graph and makes nuclear tariff more attractive to investors.

On a levelised (i.e. lifetime) basis, nuclear power is an economic source of electricity generation, combining the advantages of security, reliability and very low greenhouse gas emissions. The operating cost of these plants is lower than almost all fossil fuel competitors. The main economic risks to existing plants lie in the impacts of subsidised intermittent renewable and low-cost gas-fired generation[28].

Nuclear tariff is set by DAE under the Atomic Energy Act. However, it has to compete in the market place along with other sources of power. It is not possible for nuclear tariff to fit in with merit-based despatch, which requires the lowest tariff power source to be dispatched first. Unlike coal, nuclear power cannot be backed down. Nuclear power plants, therefore, need to be given 'must run' status. The government has to ensure, through policy, a long-term power purchase agreement with bulk buyers. Going forward, it would be worthwhile to explore co-located facilities that can absorb surplus power, thereby enhancing commercial performance even under conditions of temporarily reduced demand.

De-commissioning costs and nuclear waste

Decommissioning costs are internalised in nuclear power tariffs. The capital cost of setting up waste management facilities at the site is a part of the plant capital cost and their operation a part of O&M costs, both of which are internalised in the tariff.

2.2 Level playing field

Given that nuclear energy is a key source for non-fossil base load power and is crucial to containing the cost of deep decarbonisation, the government has to also provide a level playing field to the nuclear sector. The renewables were allowed guaranteed feed-in tariff in the initial period. Though this has been discontinued, they still have incentives like Accelerated Depreciation and Renewables Purchase Agreement. There should also be zero emission credit on the pattern of the US. In the case of renewables, there are systems cost or grid costs which are not reflected in the tariff for wind or solar energy. Renewable energy sources are also exempted from inter-state transmission charges and transmission losses for a period of 25 years from the date of the signing of the Power Purchase Agreement (PPA). These costs are also loaded onto conventional sources of power. Despite being a low emission source of energy, no comparable incentive is provided to nuclear power.

On the other hand, coal-based power plants produce CO_2 and NO_2, which has external costs. In developed countries, carbon price is loaded onto thermal tariff. Conversely, zero emission credit is given to nuclear power plants in some of the states in the US. Coal cess is included in the tariff structure for electricity in India. **However, no emission credit is given to nuclear power in India.**

With two-thirds or more of total lifetime costs spent before the day of commissioning of a nuclear power plant (NPP), investors have very little financial flexibility to react to changes in the price environment. The key point is that capital-intensive and low-carbon technologies require long-term price stability. Politicians have been willing to accord such stability in the form of guaranteed feed-in tariffs (FITs) to renewables, in particular, wind and solar photovoltaic. The same logic is behind the UK Energy Market Reform and its cornerstone, the provision of contracts for difference (CFDs) to low-carbon technologies. These FITs and CFDs should be made available to all low-carbon technologies so that they can compete on cost[29]. According to a NITI Ayog report, the coal cess of Rs. 400 per tonne, the renewable purchase obligation and electricity duty on power generation levied by states, amount to a carbon tax of USD 9.71 per tonne of carbon dioxide emission[30].

Nuclear power requires policy intervention by the government; it cannot be left to market pricing. Its two chief attributes are low emission and grid stability. Both are public goods for which no mechanism exists to ensure due compensation to the nuclear power producer. Left to itself, the market will opt for low capital, quick return solutions. Nuclear power, which requires high capital expenditure and long gestation, will not attract investment unless incentives are given. Coal cess may affect the choice between the two sources of stable base load power – coal and nuclear. It does not provide a level playing field to the nuclear sector vis-a-vis renewables.

Investors in nuclear innovation must see the possibility of earning a profit based on selling their products at full value, which should include factors such as the value of reducing CO_2 emissions that are external to the market. Policies that foreclose a role for nuclear energy discourage investment in nuclear technology.

Source: MIT report on The Future of Nuclear Energy in a Carbon-Constrained World.

Government intervention to influence the choice of electricity form has indeed been made in the case of renewables. This is needed for the nuclear sector as well. Market signals to influence choice of form of electricity is difficult. The international market in carbon trading no longer exists with the lapse of the Kyoto Protocol. India's domestic system of carbon pricing is still in a nascent stage.

2.3 Carbon pricing

The concept of carbon pricing is debated in India and is still in its nascent stage. It has three components:

1) Renewable Purchase Obligation (RPO): Applicable to DISCOMs and captive plants, ROP mechanism mandates that a certain percentage of energy mix for the industry comes from renewable sources such as

wind and solar. (With the price of solar power coming at par with that of coal power, the effectivity of this instrument is reduced).

2) Coal Cess: A cess of Rs. 400 per MT is levied on coal.

3) Perform Achieve and Trade (PAT): PAT is a market-based mechanism to incentivise energy efficiency in the large energy-intensive industries. These industries are given targets for carbon emissions and those who under-achieve their targets can comply by purchasing Energy Saving Certificates (ESCerts) from electricity exchange or by paying a penalty.

A report titled *Need for an aluminium policy in India* by NITI Ayog member V.K Saraswat and economist Aniruddha Ghosh says that apart from higher power cost, additional burden in the form of power distribution firms' obligation to purchase renewable power and coal cess of 400 a tonne, the carbon trading system and electricity duty on power generation (levied by states) have increased the second-most used metal's overall production cost. These, the report said, together amount to a carbon tax of $ 9.71 a tonne of carbon dioxide emission. The report adds that 'From a developing country perspective with low per capita consumption of electricity, this carbon tax seems to be excessive'[31].

This echoes former Chief Economic Advisor Arvind Subramanian's warning last August that India cannot allow the narrative of 'Carbon Imperialism' to come in the way of realistic and rational planning for the country's energy future[32].

While this view may have some merit, it is difficult to describe this as carbon tax. There is no comparable cess on sources of emission other than coal. Coal cess is to be utilised to make up for the shortfall in GST realisation by the states. There is also no escaping the reality of pollution in Indian cities, or the phenomenon of global warming.

2.4 Energy import bill

Fuel cost for a nuclear power plant is small. Thus, nuclear energy entails lower import bill as compared to coal. Despite India's considerable reserves, the import of thermal coal – mostly used for power generation – rose to 161.27 million tonnes for FY 2017-18, from 149.31 million tonnes the previous financial year. In value terms, India's coal imports rose by 38.2 percent to 1,384.77 billion rupees ($20.17 billion)[33].

Apart from coal for the thermal sector, imported RLNG is also used for the power sector, though the scale has come down after withdrawal of subsidy in 2016. This currently amounts to Rs 47.45 to 54.75 billion per annum.

Fueling costs in case of nuclear power is much lower than in case of thermal power. Even if one were to compare the relative import bill, if both nuclear as well as coal fired power plants were to run on imported fuel, the cost of importing uranium would be lower as compared to coal by an order of magnitude.

Comparison of fuel cost of nuclear and coal-based power plant running on imported fuel

1,000 MW Nuclear Power Plant (Light Water Reactor)	Rs 243.25 crore per annum
1,000 MW Coal Based Power Plant (sub-critical and super critical plants)	Rs. 1538 crore per annum

Note: A 1,000 MW LWR would need about 25 tonnes of such fuel per year. Based on World Nuclear Association data, the price of one kilogram of fabricated fuel of burn up 45000 MWd/t is USD 1390 per kilogram. Considering this, the fuel cost for a nuclear power plant would work out to 34.75 million USD or say Rs. 243.25 crore per year (at 1 USD = Rs. 70) [34]

The price of Indonesian coal (5,900 kCal /kg) in September 2018 was 73.22 USD/ tonne.[35] *As per the norms of the CEA, a large size sub-critical or super critical plant consumes about 3,000 tonnes/ MW per annum. Thus the annual import of such coal for a 1,000 MW capacity would work out to Rs 1,538 crore (at 1 USD = Rs. 70)* [36]

2.5 Credit vs. indigenisation

The high cost of imported reactors can be offset against soft credit terms. The credit, however, is tied to procurement from the country concerned. This in turn limits the Indian scope of work. The government has to optimise between soft credit and indigenisation if Indian companies are expected to absorb LWR technology. More importantly, local manufacture would also bring down costs and tariff and can be in line with the Make in India programme.

The UK and the UAE have managed to attract equity from foreign EPC companies and equipment suppliers. This model ensures that the vendor has a stake in the success of the project. However, India's existing Atomic Energy Act does not allow private operators, let alone foreign companies to own or run nuclear power plants.

2.6 Fleet mode construction

The government has recently approved the construction of 10x700 MW PHWRs in fleet mode. This should bring down costs, provided projects are completed in time. Delay in implementation of some of the indigenous reactors as well as KNPP has led to cost over-runs. Apart from augmenting NPCIL's capacity, this also requires the strengthening of the vendor base. There should be a competitive manufacturing base for effective utilisation of the industrial capacity. Is present capacity adequate for manufacturing critical items?

The industry needs continuous orders to bring down costs. There has been a long gap of around eight years, when no major orders were placed, resulting in diversions of capacity and manpower from nuclear to other work.

2.7 Foreign acquisition

Prime Minister Modi in a recent speech emphasised that Central Public Sector Enterprises (CPSE) should increase their geo-strategic reach. At a time, when major international companies like Areva or Westinghouse are facing bankruptcies, there could be opportunities for overseas acquisitions, at least taking part share. There have been missed opportunities in the past. BHEL was outbid by Doosan for the acquisition of Skoda Power, which had produced turbines for 1,000 MW VVER design nuclear power plants in the Czech Republic.

2.8 Acquisition of uranium assets overseas

In the past, the Indian nuclear power programme has suffered due to a shortage of uranium. In recent years, India's uranium endowments have gone up several times to around 300,000 tonnes of U3 O8 owing to intense efforts in technology infusion and uranium exploration. Besides, the country is now able to import uranium from the international market. Also, the discovery of new reserves in the North-East and Eastern regions can be expected to make a significant addition in the future. Regardless, India could also look at opportunities for acquiring uranium mining assets overseas. Counter-cyclical decisions are required for tying up uranium supply contracts.

This is the best time to firm up uranium purchase agreements, as uranium prices are down. The assured availability of uranium is essential not only for ramping up the domestic programme, but also for the ambitious export of PHWRs. We should sustain our uranium stockpile at an adequate enough level to assure flexibility and continuity in nuclear programme management, including the ability to override any potential disruption in uranium supply. Going forward, India could consider buying a share in uranium enrichment assets to support domestic and export needs.

2.9 Manpower

The steep 10-fold increase in nuclear power generation from the existing 6.7 GW to 63 GW by 2032, places a heavy demand on manpower. While some of this increase can take place in existing training, skilling, education and research programmes as a part of the natural growth strategy, special efforts would be necessary whenever new players come in. Quality assurance, safety and quality culture in new emerging organisations would need special attention. Manpower build up in quality assurance would be a major challenge and would call for the promotion of collective efforts. Trained cadre will take time to build up. This requires augmenting the capacity in NPCIL, as well as greater efforts by the vendor industry to support technical institutes, particularly for vocational training, to ensure that sufficient manpower is available to them.

The need for sufficient manpower cannot be over-emphasised. Without it, leave alone participating in export opportunities, it will be impossible to meet the demand for a fast ramp-up of existing capacity.

Chapter 3: Progress So Far

3.1 1st stage programme based on PHWRs and LWRs

India currently has 22 operating reactors in seven locations, with a combined capacity of 6.78 GWe.

Operating plants

Plant	BWR		PHWR		PWR	
	Qty	Installed Capacity MWe	Qty	Installed Capacity MWe	Qty	Installed Capacity MWe
Tarapur (TAPS)	2	320	2	1080		
Rajasthan (RAPS)			6	1180		
Madras (MAPS)			2	440		
Kaiga (KGS)			4	880		
Kudankulam (KKNPS)					2	2000
Narora (NAPS)			2	440		
Kakrapar (KAPS)			2	440		
	2	**320**	**18**	**4460**	**2**	**2000**
Total Plant Nos						**22**
Installed Capacity GWe						**6.78**

Presently, the following nuclear power projects are at various stages of construction

State	Location	Unit	Capacity(MW)
1.Gujarat	Kakrapar	KAPP-3&4	2 X 700
2.Rajasthan	Rawatbhata	RAPP-7&8	2 X 700
3.Tamil Nadu	Kudankulam	KKNPP– 3&4	2 X 1000
4.Tamil Nadu	Kalpakkam	PFBR	* 500

** being implemented by BHAVINI*

In addition, work has also commenced on GHAVP-1&2 (2X700 MW) at Gorakhpur, Haryana.

The government has also accorded administrative approval and financial sanction for the construction of twelve (12) nuclear power reactors – ten (10) indigenous 700 MW PHWRs to be set up in fleet mode and two (02) 1,000 MWe PWR units to be set up in cooperation with the Russian Federation to enhance nuclear power capacity in the country. The details of these projects are given below:

3.2 PHWRs to be set up in fleet mode

State	Location	Project	Capacity(MW)
1.Madhya Pradesh	Chutka	Chutka 1 & 2	2 X 700
2.Karnataka	Kaiga	Kaiga – 5 & 6	2 X 700
3.Rajasthan	MahiBanswara	MahiBanswara – 1 & 2	2 X 700
4.Haryana	Gorakhpur	GHAVP – 3 & 4	2 X 700
5.Rajasthan	MahiBanswara	MahiBanswara – 3 & 4	2 X 700

3.3 Light Water Reactor (LWR) to be set up in cooperation with Russian Federation

State	Location	Project	Capacity(MW)
1.Tamil Nadu	Kudankulam	KKNPP 5 & 6	2 X 1000

3.4 2nd & 3rd stage programme

Stage II – Fast breeder reactors

In the second stage of the nuclear power programme, fast breeder reactors (FBR) would be deployed. Fast reactors are designed to produce more fuel than they consume, hence termed breeders, in general. In the Indian context, 'higher breeding' is desired so that the rate at which the power capacity can grow would be higher.

The breeding capability is directly linked with the choice of the fuel type viz. ceramics (oxide/carbide/nitride) or metal form. Metal fuel type has high breeding capability compared to oxide form owing to its inherent physical characteristics. Among the ceramic options, oxide is the one which has been universally used and we have much experience with it and thus it is well established. Hence, India has consciously decided to use oxide fuel in the initial power reactors based on established technology, and then, switch over to the metal form, to provide higher breeding capacity.

India's interest in fast breeder reactors is primarily to ensure better utilisation of limited natural uranium resources available domestically as FBRs, which have the

potential to harness the energy of natural uranium by over 60 times through multiple recycles. Fast breeder reactors are also crucial for enlarging the inventory of plutonium so that a much larger irradiation capacity to produce U-233 at scale for use in the third stage programme can be built up. For this, at an appropriate stage, the FBRs would need to be loaded with Th232 as the blanket material which would be converted to U-233. With sufficient inventory and production capacity for U-233 having built up, one can then move onto the third stage. Thus, FBRs provide the essential link between the first and third stages of the power programme based on the indigenous nuclear material resources.

India started the fast reactor programme by constructing a 40MWt/13.5MWe Fast Breeder Test Reactor (FBTR) which has been in operation since 1985. The first power reactor, the 500 MWe Prototype Fast Breeder Reactor (PFBR), indigenously designed and built, is presently under advanced stage of commissioning at Kalpakkam. Towards closing the fuel cycle, a Fast Reactor Fuel Cycle Facility (FRFCF) is under construction at Kalpakkam.

Beyond PFBR, it is planned to construct six more fast breeder reactors of 600MWe each with a focus on improved economy and enhanced safety. Two of these six reactors are planned to be constructed at the site adjacent to the PFBR, whereas, another site will be identified to build four more reactors. The first of these six reactors is expected to go online in 2029, which will be followed by the deployment of subsequent reactors at regular intervals of two years. The FRFCF will be expanded to cater to reprocessing and fuel fabrication of the additional two reactors planned at Kalpakkam.

Stage III – Thorium based reactors

Thorium is important for India due to its unique position as a country with the largest thorium resources in the world. The third stage of the nuclear power programme would be based on Uranium 233-thorium systems. Commercial deployment of thorium-based reactors on a significant scale can begin only when a substantial fast breeder reactor capacity running on plutonium uranium fuel cycle is installed so as to not impede the growth potential of the nuclear power programme. U233-thorium based reactors do not provide breeding as effective as fast reactors and hence, large-scale thorium deployment is only expected after a few decades from now. It should, however, be recognised that accelerating capacities in the first two stages is crucial to India's ambition of leveraging her vast thorium resources to ensure energy security.

Chapter 4: International Cooperation, its Potential and Limitation

The NSG waiver and signing of bilateral nuclear cooperation agreements with key countries has partially relaxed the technology control regime which had circumscribed India's options since the nuclear tests. However, many of the regional or international treaties do have NPT-related clauses embedded in them and we would need to leverage our own present and future technology development to realise full potential from our international cooperation.

For example, while we have the reprocessing rights to recycle the spent fuel arising out of reactors set up under international cooperation and also there is some forward looking language in terms of transfer of enrichment and recycle technologies, we should in reality be ready to deploy our own reprocessing and recycle technologies to set up fast reactors based on fuel that is produced through recycle of spent fuel arising from reactors set up under international cooperation. While this would be consistent with our three-stage nuclear power development policy, we need to recognise that building the three stage programme around reactors set up under international cooperation would have to be done under IAEA safeguards. The Indian approach to further nuclear energy development should thus proceed on a twin track. While self-reliant development of India's three-stage nuclear power programme as has been visualised earlier would constitute the first track, rapid growth of share of nuclear power in India's electricity generation mix leveraging international cooperation should be pursued on a second parallel track which would also proceed along the three-stage nuclear power development philosophy. Recycle technology developed as a part of work under Track 1 would thus need to be taken to full maturity level to enable the closing of the fuel cycle in Track 2. We should similarly be able to leverage our domestic enrichment technology to connect imported natural uranium with the fueling needs of reactors operating under IAEA safeguards, or use imported low enriched uranium and fabricate thorium-based fuel for the export market initially (most countries pursue open fuel cycle wherein, spent fuel management is visualised as conditioning and disposal without reprocessing. In India, we pursue a closed fuel cycle policy where the entire long-life content of spent fuel would eventually be recycled and reused) and for the domestic market later, when we are ready with related back end fuel cycle technology. This later approach would in fact hasten large scale thorium utilisation in the country. The adoption of a synergistic approach between our international cooperation framework and domestic technology development can open new and significant opportunities for India. We need to proactively push the envelope on both fronts. Not doing so, could however, inhibit India's choices.

In the context of negotiations for the NSG waiver, the government has made commitments to buy reactors from American, French and Russian companies. The imported reactor stream is to provide a large part of the balance of around 40 GW capacity that is required to be added to reach the target of 63 GW by 2032. Thus, it provides an opportunity to close the capacity gap. Tie-up with foreign vendors could also help Indian companies to become a part of the international supply chain. The import of reactors will come with a commitment to supply fuel for the full plant life. Agreements have also been signed with companies from Mongolia, Namibia, Uzbekistan, Canada, Kazakhstan and Russia for the import of natural uranium for PHWRS.

A partnership with foreign vendors could help Indian companies move faster towards producing and exporting LWR/PWRs, which account for a bulk of the international market. South Korea and China have followed this trajectory. India needs to produce and operationalise a PWR of 900 MW capacity, which has been designed by DAE, to get into the export market and to minimise technology dependence.

As mentioned earlier, we should quickly mature our recycle technology and leverage it to exercise our re-processing rights with respect to the reactor stream running on imported fuel. This will also augment fuel for the second stage of the FBR programme, thus reducing the time to move onto the third stage.

However, international cooperation is subject to pitfalls and limitations. Imported LWRs are more expensive than indigenous PHWRs. The French and American reactors are expected to be more expensive than Russian LWRs. This will result in tariff beyond the target of Rs. 6.5/Kwhrs set by DAE for power generated in 2020-21. To ensure that high capital cost does not result in uncompetitive tariff, the cost of financing has to be low. Soft credit often comes with conditions for maximum procurement from the foreign vendor, limiting the scope for localisation. The government has to optimise its choices between cheap credit and higher local content. In the long run, progressive indigenisation is the more important goal. It will also help reduce capital cost and tariff. Going forward, we could also resort to competitive bidding process to reduce the capital cost of imported reactors.

Given the nature of nuclear power, supply of reactors and later spares and fuel, will be subject to regulatory approvals at the bilateral and international levels, which bring in an element of uncertainty. This can be minimised by the development of domestic capacity.

4.1 High temperature reactors

'Current nuclear power reactors produce usable energy in the form of heat at modest temperatures (approximately 300°C); this heat is then converted to electricity by the use of a steam turbine power cycle. In advanced nuclear reactors (so-called Generation-IV designs), the primary energy product is again heat but the heat is delivered at potentially much higher temperatures (500°C-800°C). These higher operating temperatures offer a potential opportunity for nuclear high temperature reactor (HTR) technology to provide useful process heat in industrial applications'.

- MIT Report on The Future of Nuclear Energy in a Carbon Constrained World

The application of **process heat** delivered by high temperature reactor (HTR) technology is being explored. This can significantly reduce emission by substituting fossil fuel in various industries. In India, this could have application in the transport sector, refineries, petrochemical industries, production of nitrogenous fertiliser, as well as desalination plants. This could be a solution to the problem of water scarcity in coastal towns like Chennai. The process heat from HTR could also be used for production of hydrogen to de-carbonise the economy. 'If hydrogen were to emerge as the preferred path for zero-carbon transportation, new methods for producing hydrogen would be needed, since the current method – which relies on steam methane reforming – generates carbon dioxide emissions'[37]. The MIT report concludes that 'our analysis of different pathways to zero-carbon transportation clearly indicates that thermo-chemical splitting of water results in the lowest overall energy requirement. This is due to the high efficiency of hydrogen fuel cell cars and the high efficiency of converting heat into hydrogen'.

Role of Hydrogen in de-carbonising economy

The goal of de-carbonising the economy requires not only reducing dependence on fossil fuel for electricity generation but also limiting their use in heavy transport, heating and industry, which accounted for 41% of the CO_2 emission in 2014. Hydrogen could fill this role, as its burning only produces water vapor.

To make hydrogen cleanly, most of it will have to come from electrolysis of water, which today accounts for only 5% of hydrogen production (the rest come from 'steam reforming' of fossil fuels). That will require vast quantities of low-cost, zero carbon electricity[38].

China launched its 2x250MWth HTGR-PM demo project in 2012 in Shandong Shidao Bay based on prototype HTR 10 reactor design. The main HTR being developed is of the 600 MWe version – the HTR-PM 600. In April 2015, the CNEC announced that its proposal for two commercial 600 MWe HTRs at Ruijin city in Jiangxi province had passed an initial feasibility review. CNEC and the provincial government are applying to the NDRC for approval. The demonstration HTR-PM is expected to be connected to the grid and start electricity generation this year.

Chapter 5: Nuclear Industry Eco System

For programme implementation in fleet mode, NPCIL has to streamline its procedures. It also requires action by vendors. Lack of vendor capacity has been a serious constraint in the past. Delay in the supply of steam generators by vendors has led to delays in the execution of the Kakrapar NPP and the Rajasthan NPP. For the fleet mode programme, NPCIL will need **40 steam generators**. There are also success stories. Out of nine reactors, six were completed on time. There is a need for transparent case studies to learn lessons and avoid a situation leading to cost and time overruns in the future.

5.1 Efficient supply chain management with no bottlenecks

While the lack of vendor capacity has at times been a serious constraint, the domestic nuclear manufacturing capability has also been experiencing stress due to under-utilisation of built-up capacity. This is due to the lack of continuity in demand, sourcing procedure and project execution process. The lack of continuity of business deters manufacturers from making long-term investments in infrastructure and human resources.

Discontinuity and unpredictability in the nuclear programme has been one of the major factors leading to inadequate enthusiasm on the part of industry. Industry has seen a cyclic start and stop during 1981, 1989, 2000 and 2008.

1. First phase of intense activity: tooling, learning, and proving capabilities.
2. 2000-2003: renewed exuberance, flurry of activities, many new suppliers entered to test the waters.
3. 2005: euphoric plans announced, investments made by companies.
4. 2011: post-Fukushima, cautious approach to Nuclear Programme.
5. 2012-present: Slowdown to accommodate post-Fukushima design changes..
6. 2017: hoping to come back.

Due to lack of continuity in the programme, vendor industries are facing financial stress, and finding it difficult to retain dedicated manpower and facilities for nuclear-related orders.

There is a need for flexibility in procedures. Some of the demands voiced by vendors are given below:

1. Continuity in orders.
2. Simplification of procurement procedures for high-tech nuclear reactor components.
3. Provision to increase in quantity of equipment on order based on a

reasonable price variation formula. Such a provision can drastically cut down the time needed for ordering, will ensure vendors/suppliers execute orders seriously in hope of getting increased numbers and hence assure faster execution cycles.

4. The above provision also encourages vendors to perform in hope for a repeat order.
5. Increase Price Variation (PV) ceiling: Current level of PV (20 percent) is not adequate and needs substantial increase. This should be based on Material and Labour Indices. (Proposed ceiling: Contract up to two years – 20 percent, 3 years – 30 percent, 4 years – 40 percent and 5 years – 50 percent).
6. Quick settlement of claims: The authority to accept changes – financial powers at the operational level for a quick settlement of extra works. The mechanism to record changes and decide cost and time implication.
7. Minimum Order Quantities (MOQs) for various exotic materials. Industries are confronted with issues pertaining to MOQs for various exotic materials. It would help to receive support in financing or holding such extra material at the project site which can be used for future programmes.
8. NPCIL to ensure that payment terms have positive cash flow and improved credit margins for the suppliers.
9. Period of IPBG (Integrity Pact Bank Guarantee) to be reduced to six months from five years. Also, common IPBG may be introduced instead of PBG for each tender.

MIT report on the Future of Nuclear Energy in a Carbon Constrained World recognises some of the advanced techniques used by NPCIL:

'In the new pressurized heavy water reactor design being deployed in India, pre-assembling the entire calendria/core package is believed to save 10-12 months in the overall construction schedule'[39].

5.2 Capacity expansion of vendor base

There is a need to expand vendor capacity, particularly in areas where existing manufacturing in India is limited.

1. Pressure Vessels, Heat Exchangers: In India, there are only a few companies which are experienced in executing work as per ASME Section III NB, NC and the equivalent Russian/French codes. For increased approvals for NPPs, this vendor base needs to be improved. NPCIL has started such efforts for equipment such as for steam generators. This effort may need to be enhanced.
2. Primary piping, insulation, instrumentation: This is a complex and long drawn job with expertise in welding, NDT etc. Only a few companies in India have done such jobs and vendor base needs to be improved.

3. Structures: Structures in Nuclear Island call for deep knowledge of ASME Codes and equivalent. Structures around Reactor Pressure Vessel, Steam Generator, Heat Exchangers, Control and Instrumentation stand need additional vendors.
4. Control and Instrumentation: For indigenisation we are possibly dependent more on ECIL but their capacity/capabilities are limited and more PSUs/Private sector companies have to contribute.
5. Civil Works: Only two companies: L&T and HCC are prominent in the domain of reactor island work. Further on Post-Tensioning/Pre-Tensioning system of Containment, there is only one French Company, Fressynet, that can introduce new technologies and save costs. There is a need for more such companies.

(The necessity of getting European qualification for Russian supplier STS, Moscow, needs to be reviewed as European certifying agencies are taking too long to issue such certificates despite completion of tests by Russian supplier STS).

1. Indian vendors could also assist in design and engineering support for site specific modifications, both for indigenous programmes and imported reactors.
2. Freeze method of splitting POs to enable distribution of work.
3. As mentioned earlier, apart from meeting domestic needs, industry must also be facilitated to enter the export market. This would allow for a better balancing of shop floor capacity and enhance the industry's competitiveness.

5.3 To improve quality of vendors

Apart from increasing vendor capacity, there is need for DAE/NPCIL to take some essential steps to improve the quality of work as required for systems and equipment using required codes and standards. Some suggestions are:

1. Nuclear Codes Standards cannot be procured by every vendor. These should be readily available in hard/soft copy from NPCIL for reference and some portions shared with suppliers on a need basis.
2. Training in technologies, codes/standards/QA/QS, sharing of previous experiences etc. This could be done under the aegis of a professional society like the Indian Nuclear Society.
3. Hand holding by NPCIL when a vendor has difficulties.
4. Qualifications of vendors to be technology and competence based and not specific machine/facility based.

5.4 Diversification in supply chain across the geopolitical spectrum

There is a need for geo-political balance in sources of technology, equipment and supply. This is actually reflected in commitments made at the time of negotiating the NSG exemption. We have made commitments to US, France and Russia. As of now, Westinghouse and EDF are in the process of undergoing or have actually undergone restructuring. Imports raise the

issue of harmonising domestic and imported reactors with different cost structures and diverse technologies. This is, however, not a major issue.

It will be instructive to study the Chinese model. China acquired nuclear reactor technologies from several countries without worrying about their diversity. They have imported reactors from EDF, Westinghouse and Rosatom. They also have PHWR reactors. They have now CP 1000 design. The over-riding consideration has been to obtain finance to ramp up production. They have successfully leveraged market size to attract both foreign investments and technology. The Chinese have also procured rights on design/manufacturing drawings and pursued an indigenous programme to make reactors on their own. The Chinese have developed and depended more on indigenous industries rather than on importing supplies from outside sources. This depends entirely upon the capacity of domestic manufacturers.

Multiplicity of types makes standardisation difficult, but China's preference appears to have been to get access to the latest technology and avoid over reliance on one country. Imports have not been seen as conflicting with domestic capacity but only as a means to close the technology gap.

The Chinese have managed to blend imports with expansion of domestic capacity and moved into exports in the early 90s. Chashma 1 was exported to Pakistan in 1993 and KANUPP II & III are under construction. They have also been able to absorb and efficiently leverage the knowledge of imported LWRs in developing Hualong 1 (HPR 1000), Gen III+ technology, independently and indigenously designed with the merger of designs from CGNPC and CNNC for export.

The Indian policy is not very different from the Chinese approach. DAE is negotiating nuclear reactor supply agreements with Russia, France, and the USA. Each of these countries is offering their own soft credit facility for these projects. Getting finances for nuclear reactor construction is a serious challenge for a country like India. India is moving ahead on imported reactor construction as soft credit is available. Credit should not restrict local procurement. It may be possible to enhance domestic content by leveraging low cost of manufacturing in India. Technology absorption is important. But the larger goal should be to make India a nuclear manufacturing hub. A systematic policy driven flexible approach should be in place.

There is a need to expand capacity. How many foreign vendors have come into the Indian market since the NSG exemption was given? What is the status of Alstom's joint venture with NPCIL and BHEL? What are the plans for expansion of nuclear divisions of major Indian vendors, including L&T, BHEL, Walchand, and Godrej? Foreign vendors have not felt encouraged to come to the Indian market even after the NSG exemption on nuclear trade. The joint venture between Alstom (now GE), BHEL and NPCIL has not taken off. Expansion of nuclear divisions of major Indian vendors, including L&T, BHEL, Walchandnagar and Godrej have been on hold. Clearly, more efforts are needed.

The government should encourage formation of industry-to-industry joint venture companies with prime suppliers of the country supplying reactors such as France,

Russia, US or Japan, so that investments and skill transfers will come from outside the country for localising equipment manufacture. Further, if a foreign supplier wants to produce equipment in the scope of a foreign reactor supplier with the help of a local supplier for Indian reactors, it should be allowed and encouraged so that Indian suppliers learn and gain the required experience and be ready to supply the same item as localised supply in due course.

5.5 Harmonising domestic and imported stream

1. There has to be a balance between the indigenous and imported programmes. The policy has to be guided by the following considerations: (i) Maintain autonomy of our strategic decision-making as well as the programmes. Strong domestic R&D component in the programme would be the key.
2. Protect and expand Indian industry to progressively become a global nuclear manufacturing hub, where necessary with JVs with foreign manufacturers.
3. Ensure an element of transparent competition with continuity of work for specialised high-tech activities.
4. Technology absorption. Indian industry has mastered PHWR technology, but has not built LWR. There would be additional technologies to be evolved going forward. Technology absorption by industry should thus be an ongoing activity.
5. Fill up gaps in industrial capacity that could lead to vulnerabilities.

Balancing the imported and indigenous streams is easier at a time, when the programme size is expanding. The current installed capacity is 6,780 MW. This has to be expanded to 63,000 MW by 2032. The steep expansion of the programme needs **imports** to supplement domestic supply. The target of 63 GW by 2032 provides scope for both imported as well as domestic stream.

Though we have obtained NSG exemption, export controls remain an issue. Along with focusing on regulatory approvals, we need to use market access as a leverage to chip away international restrictions.

In the projected expansion of 63,000 MW, the import content would need to be at least around 30,000 MW. This has **cost implications**, as imported reactors could be nearly double in capital cost as compared to indigenous reactors. While there is a need to reduce capital cost outlays through negotiations, localisation, competitive procurement etc., the higher capital cost has to be factored into the government's financial outlays.

The success of the localisation programme will help harmonise imported and indigenous stream and better integration of Indian companies in the international supply chain.

5.6 Making India a global manufacturing hub and integration in international supply chain

India should become an attractive manufacturing destination for foreign entities over and above their interest in selling reactors to India. India has a large production base, which can cater to this goal. The task of becoming a global manufacturing hub would be facilitated by a tie-up with established

foreign brands. Indian companies need to be integrated in the international supply chain.

The indigenous reactor programme by itself is not sufficient to meet the requirement of achieving the 63 GW nuclear power target by 2032. Augmenting manufacturing capability in the country is the way forward. To achieve the ambition of setting up PHWRs in fleet mode and also to be a competitor in the international market, investment in many units would be needed, overcoming the barrier of the public-private sector.

Heavy engineering facilities in the country need to be expanded to make equipment for LWRs. Indian PWR MWe designed by DAE needs to be pursued. This will serve as a platform for servicing LWRs installed through imports and in long-term could make India a potential supplier of an Indian LWR. A parallel example is CP-1000 from China.

The government should encourage international vendors to enter into supply chain arrangements. Firms like Westinghouse do not manufacture any equipment and components. They only provide design support and source components from any vendor qualified and willing to provide it in time. India is in the midst of negotiating an agreement with Westinghouse and must insist on maximising local production and integration of Indian companies in the international supply chain. Similarly, in the case of EDF, we should insist on maximum local manufacturing. This, however, requires Indian companies to be globally competitive in terms of technology and price.

Progressive localisation should over a period of time expand the Indian share of the programme. This would, however, need increased capital expenditure by major vendors, including BHEL, L&T, Walchand and Godrej. However, this is a difficult task as foreign governments are not willing to agree for rapid localisations, especially when they are giving soft loans. The case in point is the Russian contracts for Kudankulam 3, 4 5, 6, where, localisation is not happening as we would like it to happen. The localisation programme will need a great amount of support from NPCIL for the supply chain of raw material to meet the time schedule with respect to the overall project.

There is a need to draw a risk matrix for both internal and external suppliers. There is a high attrition amongst global players. NPCIL will need to keep a watch on their ownership patterns, and ensure supplies from alternate sources are available. This provides an opportunity for India to develop local suppliers and ensure there is no failure.

Export of components, material and equipment in the nuclear sector will help achieve better economies of scale. Exports would also strengthen India's case for inclusion in the NSG. There are formidable challenges however. We need to have a demonstrated capacity to build and operate NPPs. Indian industry must have an export surplus after meeting the demands of an expanded nuclear programme at home. India's core strength is PHWR. The global market is dominated by LWR, which India does not produce. PHWR, where India has a proven track record, is only a small segment of the international market. The challenge then is to create an export market for PHWRs, leveraging the advantages that thorium offers and Indian leadership in that respect, alongside becoming a global manufacturing hub for the more popular LWRs and eventually also becoming a PWR exporter.

Total no. of different types of reactors in the world	450
Pressurised Water Reactor (PWR) (Uses enriched uranium)	291
Boiling Water Reactors (Tarapur 1 & 2; uses enriched uranium)	78
Pressuried Heavy Water Reactor (PHWR)	49

Being a late entrant, it is difficult for India to break into the export market in a highly regulated industry. This is particularly difficult in developed country markets where demand is saturated and industry growth has slowed down. India thus needs to focus on developing country markets which are indeed expected to expand.

5.7 Export of PWR/LWR

Indian vendors must absorb LWR technology and get **integrated into the supply chain of major international players like Rosatom, Westinghouse and EDF** to be able to make a successful breakthrough into the export segment.

BARC has designed an Indian pressurised water reactor (IPWR) to be built with the participation of Indian industries. But acceptability in international markets needs demonstrated ability to build and operate such plants in the domestic market. So far, this has not been done. Chances of breaking into LWR segment is also linked to the supply of enriched uranium.

5.7.1 Export of PHWR

Indian PHWR may be cheaper than LWR. Small size may be better fit in the national grids of small countries. However, the success of an Indian bid may need a credit offer by the Government of India, as demand in this sector is largely in developing countries. India would face competition from China and South Korea, who have better range, experience and deeper pockets.

5.7.2 EPC

BHEL has successfully executed EPC contracts for gas-based power plants in the Middle East and Africa. BHEL has also successfully executed a number of EPC contracts in India as well. A host of Indian companies have executed EPC contracts in different fields. But this model can work only if the company has executed such projects in India. This would limit Indian companies to the export of PHWRs. Apart from civil work, installation and commissioning, Indian companies did not get orders to supply equipment for Kudankulam 1 & 2. For Kudankulam 3 & 4, equipment worth Rs. 3,500 crores is being sourced from Indian companies. However, the scope could be expanded to procure main equipment also. EPC is also risky considering the experience of EDF in Finland.

5.7.3 Sub-contract & consultancy

While supply of equipment or project execution on the EPC model may be difficult, there are two other possibilities, which could be explored:

- Sub-contract
- Consultancy

Sub-contract

This requires integration of the international supply chain. While we need to open the Indian market to foreign companies, the latter should be willing to make India a hub for production of components for export to third countries. *The government may have to impose export obligations, not simply as a condition for localisation.* The Indian sub-contract would also require export credit from Indian Government agencies/EXIM Bank.

Consultancy

We could also leverage cheaper manpower cost to tap the need for providing consultancy for operating NPPs. Indian companies have the experience of working on PHWR. NPCIL could take the lead in helping set up the consultancy. Consultancy for the much larger LWR segment would require experience in working to set up LWRs in India.

5.7.4 Balance of plant

Could Indian companies supply Balance of Plant equipment? BHEL has successfully executed EPC contracts overseas, where balance of plant equipment is exported from India.

5.7.5 Export arm

Could NPCIL consider setting up a separate export arm, along the lines of ANTRIX? Apart from exports, this could offer a range of services, including engineering, consultancy and project management. It could also undertake **operation** of new nuclear power plants in developing countries, which may not have trained manpower in the initial phase. The international exposure would help it absorb new technologies, which may be of use in India also.

The new company could be a separate profit center. While it will remain under NPCIL's control, it can be exposed to more international scrutiny. It can form JVs, and register in companies overseas requiring local partnership as a condition for participation in their market. Companies like EIL in the refinery and petrochemical sector. OVL in upstream oil production are other examples.

5.8 Foreign acquisition

The shrinking market at home may put pressure on western companies. Siemens sold off its nuclear division. AREVA had to be rescued by EDF. Given the strategic nature of the nuclear industry, Western governments would resist shifting the manufacturing base overseas. There could also be regulatory issues, as India is not a member of the NSG or a NPT signatory. **However, these governments would be open to the idea of Indian acquisition to save local jobs.** BHEL did participate in the bid for Skoda Power in 2009. Though the bid was unsuccessful, the fact that the Czech government allowed them to participate in the bid underscores the willingness of host governments to show flexibility.

Acquisition of Skoda Power would have given India an established brand name, design capacity, more than 400 patents and a track

record of supplying turbines to NPPs upto 1,000 MW (Tamelin I & II). We would also have got their export market overseas. It was a missed opportunity.

Foreign acquisitions are not simply a prestige issue, but help Indian companies to acquire technology and expand market share. This will also give concrete expression to PM Modi's call for Indian CPSEs to increase their geostrategic reach. It will also embed them in the international supply chain.

There is a view that India is struggling to cater to domestic demand and hence need not venture into the export segment. These two dimensions are complementary, not contradictory. The scale helps spread costs. The Chinese have attempted both simultaneously and have succeeded even though their nuclear power programme started much after the Indian programme. China exported the Chashma reactor to Pakistan in the early 90s. This has helped them build their export credentials without adversely affecting their domestic programme, which is much larger than the Indian programme now. It has also brought strategic gains for them. India too should show the same appetite as China to leverage existing capacities for its own strategic good. While doing so, it should build on its own resources.

In the past, NPCIL has held serious discussions with Vietnam, Cambodia and Bangladesh for setting up PHWRs there. The NPCIL follows an EPC model of construction and works with several private contractors who supply diverse components and sub-systems. Currently, NPCIL deals with about 2,000-odd supplier firms which are broadly divided into 10 work packages. A consortium approach is needed between NPCIL and Indian public and private sector vendors for successful bids in international markets. NPCIL should also be empowered to arrange soft loans for exporting reactors. In the case of the Roopor plant, which is under construction in Bangladesh by Rosatom, an agreement has been signed for supplying non-critical items. We should follow-up and expand on the opportunities available.

China has already exported nuclear power plants to Pakistan. Bangladesh is constructing VVERs with Russian help. Going forward, more countries in our neighborhood such as Sri Lanka, Vietnam and others could also embrace nuclear energy to meet their energy needs. The Indian presence in the global nuclear export market, particularly in our neighbourhood, is of importance as otherwise there is every possibility that the vacuum would be filled by other countries including China. Going beyond our neighbourhood, Asian and African countries are expected to be key emerging markets for nuclear power. Indian PHWRs should in principle be the best fit to their requirements. As mentioned earlier, India should proactively move forwards emerging as a major nuclear supplier of PHWRs fueled with a mix of thorium and imported low enriched uranium fuel. It is an area of vast opportunity for the country.

The Indian manufacturing industry is capable of exporting materials, equipment and components. In the export domain, the country should first begin by the export of components and then move onto exploring opportunities for exporting a reactor. These goals should be backed by a sound government policy. For long, India has been exporting heavy water to the outside market. Some of the other items which India can export, are listed:

List of items India can export

Opportunities for business growth, including exports and India emerging as a global hub.

Assessment of export opportunities and potential

- Nuclear reactors
- Heavy Water
- Zirconium alloys
- Cobalt
- Cesium
- Radioactive isotopes

Export as a means of sustaining viability of critical supply chain

- Forgings
- Enriched boron
- Speciality hardware
- Sodium

Modes of potential export business

Overcoming barriers

- Assured demand schedules and continuity of work
- Sustaining competition
- Transparency
- Balancing the supply chain infrastructure to ensure full loading.
- Trained human resource for construction, quality control
- Improvement in management system, values, passion.

Finance.

- Low cost finance
- Leveraging equity from other PSUs
- Tariffs and level playing field

Chapter 6: Building Greater Cost Competitiveness in Nuclear Power Human Resources & Employment

Among established players, there is a tendency to exhibit monopolistic behaviour. In this situation, the way forward for the buyer i.e., NPICL is to implement policies which not only sustain competition but also facilitate qualification and participation of new entrants, and ensure adequate work for all players.

There is a strong feeling in industry about adopting the repeat order culture. To manufacture components like reactor headers, end-shields, etc., there is an involvement of long-lead times. Building efficiency in ancillary industries is a major challenge due to the uneven order portfolio.

Fleet mode construction allows price discovery more easily and reduces the time taken in price negotiations. The government's decision to build as many as 10 nuclear power plants (NPPs) means the manufacturing process is spread over many years. This could help determine the reference price for major work packages, which NPCIL can use to force every bidder to fall in line with. This will safeguard the principle of competitive bidding.

Land cost is going to be a major factor for Greenfield projects. So, Brownfield nuclear projects must be explored. A higher land cost will neutralise all gains that might be derived from other cost reduction measures.

The industry should also be made responsible for containing the cost of equipment. In the past, NPCIL has been unable to contain losses. Thermal power-related capacity that has been lying idle for a long time must be utilised for the nuclear sector in some manner.

Ramping up the nuclear power programme from the existing 6.7 GW to 63 GW by 2032 requires huge effort to build up human resources in critical areas. This includes manpower required:

1. Within DAE and NPCIL;
2. By the vendor industry; and
3. Personnel needed for quality control and assurance work.

BARC, NPCIL and other units of DAE have been running entry level orientation and other training programmes to meet the in-house requirements of DAE and NPCIL for decades. The Homi Bhabha Nuclear Institute (HBNI) runs an excellent academic and research programme for nurturing research and its translation to technology development in advanced areas. This might have to be supplemented with courses run in IITs and other technical institutes.

The DAE has a provision for induction and orientation training of graduates from academic programmes in various disciplines run by several universities. There are a few institutions in the country providing specialised courses in nuclear engineering. The DAE also supports research in other

universities by providing extra mural funding, and giving access to facilities within DAE. NPCIL has set up Nuclear Training Centres (NTCs) for training officers, supervisors and technicians.

The nuclear power sector needs manpower for design, engineering, procurement, construction, operation, decommissioning and waste management. There is also a need for specialised manpower in regulation, quality assurance, specialised transportation and erection etc. The nuclear power programme also generates indirect employment via supply of products and services.

According to an NEA/OECD study, direct employment during site preparation and construction of a single 1,000 MW light water reactor unit is about 12.1 direct labour years per MW and indirect employment is of about 9.2 labour years per MW. The total thus is about 21.3 labour years per MW. Out of the total, 3.5 labour years are provided by graduate engineers. This amounts to engineers being 16 percent of the total. The requirement of diploma holders will be more than this and one may fix it as one diploma holder per MW for five years.

During operation, 30,000 labour years are needed, assuming the operating life to be 50 years for a 1,000 MW reactor. This translates to 600 directly employed O&M and administrative personnel. In US nuclear industry, of the total, 20 to 40 percent are graduates. In India, the nuclear industry employs more graduate engineers than the US, and one may take the higher of the US estimate, that is 40 percent graduates. The requirement of diploma holders may be placed at 40 percent and the rest 20 percent are higher secondary school pass-outs. Direct employment during an operation is thus 0.6 employees per MW. Indirect employment is roughly equal to direct employment.

The requirement of manpower for decommissioning is estimated to be 500 employees for a 10-year period and for waste management as 80 employees for a 40-year period. For the purpose of planning, one may assume manpower requirements the same as for operation for a 10-year period.

In summary, one may estimate the manpower requirement as follows:

For plant construction: 0.24 graduate engineers per MW for five years and 0.24 diploma holder per MW for five years.

For plant operation: 0.1 graduate engineers per MW and 0.1 diploma holders per MW for the life time of the plant for direct employment and 0.05 graduate engineers and 0.05 diploma holders for indirect employment.

For decommissioning and waste management: Manpower requirement for this activity can be taken as the same as for operation.

Some manpower estimates are available in the National Electricity Plan issued by the Central Electricity Authority in January 2018. A comparison indicates that estimates based on NESA/OECD studies are on the lower side. The report observes that while sufficient numbers of engineers, managers and diploma holders are available, there are gaps in the supply of personnel in certain technical skills that are imparted in Industrial Training Schools (ITIs). In terms of employment and human resource development, the major industry groups will have to take over local ITIs and train people for various activities. It was done in case of large hydropower projects. The

geographical proximity of ITIs to the project are a boon and ensures that workers are fit for trained jobs. ITIs in many places are being run on the PPP model.

6.1 Quality control and assurance (QA)

There is clearly a need for developing highly qualified professionals to ensure timely decisions on quality inspection and management. QA coverage support is a perineal issue in NPCIL jobs and often delays are due to holds during QA coverage. A provision should be made to provide three-shift coverage either through addition of manpower or by involving TPI (Third Party Inspection). QA team should be deployed fulltime at all major supplier locations. An important aspect of quality assurance is to pay attention to the qualification of manpower involved in work performance in various stages of nuclear power plant design, construction, commissioning, operation and decommissioning. A more integrated approach is necessary than pursued hitherto.

Chapter 7: Ensuring and Sustaining Neighbourhood Engagement to Overcome the NIMBY Syndrome

Neighbourhood engagement to ensure appreciation of net benefit as a result of a nuclear power plant project and visibility that the local population makes economic and social gains need to be well designed and implemented in an efficient manner. NPCIL has to undertake Corporate Social Responsibility (CSR) projects in the area around nuclear power plants in an objective manner. There will be initial dislocation in any major project. These need to be handled firmly, but fairly.

One way to address this matter particularly at the site where a large park of nuclear power plants is planned, is to take care of the needs of the local people through a Special Planning Authority (SPA). The SPA should take care of everything that a local government body does, including supply of electricity, water, sanitation etc. For large nuclear parks, this can be well within the CSR budget and should be able to overcome a significant part of Not in My Backyard (NIMBY) Syndrome. This of course requires several legal and statutory arrangements at the central and state government levels.

Risks of nuclear accident are often exaggerated. Even though the risks are low, there is always a disaster syndrome in minds of people. Thus, a sustained public outreach and a credible disaster management plan should always be in place to build confidence among the people even though risks are low.

Chapter 8: Finance

Much of the perceived pessimism about the future of nuclear power is rooted in the present scenario where there is not enough demand in the power sector. However, the demand-supply situation is bound to change if India's economic growth has to continue. This change can happen in a period much shorter than the life of nuclear power plants which exceeds 25 years. In the west, NPPs are now expected to have plant life of 60 years. NPCIL factors in a life of 40 year for new NPPs, though tariff for earlier plants was based on the 25 year life cycle. During the life-time of an NPP spanning more than three decades, the economic cycle and demand-supply situation would not remain static.

There is scope for increase in demand in the power sector as India has a very low level of power consumption compared to the international level. India's per capita power consumption is 805 kWh (2014), against the world average of 3128 kWh. For the US, the per capita consumption is 12,986, while this figure for China stands at 3927 kWh[40].

Demand for electricity will also increase as grid connectivity improves and all households are electrified. The government announced in May 2018 that the last village in the country has been connected to the grid. The power minister also stated that by the year end all households in each village will have electricity. There are 36 million households yet to be electrified. With increased connectivity, power consumption will also go up. According to an official estimate, an additional capacity of 28,000 MW will be enough to take care of this demand.

Demand for electricity will pick up as electric vehicles start replacing petrol or diesel vehicles. The government's decision to increase the share of the manufacturing sector in GDP will also give a fillip to use of electricity.

Demand for power is price sensitive. Most gas-based power plants are stranded due to either high cost of imported LNG or other priority demands for gas. Nuclear power which is rather immune to price volatility or fuel supply disruptions, would also help lower the import bill.

Nuclear energy is also clean energy. As environmental pressures grow, the demand for nuclear energy and renewables will go up. There is a move towards electric vehicles, which will increase power consumption.

However, ramping up nuclear power requires considerable resources. The government has announced a Rs. 3,000 crores per annum support to build 10 nuclear power plants. However, the dividend norms have been revised upwards, which will largely neutralise the financial support committed. In any case, the provision of government equity of 3,000 crores for 12-14 years falls far short of resource requirement, especially if we include imported Light Water Reactors.

The market mechanisms for raising resources are unlikely to work at a time when the power sector is stressed because of the large number of NPAs. About 50 GW of power plants in private sector with total CAPEX of 2.5 lakh crores and 1.75 lakh of bank exposure may face bankruptcy under new RBI norms. 12,000 MW of power plants have no Power Purchase Agreements (PPAs) or coal linkages. 11,000 MW of power plants have coal linkages, but no long-term PPAs. Out of the 25,000 MW of gas-based power plants, 14,000 MW are stranded without gas. In this business climate, partial disinvestment of government shares in NPCIL or IPO will not raise resources.

While resource requirement has gone up, paradoxically, some of the earlier incentives are no longer available to the power sector with the introduction of GST. There is a need, therefore, to evolve some sort of compensatory mechanism.

Nuclear power, like renewables, provides clean power and should be given some of the incentives given to wind or solar power. This could include feed-in tariff, must run status and facility on the lines of Renewable Purchase Obligation (RPO).

There is also a need for examining financing models used by other countries. This includes measures to support high capital expenditure, as well as bringing down power tariff.

8.1 Resource requirement

Presently, NPPs are funded with a debt equity ratio of 70:30.

1. The equity part is funded through the budgetary support route and internally generated reserves.
2. The debt part is funded through bonds, commercial borrowing, both short- and long-term, from banks and external commercial borrowing on a small scale. Russia has extended soft and long-term credit to cover the Russian scope of supplies, including initial fuel and five reloads and services.
3. Capital expenditure (CWIP) of about Rs. 30,000 crores has been incurred on projects in hand VIZ KAPP 3-4 (2 UNIT of 700 MWe, 90% complete), RAPP 7-8 (2 UNITS of 700 MWe each, 80% completed) KKNPP 3-4 (2 UNITS 1,000 MWe each 10% expenditure) GHAVP 1-2 (2 UNITS of 700 MWe each just launched 5% fin prog) and KKNPP 5-6 (2 UNITS OF 1,000 MWe each pre-project works in hand).
4. Capital cost is about Rs.15 crores per MWe for indigenous reactors and Rs. 25 crores per MWe for Russian reactors at present exchange rate.
5. Total funds of **2,20,000 crores** will be required during next 8-10 years to complete ongoing projects (RAPP 7 & 8, KAPP 3 & 4, JHAVP 1 & 2 and KKNP 3 & 4), 10 x 700 MW recently sanctioned projects and KKNPP 5 & 6.
6. **Out of this total of Rs. 220,000 crores, Rs. 66,000 crores will be required as equity and Rs. 154,000 crores as debt.**
7. **The installed capacity of nuclear power, which presently is 6,780 MWe, will be 21,980 MWe on completion**

of above mentioned plants under construction and in pipeline by 2031.

8. Funds of around **Rs.700,000 crores will be required to add 40 GWe** (20 GWe each through foreign and indigenous route) to reach the 63 GW target set in integrated energy policy.
9. The nuclear industry has to be geared for setting up 65 to70 reactors in the next 14 years.

Total fund required for reaching 63 GW target

Rs. 2,20,000 + Rs. 7,00,000 crores = **Rs. 9,20,000 crores.**

Assuming a debt:equity ratio of 70:30, this would require **equity** of Rs. 2,76,000 crores to be provided over 14 years, or around **Rs. 20,000 crores** per annum. This is not too high a number to build capacity in a critical area. This is comparable to the budget of **Ministry of Tourism** of **Rs. 20,150 crores** for FY 2018-19.

Financial position of NPCIL

Total assets around .... Rs.73,222 crores

Net worth.... Rs.33,201 crores

Liabilities.... Rs.33,116 crores

(The above is based on extrapolated data from the annual report of 2016-2017).

It is clear from the above, that neither NPCIL's internal accruals, nor the level of government support announced so far are remotely sufficient to meet the financing requirements for achieving 63 GW of nuclear power by 2032. This requires a series of measures on the part of the government in terms of incentives, for NPCIL in terms of cost cutting and for vendors in terms of timely supply of equipment.

8.2 Disinvestment, IPO and external commercial borrowing

Given the large number of NPAs in the power sector, it will be difficult to raise resources for the expansion of the nuclear power programme through disinvestment or the IPO route.

External commercial borrowing comes with strings attached. In the long run, domestic borrowing will be much cheaper.

8.3 Tie-up with PSUs

Tie-ups with PSUs could help NPCIL to raise equity. Many of the leading oil and gas PSUs have substantial reserves. They face a twin threat from depleting hydrocarbon reserves and mounting environmental pressures. They could be approached, provided their expectations of return on investment are met.

NPCIL has already approached NTPC, IOCL, ONGC, Coal India and the Satluj Vidyut Nigam.

It is understood that Indian Oil Corporation Limited (IOCL) would like to review Light Water Reactor (LWR) projects. NTPC is not in a position to invest in LWRs, but is interested in financing indigenous Pressurised Heavy Water Reactor (PHWR) projects. It is difficult for the nuclear sector to meet the expectations of PSU shareholders in terms of immediate returns. Returns on investment in LWR projects in particular take a longer time,

and hence, there is less interest in investing in them. In any case, since we expect expansion in both domestic as well as imported reactor programmes, we should be flexible and go ahead with seeking PSU investment for projects they feel interested in.

8.4 Project implementation

To bring down tariff, NPCIL has to reduce project costs. This requires freezing engineering and technology as well as standardising projects to achieve lower tariff. This is especially relevant in view of the government's approval for implementation of 10 nuclear power plants in fleet mode. Interest cost typically forms 20 percent of the project cost. A delay of a year could mean an increase of more than Rs. 1,500 crores in terms of cost. NPCIL has executed projects in 60 months time. However, there have been delays in recent projects.

A smooth supply of capital is a prerequisite for timely completion of a project. TAPs 3 & 4 were delayed due to lack of funding. Fundflow assurances help long gestation projects to a large extent. The lack of adequate funds is delaying existing projects too. NPCIL does not have any surplus money to invest.

According to the CAG report, the project cost of Kudankuam (Units I & II) went up from Rs. 13,171 crores (December 2001) to Rs. 22,462 crores (August 2014), thus amounting to an increase of Rs. 9,291crores (70.54%). Moreover, the increase in IDC due to delays was to the extent of 336 percent (Rs. 2,533 crores) and a foreign exchange variation amounting to Rs.1,750 crores, further adding to the cost of the project[41].

A satisfactory dispute settlement mechanism would be helpful in containing delays during project execution.

8.5 Retaining internal accruals

The government has agreed to provide Rs. 3,000 crores annually as budgetary support for financing the next fleet of reactors.

Though the government has promised equity, the revised government norm for dividend payments to the extent of 20 percent of government equity, instead of 30 percent of PAT, has largely neutralised the provision of equity support of Rs. 3,000 crores per annum by the government. NPCIL should be allowed to retain internal accruals for financing new capacity addition.

NPCIL is a dividend paying company with the highest level of credit rating i.e., AAA rating by CRISIL and CARE. If resources have to be generated through NPCIL's earnings, its credit rating must be preserved. This will also help reduce the government's burden in infusing equity.

8.6 Tariff

The single part tariff policy ensures that NPCIL retains a proportion of tariff amount for both operations and future expansions. This tariff policy was upheld by the last tariff committee.

Though nuclear power has a high initial tariff, it declines gradually after the recovery of large initial investments. Also, it provides clean energy without Co_2 and NO_2-related emissions. There should be emission credit or a price signal in some other form to reflect the

advantage of nuclear power over other forms of energy. This is done in developed countries.

Today, nuclear plants are running for upto 60 years. The longer the operating lifecycle, the lower would be the depreciation cost. This will bring down nuclear tariff.

The electricity load centres in the country are unevenly distributed. The peak to the average gap continues to be high. And, when there is a peak demand, solar and wind power is usually unavailable. In the absence of adequate gas availability and hydro-generation being limited to serve demand in the peak period, only base load power plants can be relied upon if they have adequate flexi-operation features. So, clearly there is no choice but to have a major share of base load power plants, namely thermal and nuclear, in the future too. Among such sources, the cost of electricity from nuclear plants is usually cheaper compared to thermal plants which are located far away from the coal pit.

There was a differential tariff structure for renewables till recently. The feed-in tariff was considerably higher than tariff for thermal power plants. While this has been phased out, there are still subsidies in the form of costs of balancing power or systems cost, which are not reflected in the tariff for renewables.

Greater indigenisation will bring down costs and tariffs, apart from generating employment and building capacity. This requires increasing vendor capacity.

8.6.1 Levelised tariff vs. single part tariff

Tariff policies along with financing and operational policies constitute important tools to shape the transition in the energy mix from existing one determined by the market to the more optimum one desirable for realising long-term energy and environment security of the country. Tariff policies are thus important to promote the growth of nuclear power. This clearly has to be managed within the limits of what the market can bear. Further, there are special aspects like issues linked to technology control, ensuring domestic value addition in an embargo constrained global market, back end of the fuel cycle and decommissioning, that need nuclear tariff policies to be differently managed.

While the levelised tariff offers a good way for relative economic comparison of different sources of electricity production over their life time, it does not form the basis of the tariff structure for power plants. Nuclear power plants currently are required to run as base load plants without being subjected to too much load fluctuations. For nuclear power plants in India, tariff is based on single part tariff, which provides a certain cushion to NPCIL as long as the normative PLF is exceeded. The latter is understandably keen on its continuation. Satisfactory tariff structure is necessary to ensure that NPCIL maintains its excellent credit rating without which it will not be able to raise resources from the market.

8.7 Merit order despatch

Merit Order Despatch allows power from the cheapest source to be despatched first to the grid. This may be applied to energy sources producing variable load. This, however, cannot be applied to the nuclear power sector. Nuclear power, unlike thermal power, cannot follow the load. It is a source of base load power, which requires guaranteed

off-take and cannot be backed down easily. Nuclear power needs 'must run' status.

8.8 Clean energy benefits

Nuclear power is a source of stable base load power, and hence, can only be compared with coal. Wind and solar being intermittent sources of energy, cannot be compared with nuclear power. Coal presents the problem of pollution. Investments are needed in base load power sources. If coal is to be replaced, then investment in nuclear sector becomes inevitable.

Nuclear like renewables, has the advantage of lowering carbon emissions and clean energy benefits should be made available to it to make it more cost competitive. The government has guaranteed feed-in tariff for wind and solar. Though discontinued since for renewables, this benefit could be considered for the nuclear sector, at least for the initial years of plant operation, when the tariff is otherwise high due to high capital costs.

Clean Energy Fund based on coal cess was discontinued. Though a cess of Rs. 400 per tonne has been re-introduced, the fund is to be used for compensating states adversely affected by the GST.

Wind and solar continue to enjoy Renewable Purchase Obligation (RPO). The government has increased the RPO target for distribution companies (Discoms) from 17 percent in FY 19 to 21 percent by FY 22 in line with the goal of achieving 175 gigawatts. However, 'renewable energy generation as a percentage of total electricity production stood at 7.8 percent last fiscal, roughly half what the government planned to achieve'[42]. Even though there is a shortfall, existence of the official target provides support to the renewable sector.

The nuclear power sector should be given incentives provided to renewables to ensure a level playing field. Renewable purchase obligation may be converted into non-fossil energy purchase obligation.

8.9 Fiscal incentives to supply of goods for setting up of NPPs

Ironically, with the introduction of GST, some of the fiscal benefits earlier available to the nuclear power sector have been lost. Supply of goods for NPPs of 440 MW or above enjoyed the following facilities under the old regime:

1. Import of finished goods at 'NIL' customs duty (as per relevant customs notification). Though this exemption continues, 18 percent IGST (Integrated Goods and Services Tax) has become payable on the total value of imports.

2. Domestically manufactured goods supplied to nuclear power plants were given the status of 'deemed export' under the Foreign Trade Policy (2015-2020). This entailed a refund of excise duty and a facility to import raw materials and components for the indigenous manufacture at NIL customs duty. Though 'deemed export' is recognised under CGST/ SGST Act, 2017, to operationalise refund a fresh notification is required. This has still not been issued. This has resulted into GST being payable on all indigenous goods mostly at 18 percent, in some cases even at 28

percent and for imported goods at 18 percent.

3. GST is levied on the inter-state transfer of goods from one project/station to another project/station of NPCIL in a separate state. The above provision is a completely new one and has made the payment of GST obligatory on any transfer of goods between projects/stations of NPCIL or between NPCIL and any other unit of DAE. The situation has arisen because NPCIL cannot claim any input tax credit on such payment of GST since its output 'electricity' is an exempt supply under GST. The inter-unit transfer of plant equipment is a normal activity for optimising inventory and is particularly important if advantage of the 'Fleet Mode' setting up of 10 units is to be reaped.

Prior to GST, average indirect tax implication on indigenous goods was only at 2.25 percent (sales tax) and NIL tax on imported goods. According to NPCIL, the net impact of increase in taxes due to GST on imported and indigenous supplies to 2X700 MWe PHWR projects comes to around seven percent of the project completion cost. The impact of IGST on imported plant and equipment for LWR based NPPs would be even higher. According to NPCIL, the impact of GST on inter-state transfer of goods would be more than 10 percent above the overall project cost.

8.10 UAE model

While India has depended upon soft credit, the UAE has succeeded in attracting equity from the foreign vendor. This has been made possible by giving a foreign consortium contract for running the NPP for 20 years and the government providing feed-in tariff. This will be kept stable in nominal terms over the whole contract period. It is expected that with time and rising gas prices, nuclear will become more competitive than gas-fired power plants. The inference is that *initially nuclear tariff will be higher than the gas-fired power plant*, which supplies 98 percent of UAE's power requirement.

The total value of the contract for the construction, commissioning and initial fuel loads for the four units is USD 20.4 billion, with a high percentage of the contract being offered under a fixed-price arrangement. The consortium expects to earn another USD 20 billion by jointly operating the reactors for 60 years[43].

KEPCO and its affiliates will invest USD 1.04 billion in Barakah One Company, a special purpose company established to build and operate an NPP in Barakah, in exchange for an 18 percent equity interest[44].

The total joint venture might be worth about USD 30 billion with roughly one-third consisting of equity and two-thirds of debt. In this arrangement, **Abu Dhabi would provide most of the USD 10 billion of equity. USD 10 billion of debt would most likely come from a Korean export-credit agency. The remaining USD 10 billion would be a mix of bank financing and sovereign debt[45].** Abu Dhabi may thus consider a direct government debt issue or a debt issue by ENEC backed by the government. In September 2012, the US Export-Import Bank approved USD two billion in financing for the Barakah plant, for US-sourced components from Westinghouse (including coolant pumps and instrumentation

and control [I&C]) as well as for services from Westinghouse and two other firms.

The USD 20 billion cost of 4,200 megawatts of electric generating capacity works out to USD 3,571 per kilowatt, which is similar to the average of recent comparable US estimates for new nuclear plants[46].

Nuclear power, as an established low-carbon base load technology, will supply a substantial part of UAE's future energy needs. So far, contract for setting up NPP to supply 4,200 MW of electricity have been given to a consortium of Korean companies.

8.11 UK model

The UK government has guaranteed EDF, the French utility company, a minimum price for electricity from Hinkley Point C of British Pound 92.50/MWh. This is linked to inflation and almost double the current wholesale price. In case of Wylfa Newydd, the government will consider investing tax payer funds for construction of the site, but with the aim of reducing the strike price for electricity to about British Pounds 15/MWh cheaper than for Hinkley.

The British model is based on the principle of 'Contract for Difference'. Under this mechanism, the government would reimburse the difference in case the tariff from NPP goes below the 'strike price', while the operator has to reimburse to government the balance in case his price realisation is above this threshold.

The UK model is more tightly negotiated than the UAE model for which many of the details of tariff and cost still remain to be worked out. The common elements are:

1. Acceptance of cost above the level of alternate modes of energy with a long-term feed-in tariff guaranteed.
2. Operatorship by the foreign vendor. In both cases, these are private sector entities. This is not possible in the Indian case without amending the Atomic Energy Act[47].

8.12 Chinese model

The Chinese programme is based on Pressurised Water Reactor (PWR). Instead of standardisation, China went in for multiplicity of designs. They imported Russian, French, American (Westinghouse) and Canadian reactors. This provided geo-political balance in supply chain. At a later stage, this meant they could make export bids in different markets.

The programme aimed at increasing localisation, and building capacity. China bought four Westinghouse AP 1000 Gen III reactors with technology transfer and complete ownership of intellectual property rights in 2008. This became the basis of CAP 1400 and ACP 100.

After Fukushima, the Chinese actually accelerated their nuclear power programme. Before 2008, the government had planned to increase nuclear generating capacity to 40 GW by 2020. The target was revised upwards to 70-80 GWe by 2020, 200 GWe by 2030 and 400-500 GWe by 2050.

The Chinese government has accepted much higher tariff for nuclear power than coal-based power plants. In July 2013 the NDRC set a wholesale power price of CNY 0.43 per kWh (7 US cents/kWh) for all new nuclear power projects, to promote the healthy development of nuclear power and guide investment into the sector. The basic coal-fired cost is put at CNY 0.3/kWh.

Through progressive localisation, the Chinese have also brought down the cost of imported reactors. CNEA estimated in May 2013 that the construction cost for two AP1000 units at Sanmen would be CNY 40.1 billion ($6.12 billion), or 16,000 Yuan/kW installed ($2440/kW), instead of CNY 32.4 billion earlier estimated. This is about *19% higher* than the latest estimate for the CPR-1000 (CNY 13,400/kW, $2045/kW), *but likely to drop to about that level with series construction and greater localisation as envisaged* [48].

Chapter 9: Recommendations at a Glance

9.1 For NPCIL

1. NPCIL must reduce project completion costs to bring down tariff. This requires creation of an environment for competitive procurement and timely completion of projects to minimise interest cost during construction.
2. The focus of NPCIL should be on rapid capacity expansion through credit.
3. NPCIL must ensure continuity of orders for vendors.
4. The requirement of fleet mode construction needs flexible procurement procedures taking into account industry demands.
5. NPCIL must prevail on international vendors to source equipment from Indian vendors both for Indian projects, as well as their projects overseas.
6. Quality control and assurance should not impede pace of production. NPCIL should increase Quality Assurance (QA) manpower to provide 3 shifts coverage for all long delivery items and items on critical pathby addition of manpower.

9.2 For DAE

7. The Fast Breeder Reactor Programme (FBR) is India's best hope for energy self-sufficiency using locally available fuel. Early movement will be a major achievement.
8. DAE has designed an indigenous Pressurised Water Reactor (PWR). There is need to bring the design to production and operation in a committed time frame. Eventually we must export it but this will depend upon its successful operation at home.

9.3 For vendors

9. Indian vendors need to expand capacity to cater to the larger domestic programme and also benefit from localisation of the imported programme.
10. Indian companies must be competitive globally in terms of price and quality to get integrated in the international supply chain.

9.4 For NPCIL and vendors

11. NPCIL and vendors must augment their human resources to manage the domestic programmes and exports simultaneously. This requires expanding inhouse training facilities, industries supporting polytechnics and IITs/Technical institutes increasing intake of students in selected areas.
12. Indian companies should attempt the export of nuclear materials, equipment, and components. There is no conflict between exports and meeting Indian demands, provided we ramp up production. Scaling up

will help achieve economies of scale and even out lean periods when there is not enough demand in the domestic market. Exports could bring India strategic gains and strengthen her credentials for NSG membership.

13. Indian companies should tie-up with established foreign vendors to participate in sub-contracts for projects overseas. Their bid will have to be supported by credit from EXIM Bank which is the standard arrangement internationally.
14. Indian companies could also provide consultancy for design licensing, project management, and operation of the nuclear power plants in countries which do not have trained manpower available.
15. NPCIL could consider establishing a subsidiary for undertaking exports overseas.
16. The acquisition of foreign companies or at least taking minority shares in foreign nuclear equipment producers could help acquire technology and production capacity.
17. Diversification of uranium purchase. Acquisition of uranium assets overseas.

9.5 For government

18. The government must provide additional resources over and above the annual support pledged to NPCIL so far. Rs. 3,000 crore per annum would cover only a small fraction of funds required to reach the target of 63 GW by 2032.
19. NPCIL's profitability must be maintained so that it has enough internal resources to finance at least part of the expansion cost of the nuclear power programme. This is also required to preserve its credit rating so that it can raise funds from the market.
20. There is need to create additional players in the public sector to own and operate nuclear power plants.
21. The UK and UAE models have successfully attracted equity from foreign equipment vendors in return for giving them operatorship on long-term basis. This could be an innovative way to close the resource gap and better risk-sharing. This would require amendment of the Atomic Energy Act.
22. The government has to harmonise the need for soft credit and localisation/ transfer of technology by foreign vendors in case of imported reactors. Export credit may bring down tariff, but if it limits 'localisation', this may defeat the objective of 'Make in India'. Increasing localiation is necessary to bring down costs and reduce tariff.
23. Negotiations with foreign vendors should be concluded speedily as imported reactors are to contribute a substantial part of the 63 GW target. Going forward, one could also consider competitive bidding for additional foreign supplied power plants.
24. The government can consider setting up a fund by borrowing from the market and loan to NPCIL for future projects can be extended from this fund. The interest and loan repayment shall commence from the actual date

of commercial operation. This will protect NPCIL from any Debt Service Coverage Risks that may arise due to heavy borrowing that will be needed to fund these projects.

25. A large quantum of borrowings/ loans is required for expansion plans envisaged. Therefore a Finance Company inline with PFC/REC could be created by/under DAE for mobilisation of funds in the form of a long-term loan for the projects. The terms can be of seven years moratorium on cash payment of interest (during the construction phase) followed by an understanding on a repayment tenure of 25-30 years. This will help in avoiding front loading of tariff.

26. NPCIL should be allowed to retain tax free bonds with a sovereign guarantee from the Government of India and also extend the same to subsidiary companies executing internal accruals for 10 years to generate internal surplus for ploughing back into new projects as equity.

27. Investment in joint ventures can be done by the government directly so that NPCIL's internal surplus can be utilised for equity funding of its ongoing and new projects.

28. NPCIL needs to factor in plant life of 40 years instead of current 25 years to reduce tariff for nuclear power plants.

29. It is understood that NPCIL puts up Levelised Tariff as part of the Detailed Project Report to the government for financial sanction of the project. It will be useful to put the Levelised Tariff in public domain to bring out a better appreciation of cost competitiveness of nuclear power vis-à-vis other forms of electricity.

30. Merit Order Dispatch cannot be applied to the nuclear sector as heavy CAPEX requires stable prices and nuclear power cannot be backed down. Nuclear power must be given a 'must run' status.

31. The nuclear sector should be allowed a level playing field vis-a-vis renewables and provided support on the lines of Renewable Purchase Obligations. Renewable purchase obligation may be converted into non-fossil energy purchase obligation.

32. The nuclear power sector should be exempted from GST on inter-state transfer of goods for project execution. This facility may also be extended to equipment supplied by vendors.

33. The government must allow flexibility in procurement and contracting to NPCIL to facilitate fleet mode construction. This is a strategic sector. India is not a member of the NSG. Cutting edge technology cannot be obtained on the basis of the cheapest quotation. A special dispensation needs to be evolved for the nuclear sector that is linked to India's energy security.

India should proactively move forward to emerge as a major nuclear supplier of PHWRs fueled with a mix of thorium and imported low enriched uranium fuel.

Chapter 10: Conclusion

The 63 GW nuclear power target by 2032 was part of Integrated Energy Policy adopted in 2006. The timelines given in the document envisaged installation of 11 GW capacity by 2010 and 29 GW by 2020. Our current capacity of 6.7 GW, therefore, represents a significant slippage.

Is the goal of 63 GW too ambitious and needs to be revised downwards? This would represent 10.33 percent of installed capacity by 2032. This is a *modest* target in terms of India's energy needs and far below the actual or potential capacities of other countries. China aims at 160 GW providing 10 percent of electricity by 2030. The comparison with China is relevant as it has broadly the same energy profile as India, with coal providing a major part of China's energy needs (64.56%)[49].

Achieving this target would, however, need concerted efforts by all stakeholders. The government has to provide finance and a level playing field to the nuclear sector vis-a-vis coal and renewables. The provision of Rs.3,000 crores per annum falls far short of the Rs.20,000 equity needed per annum to achieve the target of 63 GW. However, this is not an unreasonable expectation, considering that 'the rise in bad loans and provisioning requirements forced the government to announce a Rs 2.11 lakh crore recapitalisation plan for state-owned banks'[50].

As a bulk of the resources is to be raised through debt, the credit standing of NPCIL has to be maintained. It is clear that financing of this order cannot be raised by NPCIL alone.

The government also has to ensure a remunerative tariff structure. While the present single part tariff may be retained, NPCIL should put in the public domain LCOE (Levelised Cost of Electricity) so that there is better awareness of the benefit of nuclear power. This will also help attract more investment for the sector.

The government will have to give a clear signal to other PSUs to form joint ventures with NPCIL. This has been done in the case of the fertiliser sector. If we are to try out the UK or UAE models where foreign vendors are allowed to invest in the plant and operate it for large periods, the government will have to consider an amendment of the Atomic Energy Act. This will also require giving an assurance on a remunerative tariff structure.

To attract investment at a time when the power sector is facing acute stress, requires NPCIL to exercise tight discipline in project execution. Cost over-runs and high IDC (Interest During Construction) has been commented upon in the CAG report. To avoid it in the future, efficient supply chain management with no bottlenecks is needed. Fleet mode execution will help, but NPCIL will have to evolve procedures to ensure a better eco-system.

The Indian vendor industry needs continuous orders. It also has to ramp up capacity and be globally competitive in price and quality. This is needed to prepare for the entry of foreign vendors in the Indian market. Imported reactors are needed to close the capacity gap. At the same time, the 900 MW Indian Pressurised Water Reactor (PWR) designed by DAE needs to be taken forward to the production and operation stage. The eventual target should be to export along the lines of the Chinese CAP 1000. However, it will not have market acceptability unless we demonstrate successful operation at home. India should also proactively move forward to emerge as an exporter of its very successful and cost competitive PHWR. Fueled with a mix of thorium and imported low enriched uranium fuel, these reactors offer proliferation resistance and improved safety and can make a significant contribution to climate protection.

Autarky is not the solution. Indian companies have to be prepared not only for Make in India for India but for the global market. This requires them to be fully integrated with the international supply chain. The Chinese model has shown that expansion of domestic capacity and exports can be attempted simultaneously.

The report has discussed a number of structural issues, including the creation of more joint ventures or subsidiaries of NPCIL. For Russian, American and French imported reactors, separate joint ventures may be needed.

Apart from finance, ramping up production will require a massive increase in trained manpower. This is a challenge and a boon in terms of employment generation.

The requirement for more energy is to be reinforced by the need for clean energy. India's present commitments under the Paris Convention are voluntary. As global warming worsens, there will be pressure to accept more stringent, mandatory requirements. While full potential of renewable sources including large hydro should be exploited, the potential is less than a quarter of India's projected requirement of 8,600 billion units per annum. Therefore the share of nuclear power as a source of stable, base load power in India's energy mix will have to go up.

End Notes

1. NITI Aayog (2017). *Draft National Energy Policy*. New Delhi: NITI Aayog, Government of India.
2. World-nuclear.org. (2018). *World Nuclear Association - World Nuclear Association*. [online] Available at: http://www.world-nuclear.org/ [Accessed 1 Aug. 2018]. Eia.gov. (2018). *U.S. Energy Information Administration (EIA)*. [online] Available at: https://www.eia.gov/ [Accessed 1 Aug. 2018].
3. World-nuclear-news.org. (2018). *World Nuclear News*. [online] Available at: http://www.world-nuclear-news.org/ [Accessed 2 Aug. 2018].
4. The Future of Nuclear Energy in a Carbon Constrained World. (2018). [online] Massachusetts Institute of Technology. Available at: http://energy.mit.edu/wp-content/uploads/2018/09/The-Future-of-Nuclear-Energy-in-a-Carbon-Constrained-World.pdf [Accessed 6 Sep. 2018].
5. Special Report on Global Warming of 1.5°C. (2018). [online] Intergovernmental Panel on Climate Change. Available at: http://www.ipcc.ch/report/sr15/ [Accessed 18 Oct. 2018].
6. The Future of Nuclear Energy in a Carbon Constrained World. (2018). [online] Massachusetts Institute of Technology. Available at: http://energy.mit.edu/wp-content/uploads/2018/09/The-Future-of-Nuclear-Energy-in-a-Carbon-Constrained-World.pdf [Accessed 6 Sep. 2018].
7. The Times of India. (2018). *Power tariff soars to a decade high of Rs 18/unit in spot market - Times of India*. [online] Available at: https://timesofindia.indiatimes.com/business/india-business/power-tariff-soars-to-a-decade-high-of-rs-18/unit-in-spot-market/articleshow/66045118.cms [Accessed 3 Oct. 2018].
8. Tricks, H. (2018). What would it take to decarbonise the global economy?. [online] The Economist. Available at: https://www.economist.com / technology-quarterly/2018/11/29/what-would-it-take-to-decarbonise-the-global-economy?fsrc=scn/fb/te/bl/ed/whatwouldittaketodecarbonisetheglobaleconomyconqueringcarbondioxide [Accessed 1 Dec. 2018].
9. World-nuclear.org. (2018). *Plans for New Nuclear Reactors Worldwide - World Nuclear Association*. [online] Available at: http://www.world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx [Accessed 23 Oct. 2018].
10. International Status and Prospects for Nuclear Power 2017. (2017). [online] International Atomic Energy Agency. Available at: http://International Status and Prospects for Nuclear Power 2017 [Accessed 1 Aug. 2018].
11. Pris.iaea.org. (2018). *PRIS - Home*. [online] Available at: https://pris.iaea.org/PRIS/home.aspx [Accessed 3 Dec. 2018].
12. International Status and Prospects for Nuclear Power 2017. (2017). [online] International Atomic Energy Agency. Available at: http://International Status and Prospects for Nuclear Power 2017 [Accessed 1 Aug. 2018].
13. World-nuclear-news.org. (2018). *Japanese Cabinet approves new basic energy plan - World Nuclear News*. [online] Available at: http://www.world-nuclear-news.org/NP-

Japanese-Cabinet-approves-new-basic-energy-plan-0307184.html [Accessed 1 Aug. 2018].

14. Pris.iaea.org. (2018). PRIS - Reactor status reports - Under Construction - By Country. [online] Available at: https://pris.iaea.org/PRIS/WorldStatistics/UnderConstructionReactorsByCountry.aspx [Accessed 3 Dec. 2018].
15. Ibid.
16. World-nuclear.org. (2018). *Economics of Nuclear Power*. [online] Available at: http://www.world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx [Accessed 2 Aug. 2018].
17. MIT, (2009). *Update of the MIT 2003 Future of Nuclear Power*. [online] Available at: https://web.mit.edu/nuclearpower/pdf/nuclearpower-update2009.pdf [Accessed 4 Aug. 2018].
18. World-nuclear.org. (2018). *Economics of Nuclear Power*. [online] Available at: http://www.world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx [Accessed 2 Aug. 2018].
19. Srikanth, D. (2018). India's Sustainable Development Goals - Glide Path for India's Power Sector. *Energy Policy*, 123, pp.325-336.
20. Special Report on Global Warming of 1.5°C. (2018). [online] Intergovernmental Panel on Climate Change. Available at: http://www.ipcc.ch/report/sr15/ [Accessed 18 Oct. 2018].
21. Ibid.
22. The Future of Nuclear Energy in a Carbon Constrained World. (2018). [online] Massachusetts Institute of Technology. Available at: http://energy.mit.edu/wp-content/uploads/2018/09/The-Future-of-Nuclear-Energy-in-a-Carbon-Constrained-World.pdf [Accessed 6 Sep. 2018].
23. World-nuclear.org. (2018). *Economics of Nuclear Power*. [online] Available at: http://www.world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx [Accessed 2 Aug. 2018].
24. International Status and Prospects for Nuclear Power 2017. (2017). [online] International Atomic Energy Agency. Available at: http://International Status and Prospects for Nuclear Power 2017 [Accessed 1 Aug. 2018].
25. Ibid.
26. NITI Aayog (2017). *Draft National Energy Policy*. New Delhi: NITI Aayog, Government of India.
27. Ibid.
28. World-nuclear.org. (2018). *Economics of Nuclear Power*. [online] Available at: http://www.world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx [Accessed 2 Aug. 2018].
29. Nuclear Energy System Assestment. (n.d.). International Atomic Energy Agency.
30. Prasad, G. (2018). *Need to ease carbon taxes to help energy-intensive industries compete globally: NITI Aayog*. [online] https://www.livemint.com/. Available at: https://www.livemint.com/Politics/h55jAWHSdzUq1djhcFN7eK/Need-to-ease-carbon-taxes-to-help-energyintensive-industri.html [Accessed 31 Jul. 2018].

31. Ibid.

32. Ibid.

33. NITI Aayog (2017). *Draft National Energy Policy*. New Delhi: NITI Aayog, Government of India.

34. World-nuclear.org. (2018). *Economics of Nuclear Power*. [online] Available at: http://www.world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx [Accessed 2 Aug. 2018].

35. Kannan, D. (2018). *Indonesia sets Oct HBA thermal coal price at $100.89/mt, down 3.7% on month | S&P Global Platts*. [online] Spglobal.com. Available at: https://www.spglobal.com/platts/en/market-insights/latest-news/coal/100818-indonesia-sets-oct-hba-thermal-coal-price-at-10089mt-down-37-on-month [Accessed 9 Oct. 2018].

36. Cea.nic.in. (2015). *Norms for Coal Consumption in TPP's*. [online] Available at: http://www.cea.nic.in/reports/others/thermal/tppd/coal_cons_norms.pdf [Accessed 9 Dec. 2018].

37. The Future of Nuclear Energy in a Carbon Constrained World. (2018). [online] Massachusetts Institute of Technology. Available at: http://energy.mit.edu/wp-content/uploads/2018/09/The-Future-of-Nuclear-Energy-in-a-Carbon-Constrained-World.pdf [Accessed 6 Sep. 2018].

38. Tricks, H. (2018). What would it take to decarbonise the global economy?. [online] The Economist. Available at: https://www.economist.com / technology-quarterly/2018/11/29/what-would-it-take-to-decarbonise-the-global-economy?fsrc=scn/fb/te/bl/ed/whatwouldittaketodecarbonisetheglobaleconomyconqueringcarbondioxide [Accessed 1 Dec. 2018].

39. The Future of Nuclear Energy in a Carbon Constrained World. (2018). [online] Massachusetts Institute of Technology. Available at: http://energy.mit.edu/wp-content/uploads/2018/09/The-Future-of-Nuclear-Energy-in-a-Carbon-Constrained-World.pdf [Accessed 6 Sep. 2018].

40. World-nuclear.org. (2018). *Economics of Nuclear Power*. [online] Available at: http://www.world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx [Accessed 2 Aug. 2018].

41. Comptoller and Auditor General of India (2017). *Report of the Comptroller and Auditor General of India on Kudankulam Nuclear Power Project, Units I and II*. Comptoller and Auditor General of India.

42. Ram, R. (2018). Govt's renewable energy usage targets ambitious; scaling up has helped. [online] https://www.livemint.com/. Available at: https://www.livemint.com/Money/enQ7h8JaD6rKXGXiMTsORM/Govtsrenewableenergyusagetargets-ambitious-scaling-up.html [Accessed 7 Aug. 2018].

43. World-nuclear.org. (2018). *Nuclear Power United Arab Emirates | UAE Nuclear Energy | Abu Dhabi | Dubai - World Nuclear Association*. [online] Available at: http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-arab-emirates.aspx [Accessed 22 Sep. 2018].

44. Ibid.

45. Bloomberg.com. (2018). *UAE's Nuclear Power Program said to cost $30 billlion*. [online] Available at: https://www.bloomberg.com/news/articles/2011-11-24/u-a-e-s-plan-to-develop-nuclear-power-facilities-said-to-cost-30-billion [Accessed 18 Sep. 2018].

46. Kapalan, S. (2008). *Power Plants: Characteristics and Costs*. [online] Congressional Research Service. Available at: https://fas.org/sgp/crs/misc/RL34746.pdf [Accessed 5 Aug. 2018].

47. Pfeifer, S. (2018). *High costs and renewables challenge the case for nuclear power | Financial Times*. [online] Ft.com. Available at: https://www.ft.com/content/21305834-5376-11e8-84f4-43d65af59d43 [Accessed 9 Aug. 2018].

48. World-nuclear.org. (2018). *China Nuclear Power | Chinese Nuclear Energy - World Nuclear Association*. [online] Available at: http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx [Accessed 9 Aug. 2018].

49. Ibid.

50. BloombergQuint. (2018). *Economic Survey: Banking Reforms Must Follow Resolution AndRecapitalisation*. [online] Available at: https://www.bloombergquint.com/union-budget-2018/economic-survey-banking-reforms-must-follow-resolution-and-recapitalisation#gs.1N=43dk [Accessed 5 Aug. 2018].

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