



DEPARTMENT OF ATOMIC ENERGY PUBLIC SECTOR ENTERPRISES

Driving Growth through Industrial Excellence

AMRIT KAAL VISION DOCUMENT







परमाणु ऊर्जा विभाग

DEPARTMENT OF ATOMIC ENERGY



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अमृत काल AMRIT KAAL संकल्प प्रलेख VISION DOCUMENT

PART – B

Public Sector Undertakings

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Atomic Energy Programme for a Sustainable Socio-economic Growth

India is poised for another exciting phase in its history. Riding on the back of glorious achievements of the past seven decades, the country has now set its sight on tapping new and sustainable growth engines to realise an accelerated pace of development. The Government of India's (GoI's) flagship 'Amrit Kaal' 2047 roadmap envisions the country's rapid transition to a global powerhouse of advanced capabilities for sustaining high rates of economic growth. Science and technology will continue to be a mainstay in GoI's long-term goal of transforming the country into 'Viksit Bharat' by the year 2047 by promoting national scientific research and innovation landscape.



Dr. Ajit Kumar Mohanty
Secretary to the Government of India,
Department of Atomic Energy &
Chairman, Atomic Energy Commission

The GoI's 'Amrit Kaal' roadmap envisions a broad-based shift towards clean energy mix to augment the national energy generation capacity and to accomplish the ambitious goal of curtailing emissions to the targeted 'net zero' gradually by 2070. The broader outcomes envisaged by the nuclear energy vision would immensely contribute to India's 'net zero' commitment.

In 1955, Dr. Homi Jehangir Bhabha, in his Presidential address at Geneva Conference, said- "In a broad view of human history, it is possible to discern three great epochs. The first is marked by the emergence of the early civilizations in the valleys of the Euphrates, the Indus and the Nile; the second by the industrial revolution, leading to the civilization in which we live; and the third by the discovery of atomic energy and the dawn of the atomic age, which we are just entering. Each epoch marks a change in the energy pattern of society".

Dr. Homi Jehangir Bhabha emphasized that "for the continuation of our civilization, and its further development, atomic energy is not merely an aid, it is an absolute necessity". At the crucial juncture of the third epoch, deciding the roadmap for achieving a new energy mix for a sustainable socio-economic growth of the world is significant, and nuclear energy would be in the vanguard. In this positive spirit, the Department has now chalked out a robust 'Amrit Kaal' roadmap for guiding its future course of action in core and advanced areas of nuclear energy programme of the country.

Seventy glorious years of Dedication, Advancement and Excellence:

Research Reactors and Nuclear Power Programme

Dr. Homi J. Bhabha recognized the importance of energy for the growth of our nation and the role that nuclear energy has to play in India. Synchronized with this philosophy, the Department of Atomic Energy (DAE) has been successful in delivering the objectives over the last 70 years in the true spirit set in a self-reliant manner. The Indian nuclear energy programme was launched as early as in 1948, when the Atomic Energy Commission (AEC) was constituted and later the Department of Atomic Energy (DAE) was established in 1954. Thus began India's journey for harnessing nuclear energy and radiation technology for peaceful purposes in the areas of power production, applications of radioisotopes in the fields of medicine, agriculture, industry and research. The initial thrust to the nuclear programme was provided with the commissioning of a 1 MW, swimming pool type research reactor 'APSARA' in 1956 at Trombay, Mumbai. In just over a year, scientists and engineers of the department completed the construction of APSARA, and with that India became the first Asian country outside erstwhile Soviet Union to have designed and built its own nuclear reactor. The entire world was eying the phenomenal initiation and development of Indian Nuclear Energy Programme. On 20th January, 1957 during the formal inauguration of APSARA, and Atomic Energy Establishment at Trombay (AEET) by the then Honourable Prime Minister Pandit Jawaharlal Nehru, a delegation of 50 high level foreign dignitaries representing 30 countries witnessed the occasion.

Research reactors are primarily meant to provide neutron source for fundamental research and their applications in a variety of areas including healthcare. All upcoming technologies are first proven in a research reactor prior to their application in a nuclear power reactor. APSARA was instrumental in carrying out advanced research in the field of neutron physics, fission physics, radiochemistry, and R&D on reactor technology for the Indian scientist and engineers. Neutron radiography carried out in APSARA had been used for components of space programme.

This success and experience led to the construction of a vertical tank type 40MW, the second research reactor in 1960, named Canada India Reactor Utility Services or CIRUS. The need was already felt for a high neutron flux high power research reactor, which would cater to the additional requirement of radioisotope production, and for more advanced research. This reactor built under close collaboration with Canada, was similar to Canadian NRX reactor, but with few changes based on location and requirement. CIRUS reactor was solely catering to the country's radioisotope requirements till August 1985, when the third research reactor 'DHRUVA' became operational. This is an even higher neutron flux, 100 MW capacity research reactor designed, constructed and commissioned indigenously. For last 40 years Dhruva has been extensively utilized for engineering and beam tube research, testing of equipment and

material, and large-scale production of radioisotopes. Later, looking at the strategic interest of the country, and Bhabha's vision of three stage nuclear programme, indigenously built reactors were, ZERLINA, PURNIMA series at Trombay and KAMINI at Kalpakkam.

In parallel, the nuclear power programme also began its journey with the establishment of the twin units of Boiling Water Reactors (BWRs) at Tarapur in 1969. The power programme has now expanded significantly with 24 reactors being currently operational with a capacity of 8780 MW (excluding RAPS 1) in the country. In addition, 8 reactors with total of 6600 MW are under construction, and 10 reactors with total capacity of 7000 MW are in the advanced stage of beginning the construction. On progressive completion of these reactors by 2031-32, the installed nuclear capacity is expected to reach 22,380 MW (excluding RAPS 1). As a new initiative towards energy security, the Government of India approved 'Anushakti Vidhyut Nigam Ltd.' (ASHVINI), a Joint Venture (JV) between NPCIL and NTPC Ltd., to build, own, and operate nuclear power plants in the country. To start with, the Mahi Banswara Rajasthan Atomic Power Project (MBRAPP), a 4x700 MWe PHWR project has been undertaken by ASHVINI.

Three Stage Nuclear Power Programme

The celebrated three stage nuclear power programme of India envisioned by Bhabha, begins with (Stage -1) the Pressurized Heavy Water Reactors (PHWRs) where natural uranium (U) based fuels are used to generate electricity, and in turn fissile plutonium (^{239}Pu) is produced. In the second stage (Stage-2), Pu based fuels are used to enhance nuclear power capacity, and further to convert fertile thorium (Th) into fissile ^{233}U , a key step for utilisation of vast thorium reserves in India and provide energy security to the country. To achieve success in the Stage-2, Fast Breeder Reactors (FBR) are to be made operational. The Fast Breeder Test Reactor (FBTR), the flagship reactor of the second stage of the Indian nuclear power program, attained first criticality on 18th October 1985, when all eyes were at Kalpakkam. As a signature of advancement, in March 2022, the reactor was successfully operated at its design capacity of 40 MWth. Further to this direction, a 500 MWe Prototype Fast Breeder Reactor (PFBR) is in the advanced stage of achieving criticality. In a historic moment at the 70th year of formation of DAE, the Honourable Prime Minister Shri Narendra Modi witnessed the commencement of "Core Loading" at India's first indigenous Fast Breeder Reactor (500 MWe) at Kalpakkam, Tamil Nadu on 4th March 2024. In line with the true spirit of Atmanirbhar Bharat, PFBR has been fully designed and constructed indigenously by DAE with significant contribution from Indian industries. Once commissioned, India will only be the second country after Russia to have commercial operation of Fast Breeder Reactor. The Stage 3 of the power programme, consisting of advanced thermal and breeder reactors, will use the ^{233}U so produced in Stage 2 for the country's long-term energy security. The three-stage nuclear power programme thus ascertains optimal utilization of uranium and thorium reserves.

The attainment however, is inter-linked with the establishment of an efficient closed fuel cycle approach with recycling of both fissile and fertile components of the spent fuel to appropriate reactor systems. Starting way back in 1964 with the commissioning of a plant based on PUREX technology to reprocess spent fuel from the research reactor CIRUS followed by building a power reactor reprocessing facility, India has mastered in exercising closed fuel cycle involving reprocessing, recycling of fissile material and conditioning of radioactive waste. Looking at the growth of nuclear power programme of the country, the department is constructing an Integrated Nuclear Reprocessing Plant (INRP) at Tarapur. In parallel, to meet the challenges of PFBR spent fuel reprocessing, a Demonstration Fast Reactor Fuel Reprocessing Plant, has been constructed, which was ceremonially dedicated to the nation by the Honourable Prime Minister Narendra Modi on 2nd January, 2024. The large-scale commercial Fast Reactor Fuel Cycle Facility (FRFCF) is also under construction at Kalpakkam.

Harnessing Atomic Energy for Societal Benefits

Cancer Care

In addition to the nuclear power programme, radioisotopes produced in research and power reactors have played a key role in improvement of health care, agriculture, food preservation, and several other areas to benefit the societal programmes of the country. Nuclear medicine, a widely recognized field utilizes trace amounts of radioactive substances for the diagnosis and treatment of various conditions, including cancer, neurological and cardiac disorders. In India, DAE is the sole producer of radioisotopes from the time of the operation of CIRUS and DHRUVA reactors where number of radioisotopes such as ^{99}Mo , ^{131}I , ^{125}I , ^{153}Sm , ^{32}P , and ^{177}Lu for medical applications were produced to meet the demand of radioisotopes of the country. It is worth mentioning that millions of patients in India have been benefitted for nearly half a century from the radioisotopes produced in the CIRUS reactor. The availability of indigenously produced radioisotopes opened up the opportunity of using these isotopes in formulating radiopharmaceuticals in nuclear medicine. DAE is involved in the production as well as the development of targeted disease-specific radiopharmaceuticals for improved outcomes. More than 18 radiopharmaceuticals / radiochemicals and freeze-dried kits have already been developed. These are being used in hospitals for tumour imaging; bone pain palliation; liver, breast, and prostate cancer therapy and so on. The medical cyclotron facility in Kolkata, Cyclone-30 has been facilitating the production of cyclotron-based radioisotopes for healthcare applications. Production and regular supply of ^{18}F -FDG, an extremely critical short-lived radiopharmaceutical used in the PET detection of cancer, Gallium-68 used in Gallium-based radiochemicals such as $^{68}\text{GaCl}_3$, for imaging of neuroendocrine cancers and prostate cancer are examples of radioisotopes being produced in the country for the first time using this medical cyclotron. Recently as a significant milestone for scientific and industrial advancement, the Heavy Water Board (HWB) of DAE has achieved a groundbreaking

capability in the production of ^{18}O enriched water, which is required for Positron Emission Tomography (PET) scanning for ascertaining the presence of cancer cells / malignancies.

DAE has played pivotal role in country's cancer care programme by employing radiation technology developed in-house. Radiation has the property of killing cancerous cells and radiation therapy can be administered externally for treatment of tumours, which are approachable from outside without collateral damage to healthy tissues. A teletherapy machine, has been developed for this purpose, which has been deployed extensively in India and some centres in abroad as well. A recent contribution of DAE has been the development of an eye plaque for treatment of ocular cancer. Ru-106, a radioisotope recovered from the spent fuel is integrated into circular eye plaques for use in the treatment of eye cancer. Extremely small Yttrium-90 glass spheres measuring just 30 micrometres in size and known as Bhabha Spheres, have been developed for the treatment of a specific type of liver cancer. I-131 based radiopharmaceuticals for thyroid cancer, Lu-177 based radiopharmaceuticals for treatment of neuroendocrine cancer and Sm-153 based radiopharmaceuticals for bone pain palliation are some other prominent examples.

More than five lakh patients receive affordable treatment every year at Tata Memorial Centre (TMC) in Mumbai, which is a constituent unit of the DAE. From 740 beds in 2017, TMC - Hospital has grown to 2700 beds. TMC has now expanded to six other hospitals located in Varanasi, Guwahati, Sangrur, Visakhapatnam, Chandigarh and Muzaffarpur. The Advanced Centre for Treatment, Research and Education in Cancer (ACTREC) has increased its capacity to 900 beds, offering state-of-the-art treatments with specialized facilities for solid tumour chemotherapy, management of haemato-lymphoid cancers, radionuclide isotope therapy, and Proton Beam therapy unit with three gantries, the first-of-its-kind in the government sector. Further, the National Cancer Grid (NCG) has been established with the aim of creating a coordinated system for cancer care that would ensure that patients receive the best possible treatment, regardless of their location or socio-economic status. The NCG includes more than 280 cancer centres and research institutions across India, and it is supported by the Department of Atomic Energy and the Tata Memorial Centre. One of the key objectives of the NCG is to improve the quality of cancer care in India by promoting the use of evidence-based treatments and best practices. The network treats over 750000 new cancer patients annually, which is over 60% of India's cancer burden. TMC has been recognised as an Anchor Centre for the International Atomic Energy Agency's (IAEA) 'Rays of Hope' programme.

Agriculture and food preservation

Continuous mutations in biological systems occur on a very slow time scale, influenced by environmental conditions. However, direct exposure to ionising radiations such as gamma rays from a radioisotope can induce accelerated mutations. DAE has an extensive programme on creating induced mutations in various crops, a technique known as mutation breeding. The method involves exposing seeds to controlled beams of gamma radiation, leading to

favourable as well as unfavourable mutations in them. Seeds with desirable traits are selected and multiplied. 71 Trombay crop varieties including groundnut, rice, mustard, mung bean, cow peas, chick peas, and wheat, with enhanced traits such as non-GMO, climate resilience, high-yield, early maturity, and improved disease resistance, have been developed through mutation breeding and are widely cultivated across the country.

Pest infestation, contamination and mould infestation are some of the major problems being faced by the agricultural sector, leading to substantial losses to the extent of 20-30% of the produce. Prevention of post-harvest spoilage is therefore of great significance. The radiation processing offers an eco-friendly solution to this problem. India's first pilot radiation facility 'The Food Package Irradiator', was commissioned in 1967 at BARC. Since then, four additional food irradiation facilities have been commissioned in the Government Sector across Maharashtra and Gujarat. Food irradiation processing is a method approved by several organizations including International Atomic Energy Agency (IAEA), World Health Organization (WHO), Food and Agriculture Organization (FAO), and Food Safety and Standards Authority of India (FSSAI). DAE has also developed irradiation technology for preservation of fruits, vegetables, pulses, spices, sea food etc. by radiation processing and has transferred the technology to private entrepreneurs. DAE has developed an integrated operating procedure utilizing irradiation and onion-specific cold storages, demonstrating the extension of the storage period for 'rabi' onions up to seven and a half months. This breakthrough not only ensures an extended storage life but also maintains the high quality of onions. The KRUSHAK food irradiation facility in Lasalgaon, Nashik, Maharashtra, has been upgraded for conducting the preservation trials and technology demonstrations of the breakthrough protocol in 2024. The successful demonstration of the large-scale trial marked a major milestone in advancing food preservation and hygienisation practices in India, reflecting DAE's unwavering commitment to agricultural innovation. Currently, 28 such commercially operated facilities are available around the country. Radiation processing protocol for mangoes has been developed successfully, and these fruits are now being exported to four countries across the world, USA, Australia, Malaysia and South Africa.

These are just a few glimpses of the vast potential of nuclear energy and radiation technology applications across various aspects of our lives. Achieving a balance between maintaining and sustaining our ecosystem and biodiversity, as pursuing developmental goals, requires innovative solutions. Many of the technologies developed by the DAE are steps in that direction, offering far-reaching benefits in energy, healthcare, nutrition and general well-being in a sustainable manner.

Basic Science Research

It is logical to believe that fundamental research serves as the backbone of scientific discoveries which actually creates the groundwork for applied research and technological advancements, towards improving the quality of human life, as all these are closely connected. Indeed, the

history of science has shown that all genuine knowledge has been for the potential use of mankind.

“The pursuit of science and its practical application are no longer subsidiary social activities today. Science forms the basis of our whole social structure without which life as we know it would be inconceivable...”

~ Homi Bhabha

(in his lecture at the inauguration of TIFR in December 1945)

Bhabha believed that science has advanced at an accelerating pace since the early 20th century, widening the gap between the Global North and lower-middle-income countries. It is only by adopting the most vigorous measures and by putting forward utmost efforts into the development of science can bridge the gap. Undoubtedly, by this time Indian scientists including luminaries like C. V. Raman, Satyendra Nath Bose, Meghnad Saha and many others, had made significant contributions to the advancement of science, which are now integral to the fabric of modern science. With the aim of advancing science in India at a pace befitting the country's talent, Bhabha sought Sir J R D Tata's support to provide the necessary conditions and financial backing for establishing a scientific institute. This institute would promote original research at the frontiers of nuclear physics, cosmic rays and high energy physics. With financial support from the Sir Dorabji Tata Trust, Tata Institute of Fundamental Research (TIFR) was initially established within the premises of the Indian Institute of Science (IISc), Bangalore. Later it was shifted to Bombay, where it was formally inaugurated on December 19, 1945. Since 1955, the main funding responsibility of the institute lies on GoI through DAE. Starting with high energy cosmic ray research, TIFR has now grown to become one of the most premier and prestigious research institutes of this country, pursuing research activities across physical, chemical and life sciences. The approach to fundamental research as exemplified by the atomic energy program, has been characterized by a commitment to curiosity-driven research, crucial for driving innovation, creating paradigm shifts, and contributing to long-term national development. Starting with the establishment of TIFR, Bhabha facilitated creation of various other institutions of excellence, such as Saha Institute of Nuclear Physics, Institute for Mathematical Sciences. Later, the DAE has either established or aided institutes like, Harish-Chandra Research Institute (HRI), National Institute of Science Education and Research (NISER), Institute of Physics (IOP) and Institute for Plasma Research (IPR). The latest in this series is the Homi Bhabha National Institute (HBNI), a deemed-to-be university, which continues to advance scientific research and innovation in the country through its constituent DAE, and DAE-Aided institutes. DAE support and nurture basic research in Indian institutes and universities by funding through the Board of Research in Nuclear Sciences (BRNS). Collaborative programmes between researchers in universities and DAE scientists, are encouraged by BRNS in order to increase academic interactions.

Dr. Bhabha initiated the balloon experiments in India at TIFR in 1948 for research in Astronomy, Astrobiology, and High Energy Physics. The TIFR balloon facility in Hyderabad today has the capability to launch heavy pay loads up to 1200 kg gross weight to altitude of 32 km for astronomy experiments and lower payloads for high energy physics research. The facility achieved the landmark of 500 scientific balloon launches in 2018. In cosmic ray research, India thus has a rich and long history. Researchers at TIFR detected the atmospheric Cherenkov radiation in early seventies, and also established an array of 25 distributed Cherenkov telescopes, known as the Pachmarhi Array of Cherenkov Telescopes (PACT), in Madhya Pradesh. Later in 2002 an array of seven telescopes was setup at Hanley to observe high energy gamma rays from celestial objects at lower energy. GRAPES-3, a near-equator astroparticle physics research facility at Ooty is being led by TIFR and operated by international consortium of several institutes of India and Japan.

The Giant Metrewave Radio Telescope (GMRT), an array of 30 radio telescopes used for investigating a variety of radio astrophysical phenomena ranging from the nearby solar system to the edge of the observable universe, is developed by TIFR, a grant-in-aid institution of DAE. Located at Narayangaon in Pune, GMRT has been accorded the prestigious IEEE Milestone status in 2020 in recognition of the global impact of GMRT, with users from 40+ countries worldwide, and the fact that it was designed and built entirely in India, with innovative ideas. GMRT is only the third such IEEE Milestone recognition for an Indian contribution to date, after the one for the pioneering work by Sir J. C. Bose on radio waves in 1895 and the one for the Nobel Prize-winning discovery by Sir C. V. Raman in 1928.

Bhabha Atomic Research Centre (BARC) started the Very High Energy gamma ray astronomy programme by setting up country's first imaging telescope called TACTIC at Mt Abu in 1997. The same year, it detected gamma ray emission from the Active Galactic Nuclei, Mrk 501 first time along with four other imaging telescope facilities around the globe. A high-altitude research laboratory at Gulmarg is also managed by BARC, where research in the field of cosmic ray astrophysics, radioastronomy, and atmospheric neutron monitoring is being carried out. Recently, the Major Atmospheric Cherenkov Experiment (MACE) Observatory at Hanle, Ladakh was formally inaugurated as a part of the Platinum Jubilee year celebrations of the DAE. MACE is the largest imaging Cherenkov telescope in Asia, situated at an altitude of approximately 4,300 meters, making it the highest of its kind in the world.

The DAE has placed paramount importance on accelerators-based research in the country. Over the years India has achieved the capability to design, build and operate accelerators and carry out accelerator-based research programmes in the frontiers of nuclear science. In the 1960s, a 5.5 MV Van de Graaff accelerator was installed at BARC, Mumbai. Later a folded 7 MV tandem accelerator has also been installed at BARC. These low energy accelerators are meant for basic and applied research in several interdisciplinary areas. The variable energy cyclotron was commissioned in the early 80's and was the first accelerator facility in the country for advanced experimental nuclear physics research. The 14 MV tandem Van de

Graaff (Pelletron) accelerator was set up and commissioned at the TIFR campus in 1989, as a collaborative BARC-TIFR program. Several low energy electron accelerators are being operated at different institutes of the country including DAE for fundamental research and applications. As the beginning of an active programme to develop accelerator-driven technology for nuclear waste transmutation and power generation, BARC has recently demonstrated 20 MeV proton beam in its Low Energy High Intensity Proton Accelerator (LEHIPA) facility.

Two synchrotron radiation sources INDUS-I and INDUS-2, which are 3rd generation light sources, have been designed in the nineties and are being operated at RRCAT, Indore. Indus-1 was the country's first synchrotron generator with a 450 MeV storage ring. Indus-2 has a beam energy of 2.5 GeV and critical wavelength of about 1.98 angstrom. The beam lines developed by DAE scientists in INDUS-1 & 2 are also being used by several universities and institutions for pursuing research in the areas of material science, electronic structures, spectroscopy, imaging and crystallography.

International Collaboration and Mega Science

India is also collaborating with major international accelerator facilities in Europe, USA and Japan. Under the CERN-India agreement, India is making in-kind contributions, to the Large Hadron Collider (LHC) at CERN. The scientists from DAE have also participated in the DØ experiments at the FERMILAB, USA, which led to the discovery of the top quark. As part of Indian Institutes and FERMILAB collaboration, several new and advanced technologies for high-intensity proton accelerators are being developed at multiple centres of DAE. The groups from BARC had joined the PHENIX collaboration for relativistic heavy ion collision experiments using the BNL relativistic heavy ion collider (RHIC) in the past.

As a part of Mega Science, India has conceived an international project, Laser Interferometer Gravitational-wave Observatory “(LIGO)-India”, which is a collaborative project between the USA and India. The LIGO-India testing and training facility at RRCAT, Indore was inaugurated in December, 2024, which would serve as a staging and assembly lab for LIGO-India detector subsystems.

DAE-BARC in close association with other defence departments of Government of India, is continuously working on developing technologies for national security. I recall that, two weeks after “Operation Shakti”, the then Honourable Prime Minister Shri Atal Bihari Vajpayee stated that “India is now a nuclear weapon state”. He further emphasized, “Our strengthened capability adds to our sense of responsibility”, a principle that India upholds with pride. The Silver Jubilee of “Operation Shakti” was celebrated on 11th May 2023 in the Pragati Maidan, New Delhi, when the Honourable Prime Minister, Narendra Modi virtually inaugurated five nuclear technology-linked cancer care centres in two states, and a rare earth permanent magnet plant in Visakhapatnam.

Way forward: Entering the era 'Amrit Kaal'

The milestones already achieved by DAE institutions are vast and encompass a broad range of areas. In this positive spirit, DAE has now chalked out prospective growth drivers for nuclear and allied sector expansion in the country in the next two-and-a-half-decade period. It is envisioned to design, construct, install and commission new general purpose research reactors & developmental reactors for special purpose in BARC-Vizag campus, where infrastructure development work is progressing in full swing. Developmental reactors such as high temperature reactor are for green hydrogen production and utilisation of thorium after breeding into uranium. The new reactor programme would also support the three-stage nuclear power programme by emphasizing on indigenous technology development for IPWR and FBR for 1st & 2nd Stage of Indian nuclear power programme as well as for realization of 3rd stage for long term energy security. The nuclear fuel cycle covering front end as well as back end of fuel cycle will back up the ambitious programme. An integrated nuclear recycle plant (INRP) being constructed would integrate all the facilities operating in spent fuel storage, reprocessing, waste management and MOX fuel fabrication. A fast reactor fuel cycle facility (FRFCF) will be commissioned at Kalpakkam.

"The five Public Sector Undertakings (NPCIL, BHAVINI, UCIL, ECIL & IREL) of DAE are primarily responsible for *development* in production of nuclear power to provide support in achieving energy security in a sustainable manner. Together NPCIL and BHAVINI envision to reach installed capacity of about 58000 MW by 2047. The other PSUs will work in tandem and support the programme by augmenting fuel production facility, developing required electronics and instrumentation and by supplying necessary rare materials.

The accelerator programme aims at long term energy security in a sustained manner through phase wise development of high energy proton accelerators typically 1 GeV for accelerator driven sub-critical systems, as well as for transmutation and incineration of nuclear waste. For the same purpose a high-energy high-intensity proton cyclotron systems with a final energy of 800 MeV is also envisaged. It is now proposed to indigenously develop a state-of-the-art 4th generation high brilliance synchrotron radiation source (Indus-3) in India. The proposed Indus-3 (6 GeV, 200 mA) will provide a significant boost to the national scientific and research community as well as applied and industrial research.

In radio astronomy, expanding the GMRT facilities to reach unprecedented sensitivities would enable transformational, high-impact science. In astrophysics research, looking ahead, the MACE project and its proposed expansion with array telescopes aim to foster international collaborations, advance India's contributions to the study of the universe, and bolster India's position in the global scientific community. The observatory will also serve as a beacon of inspiration for future generations of Indian scientists, encouraging them to explore new frontiers in astrophysics. The mega science project LIGO-India will be built at Hingoli in Maharashtra by DAE and the Department of Science and Technology (DST), GoI, in

collaboration with the National Science Foundation (NSF), USA. Honourable Prime Minister Shri Narendra Modi laid the foundation stone of (LIGO-India) on National Technology Day, 2023. The scientific goals of which are to advance research in astronomy and fundamental physics. The source of gravitational waves, which are predicted to be emitted by collision of the objects like black holes, neutron stars and supernova, is expected to be detected.

Progress is an open-ended endeavour and I am confident that DAE institutes together will leverage the insights within the roadmap to propel the organizations forward, contributing to the realization of a brighter and more technologically advanced India.

I am extremely happy to announce the release of the report titled 'Amrit Kaal Vision Document,' a comprehensive document that represents charting a strategic course for the continued success of the R&D Units, PSUs, Industrial Units, and Aided Institutions. All the Unit Heads of DAE anchored this activity, and the collective efforts of all units are commendable. The roadmap will be instrumental in achieving our collective ambition—the creation of a self-sufficient and technologically unparalleled India by 2047.

Jai Hind



Dr. Ajit Kumar Mohanty

Secretary, DAE and Chairman, AEC

August, 2025

1. Introduction

DAE encompasses all the areas related to power and non-power applications of atomic energy which includes exploration, identification and processing of uranium resources and atomic minerals, fabrication of nuclear fuel, production of heavy water, construction and operation of nuclear power plants, nuclear fuel reprocessing and waste management. The vision of the Department of Atomic Energy (DAE) is to empower India through technology, creation of more wealth and providing better quality of life to its citizen. This is to be achieved by making India energy independent, contributing to provision of sufficient, safe and nutritious food and better health care to our people through development and deployment of nuclear and radiation technologies and their applications.

The Public Sector Undertakings of DAE are commercial organisations involved in delivery of products related to atomic energy. The PSUs of DAE at present are Nuclear Power Corporation of India Limited (NPCIL), Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI), Uranium Corporation of India Limited (UCIL), Electronics Corporation of India Limited (ECIL) and Indian Rare Earth Limited (IREL).

NPCIL and BHAVINI are involved in commercial power (electricity) generation using nuclear fuels. UCIL's mandate is to mine and process uranium for production of nuclear fuel. ECIL provides the required support in terms of control and instrumentation required for nuclear power sector, while IREL mines and processes Zircon required for nuclear power plants and monazite for production of thorium. ECIL and IREL are also into other commercial activities – ECIL provides electronics for Defence, Homeland security, Aerospace and IT & E-Governance. IREL produces Rare Earths for industry and other applications.

The five PSUs of DAE primarily serve the clean Energy vertical of the Department of Atomic Energy and have a vital role in providing the country energy security in a sustainable manner. The PSUs Vision Amrit aal (2047) is the integration of the visions of the respective companies in line with the National goals and DAE's vision.

2. India's Nuclear Power Programme

India's first nuclear power plant – TAPS 1&2

To demonstrate the feasibility of introduction of nuclear power in the then existing electricity grids, after extensive studies, it was decided to set up two units of Boiling Water Reactors (BWR) to be supplied by GE, USA on a turnkey basis. The construction of these reactors commenced at Tarapur, Maharashtra in 1964. They began commercial operation in October 1969. At 210 MW each, they were then the largest size power plants in the country and first nuclear power plants in Asia. These are currently the oldest nuclear power plants in operation in the world.



TAPS 1&2

India's first PHWRs – RAPS 1&2

Even as TAPS 1&2 were being constructed, India embarked on the construction of the first PHWR in collaboration with Atomic Energy of Canada Limited at Rawatbhata in Rajasthan. Canadians then had been building PHWRs in their country. This project was very important as it would be the harbinger of a series of PHWRs of 220 MW that were envisioned as the first stage of India's indigenous three-stage programme



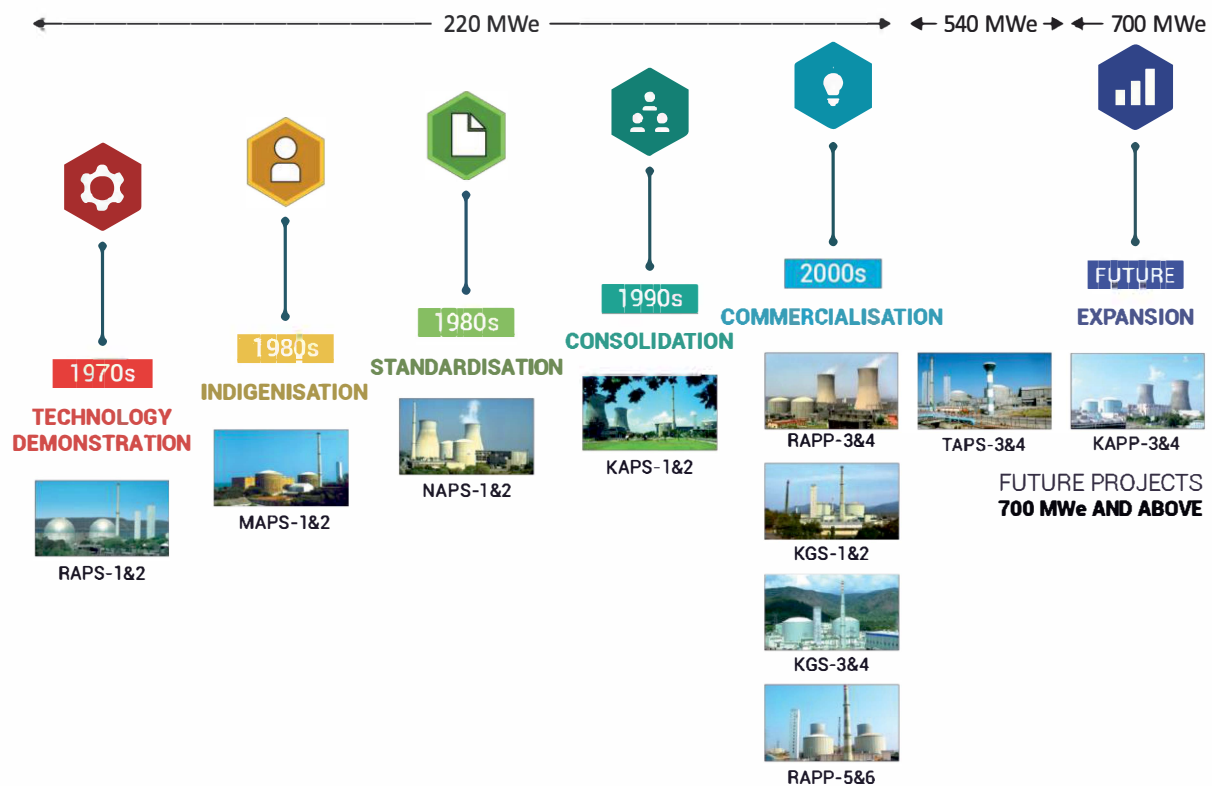
RAPS 1&2

The International Isolation and technology denial Regime

The first unit, RAPS-1 was completed in 1973. The second unit RAPS-2 was under construction, when in 1974 all assistance by Canada was withdrawn and an international technology denial and embargo regime commenced following the conduct of the first Peaceful Nuclear Experiment by India.

Indigenisation and Evolution of PHWR technology

Following the imposition of technology denial regime, Indian scientist and engineers successfully completed RAPS-2 and commissioned the unit in 1981, which continues to operate even today. Following successful operation of RAPS-2, India accomplished full indigenisation of with the design, construction and commissioning of MAPS 1&2. This was followed by standardisation, consolidation, commercialisation and increase in unit size from 220 MW to 540 MW and now to 700 MW. At present, one PHWR of 200 MW, fourteen of 220 MW, two of 540 MW and two of 700 MW are in operation.



PHWR Evolution

Additionalities to the three-stage programme:

In parallel to the indigenous three-stage programme, additionalities based on imports have been introduced, essentially for faster nuclear power capacity addition in the near term, considering the lead times involved in the indigenous nuclear power programme.



KKNPP 1&2 (2 x 1000 MW)

International Cooperation in Nuclear Energy

Following the fruition of international cooperation in nuclear energy in 2008, international agreements for cooperation in nuclear energy were concluded to end the country's international isolation and access global markets for nuclear commerce. This opened up the possibility of import of fuel for use in reactors under IAEA safeguards and setting up nuclear power reactors based on technical cooperation with foreign countries. Two 1000 MW Pressurized Water Reactors (PWR) in cooperation with Russian Federation at Kudankulam (KKNPP 1&2) have been set up and are in operation. Four more 1000 MW PWRs (KKNPP- 3 to 6) are being set up at the same site in Tamil Nadu.

The Government has also accorded 'in principle' approval of four sites at Jaitapur in Maharashtra, Kovvada in Andhra Pradesh, Chhaya Mithi Viridi in Gujarat and Haripur in West Bengal for setting up nuclear power reactors with foreign cooperation.

2.1 Energy Demand and Need for Nuclear Power

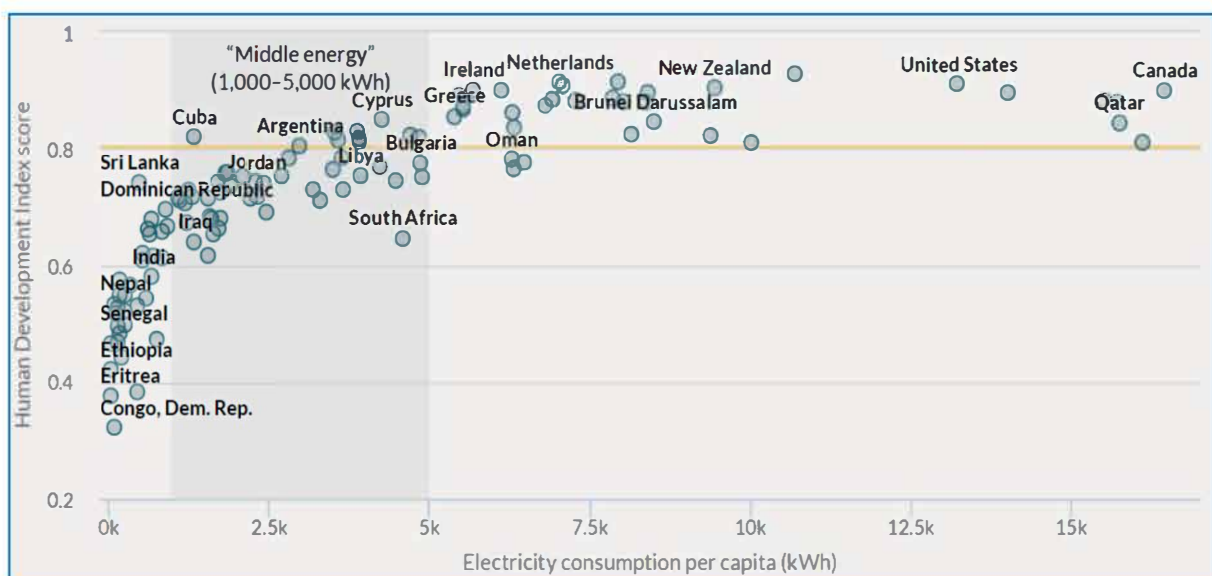
Viksit Bharat

India aspires to be a developed country (Viksit Bharat) by 2047, the 100th year of its independence. The period up to 2047, in which it is to be happened, is Amrit Kaal. The key drivers for developing the Vision are

- Viksit Bharat by 2047,
- Approach to Net Zero by 2070 and
- Atma Nirbhar Bharat

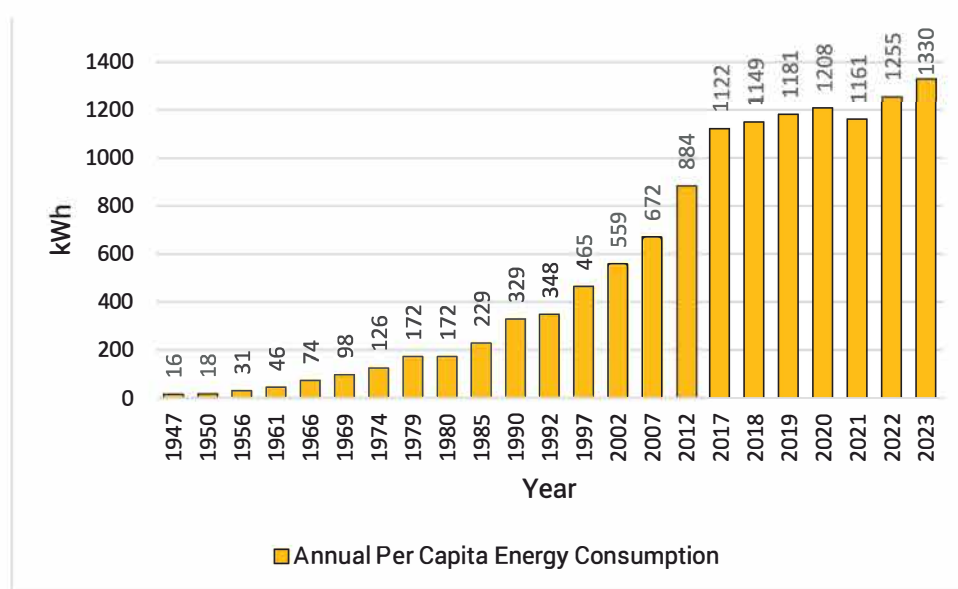
The legitimate aspirations of the country to achieve its development objectives and providing higher standards of living for its people require raising the per capita consumption of energy. Multiple studies over time have shown a positive correlation between the Human Development Index (HDI) and per capita energy / electricity consumption.

A high economic growth is required to achieve the desired HDI of about 0.8. Vision India 2047 also aims to make India a global leader in innovation and technology, a model of human development and social welfare, and a champion of environmental sustainability.



Ref: Center for Global Development

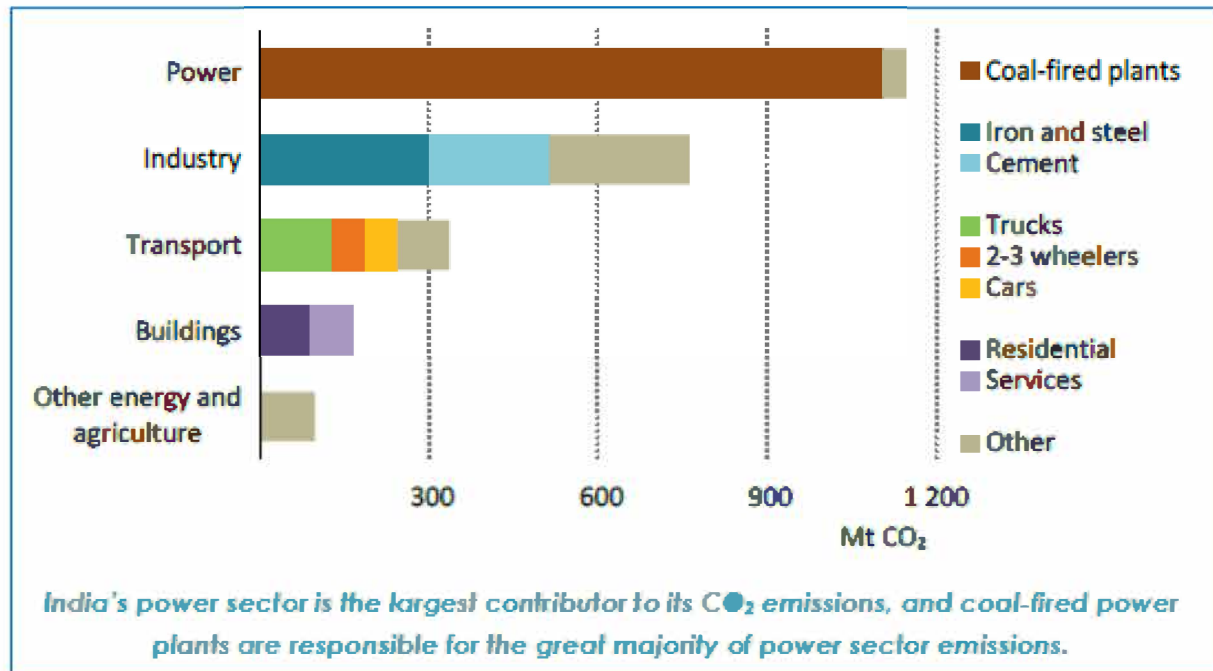
For a Viksit Bharat and meeting the aspirations of our people, providing quality power in the required quantity and at affordable price is essential. The per capita electricity consumption of the country was 1330 kWh in FY 2022-23 against the world average was around 3800kWh. In the last five years, peak demand in India has registered about 5% annual growth. Based on this and considering actual peak demand of 216 GW in 2022-23, the projected peak demand in the year 2046-47 works out to about 700 GW. Projections made in studies by various agencies indicate the need of realization of installed capacity over 1500 GW by 2047 as against the present capacity of about 442 GW.



Another important driver for Vision Amrit Kaal is clean energy transition to Net Zero by 2070. Apart from decarbonising the power generation sector, a huge effort is needed to decarbonise the hard to abate sectors like industries. This would envisage increasing the share of electricity in the energy consumption, and producing clean Hydrogen, which could potentially replace fossil fuels as the energy carrier. Accordingly, India is pursuing energy transition in various sectors including electricity, industry, transport, agriculture, household items etc.

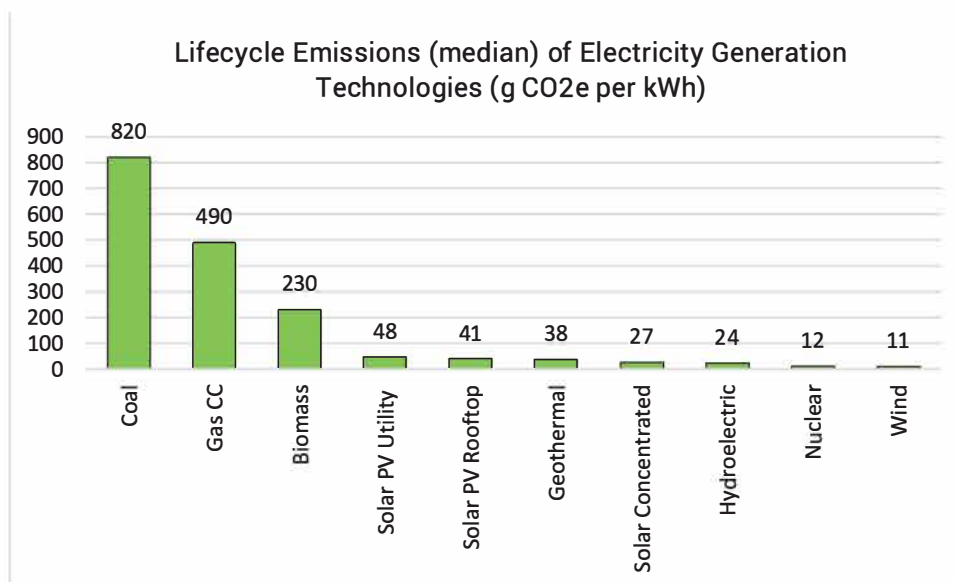
India is a major force in the global energy economy. Energy demand has increased significantly over the last two decades, propelled upwards by a growing population and the industrial growth. Transport sector has also recorded increasing growth trend in terms of distance travelled and consequent energy consumption. Appliances for households are projected to rise manifold. All the above factors have contributed sharp rise in CO₂ emission by various sectors

specifically power, Iron & steel, Cement, transport sectors. The energy sector is the major source of greenhouse gas emissions today and holds the key to averting the worst effects of climate change.



Source: IEA – India Energy Outlook 2021

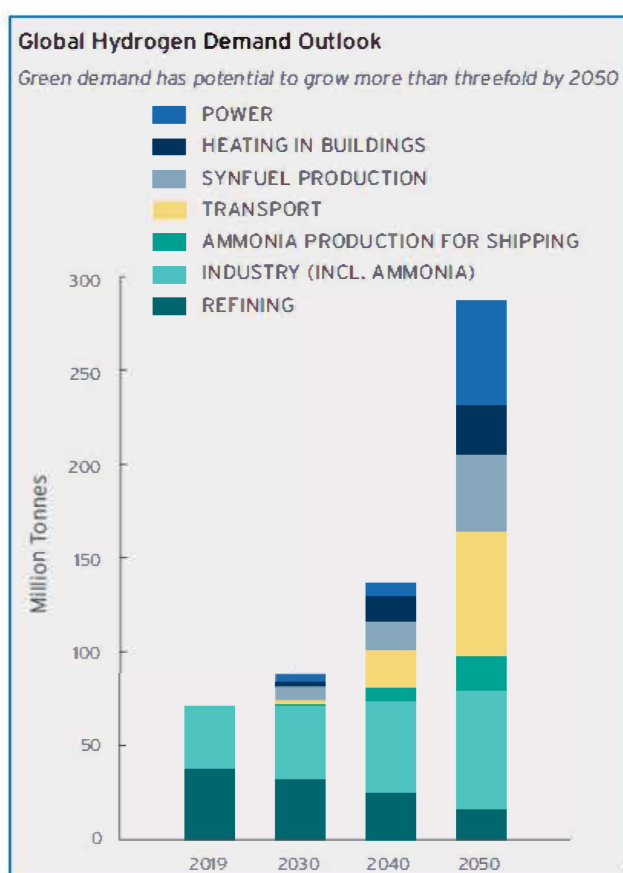
To meet the anticipated growth in demand for energy in the coming years, technological options need to be chosen which are optimal in the medium as well as long term. There is a need for acceleration of development and deployment of clean technologies such as nuclear, renewable, electrolyzers, carbon capture and storage (BECCS), high efficiency fuel cells etc. Net-zero is not possible without substantial nuclear power and Renewable Energy (RE) generation by 2070. Due to its compelling merits as clean energy (CO₂ free), 24x7 availability as base load power, safe, reliable, economically viable and having vast operating experience, nuclear power has an important role to play towards India's net-zero target by 2070. There is a need for acceleration of development and deployment of clean technologies such as nuclear, renewables, electrolyzers, carbon capture and storage (CCS), high efficiency fuel cells etc.



Source: *Annexe III Technology Specific Cost and Performance Parameters. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*

India has to radically transform its energy landscape and prioritise renewable energy, nuclear energy, electrification, hydrogen adoption and carbon removal strategies. Renewable electricity is growing at a faster rate in India than any other major economy. Grid decarbonisation, industrial decarbonisation and transport transition are expected to address nation's current emissions to a large extent.

Hydrogen demand in India could grow more than fourfold by 2050, representing almost 10% of global hydrogen demand. Initial demand growth is expected from mature markets like refinery, ammonia,



Source: NITI Aayog–Harnessing Green Hydrogen

and methanol, which are already using hydrogen as industrial feedstock and in chemical processes. In the longer term, steel and heavy-duty trucking are likely to drive the majority of demand growth, accounting for almost 52% of total demand by 2050. The global demand is projected at about 300 million tonnes by 2050.

2.2 India's electricity installed capacity requirements

According to studies conducted by the NITI Aayog, India may be witnessing a steady growth in the share of electricity in its energy demand, which is expected to reach 25% by 2047. The share of electricity in energy demand is estimated to be 20.6% by 2030, which was estimated at 18.3% in 2021. In light of the NZ 2070 commitments, the expected share of electricity in the total energy demand is expected to rise to around 47-52% by 2070. This growth in electricity in view of the Net Zero commitments would have to be primarily met from Nuclear and renewable sources. Coal would necessarily have to be combined with Carbon Capture and sequestration technologies. Various studies by think tanks like NITI Ayog, Vivekananda International Foundation (VIF), Principal Scientific Advisor to Prime Minister (by IIM Ahmedabad) have projected the electricity requirements and sources of electricity generation for achievement of Net Zero by 2070.

The study commissioned by PSA to GoI (carried out by IIM A) indicates that a total Final Energy Consumption (FEC) of 15,400 TWh/y is possible by 2070 and the per-capita electricity consumption in 2070, considering an average HDI of 0.800 may range from 5,100 - 8,400 kWh/capita/year and for HDI of 0.900 between 10,400-13,200 kWh/capita/year across various scenarios.

The study by IIM A projects the requirement of installed nuclear power capacity in various Net Zero scenarios as follows:

Net Zero by 2070 Scenario	Nuclear Installed Capacity (GW)	
	2050	2070
NZ-1 (Thrust on Nuclear)	265	331

NZ-2(Thrust on Fossil fuels with CCUS)	75	78
NZ-3 (Thrust on Renewables)	75	207
NZ-4 (Integrated Scenario)	95	178

The VIF study projects a per capita electricity consumption of 18757 kWh to 15047 kWh by 2070 to cater to a low carbon economy which includes e-mobility, supplying process heat to industry and hydrogen production. It projects a maximum nuclear capacity of 284 GW to 3139 GW by 2070 across various scenarios. Thus, it becomes clear that a minimum installed nuclear power capacity of about 200 GW is needed by 2070 and about half of it i.e. 100 GW by 2047 which is halfway to 2070. Thus, the country needs about 100 GW nuclear power capacity by 2047.

2.3 Nuclear Power Vision 2047

As it becomes clear that the country needs a nuclear power capacity of about 100 GW or 1,00,000 MW by 2047, including for decarbonisation of hard to abate industries like steel, metals, cement etc., necessary roadmap to reach the capacity has to be drawn up. The present installed nuclear power capacity in the country is 8780 MW comprising of 24 reactors (excluding RAPS 1). In addition, 8 reactors with a capacity of 6600 MW are under construction and 10 reactors with a capacity of 7000 MW are under pre-project activities. On progressive completion of these reactors, scheduled by 2031-32, the installed nuclear power capacity is expected to reach 22,380 MW (excluding RAPS 1).

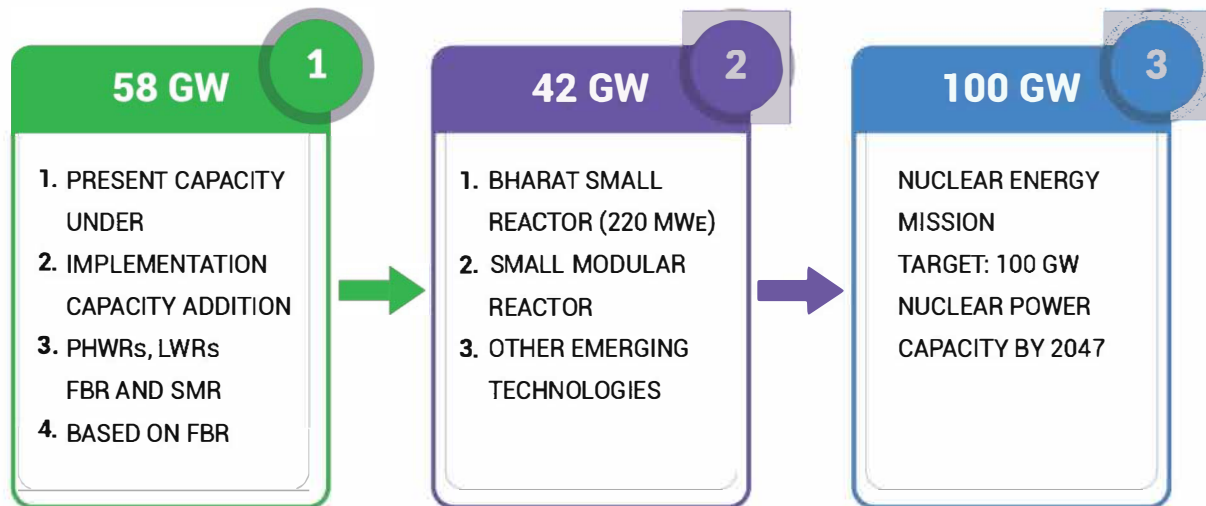
Presently the two PSUs of DAE viz. NPCIL and BHAVINI are engaged in setting up nuclear power plants in the country. While NPCIL is mainly engaged in nuclear power generation from PHWRs and LWRs, BHAVINI is engaged in setting up FBRs. Based on the available sites and technologies and other inputs, it is possible for NPCIL to envision adding about 33,000 MW of additional capacity during the period 2032 to 2047 and BHAVINI, a capacity of about 3300 MW. Thus, reaching a capacity of about 58,000 MW is possible to be set up by NPCIL and BHAVINI, by 2047 based on existing technologies like PHWRs, LWRs and FBRs. There is no specific plan for the balance 42,000 MW needed, which could be set up based on both existing

and emerging new technologies, mainly for decarbonisation of hard to abate industries (in captive mode), adopting business models involving private sector, which are being worked out. Further, it is proposed to evolve business models to enable private investment for setting up this capacity by the private sector. Potential for more than 42,000 MW exists in the country for decarbonising of industries presently using captive thermal power plants (most of which run on coal or diesel). Thus, a significant capacity for decarbonisation is expected to be realised through Small Modular Reactors (SMR). While many SMR designs are still under development, NPCIL's standard 220 MW Pressurised Heavy Water Reactors (PHWR) already in operation in the country, upgraded to reduce the land requirement and make it deployable close to the industries for use as a captive power plant is found to be an ideal solution for the purpose. This upgraded 220 MW PHWR is termed as Bharat Small Reactor (BSR) is one of the candidates for large scale deployed in the near future.

In addition, a Bharat Small Modular Reactor (BSMR-200) a small and modular pressurised light water reactor of capacity ~220 MWe which can utilize the balance of plant of 220 PHWRs for augmentation of nuclear capacity in India at a faster rate is being designed. It will have a reactor pressure vessel (RPV) with four loops connecting to pumps and steam generators: a loop type reactor very similar to AP300 of Westinghouse, USA or Rolls Royce SMR of UK in design, but with lower power generation capacity. This will also be a stepping stone in setting up large size indigenous PWR plants in future.

DAE (BARC) is also in the process of development of gas cooled high temperature micro modular reactor. (GCMMR) (<10 MWe), with advanced features. The detailed design is being worked out. The high temperature steam from these reactors will be directly used for carbon free hydrogen production either through chemical reaction like Iodine-Sulphur, Cu-Cl or steam electrolysis. These reactors are also planned to be deployed in the time leading up to 2047.

Thus, possible capacity addition based on technologies is as follows:



Towards realising the Nuclear Energy Mission

While the 58 GW capacity is expected to be implemented by NPCIL, BHAVINI and Joint Ventures of NPCIL, the 42 GW is expected to come largely with public and private sector participation, in evolving business models within the existing legal framework.

3. Nuclear Power Corporation of India Limited (NPCIL)

“To be globally proficient in nuclear power technology, contributing towards long term energy security of the country.”

The design, construction and operation of nuclear power plants in the country was started as a departmental activity in the early sixties, by the Department of Atomic Energy (DAE), Government of India. In the year 1967, Power Projects Engineering Division (PPED), a division of the DAE, was formed and entrusted with this responsibility. PPED was converted to Nuclear Power Board (NPB) in the year 1984, with increased delegation of powers. For the planned expansion of nuclear power programme, it was felt necessary to create a framework for faster decision-making and also to tap funds from capital market. Accordingly, NPB was converted into Nuclear Power Corporation of India Limited (NPCIL), a fully owned company of the Government of India, Department of Atomic Energy and registered on 3rd September 1987, under the Companies Act of 1956. The company started functioning from 17th September, 1987. The assets of the Nuclear Power Board excluding Unit-1 of Rajasthan Atomic Power Station (RAPS-1) were transferred to NPCIL on its formation.

NPCIL activities include all aspects of nuclear power reactors. These include Siting, Design, Construction, Commissioning, Operation & Maintenance, Renovation & Modernisation, Life Extension and Waste Management. NPCIL is mainly tasked with implementation of the first stage of nuclear power programme – comprising of Pressurised Heavy Water Reactors (PHWR) and Light Water Reactors (LWR) set up with international cooperation. NPCIL has evolved into an organisation with expertise in all aspects of nuclear power with experience in multiple reactor technologies PHWR and LWRs (BWRs and VVERs).

Growth & Evolution of NPCIL

Established legacy: A CPSE under DAE, incorporated in 1987, to build and operate nuclear power plants. Fully owned by the government of India and has equity participation in BHAVINI for fast breeder reactors.

Robust reactor fleet: Operates nuclear reactors with a capacity of 8180 mw, spanning PHWRs, BWRs, and VVERs, and has 8 reactors (6800 mw) under construction. Engaged in fleet-mode deployment of PHWRs.

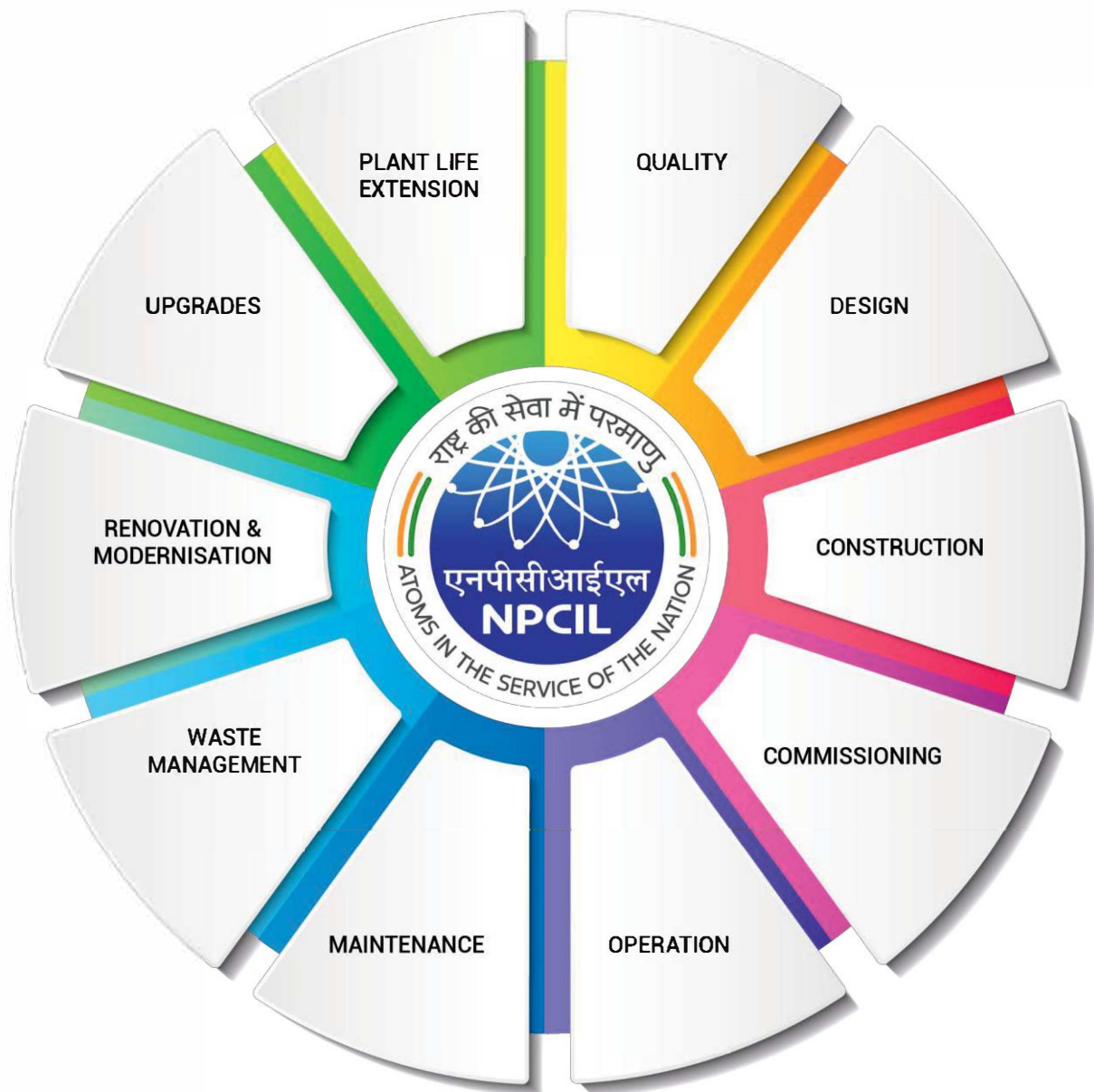
Strong financial backbone: NPCIL is a AAA-rated, consistently profit-making and dividend-paying company. Manages 1,68,235 crore in assets with a net worth of 60,821 crore.

Sustainable development and social commitment: Actively involved in CSR initiatives, neighbourhood welfare, biodiversity conservation and public outreach, engaging with communities around the nuclear power plants.

Global standards and collaboration: Maintains ISO-certified EMS and OHSMS, follows ALARA safety principles & collaborates with WANO, COG and IAEA to enhance global nuclear safety & reliability.

Vision for energy security: Aims to provide safe, eco-friendly and economy viable energy to meet India's rising electricity demands driven by the vision 'to be globally proficient in nuclear power.

Since its incorporation in September 1987, NPCIL has transformed substantially, growing in all aspects and achieving several landmarks. At the time of its inception, there were six reactors in operation (TAPS 1&2, RAPS 1&2 and MAPS 1&2) and four reactors under construction (NAPP 1&2 and KAPP 1&2). These reactors with the exception of RAPS-1 were transferred to NPCIL. The value of these assets was Rs. 1313 crore. While TAPS 1&2 are Boiling Water Reactors (BWR) of 160 MW each, the others are Pressurised Heavy Water Reactors of 220 MW size.



NPCIL: Many companies in one

3.1 Evolution in Technology

The 220 MW PHWR design which evolved from RAPS 1&2 (AECL Canada) to MAPS 1&2 (first indigenous PHWR) prior to formation of NPCIL was indigenised, improved and standardised with NAPS-1&2 and KAPS-1&2. Eight more 220 MW reactors – Kaiga 1 to 4 and RAPS 3 to 6 of the design were set up by NPCIL. The PHWR design was scaled up to 540 MW capacity and two such units (TAPS-3&4) were set up at Tarapur, Maharashtra Site. This design

was further uprated to the state of the art 700 MW with advanced safety features; and the first twin unit of 700 MW PHWR, KAPP-3&4 are in commercial operation. Four more units of 700 MW PHWR are under construction and ten more have been accorded sanction, which are expected to be progressively completed by 2031-32.

NPCIL has also set up two 1000 MW Pressurized Water Reactors (PWR) in cooperation with Russian Federation at Kudankulam (KKNPP 1&2) and has gained valuable experience in construction and operation of these reactors. Four more 1000 MW PWRs (KKNPP- 3 to 6) are being set up at the same site.

NPCIL has, over the years, developed comprehensive capabilities in nuclear power technology. This encompasses design of Systems, Structures & Components, Safety analysis, Licensing, manufacturing of nuclear equipment (with Indian industries), Construction and Operation of nuclear power plants. In addition, NPCIL has developed technologies for life management and maintenance, in association with other units of DAE. Adopting these technologies, NPCIL has successfully carried out Enmasse Coolant Channel Replacement (EMCCR), Enmasse Feeder Replacement (EMFR) in several reactors, introduction of Spargers in MAPS-1&2, repair of Calandria Vault in KAPS-1, in situ repair of tri-junction joint in Kaiga-3 Endshield and Over Pressure Relief device in RAPS-1 etc. These jobs were carried out with minimal radiation exposure and at much lower cost than internationally prevalent. Thus, NPCIL has evolved today into an organisation with expertise in PHWRs of different sizes, BWRs, and large capacity PWRs.

3.2 Addition of Capacity

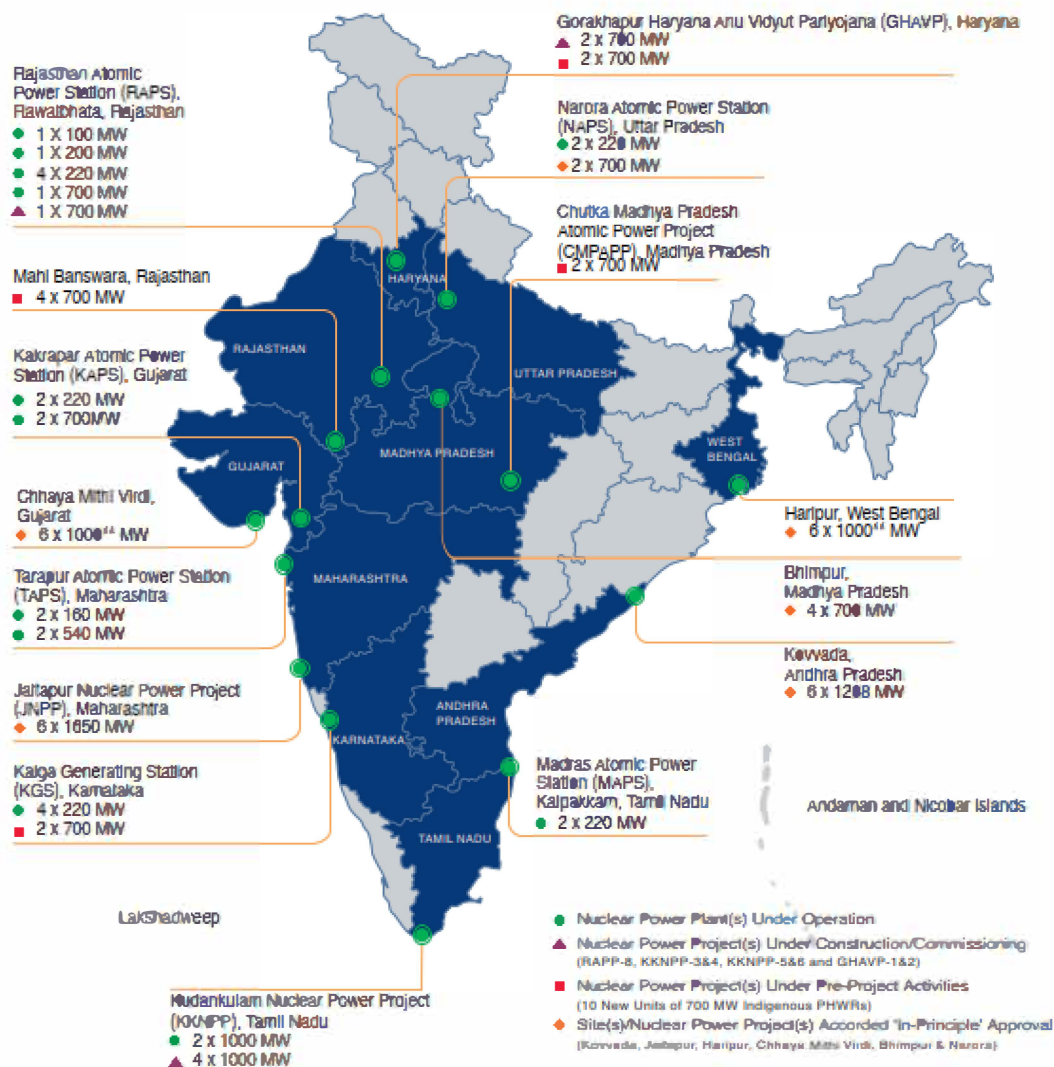
At the time of its incorporation, there were six reactors in operation - TAPS 1&2, RAPS-1&2 and MAPS 1&2 of which five reactors, excluding RAPS-1 were transferred to NPCIL with a capacity of 1010 MW. This capacity has now grown about eight-fold to 8180 MW with 24 reactors in operation. The present locations of NPCIL sites are given below:

Nuclear Power Plants and Sites in India

Total installed capacity - **8780 MW** [excluding RAPS-1(100 MW)]

Total capacity : Under construction - **6100 MW**

Under pre-project activities - **7000 MW**



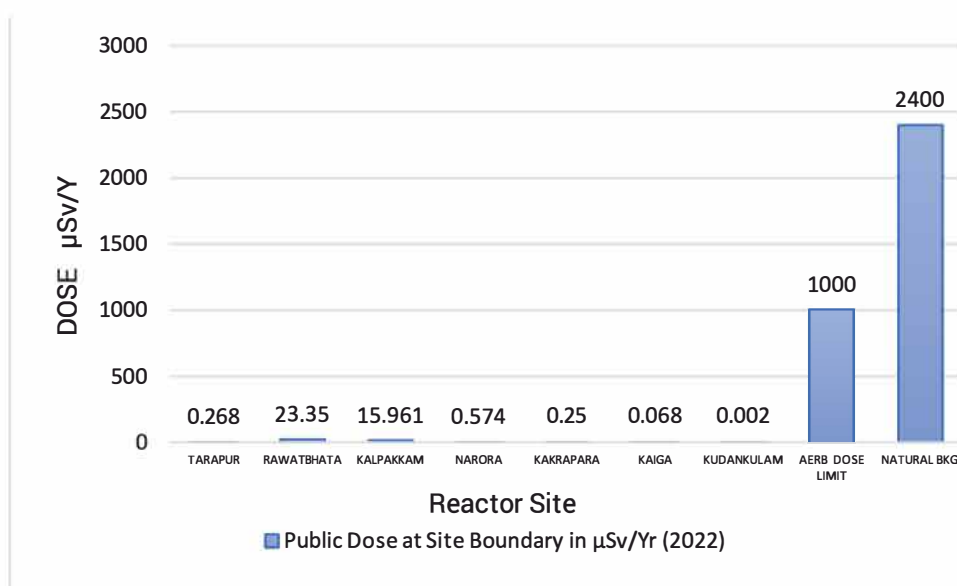
Note: Map for representation only. Not to scale

*RAPS-1 (100 MW PHWR, presently under extended shutdown) is owned by Department of Atomic Energy (DAE) and managed by NPCIL.

3.3 Performance of Operating Plants

Safety Performance Ever since its inception, NPCIL has had an impeccable safety record. There has not been any accident or incident of release of radioactivity in the public domain beyond stipulated limits. Indian nuclear power reactors have registered about 620 reactor-years of safe operation (as of August, 2024).

Environmental Survey Laboratories (ESL) are established at each site before the start of reactor operation which collect site-specific baseline radiation data from natural sources like cosmic rays, rocks, soil etc. After the plant goes into operation, environmental matrices like air, water, soil, crops, fish, milk etc. are monitored for radioactivity in an area up to 30 km around the plant. The data collected over 50 years of operation in India has shown that the increase in radiation level around nuclear power plants has been negligible and within the variations in the natural background.



Public Dose at NPP Sites

The radiation dose from NPCIL's nuclear power plants has been found to be a negligible fraction of the limit stipulated by AERB. As against the AERB limit of 1000 micro-Sievert per year at the exclusion zone (site) boundary, the actual value is found to be in the range of 0.004 to 27.72 micro-Sievert per year at NPCIL plant sites. The average natural background radiation in the country is 2400 Micro-Sievert per year. Expert safety reviews, following the Fukushima incident in Japan, found that NPCIL reactors are safe against extreme natural events and have margins and features in design to withstand them. The recommendations made to take the safety to a higher level have also been incorporated in design.

Generation Although NPCIL's installed capacity only grew by about six-fold, NPCIL's annual generation has grown about eight to nine-fold since its inception. The annual generation, which was about 4000 to 5000 MUs per annum in the first five years from 1987-88 to 1991-92, has now grown to over 40000 MUs. The highest generation in 2019-20 was 46472 MUs. It was 43029 MUs in 2020-21 and in the first seven months of the current year, has been 26323 MUs.

Plant Load Factor NPCIL's Plant Load factor was low in the initial days (around 50% or lower). Resulting out of various improvements made, it steadily increased to over 80% by 2002-03. There was a dip in Capacity Factor from 2003-04 to 2008-09 due to fuel demand-supply mismatch, but it again increased with improved fuel availability and stabilised at about 80%.

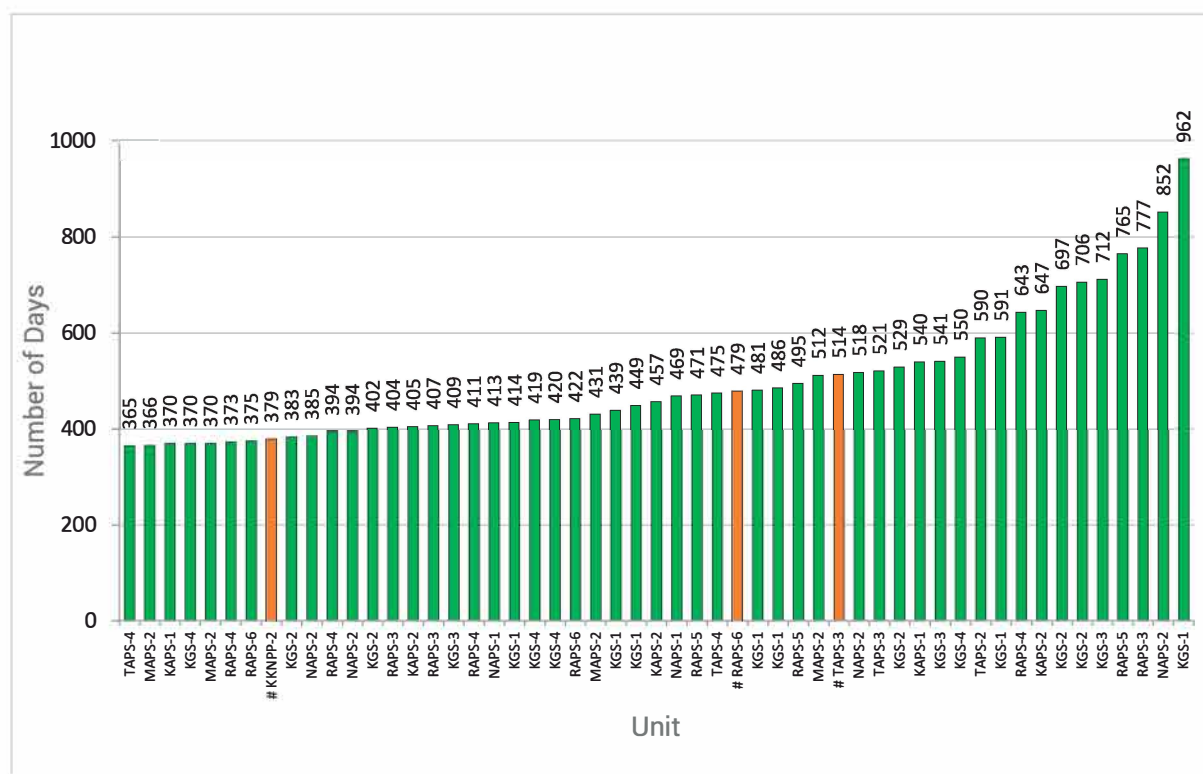
Landmark Achievements In addition to several significant achievements by NPCIL over the years, it recently had two world class land mark achievements:

Completion of 50 Years of Safe Operation of TAPS 1&2: These reactors commenced operation in 1969 and were the first nuclear power reactors in India & Asia. They are presently the oldest reactors in operation in the world having completed 50 years of operation in October 2019. These were originally set up by General Electric, USA on turnkey basis. Indigenous technological solutions were developed and implemented to ensure highest level of safety and efficient operation of the units (in an international technology denial and embargo regime prevalent from 1974 to 2008). The units underwent major upgradations in 2005 and 2016. The units are presently undergoing major refurbishment.

3.4 Continuous Operation - World Record of 962 Days By KGS-1

Kaiga Generating Station Unit-1 had set the world record by operating continuously for 962 days before being shutdown on 31st December 2018 for planned surveillance checks and mandatory tests (It now holds the record for the second longest continuous run among nuclear power reactors in world till date). Being a fully Indigenous PHWR fuelled by domestic fuel, this feat bears testimony to the maturity achieved by the country in all aspects of nuclear power technology. In addition, NAPS-2 (852 days), RAPS-3 (777 days) and RAPS-5 (765 days)

have operated continuously for more than two years. NPCIL reactors have operated for more than a year 53 times (as of July 2025) so far.



*Continuous operation for more than a year registered by NPCIL's Reactors as on 24.07.2025
(53 times), # Unit is continuing to operate*

Financial Strength: The value of assets transferred to NPCIL at the time of its formation was Rs. 1313 crore. The total assets have grown manifold and by March 31, 2025 stood at Rs.1,91,607 crore. Its net worth has also grown manifold and stood at Rs.65,475 crore as on March 31, 2025. NPCIL has been a consistent profit making and dividend paying company. In its 37 years of existence, NPCIL has consistently made profit, barring in two years 1993-94 and 1994-95. Its instruments are accorded AAA rating - the highest.

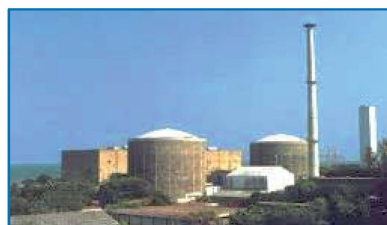
3.5 Capacity Addition & Vision for Amrit Kaal

Present Capacity: NPCIL's present installed capacity is 8780 MW comprising of 24 reactors. In addition, it is also responsible for operation of RAPS-1 (100 MW), owned by

the Department of Atomic Energy. Thus, it operates 25 reactors with a total capacity of 8880 MW. The technology wise break up of operating reactors is as follows:

Unit Capacity (MW)	No, of Units	Unit Particulars	Total Capacity (MW)
PHWRs			
100	1	RAPS-1	100
200	1	RAPS-2	200
220	14	MAPS 1&2, NAPS 1&2, KAPS 1&2, RAPS 3&4, RAPS 5&6, KGS 1&2, KGS 3&4	3080
540	2	TAPS 3&4	1080
700	3	KAPS 3&4, RAPS 7	2100
PHWRs Total			6560
LWRs			
160	2	TAPS 1&2 (BWR)	320
1000	2	KKNPP 1&2	2000
LWRs Total			2320

Of these 24 reactors, 8 reactors with a capacity of 2400 MW are fuelled by domestic uranium. The remaining 16 reactors are under IAEA safeguards and are fuelled by imported uranium.

**Tarapur 1&2****(2 x 160 MW)****Rajasthan 1 to 6****(100-200; 4 x 220 MW)****Madras 1&2****(2 x 220 MW)****Tarapur 3&4****(2 x 540 MW)****Kakrapar 3&4****(2 x 700 MW)****Kudankulam 1&2****(2 x 1000 MW)****Narora 1&2****(2 x 220 MW)****Kakrapar 1&2****(2 x 220 MW)****Kaiga 1 to 4****(4 x 220 MW)**

Nuclear Reactors in Operation

700 MW PHWRs: The 700 MW PHWR design is now well established with the successful operation of KAPS 3&4. These indigenous PHWRs have advanced safety features and are among the safest reactors in the world. While these reactors have been designed, constructed, commissioned and operated by NPCIL, the supply of equipment and execution of contracts have been by Indian industries / companies, and thus the true reflection of the spirit of Atma Nirbhar Bharat. These reactors will be the mainstay of India's nuclear power programme in the Amrit Kaal.



KAPS 3&4 (2X700 MW)

Capacity under construction:

Presently there are eight reactors with a total capacity of 6100 MW by NPCIL comprising of 3 PHWRs and 4 LWRs with foreign cooperation. The details are as follows:

Unit Capacity (MW)	No, of Units	Unit Particulars	Total Capacity (MW)
PHWRs			
700	1	RAPS 8	700
700	2	GHAVP 1&2	1400
PHWRs Total			2100
LWRs			
1000	2	KKNPP 3&4	2000
1000	2	KKNPP 5&6	2000
LWRs Total			4000



RAPP 7&8

The glimpses of LWRs under construction are shown below:



KKNPP 3&4



KKNPP 5&6

KKNPP 3&4 and KKNPP 5&6 are expected to be completed in 2026 and 2028 respectively. In addition, pre-project activities are in progress in respect of 10 PHWRs of 700 MW accorded sanction at four sites. The details of the locations and capacity are as follows:

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

These projects are scheduled to be completed progressively by 2031-32. Thus, on completion of the projects under construction and accorded sanction, NPCIL's capacity is expected to reach 21980 MW by 2031-32.



Kaiga 5&6

However, in respect of the Mahi Banswara and Chutka projects, while land acquisition process has been completed and R&R Package awarded, physical possession is yet to be fully obtained as the shifting of PAPs has just been initiated by the respective state governments. These projects may therefore spill over beyond 2031-32 though all efforts will be put to complete them on schedule once full access to the land is made available. Mahi Banswara project is proposed to be implemented by Anushakti Vidhyut Nigam Ltd., (ASHVINI), a joint venture of NPCIL & NTPC Ltd. The process of allocation of the project to ASHVINI is under consideration of the Government.

3.6 NPCIL Vision Capacity Addition beyond 2031-32 in Amrit Kaal:

Based on the availability of sites, technologies, supply chain feasibility and other inputs, possibility of setting up another about 33,000 MW by NPCIL is envisioned, apart from participation in the BSR programme to be implemented with private participation. The proposed technology wise capacity addition is as follows:

700 MW PHWRs:

- a. **At existing sites:** A committee was constituted in NPCIL to explore feasibility of setting up of additional 2x700 MW PHWR units at existing sites of Kakrapar, Rawabhata, Narora, Jaitapur, Kalpakkam and Tarapur.

Based on the preliminary feasibility study, field survey and plant engineering requirements, setting up of 2x700 MWe PHWR units at Rawatbhata, Karkrapar, Narora and Jaitapur sites (in addition to locating 6X1730 MW EPRs with French cooperation) was found feasible. However, at Tarapur and Kalpakkam sites, it was observed that there is lack of sufficient space for locating new units.

Six PHWRs of 700 MW each are proposed to be set up at following existing sites:

- **Rawatbhata: 2 more units may be set up (RAPP-9&10)**
- **Kakrapar: 2 more units may be set up (KAPP-5&6)**
- **Narora: 2 more units may be set up (NAPP-3&4)**

Further confirmatory studies and analysis is planned at these sites for taking up necessary steps towards setting up projects.

- b. **Bhimpur Site in M.P** The Government of India had accorded 'in-principle' approval of site at Bhimpur Madhya Pradesh in August 2011 for setting up 4x700 MHWRs subject to commitment for water which was yet to be confirmed by State government. No progress could be made so far as the state had not given assurance of providing the required quantity of water. However, the recent discussions with the state government have indicated that the water can be made available for the project. Accordingly, pre-project activities are being initiated at the site.

Thus, four PHWRs are proposed to be set up at Bhimpur site in Madhya Pradesh:

Bhimpur 1&2: 2X700 MW

Bhimpur 3&4: 2X700 MW

- c. **New Site for Fleet of 10X700 MW PHWRs** The Site Selection Committee of the Government is in the process of identifying new potential sites. A new coastal site is to be identified for setting up a fleet of 10 PHWRs of 700 MW each.

New Site: 10 X700 MW

LWRs: The sites at Jaitapur in Maharashtra and Kovvada in Andhra Pradesh have been accorded in principle approval for setting up 6X1730 MW EPRs with French cooperation and 6X1208 MW AP 1000 reactors with US cooperation respectively. Land has been acquired and presently discussions with technology partners from France and USA are in progress to arrive at a viable project proposal. On finalisation of a project proposal, the same will be put up to the Government for financial sanction and administrative approval. Work on these projects will be initiated after sanction of the Government.

Jaitapur Site: 6 X 1730 MW EPRs

Kovvada Site: 6X1208 MW AP1000 New LWRs proposed to set projected capacity by 2047 based on above envisaged projects works out to be about 23948 MW as summarised below:

Thus, the capacity buildup proposed by 2047 including present capacity, capacity under implementation and new capacity proposed is as follows:

Technology	Particulars	Capacity (MW)	
		Individual	Total
PHWRs, LWRs, BWRs	Present Capacity (19 PHWRs, 2 LWRs, 2BWRs)		8180
Indigenous Pressurized Heavy Water Reactor - 700 MW	Capacity under implementation (14 PHWRs) - target 2031-32	9800	23800
	Possible Capacity Addition		
	• Additional PHWRs (2X700 MW each) at existing sites of Kakrapar, Rajasthan, Narora	4200	

	• PHWRs at Bhimpur, M.P approved in principle (4X700)	2800	
	• Fleet of PHWRs at New Site	7000	
Light Water Reactors with International Collaboration	Capacity under implementation (4 LWRs) - target 2031-32	4000	21628
	Possible Capacity Addition		
	• LWRs at Jaitapur (6X1730MW)	10380	
	• LWRs at Kovvada (6X1208 MW)	7248	
Total			53608

3.7 Inputs required for the programme:

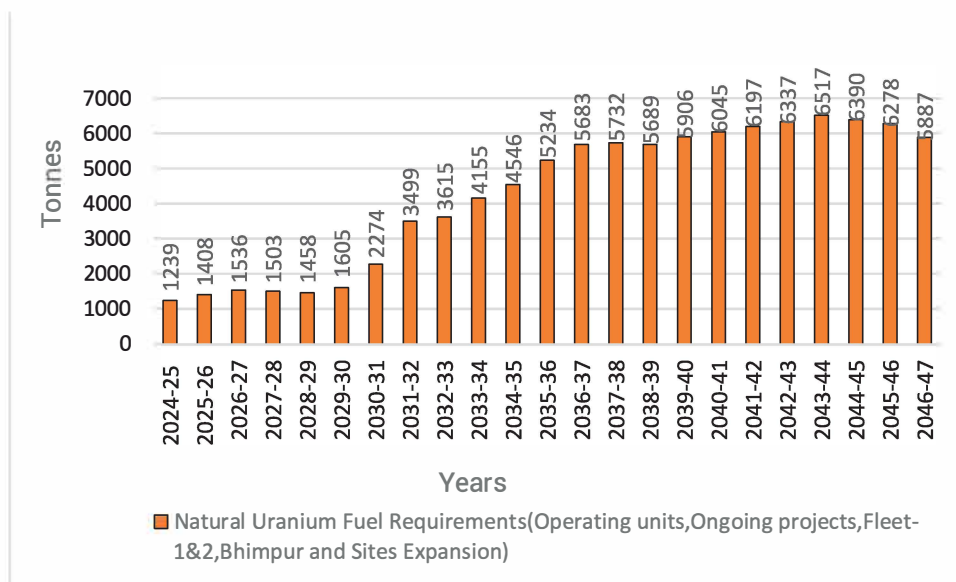
PHWRs:

Major Equipment & Components

32 PHWRs are tentatively to be implemented in the span of about next 20 years. Major long manufacturing cycle equipment and components include Primary Circulation Pumps (PCPs), Steam Generators, Calandria, End Shields, Reactors Headers, Pressurisers, Fuelling Machine etc. A large number of these equipment & components are to be manufactured and supplied in next 20 years progressively. In view of limited number of qualified indigenous vendors, manufacturing and timely supply of these items needs to be planned meticulously and mitigation measures to be evolved in advance to avoid any slippage in supplies. Advance procurement of these long delivery equipment and components are to be planned accordingly.

Fuel

PHWRs fuel require natural Uranium dioxide fuel (UO₂). Fuel requirement for operating PHWRs as per tentative implementation schedule is indicated below (PLF for operating units is considered at 90%):

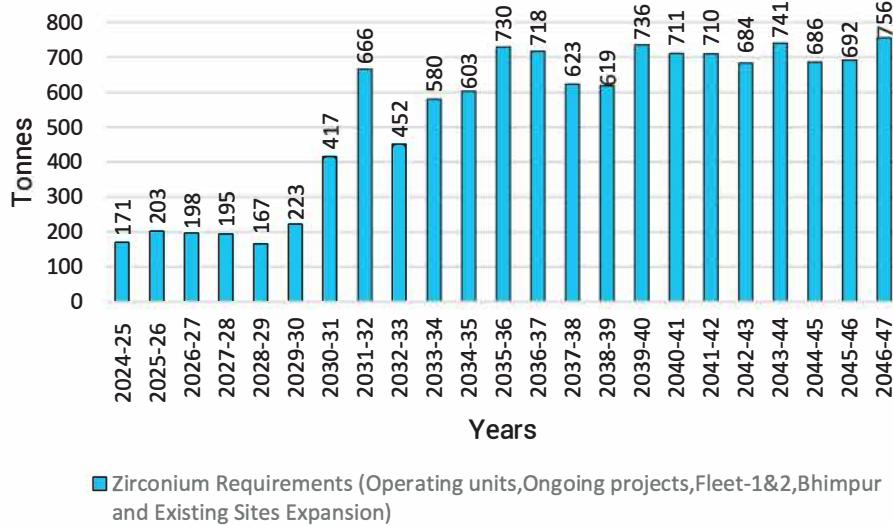


Total requirement up to 2047 works out to be about 98000 tonnes. As requirement of fuel quantity is huge, this is to be met by augmenting indigenous production as well as importing fuel through various routes like direct import, JV for uranium mining abroad, reprocessing of LWR spent fuel, exploring new fuel design etc. Fuel fabrication facility also needs to be matched accordingly. Uranium Corporation of India Limited and Nuclear Fuel Complex activities are to be planned accordingly.

Considering that this would be the most critical input for this entire programme, there is a definite need for creation of strategic reserve (may be for 5-10 years) pool, to mitigate the risk of unavailability of adequate fuel.

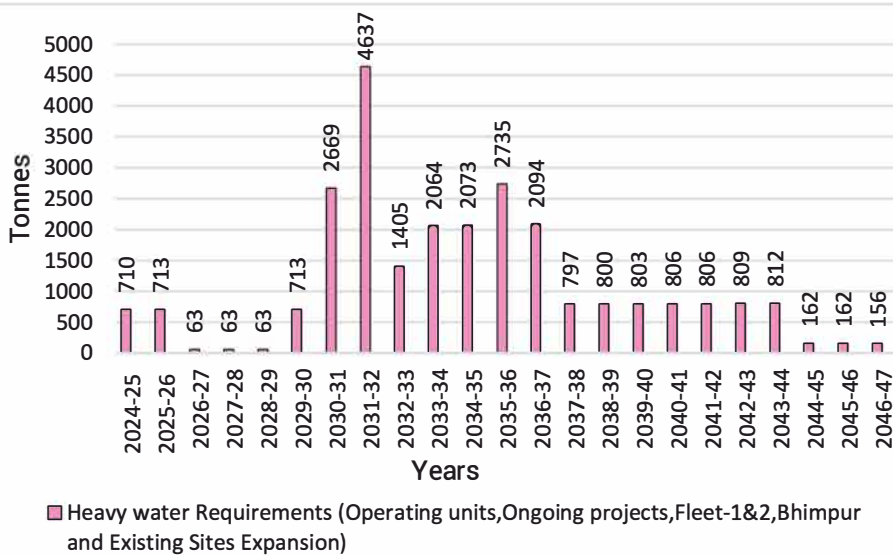
Zirconium

In PHWRs, Zirconium is required for structural material calandria tubes and coolant channels as well as for fuel cladding. Zr requirement for constructing and operating PHWRs as per tentative implementation schedule is indicated below (PLF for operating units is considered at 90%). Total requirement up to 2047 works out to be about 12000 tonnes.



Heavy Water

In PHWRs, Heavy Water (D_2O) is required as inventory for moderator system as well as for PHT system. D_2O requirement for initial inventory and make up during operation of PHWRs as per tentative implementation schedule is indicated below:



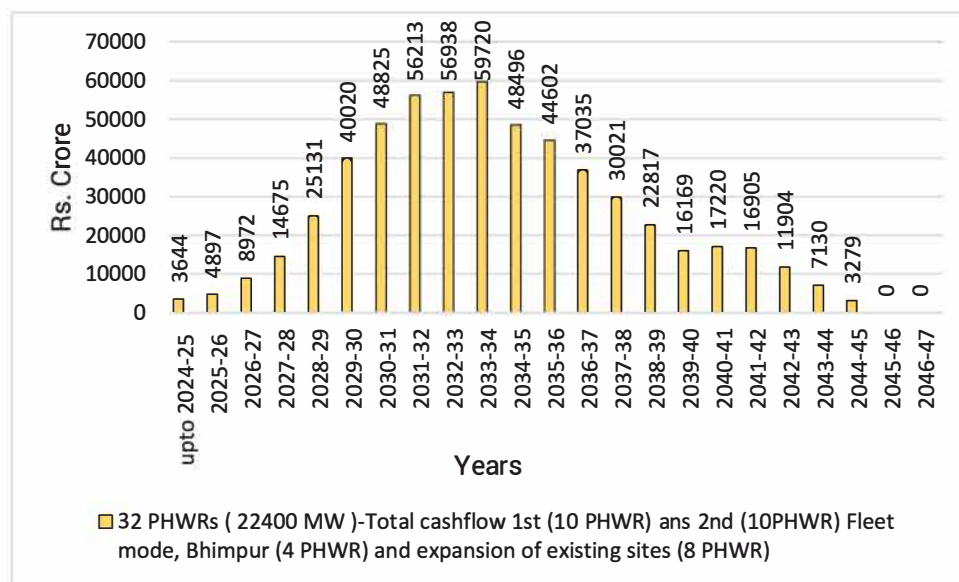
Total requirement up to 2047 works out to be about 26000 tonnes.

However, the accurate estimates and plans for Fuel & Heavy Water are being drawn up by the R&D units vertical.

3.8 Gross Estimated Outlay

In the implementation of nuclear power projects so far, project completion costs have been varying due to several factors including technological development, safety features, delay factors, financial factors etc. As per experience gained so far and considering present and future competitive environment for power sectors, it is envisaged that economy of nuclear power in terms of yearly tariff is going to play an important role. Base cost of nuclear power, thus, is going to be an important area to be optimised to meet the challenges of competitive environment. Considering this, on gross basis, projected cash flows have been worked considering base cost of 2x700 MW project at Rs.20000 Cr at 2024-25 price level. Based on this, economy of PHWRs may be sustainable with a reasonable return on equity. Cash flow is projected with above assumed base cost, interest rate @6.5% p.a., escalation @5% p.a. and Debt-Equity ratio 2:1. Total completion cost works out to be about Rs.5,75,000 Cr. which corresponds to be about Rs. 25 Cr per MW compared to about Rs. 16 Cr per MW for recently completed project KAPP-3&4.

However, these figures are indicative only and need to be fine-tuned considering prevailing several scenarios at the time of actual implementation of respective projects.



In addition to above, balance capital outlays for RAPP-7&8 and GHAVP-1&2 are to be met as per their latest revised cost estimates

LWR Inputs: The fuel and major components for LWRs are expected to be sourced through import in line with the detailed project proposals finalized. As regards cost and funding, these can be determined only on finalization of the project proposals. These will be finalized and the viable project proposals put up for consideration of the Government.

3.9 NPCIL Participation in BSR programme:

The goals for achieving Net Zero of various countries from 2050 to 2070 for addressing impacts of climate change have led to a series of measures to decarbonise the energy sector, particularly the hard to abate industries like steel, aluminium, metals, cement etc. Economic measures like proposed imposition of carbon border taxes on metal products have also brought a sense of urgency to the industry to decarbonise their manufacturing processes by switching to clean energy sources from fossil fuels predominantly coal.

Nuclear is a clean source of baseload electricity available 24X7. It has lifecycle carbon emissions comparable to that of renewables like hydro and wind. These attributes have made nuclear power an attractive candidate for industries wanting to make the switch from coal based captive power plants. This spurred an interest in Small Modular Reactors (SMR). While many SMR designs are still under development, the standard 220 MW Pressurised Heavy Water Reactors (PHWR) already in operation in the country were found to be an ideal solution for the purpose.

The standard 220 MW PHWR though not exactly modular, has a proven safety and generation performance record. Its design is being further upgraded with provision of a steel liner in the inner containment, electrical penetration assemblies, all Fukushima related upgrades and modifications in Instrumentation and Control systems to reduce the land requirement and make it deployable close to the industries for use as a captive power plant. This upgraded 220 MW PHWR is termed as Bharat Small Reactor (BSR).

The business models to enable private funding by the industries seeking these BSRs, within the existing legal framework have been explored and finalised. These are presently under consideration of the Government. The proposals being explored broadly envisage provision of land, cooling water and capital by the private entity, with the design and operation & maintenance by NPCIL (for a consideration). The private entity can have the right to use the electricity produced from such plants for its captive requirements. The construction and procurement of components and equipment could be by the private entity under supervision of NPCIL to ensure the design intent is fully met. The Fuel and Heavy Water, which are strategic materials will continue to be owned by the Government and leased to the entity for a consideration as is being done presently.

Finalising an optimum business model within the existing legal architecture, drafting a suitable Request for Proposal (RFP) in line with the finalised business model and obtaining the approvals of the Government of India for the same have been targeted for the near future. While the exact capacity of BSRs to be set up by 2047 remains to be assessed, it is expected that some capacity of the 42 GW more need by 2047 may come from BSRs.

3.10 Other Technologies:

In addition, Bhabha Atomic Research Centre (BARC) and Nuclear Power Corporation of India Limited (NPCIL) are also working on co-development of a 220 MW SMR based on Light Water Reactor (LWR) technology. It is proposed to use all the other elements of the BSR, with only replacement of the reactor core. Further, NPCIL also proposes to develop a large size Indian LWR in collaboration with BARC, taking off from the 220 MW LWR based SMR. NPCIL will take up other new reactor technologies developed indigenously in the commercial domain once their viability is established.

Hydrogen Production:

To seize the emerging business opportunities in production of Hydrogen from nuclear power, NPCIL has resolved to take enabling steps for entering into the business of clean Hydrogen generation from nuclear power at an appropriate time. In this context, to gain experience in

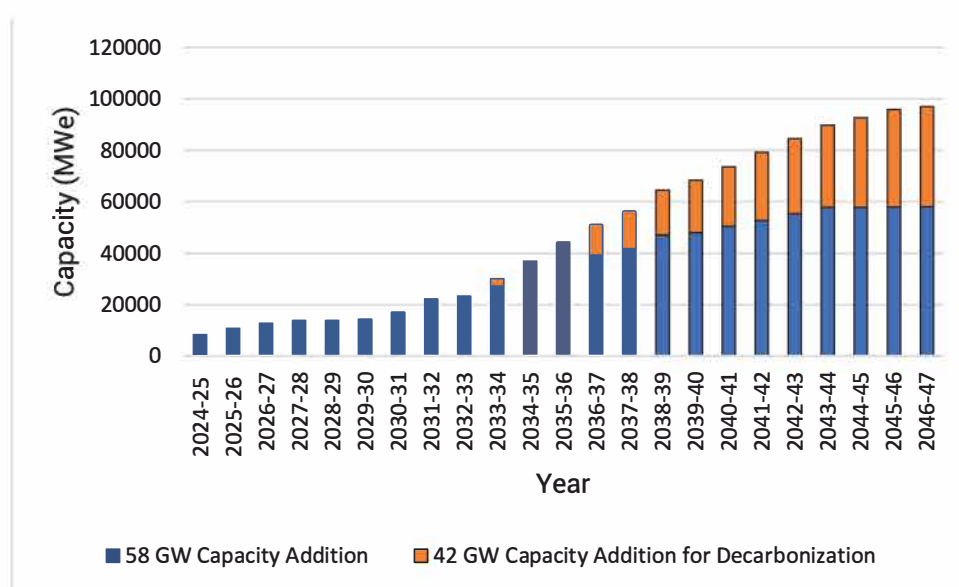
Hydrogen production and related aspects, NPCIL has set up small Hydrogen Generation Plants and associated systems with 10 Nm³ per hour capacity at Rawatbhata and Tarapur site, mainly to meet in house Hydrogen & Oxygen needs. NPCIL will consider commercially deploying Hydrogen producing reactors being developed by BARC or facilities using electrolysis at an appropriate time depending on evolving market scenarios.

Export of Reactors & Services:

NPCIL has potential to export PHWRs particularly the partially modular BSRs to countries requiring small reactors, particularly those new entrants to nuclear power. Indian PHWRs are among the most economical in the world and thus are competitive. NPCIL also has expertise in carrying out 'in core' jobs like Enmasse Coolant Channel Replacement, Enmasse Feeder Replacement, in core repairs and other Renovation and Modernisation, safety upgrades etc. These activities are carried out at costs that are very competitive. Thus, NPCIL can also export nuclear services, as and when opportunities emerge.

Capacity Buildup Vision:

Based on the doctrine of earliest possible start, availability of land, fuel and resolution of all other constraints / issues, the ambitions capacity addition for Vision Amrit Kaal (including capacity addition by BHAVINI) could be as follows:



4. Bharatiya Nabhikiya Vidyut Nigam (BHAVINI)

“To provide sustainable energy security to Nation”.

Bharatiya Nabhikiya Vidyut Nigam (BHAVINI) is mandated for the construction, commissioning and operation of Fast Reactors i.e. the second stage of the three-stage nuclear power programme. Department of Atomic Energy has the mandate for providing energy security to the nation by pursuing the three-stage programme for Nuclear Energy.

The first stage programme with a combination of Pressurised Heavy Water Reactors (PHWRs) and Light Water Reactors (LWRs) have reached a level of maturity. The fuel reprocessing technology for thermal reactor (PHWR) spent fuel has also been established. The reprocessing plants operating presently are giving satisfactory performance and are producing feed material required for the second stage programme.

The second stage programme envisages deployment of Fast Breeder Reactors (FBR) to increase nuclear power generation and thereby increase its share in total electricity generation, with better utilisation of uranium. This requires development of technology i.e. design of Sodium cooled fast reactors, associated fuel cycle and related technologies. Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam is the nodal agency for the development of Fast Reactor technology in the country and Bharatiya Nabhikiya Vidyut Nigam (BHAVINI) is mandated for the construction, commissioning and operation of Fast Reactors.

Large-scale thorium utilisation is envisaged in the third stage of Indian Nuclear Power Programme.

4.1 Prototype Fast Breeder Reactor (PFBR)

BHAVINI has constructed the 500 MWe Prototype Fast Breeder Reactor (PFBR) at Kalpakkam, Tamil Nadu and currently it is at advanced stage of integrated commissioning. The reactor assembly is boxed up and the major milestones of filling of 1150 tons of liquid sodium in the Main Vessel of the reactor, purification of the filled sodium along with Commissioning of Primary Sodium Pumps are completed. The secondary sodium loops are filled and secondary

sodium pumps are re-commissioned. All the four SGDHR loops are filled with sodium and commissioned. Currently, isothermal testing at higher temperature has been completed and the plant is poised towards fuel loading activities. Upon obtaining regulatory clearance, start of Fuel loading towards First Approach to Criticality will commence which will take about four months' time to complete. This will be followed by physics experiments and power operation.

Contribution of other DAE units towards FBR programme

IGCAR, Bhabha Atomic Research Centre (BARC), Nuclear Fuel Complex (NFC), Heavy Water Board (HWP) and BHAVINI are contributing significantly towards FBR programme.



PFBR

BARC is contributing towards the technology development, fissile material production, fabrication of fuel, development of alternate/ advanced fuel, special equipment, components, detectors etc. NFC is contributing in the programme by manufacturing core structural components e.g. cladding, hex-cans, other associated hardware, radial blanket fuel pins and assemblies of various types required for the reactor. Heavy Water Board (HWP) has been supplying enriched Boron carbide pellets for PFBR and has developed the process for nuclear grade sodium production for future FBRs. Requirements of solvents for reprocessing are being

met by HWB. Spent fuel discharged from PFBR will be processed in a co-located Fast Reactor Fuel Cycle Facility (FRFCF) at Kalpakkam, where all the activities of the fuel cycle such as Fuel reprocessing, Fuel fabrication and waste management will be carried out, thereby closing the fuel cycle of PFBR and enabling its sustained operation.

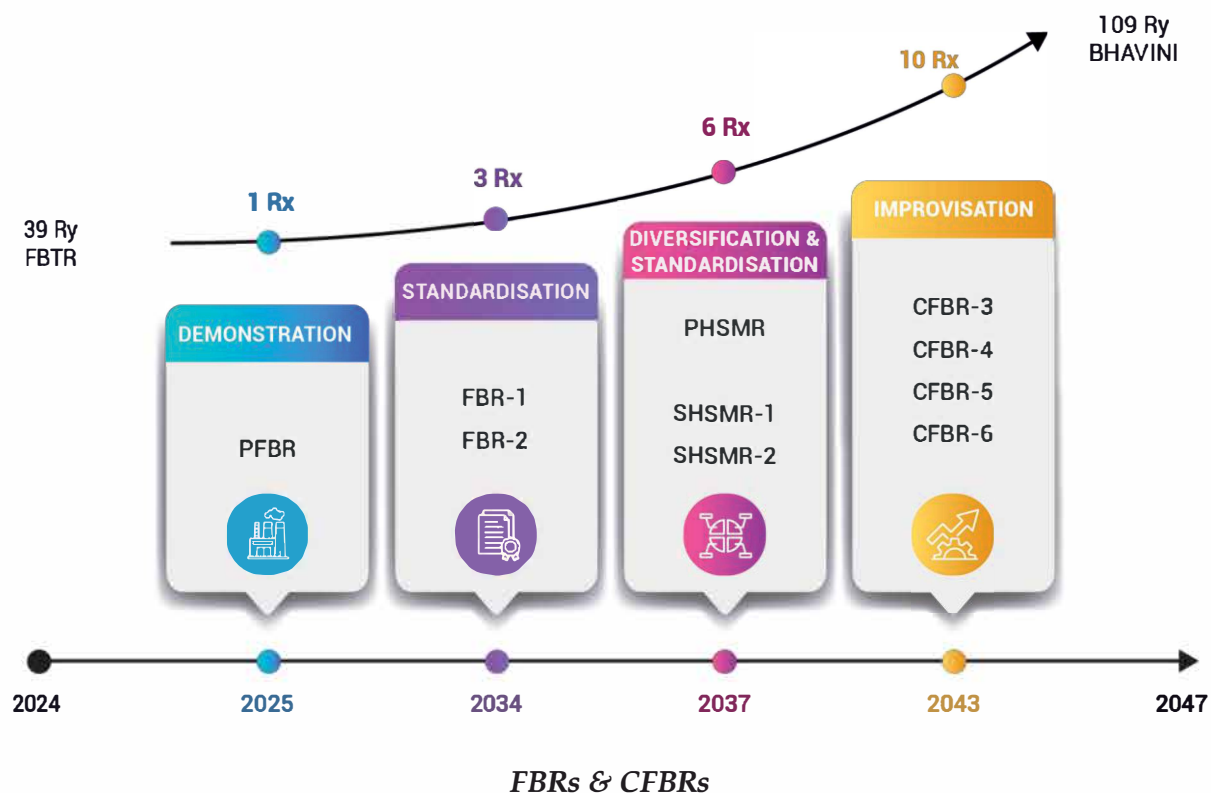
4.2 BHAVINI's Vision – 2047

BHAVINI proposes to make the Fast Reactor technology a mature, economical, sustainable and viable option for energy production by the year 2047. This requires deployment of oxide fuelled FBRs and setting up of fuel cycle facility to cater to the requirement of these reactors. PFBR will be operational in the end of 2025 in which full scale technology development and design validation of PFBR will be demonstrated.

Subsequently, construction of 6 FBRs of 500 MWe capacity (FBR 1 to 6) will be launched during next 20 years. FBR 1&2 will be launched by the year 2025 at Kalpakkam and the project will get completed by 2032-33 confirming the techno commercial viability of Sodium Cooled Fast Reactors.

First fleet of Commercial Fast Breeder Reactors (CFBR 3,4,5 & 6) and its fuel cycle facility (FRFCF-II) will be launched at a new site. Action for site selection will be initiated shortly. This site will also have a Prototype Hybrid Small Modular Reactor of 100 MWe capable of generating both electricity and Hydrogen by the year 2047.

The necessity of deployment of Fast Breeder Reactors was felt in the very early period by founding fathers of Indian nuclear programme. A decision was taken to set up a test reactor FBTR at Kalpakkam. The fuel proposed for this reactor was (U, Pu) O₂ mixed oxide (U enriched to 85%). To begin with, R&D work on MOX fuel for FBTR was initiated. However, because of non-availability of enriched Uranium, a Plutonium rich Mixed Carbide (U_{0.3}Pu_{0.7}) C was chosen as the driver fuel. This selection preceded extensive developmental work resulting in setting up of a Mixed Carbide fuel fabrication line at Radio-metallurgy Laboratory, RLG, BARC, Trombay.



FBTR is in operation since 1985 and serves as a test bed for irradiation of various fuels, structural materials, components, isotope production and other experiments. Short length PFBR fuel pins containing MOX fuel, sphere-pac fuel, in-core neutron detectors also have been tested. This reactor has given valuable operating experience of over 38 years. A large number of reactor physics and safety related engineering tests were also conducted. The training of operating personnel of PFBR has also been done in FBTR. FBTR has the potential to operate up to 2032 and beyond by carrying out life extension exercise.

The experience gained in the construction, commissioning & operation of FBTR including the focussed R&D programme on related technology e.g., fuel fabrication, cladding/hex-can manufacture, Enriched Boron Carbide production, Sodium handling etc. provided necessary confidence to launch the construction of Prototype Fast Breeder Reactor. Some of the critical equipment like Inclined Fuel Transfer Machine, neutron detectors have been developed by BARC. The fuel supplied for PFBR was manufactured by BARC at an industrial scale fuel fabrication plant, AFFF, Tarapur. The hardware for making fuel pins, manufacture of radial blanket pins, EBC pins, and manufacture of various types of sub-assemblies were done by

NFC. NFC will be able to meet the requirement of core structural components for future FBRs by setting up of new plants at Hyderabad and at a new site. IGCAR has designed 500 MWe PFBR (MoX fuel & Sodium cooled) and it is proposed to deploy 2 such reactors of same design (FBR 1 & 2) at Kalpakkam.

To accelerate the process of multiplying the power generation capacity with Fast Reactors, in comparison to MoX fuel, Metallic fuel (U-23Pu-6Zr) will be more viable with high breeding ratio (1.35-1.4) and low doubling time (9.4 y). Accordingly, the next four similar reactors (CFBR 3,4,5 & 6) with Metallic fuel are proposed to be setup in a new site with collocated Fast Reactor Fuel Reprocessing Facility (FRFCF II). These reactors are proposed to have Thorium as blanket and with advanced safety features meeting Gen-IV reactors.

4.2.1 Prototype Hybrid Small Modular Reactors & Standard Hybrid Small Modular Reactors (PHSMR & SHSMRs 1 & 2)

Prototype Hybrid Small Modular Reactors (PHSMRs) - with multitude of applications including electricity generation, grid integration of renewables, process heat, desalination and hydrogen production which supports de-carbonization of hard-to-abate sectors of the economy are opening up new avenues for deeper and accelerated adoption of nuclear technology. Among the many types of SMRs based on the basic nuclear technology employed in the design, the Sodium Fast Reactors (SFRs) has its own advantages of Plutonium & Minor Actinides burning, longer gap between refuelling due to excess reactivity margin and hydrogen production for decarbonised energy system due to its higher thermal efficiency. Accordingly, it is proposed to construct one 100 MWe PHSMR with SFR technology (for electricity generation & hydrogen production) at the new site that will be identified for constructing CFBRs (3,4,5 & 6). On successful operation of PHSMR for 12 months, two Standard Hybrid Small Modular Reactors (SHSMRs-1 & 2) of 100 MWe each will be constructed.

BARC is already involved in designing the SMRs. LMFRs with lower power production (<50MWe) and with a core life of 30 years operation without refuelling may also be compactly designed. In absence of refuelling requirement and eliminating rotatable plugs & fuel

handling machines will make the reactor more compact in its size and may also prove economical.

4.2.2 Hydrogen Production in PHSMR & SHSMRs

Hydrogen is expected to play important roles in decarbonised energy systems, as an energy source as well as a storage vector to enhance power system flexibility. However, hydrogen is not a primary energy resource and has to be produced using different chemical processes. Compared to conventional Steam Methane Reforming, water electrolysis method, is the cleanest way to produce hydrogen, provided it uses a decarbonised electricity source. Fast Reactor with its higher thermal efficiency would be a viable source for hydrogen production with the later method by water electrolysis.

Important milestones

Facility/ Plant	Site	Start of construction	Commercial operation
FBR-1 (500 MWe)	Kalpakkam	2026	2033
FBR-2 (500 MWe)	Kalpakkam	2026	2034
CFBR-3 (500 MWe)	New site	2033	2041
CFBR-4 (500 MWe)	New site	2033	2042
CFBR-5 (500 MWe)	New site	2034	2042
CFBR-6 (500 MWe)	New site	2034	2043
PHSMR (100 MWe)	New site	2030	2033
SHSMRs-1 (100 MWe)	New site	2033	2036
SHSMRs- 2 (100 MWe)	New site	2033	2036

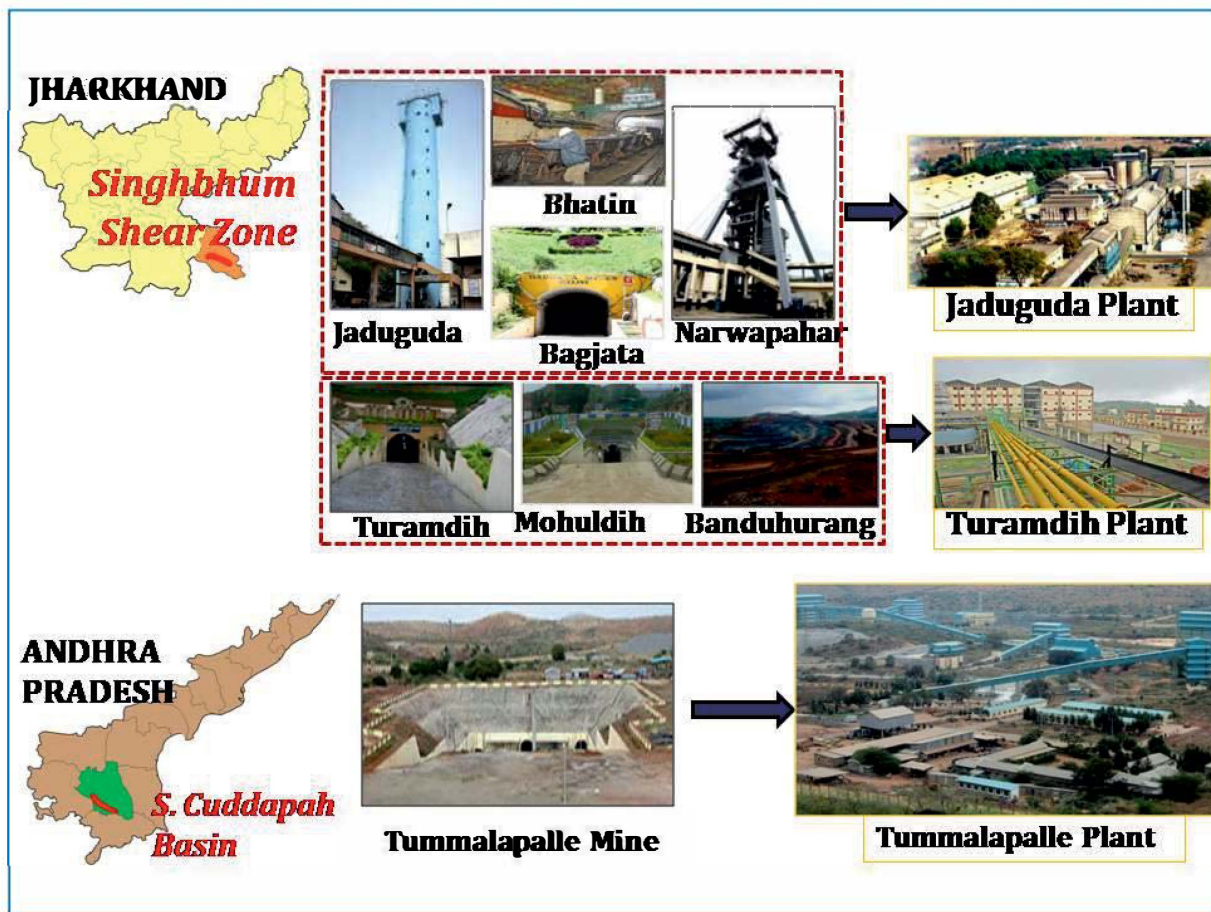
4.3 Conclusion and way forward

The fast reactor programme with closed fuel cycle will increase the nuclear power production capability from our limited uranium resources. Fast breeder reactors will produce sufficient fissile material to support a greater number of FBRs. In due course of time, these FBRs will produce sufficient fissile material to launch the third stage nuclear power programme based on Thorium. Due to SFRs advantages of compact size, longer refuelling interval and other favourable factors, this technology is more viable for constructing SMRs. Additionally, as the FBRs operate at higher thermal efficiency compared to other reactors (PHWR, LWR), it will be more efficient to utilise the heat for hydrogen generation along with electricity generation in Prototype & Standard Hybrid Small Modular Reactors (PHSMR & SHSMRs). The site required for setting up of CFBR 3,4,5 & 6 along with co-located reprocessing plant will be explored either in a coastal site or in an inland site with adequate water supply facility. Construction of FBTR-II with metallic fuel and establishing the reprocessing (Metallic & Thorium) at the earliest will accelerate the usage of Metallic fuel & Thorium blankets in commercial FBRs towards expansion of FBR programme. Similarly, freezing the design & obtaining regulatory clearance of Fast Reactor based SMRs at the earliest will enable the modularisation required for construction of SMRs at minimum time. Accordingly, the existing supply chain may be sensitised and new vendors would be developed for supply of the components in time for the expansion programme. Currently, BHAVINI is constructing the PFBR and planned to construct FBR 1 & 2 with similar specifications as designed by IGCAR. The construction, operation & maintenance experience of these reactors will pave way for a good designer for future FBRs.

5. Uranium Corporation of India Limited – UCIL

“To constantly strive to develop and implement a technology suitable for mining and processing of uranium ore at a competitive cost and to diversify towards mining, tunnelling and process related consultancy and other project implementation ventures.”

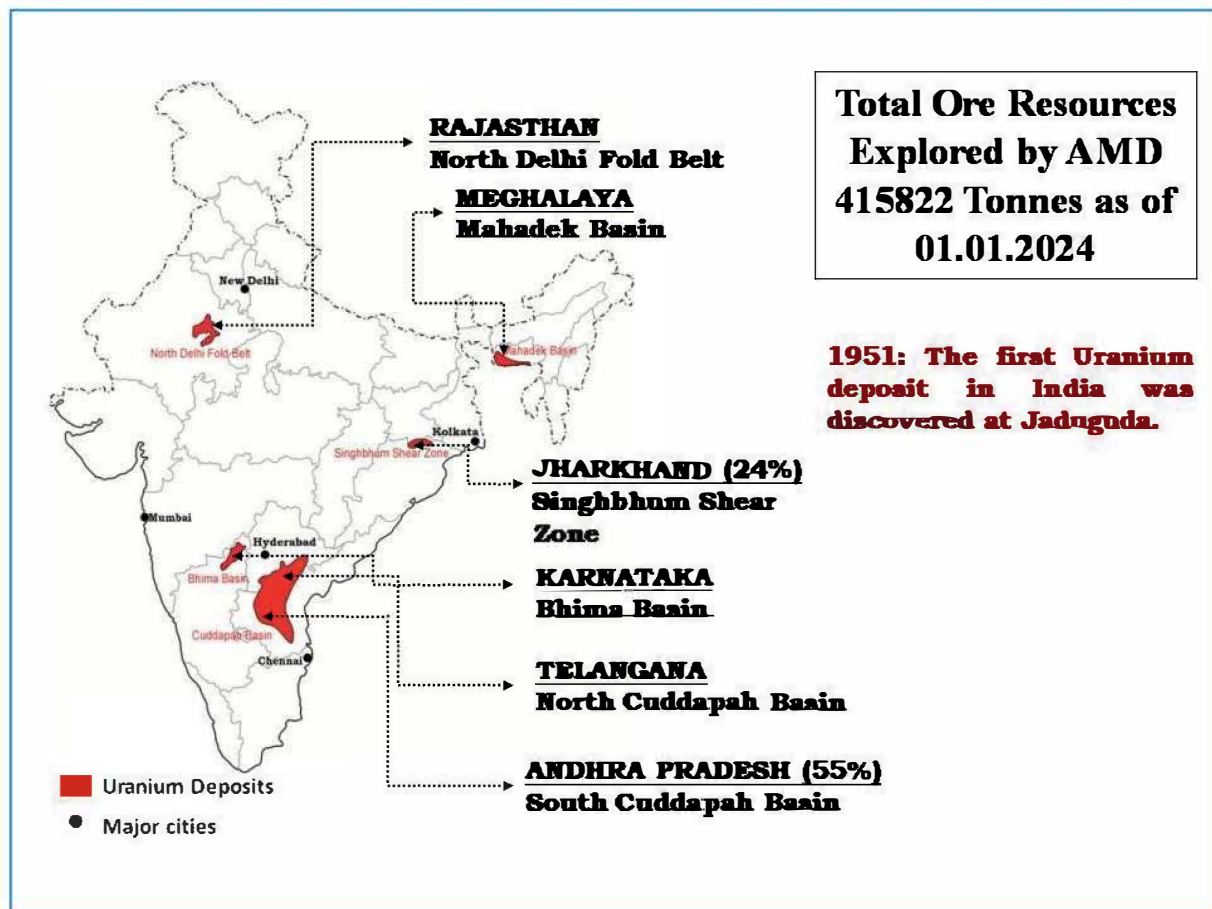
Uranium Corporation of India Limited (UCIL), established on October 16, 1967, is the only uranium mining company in India and has over the years excelled in various fronts with technological advancements in all areas of its operations. Practices of uranium mining, processing and waste management adopted by UCIL are under continuous up-gradation and are in line with eco-friendly global best practices. As of now, UCIL operates six underground mines (Bagjata, Jaduguda, Bhatin, Narwapahar, Turamdih and Mohuldih) and one open pit mine (Banduhurang) in the Singhbhum shear zone in the State of Jharkhand. Ore produced from these mines are processed in two process plants located at Jaduguda and Turamdih in the same region. UCIL is operating a large underground mine and process plant (based on a new indigenous alkaline technology) in Proterozoic Cuddapah basin at Tummalapalle, YSR District in Andhra Pradesh.



Operations in Jharkhand and Andhra Pradesh

In order to cater the fuel requirements of upcoming reactors, Atomic Energy Commission has accorded in principle approval for 13 projects which includes capacity expansion of some of its existing units as well as for establishing new projects in various parts of the country. In line with DAE's requirement, UCIL has already outlined a plan for massive expansion which includes maintaining sustained supply from existing facilities, modernization and capacity expansion of some existing units and construction of new production facilities (mines and plants) in different parts of the country.

Indian uranium deposits are small to medium tonnage deep seated deposits and are low grade compared to international deposits. Due to the extremely poor grade of Uranium, cost of mining and processing of Indian uranium bearing ores is higher than international uranium price. Presently, uranium pricing is administered on a cost-plus basis by the Department of Atomic Energy in consultation with Chief Advisor Cost, Department of Expenditure, Ministry of Finance.



Total Ore Resources as of 1st January 2024

5.1 Present status and future plan

Domestic Sources:

The existing production centres of uranium concentrates at Jaduguda, Turamdih and Tummalapalle, in the states of Jharkhand and Andhra Pradesh, may continue to produce at the existing rate i.e., about 7500 Tons per day (TPD) as additional resources have been discovered within the leasehold areas and also in the adjoining areas. The opening up of the deposits in next 10 years (T_0+10) in the adjoining areas will contribute to increase the existing production capacity from 7500 TPD to over 20000 TPD.

UCIL has initiated pre-project activities to open up new green field projects in other states, viz. Rohil in Rajasthan, Kannampalle in Andhra Pradesh, Gogi and Kanchankayi in Karnataka,

and Jajawal in Chhattisgarh. UCIL will endeavour to open up deposits in Meghalaya and Telangana as and when a favourable atmosphere for the same prevails. The opening up of these new deposits will contribute to increase the production capacity more than two-fold in the next 25 years.

If the planned projects of UCIL turn into production centres, the additional quantity of Uranium concentrate (Yellow Cake) can contribute significantly to the fuel requirement of the upcoming reactors of NPCIL in next 10 to 15 years subject to the obtaining of statutory clearances.

5.2 Plan for Expansion up to 2047

Up to 2032	2032-2047
Rohil Project (2500 TPD)	Lambapur & Peddagattu
Tummalapalle Expansion (1500 TPD)	Chitrial Project
Kanampalle (6000TPD)	Kanampalle Expansion (6000 TPD)
Gogi (500 TPD)	RKPL East Deposit (6000 TPD)
Kanchankayi (400 TPD)	KPM Project
Jajawal (450 TPD)	More new projects based on discoveries by AMD
Banadungri (1500 TPD)	
Garadih (500 TPD)	

5.3 Import potential with JV abroad for mining

UCIL, in addition to developing domestic resources, is also putting efforts to increase production capacity over the next 10 years from international expansion by forming a JV with a suitable strategic partner to meet the fuel requirement of reactors (12nos.) proposed under DAE safe guards. With respect to identification of suitable assets for acquisition of uranium

resources in overseas countries, responses from leading uranium producing companies against floated RFI have been received and due diligence of data is in process. As the next step, an EOI to onboard a reputed Indian firm as a strategic partner to identify/ shortlist firms having the financial and technical capacity to develop and operate overseas uranium assets in partnership with UCIL was floated and the responses received are being evaluated.

5.4 Challenges

Uranium production in the country has always been subjected to various challenges.

- The uranium deposits discovered by AMD over last six decades are of low to medium grade, small in tonnage and also complex in nature (deep seated).
- The country's largest uranium deposit discovered by AMD in the year 1987 in the Proterozoic Cuddapah basin is at Tummalapalle, Andhra Pradesh. This deposit is hosted by carbonate rock having two lodes i.e. Hang wall lode and Footwall lode. The major uranium resources are lying in Hang wall lode. Due to the presence of water bearing weak strata/ rock (Red Shale), the mining of hang wall lode has several issues. The support issues related to mining of hang wall lode have been overcome with intensive scientific studies and mining of hang wall lode is also now being done.
- Also, for the first time in the country, the alkaline processing technology developed by a joint team of BARC, AMD and UCIL was adopted for Tummalapalle plant. However, due to constraints in settling & filtration characteristics of product precipitate, the plant could not achieve its desired capacity. Subsequently, upon detailed research and on-site modifications, the issues were resolved by installing Re-dissolution System facility and plant could start achieving its desired capacity.

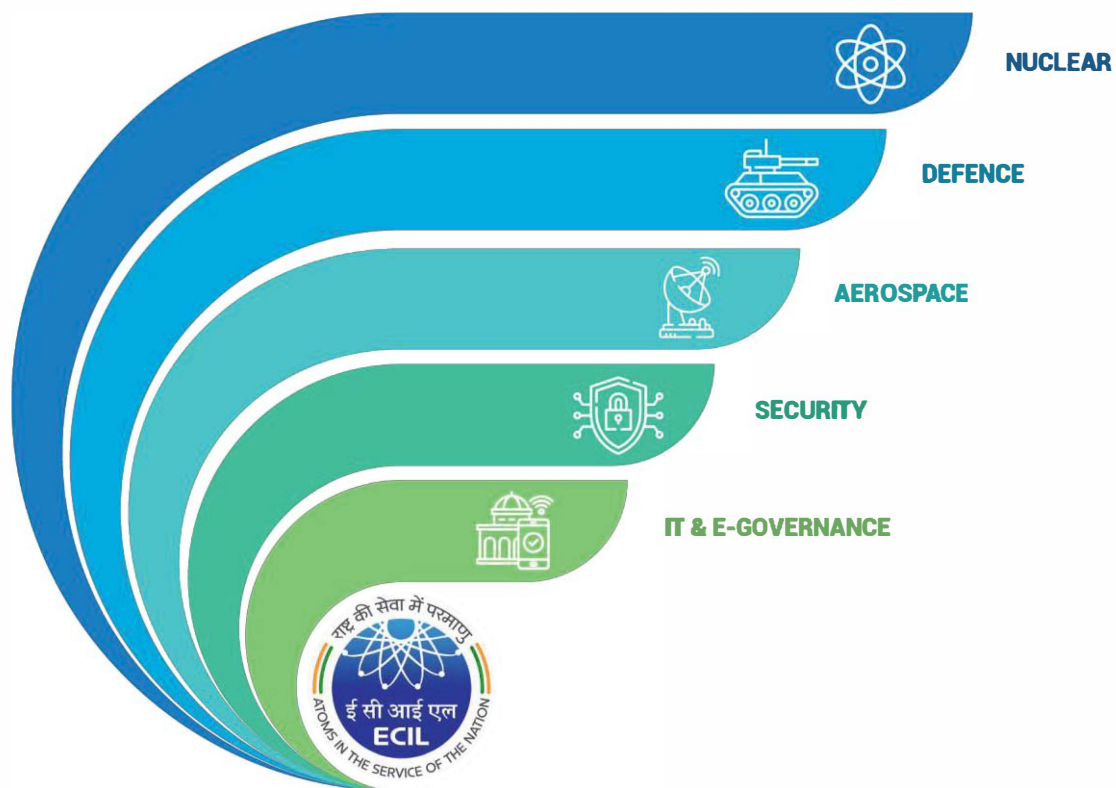
5.5 Conclusion and way forward

Mining of uranium ore from the mines in Jharkhand region is carried out from deeper levels as the ore reserves in the upper levels have almost depleted. In view of this, scope for increasing the production from existing mines in Jharkhand is very less. However, UCIL will continue the operations in Jharkhand & AP at 100% capacity. As setting up of a green-field project often involves acquisition of substantial land from local population, UCIL would acquire the requisite land as per its and resettlement Policy. MOUs/Joint venture with State government, mining PSUs for undertaking mining operations may be initiated. Further, in order to cater any shortfall in production of uranium concentrate to fuel the reactors under domestic safeguards, it is proposed to form a Joint Venture with NPCIL & NTPC to acquire the overseas mines as NTPC has an ambitious plan to venture non-fossil fuel generation to achieve the net zero targets by 2070.

6. Electronics Corporation of India Limited (ECIL)

“To contribute to the country in achieving self-reliance in strategic electronics.”

The genesis of Electronics Corporation of India Limited (ECIL) can be traced back to the work undertaken at the Electronics Production Division, Reactor Controls Division, and Computers Group of the Atomic Energy Establishment, Trombay (AEET) since its inception. By the late 1960s, AEET had a significant electronic group, wherein research and development were carried out on silicon crystal, compound semiconductors, ceramics, transistors, diodes, carbon resistors, metal-film resistors, and tantalum capacitors. Additionally, analog and digital computer modules were manufactured and successfully tested. Recognizing the nascent state of the electronics industry in India and its anticipated future requirements, a need was felt to establish an independent entity dedicated to Nuclear Electronic Instruments/systems and Electronic Components.



FOCUS ON HIGH TECHNOLOGY & LOW VOLUME **PROJECTS OF NATIONAL IMPORTANCE**
MULTI-PRODUCT MANUFACTURING / PROJECTS WITH LONG GESTATION PERIODS
 CONTRIBUTIONS TO MAJOR INTERNATIONAL **DISCOVERY SCIENCE PROGRAMMES**

Against this backdrop, Electronics Corporation of India Ltd a Schedule- 'A' CPSE under the Department of Atomic Energy was established in April 1967 with the main objective of meeting the requirements of nuclear electronic instruments & systems, nuclear detectors & monitoring systems for Nuclear Power Programme of the country. ECIL has since expanded and diversified into a multi-product, multi-disciplinary and multi-technology organisation providing cutting-edge technology solutions of national importance in Defence, Aerospace, Security, IT & e-Governance sectors besides meeting the core mandate of DAE requirements in nuclear sector.

ECIL pioneered the development of a number of products in India earning it the name and fame as the torch-bearer of Electronics and IT revolution in the country. These products include Black & White TV, Digital Computers, Control and Instrumentation products for Nuclear Power Plants, Automatic Message Switching Systems, Programmable Logic Controllers and Electronic Voting Machines.

Subsequent to the shock of opening up the Indian market for imports during 90's, the company has consciously moved in to projects from products leveraging its multidisciplinary and system integration competencies.

Meanwhile, the outside environment in which ECIL is operating is also undergoing fundamental changes. The Nuclear energy sector is poised for rapid growth. This program will be supported by reprocessing plants and fuel fabrication facilities all of which have a substantial C&I component. This would mean substantial business of C&I equipment over the coming decades. These open up unprecedented opportunities to ECIL – the only fully integrated nuclear C&I company in the country. It also brings in foreign players and increased competition. Similar far-reaching changes are underway in the domestic defence and aerospace electronics sector. Homeland security and information security domains too are set to grow.

ECIL's state-of-the-art infrastructure, manufacturing and quality systems meet all the requirements of products for Defence, Nuclear and Space. The infrastructure includes facilities for CAD, ASIC/VLSI design, Hybrid Microcircuits and PCB manufacture, High Density Interconnect facility, Automatic SMD Insertion Machines, On-line PCB Test Equipment,

Secure Manufacturing Facility, calibration and characterization of Radiation Instruments, Compact Antenna Test Range facility, Seeker and C4I systems manufacturing facility, SSRFPA facility, Environmental Testing, Calibration Laboratories and EMI/EMC Test facility.

All the business divisions of ECIL are certified for ISO 9001:2015 Quality Management System and the company is certified for ISO 14001:2015 Environmental Management System and ISO 45001:2018 for Occupational Health and Safety.

The typical business operations of ECIL today involve large, one-of-a-kind projects with long execution periods, high technology content, substantial R&D effort with attendant uncertainties. Most importantly these projects demand a different set of skills and competencies- business development, order booking, system engineering, project management and sub-contracting.

As per Department of Public Enterprises (DPE) guidelines, the Company is grouped in the sectorial category of “Multiproduct manufacturing with long gestation period”. The other PSU’s in the sector include 9 Defence PSUs (BEL, BDL, MIDHANI, MDL, HSL, GRSE, HAL, BEML & GSL), BHEL, HMT Machine Tools under Heavy Industry category and Cochin Shipyard Limited.

6.1 Electronics & Instrumentation (E&I) for Nuclear Sectors

ECIL’s products and capabilities in the nuclear sector span components to systems, all plants of nuclear fuel cycle and C&I systems for every type of nuclear power plant in India (PHWR, FBR, PWR). For all the standard products, ECIL provides life cycle support services from consultancy through design, engineering, manufacturing, qualification, I&C, AMC and refurbishment. The products exemplify a range of capabilities for engineering custom solutions with large indigenous content.

The technology and products developed by ECIL have contributed to the advancement of the country's nuclear power programme which includes a wide range of devices and systems for

reactor safety, regulation, radiation monitoring and environmental protection. The key contributions/projects executed are highlighted below: -

- Starting from the design and development of control systems for the Apsara Reactor, the C&I package for all the operating Nuclear Power reactors in the country (except RAPS-1, supplied by Canada and TAPS-1&2 - supplied by USA) were designed by BARC/NPCIL and supplied by ECIL, establishing self-reliance and self-sufficiency in this regard. The restrictions placed and the sanctions imposed on India after the Pokhran Experiments have had minimal impact on this product stream of ECIL. The synergic relationship between BARC-NPCIL-ECIL has been consistently strong and the same is getting extended to IGCAR and BHAVINI in a significant measure
- The products manufactured by ECIL ensure the safe and reliable operations of Indian Pressurized Heavy Water Reactors (PWHRs). This includes systems for reactor control & protection, fuel handling controls and main & emergency air lock systems, among others.
- Utilizing BARC's technology expertise, ECIL has consistently supplied a range of radiation detectors for DAE's nuclear power program for over four decades to use in critical applications like "Start-up," "Reactor Protection," Reactor Power Regulation and Effluents & Area Monitoring systems in Nuclear Power Reactors.
- Reactor instrumentation systems like Neutron Flux mapping system, Neutronic channels, Delayed Neutronic systems etc. were supplied to nuclear power plants, designed to monitor and control various aspects of reactor operation. These systems provide essential data to operators, enabling them to maintain safe and efficient operation of the reactor.
- Different types of radiation monitors were supplied to all nuclear power plants and Reprocessing plants to maintain safe operations, complying with regulatory requirements, and protecting human health and the environment from the potential hazards associated with ionizing radiation.
- Various Health Physics systems supplied assess the radiation exposure levels, identifying potential hazards and implementing necessary measures to mitigate risks to both human health and the environment.

- Instrumentation systems were supplied to nuclear power plants, reprocessing plants and other DAE establishments for fuel handling and nuclear waste handling, treatment, storage, and disposal of radioactive waste generated from various nuclear activities, including nuclear power generation, medical applications, research, and industrial processes.
- ECIL with the technical support of BARC has played a pivotal role in advancing nuclear technology for FBR by supplying precise Control and Instrumentation (C&I) systems for the Prototype Fast Breeder Reactor (PFBR) at Kalpakkam.
- ECIL has undertaken upgrades for various power plants including NAPP-1&2, RAPP-3 to 6, KAIGA-1 to 4, TAPP-3 & 4, and KAPP-1&2.
- Developed new products such as Passive Catalytic Recombiner Devices and Hydrogen Steam Concentration Monitoring System for KAPP-3&4.
- ECIL has also supplied Radiation detection equipment to all Seaports & Airports to prevent illegal flow of nuclear materials in either direction.

The company continues to innovate and supply new products to further enhance the safety and performance of nuclear power plants in India.

6.1.1 Current Projects

The key ongoing activities with regards to Electronics and Instrumentation are appended below: -

- 2x1000 MW Advanced Light Water Reactor at NPCIL, KKNPP-1&2, Kudankulam.
- I&C of entire control instrumentation encompassing erection of 400 main control room panels, 1600 signal processing & I/O cabinets, 1100 local control panels, 2500 junction boxes, calibration and installation of 20,000 process field instruments, 1000 instrument racks, 250 km field routing and cabling, 23 lakhs wire termination etc.

- Commissioning of 10 types of communication systems to ensure routine and emergency communication within the plant.
- Commissioning of Automated Radiation Monitoring System
- Fire alarm system for the entire plant having about 14000 sensors and associated controllers. TPTS(DCS) panels, ULCS workstations & networking, RCD and ESFAS cabinets, reactor protection system etc.
- Total plant Security & Access control system which includes Turnstyle gates, hand geometry readers, control units, control software, about 300 cameras, 60 microwave detectors, 200 intrusion detectors, 250 contact condition monitoring sensors & associated controllers, distress alarm system, guard tour monitoring system, x-ray baggage scanners, Campus-wide fiber optic networking etc.
- Replacement of Russian-supplied delicate HCS fiber optic cables with indigenously customized HCS cables for better pull strength and communication between ESFAS & MCR. Also, review of voluminous Russian drawings & documents for preparation of terminal lists, procedures for erection etc.
- Automated radiation monitoring systems, Fire alarm systems and Access control system are under AMC.
- 1x500 MW Prototype Fast Breeder Reactor at Bhavini, Kalpakkam
- Design, engineering, supply, installation and commissioning of control instrumentation, sodium leak & level detectors, radiation monitoring system and Neutronic instrumentation on EPC basis meeting NPP Quality requirements.
- Main control room panels, 170 signal processing cabinets, 64 remote terminal units, 300 junction boxes, 500 km field cabling, 153 radiation monitors, 60 neutron detectors etc., 200 km fibre optic cabling & networking, PLC based local control panels for fuel handling machine operation etc.

- Automated Radiation Monitoring System (ARMS) for KKNPP-3&4, Kudamkulam. The System is designed and developed for the KKNPP-3&4 radiation safety assurance by means of on-line receiving and processing of the data of the plant parameters, which characterize the NPP radiation condition on all modes of operation including design-basis and beyond design-basis accidents.
- SCADA and Radiation monitors for FRFCF.
- Comprehensive AMC for full scope Simulator for operator training at Bhavini and scaled-down simulator for software testing installed at IGCAR.
- AMC of C&I Systems for TAPS 3&4, KGS 1 to 4, RAPS 3 to 6.
- AMC of NPCNET VSAT communication system for 15 Nuclear Power Plant Sites.
- Various Radiation monitoring systems supplied to FRFCF, Kalpakkam and INRP Tarapur
- Nuclear instrumentation and Radiation Monitoring Systems were supplied to various research reactors of BARC and laboratories of IGCAR.

6.1.2 Near-Term Opportunities

Working together with BARC and NPCIL over the past five decades, ECIL has gained specialized knowledge and expertise in the nuclear domain and has established advanced infrastructure for the production, testing, and quality assurance of these systems. The collaboration between ECIL and NPCIL includes design, development, manufacture, supply, installation, and commissioning of control systems, as well as life cycle support including technology obsolescence management.

The opportunities as envisaged by ECIL include -

- Engineering, manufacture, qualification, test, supply, installation and commissioning of the Control & Instrumentation (C&I) equipment for the operating as well as upcoming indigenous and Nuclear Power Plants established under foreign collaboration. The major

equipment includes Main Control Room and Control Equipment Room, Radiation Detectors, Nuclear Instrumentation systems, Radiation Monitoring Systems, Field Instrumentation, Industrial Systems, Simulators for operator training and Security Solutions which includes Physical Protection System, Intrusion detection system, CCTV surveillance system, Access control system, Time & Attendance System & Visitor Management System.

- Design, manufacture, testing, supply, installation and commissioning of Training simulator system and procurement of Simulation Tools for the upcoming indigenous and imported plants.
- Participation in Installation and Commissioning of C&I systems for imported reactors and contribution to gradual indigenisation of these reactors.
- Development Cum Production Partner (DCPP) for futuristic requirements to meet requirements of indigenisation and in-service inspection requirement of NPP including requirements arising from Small Modular Reactors (SMRs).
- Maintenance services under AMC for equipment including the Control Room, environmental monitoring systems, industrial systems, field instruments, simulator systems, integrated security systems, IT and Communication Systems and all mutually agreed upon equipment at the NPPs.

The business opportunities stem from the projected expansion in the Nuclear Power Program, opening up of domestic nuclear power sector for international commerce, the strategic nuclear program including propulsion systems, planned construction of new fuel processing plants, fuel fabrication plants and anticipated contribution to international mega science projects such as ITER and FAIR.

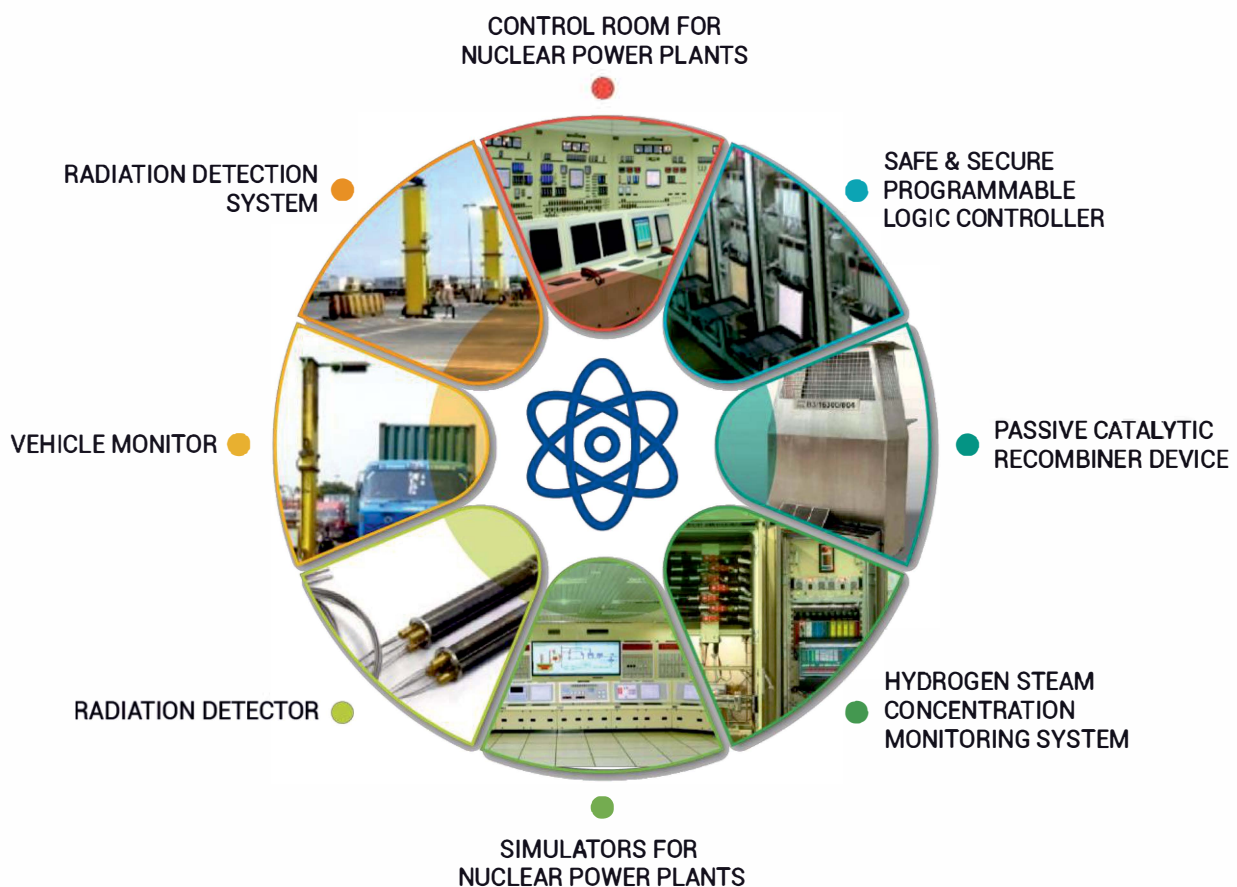
6.1.3 Projected E&I demand as per Vision 2047

The commitments of Government of India towards 'Net zero' highlights the importance of collaboration and innovation in the Nuclear power sector, as well as the potential for

significant contributions to India's energy landscape and the global goals for clean energy. Based on the Projected E&I demand emanating from requirements of NPCIL, BHAVINI, Nuclear Recycling Board (NRB) and other activities being undertaken by ECIL in the nuclear domain. The vision of nuclear vertical is summarized in succeeding paragraphs.

6.2 Nuclear Vertical

All the indigenously built nuclear power plants and reactors across the country have the vital Instrumentation and Control (I&C) systems engineered & manufactured by ECIL. ECIL's foot print of I&C systems span diverse reactor technologies and the entire nuclear fuel cycle - pressurized heavy water reactors (PHWR), fast breeder reactors (FBR), compact light water reactors (LWR) and reprocessing plants. All of these I&C systems are based on indigenous system designs.



Nuclear Vertical

The control and automation products which ensure safe and reliable operation of Indian PHWRs include reactor control systems, fuel handling controls, primary and secondary shutdown systems, power supplies, computerized operator information systems and full scope replica simulators. ECIL also develops, manufactures and supplies full range of radiation detectors and nuclear instruments for protection, control, health & environmental monitoring. These include self-powered neutron detectors, uncompensated ion chambers, radiation monitoring systems, health physics instruments etc.

ECIL has commissioned several supervisory control and data acquisition (SCADA) systems for nuclear, oil and gas sector as well as for power management. ECIL is also supplying radiation detection equipment to all seaports and airports to prevent illegal flow of nuclear material.

The yearly revenue of the Nuclear Vertical during the last decade was in the range of Rs 250 Crores to Rs 460 Crore.

The key identified business opportunities, technologies and products to meet the future requirements of Nuclear Sector is tabulated below.

Business Opportunities
• Control & Instrumentation (C&I) systems for Pressurised Heavy Water Reactors • C&I systems for Fast Breeder Reactors • Radiation Detectors for upcoming Reactors • Reactor instrumentation systems for upcoming Reactors • Nuclear and Radiation Monitoring systems for LWRs with foreign collaborations • Electronic equipment for Compact Reactors • Radiation Instruments for reprocessing plants for Nuclear Recycle Board • Control and Instrumentation systems for primary and secondary plants of nuclear submarines • Radiation Detection Equipment for Homeland security • Health Physics instrumentation • SCADA systems for Power, Steel, Oil and Gas sectors

- Training Simulators
- Power Electronics for Discovery Science Programs
- Medical applications

Thrust areas/Product

- Development of new generation Secure PLC, Programmable Logic Controller
- Conventional C&I Systems
- High Sensitivity Neutron Detectors, High range and high energy Gamma Detectors
- Next generation neutronic channels: Delayed Neutron Channels, Pulse Safety Channel, Power Pulse Safety Channel, Wide Range Control Channel, Campbell Safety Channel, Reactivity Safety Channel, Reactivity Control Channel, P/Q Channel, Counting channel etc
- Trip Logic Unit, Portable Tritium in Air Monitor, Gamma Spectroscopic instruments, Low Activity Alpha/Beta Monitor, Low Energy gamma monitors, Iodine-121 monitor
- Nuclear and Radiation monitors of various ranges and sensitivities scaled to compact reactor specifications.
- Compact Alpha/Beta Continuous Air Monitors, Radon Monitor, Nuclear Waste Monitoring.
- Radiation and Gas Monitoring Systems
- Nuclear Radiation detection systems for sea ports and airports, Isotope identifiers
- Whole body monitors, Wireless dosimeters
- Accident Mitigation systems for Nuclear Power Plants
- Distributed Digital Control Systems, Supervisory Control and Data Acquisition Systems
- High Voltage Power Converters
- Simulators
- Medical Equipment based on
 - LINAC technology
 - Cyclotron

Future outlook

The government has taken several measures to expedite expansion of nuclear power generation in the country and to fast-track India's domestic nuclear power programme. It has accorded approval for setting up NPPs in fleet mode. To mitigate carbon emissions by 2070, several large sectors, including the steel industry, are considering nuclear power as a viable alternative to power generation. Discussions on Small Modular Reactors (SMRs) are gaining momentum in the country. The company is actively pursuing the opportunities arising from the new NPPs whilst continuing to support the infield systems supplied to various NPPs. The C&I requirement for the upcoming Nuclear Reactors and ongoing up-gradations gives a positive outlook to the nuclear vertical of the company.

Nuclear Power Corporation of India Limited (NPCIL) has a vision for capacity expansion from 7480 MW to 100108 MW by 2070. NPCIL plans to set up Pressurized Heavy Water Reactors (PHWR) and Light Water Reactors (LWR), towards capacity addition of 14500 MW by 2032. Further capacity additions of 35000 MW are planned for implementation by 2047.

Based on the business prospects with regards to upgrades and Vision plan of NPCIL, the estimated value for upgradation of operating reactors, supply of C&I systems for new upcoming reactors and supply of Radiation Instruments & Detectors is likely to result in an annual revenue in the range of 400-600Cr.

BHAVINI is now constructing and commissioning the first 500 MWe Prototype Fast Breeder Reactor (PFBR) at Kalpakkam and the commercial operations are planned from FY 2032. BHAVINI has plans of capacity addition to the tune of 3300 MW by 2040.

Based on vision plan of BHAVINI, ECIL expects to meet the Electronics and Instrumentation requirement to the tune of Rs 100-150 Crore from FY 2026 onwards.

The requirements of Advanced Technology Vessel Program (ATVP) will continue to be stable at an average requirement of systems to the tune of Rs 150-200 Crore.

ECIL anticipates the need for nuclear and radiation monitoring systems for reprocessing plants at INRP Tarapur and FRFCF Kalpakkam. Against this requirement, approximately Rs. 150 Crore in business is expected annually, contingent upon the progress of various phases.

Accordingly, taking into consideration the above major opportunities, service orders and requirements of RDE for sea ports, airports and land borders the company is likely to achieve a yearly revenue in the range of 600- 800 Cr from FY 2026-27 and thereafter grow at an average of 8-10 Percent.

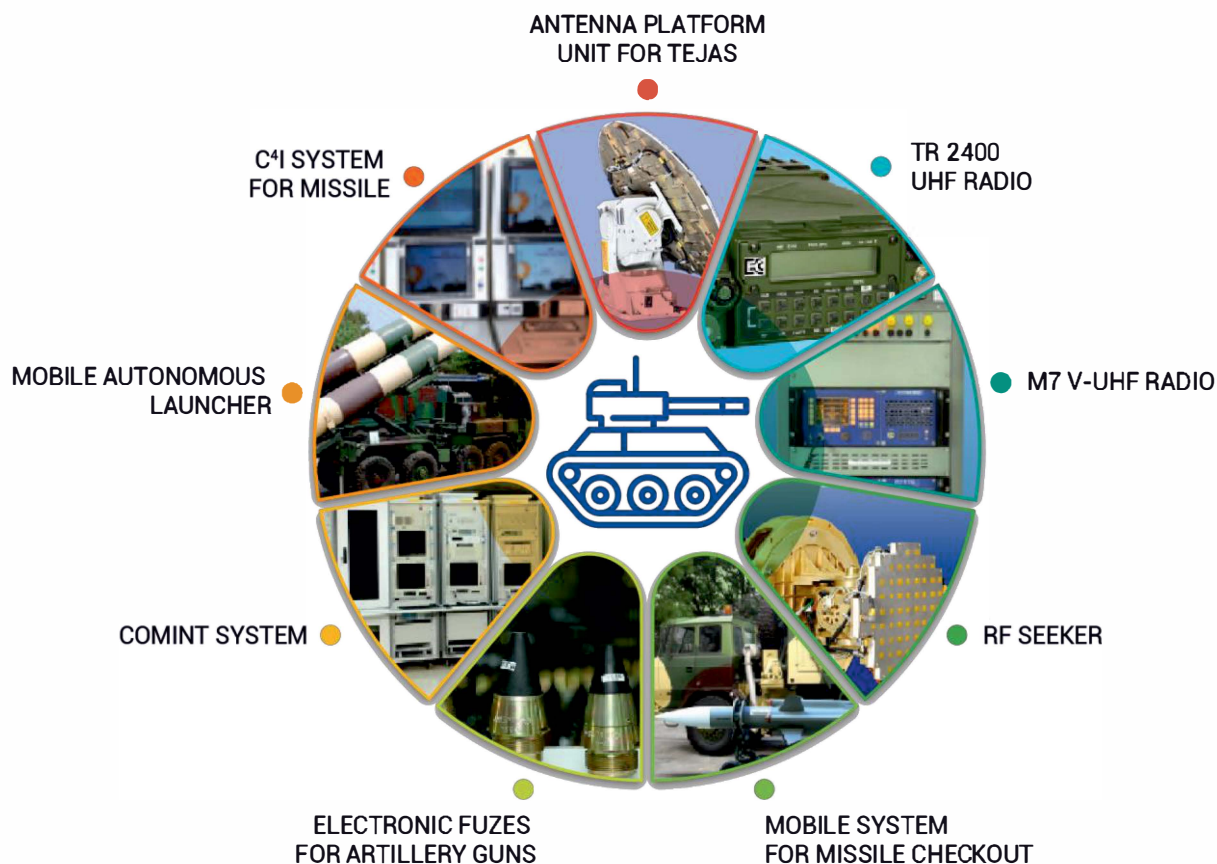
ECIL Verticals -Business Projections

The business outlook and the identified technology domains in the Nuclear Sector are highlighted in the previous chapter, the other verticals of Business operations and the envisaged growth is brought out in the succeeding paragraphs

6.3 Defence Vertical

Defence is key business vertical of ECIL having a range of products viz. Communication Systems, Electronic Warfare Systems, Universal Electronic Fuzes for Artillery, C4I for Missile Systems, RF Seeker for Missiles and Encryption Systems.

ECIL has been supplying a wide range of professional grade components, equipment and integrated strategic systems to all the three wings of the Armed Forces. The contributions of ECIL to Defence Sector span from Secure Communication systems, Electronic Warfare Systems, Simulators, COMINT & Interception Systems, Antenna, SATCOM Systems & Networks, Stabilized platforms for air-borne Radars, C4I & Missile Support Systems, Encryption and Secrecy Systems, Electronic Fuzes, Precision Electro-Mechanical Components, Sensors and Inertial Navigation Systems etc.



Defence Vertical

The yearly revenue of the Defence Vertical during the last decade was in the range of Rs 330 Crores to Rs 790 Crore.

The key identified business opportunities, technologies and products to meet the future requirements of Defence Sector is tabulated below.

Business Opportunities
• Missile Programs • Electronic Warfare Systems and ELINT system for defence sector • Integrated COMINT systems • Electronic Fuzes for Indian Army • Military Communication Systems including Software Defined Radios • Active Radar Seekers for Missile Programs

- Anti-Drone systems
- Systems /applications for 5G technology
- IOT based systems
- Unmanned Underwater vehicles for Naval applications

Thrust areas/Product

- C&I Systems for missiles
- On Board Computer for missiles, LRUs.
- EW Next Generation Seeker for Missiles
- Missile Checkout systems
- High Power amplifiers
- Smart Jammers for RCIED and Drone applications
- Development of Anti Drone systems
- Indigenisation of Artillery Fuze Components
- Software Defined Radios for Air and Naval applications
- Development of Mobile Integrated Network Terminal (MINT)
- Development of GPS/GIS based Mine Recording Systems (GBMRS)
- AI/ ML based Simulators

Future outlook

Several modernisation and indigenisation programmes are being undertaken by all the three services. The Ministry of Defence has laid out an expansive plan for modernisation of obsolete equipment through the long-term perspective plans, capability plans, capability roadmaps and capital acquisition plans. The vertical is pursuing development of several solutions and actively participating in several Make-II projects. The outlook for the sector is promising and the corporation is likely to see enhanced revenue from this vertical.

The defence vertical is likely to achieve a yearly revenue in the range of 700- 800 Cr from FY 24-25 and thereafter grow at an average of 7-10 percent.

6.4 Homeland Security

Homeland Security Vertical delivers integrated security solutions to vital installations of the country and is engaged in supply of various kinds of jammers to meet the security requirements of government agencies. This vertical is making inroads into providing solutions for Smart & Safe City projects and CBRN solutions.



Security Vertical

The key identified business opportunities, technologies and products to meet the future requirements of Homeland Security Sector is tabulated below.

Business Opportunities
• Integrated Security Systems • Smart & Safe City, Campus Projects • Secure Communication Systems

• Cyber security systems • Indigenous Network Switches and routers • CBRN Threat Detection & Mitigation System • AI/ML based security solutions
Thrust areas/Product
• Indigenous Dual view XBIS (X-ray Baggage Inspection system) • X Ray based Container Scanning System • LINAC for multiple applications • AI & Block Chain based Solutions for security technology applications • Radar based Perimeter Intrusion Detection System • Terra Hz & mm Wave based Scanners for application at Airports and Seaports • Integrated Command & Control Centre (ICCC) Applications for Integrated Security Solution • Indigenous Container Scanner System • Physical Protection system for Nuclear Power Plants and strategic assets of the nation • Managed Cyber Security Operation Centre • Web based Enterprise Level Access Control System • Chemical, Biological, Radiological and Nuclear (CBRN) Threat Detection Sensors integration and annunciator systems • Smart Perimeter Protection systems • Vehicle Tracking Systems

Future outlook

The outlook of this segment is positive with numerous opportunities emerging in providing Security Solutions to vital and Strategic installations. The facility towards Chemical, Biological,

Radiological & Nuclear (CBRN) threat detection and providing CBRN solutions set up under the vertical will commence execution of projects during the FY 24-25.

6.5 Aerospace

ECIL has supported country's space program by setting up the ground antenna network at all ISRO centres for communication and remote sensing satellites. ECIL has well established core capabilities in the area of design and manufacture of antennas, large reflectors, microwave links and SATCOM networks. Aerospace vertical is engaged in design, development, manufacture of Antenna Systems and providing SATCOM solutions to meet space and defence requirements. It also undertakes manufacture of Electromechanical components such as Gyros, Synchros and Actuators. This vertical is foraying into manufacture of Carbon Fiber-based antenna products.



Aerospace Vertical

The key identified business opportunities, technologies and products to meet the future requirements of Aerospace Sector is tabulated below.

Business Opportunities
• Indian Space Programs • Weather Radars • UAV programs • Light Combat Aircraft Program • VSAT Programs • Military Communication Programs • Discovery Science Programs • Navigation Systems • Carbon Fibre based antennas • Inertial Sensors and Actuators
Thrust areas/Product
• Antennas for Satellite Communication • Electro Mechanical Actuators (Up to 2 T) • Satellite terminal for Nuclear Submarine • Ground station Antennas for Missiles Tracking • Ground Stations for Antarctica • Space Grade Antenna for Satellites. • Antennas for Radio astronomy applications. • Ground Station for Deep Space Networks • Precision components for classified projects • Communication Networks for Strategic Applications • Carbon fibre Antennas

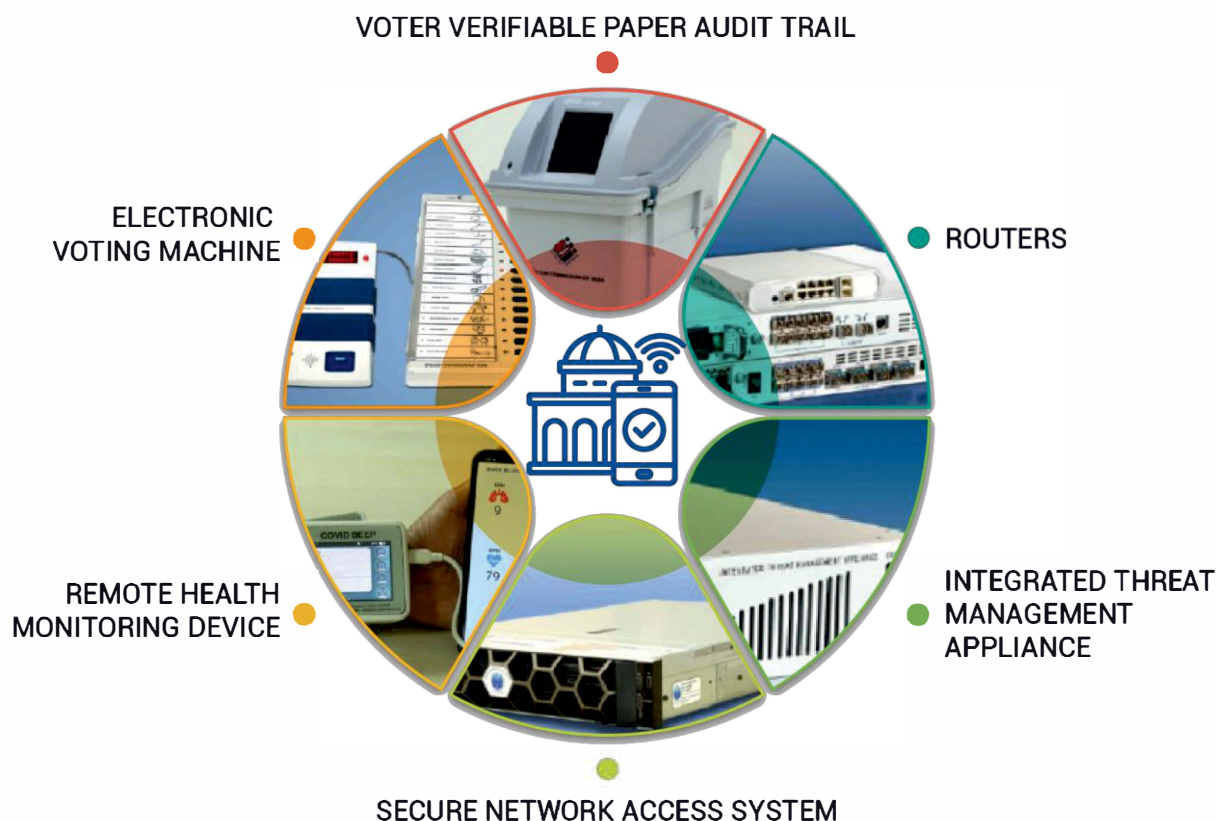
- Stabilized Platforms for aircrafts
- Ship borne Antenna Terminals
- GSAT 7B based SATCOM application for Indian Army.
- SATCOM on the move
- UAV Tracking Antennas
- Export of Satellite Communication Antennas of 11m, 13.5m, 18m & 21m with necessary development
- COTM Antennas for Railway Wagon
- Unfurlable Antennas for Strategic applications
- 21m MACE Telescope for Astro Physics requirements (2Nos)

Future outlook

The company has been building in-house solutions to meet the futuristic requirements. The new infrastructure in terms of Special Component Manufacturing Facility (SCMF) and Carbon Fiber Reinforced polymer (CFRP) facility established in the Aerospace vertical is planned to be put to use towards enhanced value addition and realisation of new products.

6.6 e-Governance

The IT and e-Governance vertical is engaged in manufacture of Routers, Network Switches, EVM & VVPATs and provides IT and Cyber Security Solutions. The revenue of the vertical is cyclical and largely dependent on orders from Election commission of India and state election commissions.



IT, Telecom, and e-Gov Vertical

The key identified business opportunities, technologies and products to meet the future requirements of IT & e-Governance Sector is tabulated below.

Business Opportunities
• Elections for States, Local bodies and Parliament • e-Governance Programs • Public Distribution Programs • Smart City Programs • Telecom network Programs
Thrust areas/Product
• Development of products/ solutions with respect to Crypto products and Cyber

Security

- Secure Network components
- Electronic Voting Machines and VVPAT
- Remote Health Monitoring Systems
- Automatic message switching system for Air traffic applications
- Totalizers for Electronic Voting Machines
- Remote Voting Machines
- EVMs for Physically impaired voters.
- S3 model EVMs for SECs.
- e-Governance solutions
- Telecom Products

Future outlook

Several in-house measures taken in terms of infrastructure augmentation have accelerated the process of mass manufacturing. Several steps taken in terms of technical partnerships have enabled ECIL towards providing IT and Cyber security solutions. Undertaking PCB assembly through contract manufacturing has been identified as one of the focus areas for near future towards full utilization of the state of art facility and to ensure continuous revenue business.

Challenges in Business Operations

The main challenges, and mitigation measures towards sustainability and growth of the corporation have been identified, which are manpower recruitment and retention, lack of marketing, knowledge management, and increased global competition. In consideration of these challenges, the business strategy has been focused on the following:

- Progressive increase in R&D manpower and R&D expenditure.
- Early identification of technological needs and *Suo moto* development of products for envisaged requirements.

- Implement ERP at an early date towards streamlining of processes and clear visibility on operations.
- Increase value addition in all sectors of business.
- Strengthen the collaborations with national laboratories and academic institutes with focus on indigenous technology development. Build capacity for effective technology absorption and assimilation.
- Continuously evaluate the outsourcing decisions against in-house manufacturing.
- Look for technology transfer arrangements with localization opportunities.
- Build-up capacity and capability in technologies and products of strategic importance such as radiation detectors and instruments, inertial sensors, seekers and information security.
- Plan human resource development required for the knowledge-intensive specialised areas by training at induction level and continuous training programs. Implement HR policies which promote talent attraction & retention.
- Leverage IT in all its operations to enhance efficiency, accuracy and transparency.
- Modernize and upgrade infrastructure related to work places, design & engineering, production, testing & qualification so as to improve efficiency, aesthetics, safety, security and environmental objectives.
- Locate “design & engineering centres’ in areas nearer to major customer locations or sites so as to reduce cycle times related to requirements capture and engineering.
- Factor in life time support requirement in to the business processes.
- Achieve and maintain rating of ‘Very Good’ and above for MoU performance

Action plan to meet Future Requirements

Realisation of vision requires comprehensive upgradation of corporate service functions and infrastructure in the areas of Integrated Corporate R&D centre, IT services, business process re-engineering & deployment of ERP, information security, planning & monitoring, safety and HR processes. The envisaged actions on these aspects is enumerated in the succeeding paragraphs.

6.7 Research & Development

- (a). ECIL has been a technology driven company right from its inception. The opportunities to engineer and productionise the technologies developed at BARC has generated and nurtured substantial scientific temper within the organization to pioneer a number of technologies and bring out a host of products. The technology handling capability has been providing the Company the flexibility to synergise the efforts in various divisions of the organization to offer customized products and solutions to the clients.
- (b). On an average the company has been spending around 3% to 4% of its turnover on R&D. The R&D funding from DAE through the Technology Development Council (TDC) has been a very successful model for product development.
- (c). Customer-specific R&D and Technology Management continues to be under the respective divisions and verticals to effectively address the requirements and channelize the resources with focus on time to market/deliver. The key identified technologies have been covered under the respective business verticals.
- (d). The company has identified R&D as the key enabler for development of new products and technologies. Accordingly, it intends to enable R&D through in-house expenditure to the tune of 8-10 % of PAT.

6.8 Marketing

- (a). In addition to technology strength, the Company has recognized the need to strengthen marketing in order to meet competition both from established Indian players and reputed multinational companies. The product streams of ECIL are re-grouped and a sectoral focus is consciously brought in. The marketing strategies are therefore evolved at the sectoral level based upon the inputs from various agencies and the market research.
- (b). The Corporate Business Development Group (CBDG) facilitates the marketing initiatives through positioning the Company at various levels and building its image. A need has

been felt to intensify the marketing of business initiatives of the Company and also to facilitate export endeavours of the Company by strengthening CBDG.

6.9 Infrastructure

- (a). The infrastructure created at the time of inception of the Company largely catered to the requirements of the plans and programmes of yesteryears. The product profile, the technology mix, revised mission and objectives and above all the endeavours of the Company to negotiate a comprehensive trajectory change necessitated a review of the continued relevance of existing infrastructure.
- (b). Considering that Electronics and Instrumentation form a critical element in the strategic programmes of DAE. The R&D programs at BARC are focused to achieve independence in all aspects of enabling technologies such as C&I, including sensors, detectors, drive systems, computation platforms, communication and software. Engineering, prototyping and long-term sustenance of technology developed at BARC require building up of requisite capabilities in the industry to support these programs. Accordingly, through MOU, BARC and ECIL have jointly established technological infrastructure at ECIL for the design, development, prototyping characterization, evaluation, instruments, and systems.

6.10 Human Resources Management.

Considering the age composition and retirement profile of the present employees the manpower requirements over the period have been identified. Concurrent with the efforts to improve the operational performance of the company, several measures are being initiated to raise the quality of Human Resources. This involves training at induction level, skill upgradation programs and project management programs. Taking into account separations the Manpower recruitment is considered vital for the planned growth of the company. In fact,

ability to attract the best talents and retain them will be the single most important factor in realizing the vision.

6.11 Conclusion and way forward

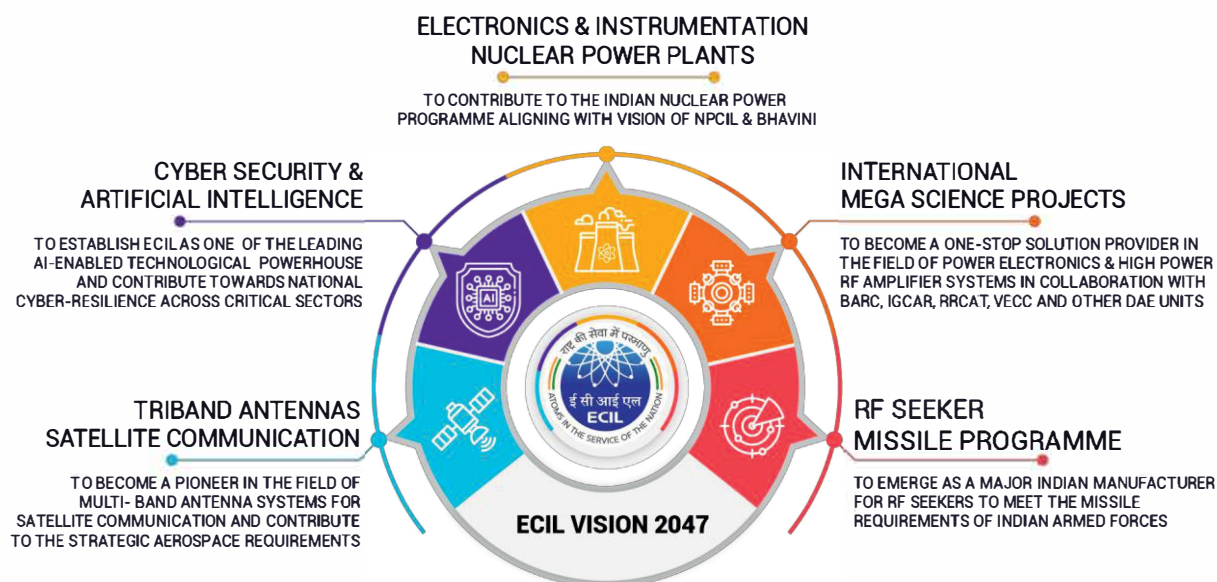
Electronics systems are ubiquitous and have far reaching implication in development of new technologies. ECIL, the electronic arm of the DAE over the past five plus decades, not only met the prime objective of becoming self-reliant and self-sufficient in the field of Control & Instrumentation for the Indian Nuclear Power Programme but has also emerged as an important national asset in the field of Electronics. The pioneering spirit displayed by the company with support of BARC and DAE units from its formative period has enabled it to realise several noteworthy products and systems needed in the domains of atomic energy, defence, space and security sectors in addition to few other fields of social or economic significance to the Country.

ECIL is poised to meet the technological challenges involved, given the internal strengths, focus and the springboard of developmental support from premier national R&D institutions of Atomic Energy, Defence and Space. The umbilical connections with BARC and the developmental linkages with other DAE Units like IGCAR, VECC and RRCAT have resulted in a strong technology base for catering to the requirements of the Atomic Energy Sector. Similarly, the development associations with Defence Research and Development Organization (DRDO), Aeronautical Development Authority (ADA) etc. have enabled ECIL to enhance its product base and project execution capabilities in the defence Sector. The strong relationship forged with Indian Space Research Organization (ISRO) is paving the way for executing technologically complex projects of national relevance in the space sector.

Whilst the synergy with BARC and other DAE institutes continues to be strengthened, with the changing business dynamics, ECIL is constantly adopting and collaborating with industry and academic institutes to further 'AtmaNirbhar Bharat' and Make in India Initiatives.

Keeping in view, the enormous opportunities emerging in the nuclear sector, the Company hopes to attain and maintain a significant share of its turnover from nuclear sector. Towards

this, the Company has launched many initiatives to synergize the capacities, capabilities, expertise and suitable augmentation of infrastructure. Further, Human resource has been the most valued IP of the company and will continue to be of increased importance considering the high technology area company is operating.



ECIL Amrit Kaal Vision

ECIL's operations are focused on strategic electronic products and niche technologies in the chosen sectors viz., Nuclear, Aerospace, Defence, Homeland Security, IT & e-Governance. The strategic electronics sector globally is expected to grow at a CAGR of 4%-6%. The domestic growth in the strategic electronics sector is likely to be higher than the global growth. Further, the large-scale modernisation of the defence forces with focus on self-reliance with increased local manufacturing are going to boost the strategic electronics sector of the country.

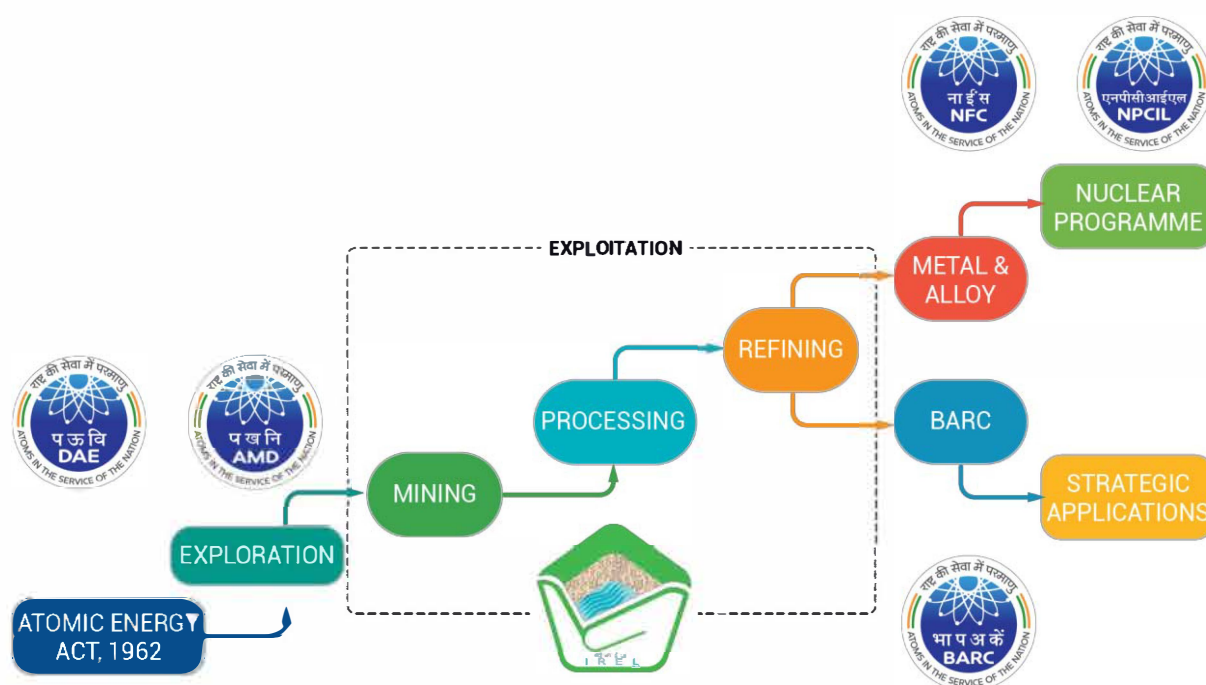
In this backdrop the company revenues are likely to grow at an average of 7 to 8% in the coming decade. This would be achieved by enhancing/ diversifying the Product range through in-house developments, in collaboration with DAE units, DRDO and with strategic partnership with Startups and Private Industries and mitigating challenges. The company aims to achieve a revenue target of Rs 4000 Crores by 2030 and Rs 5000 Crores by 2035.

7. Indian Rare Earths Limited – IREL

“To be a significant contributor to the global clean energy mission by providing high-quality performance-enhancing materials and operating in a socially responsible manner.”

IREL (India) Limited, a Mini-Ratna Category-I company, is a Central Public sector undertaking under the administrative control of the Department of Atomic Energy. IREL is engaged in Mining, Concentration and processing of Mineral Sand to produce Processed Minerals. One of the minerals produced which is also a prescribed substance is further cracked to produce strategic compounds and mixed Rare Earth Concentrate. The mixed Rare Earth Concentrate is further refined to produce separated individual High Pure Rare Earths.

IREL has 23 products of 36 different grades with 8 products having value chain within DAE. Some of the essential material supplied to DAE include NGADU, Zircon, Thorium, Samarium, ⁷³Gadolinium Nitrate, Dysprosium.

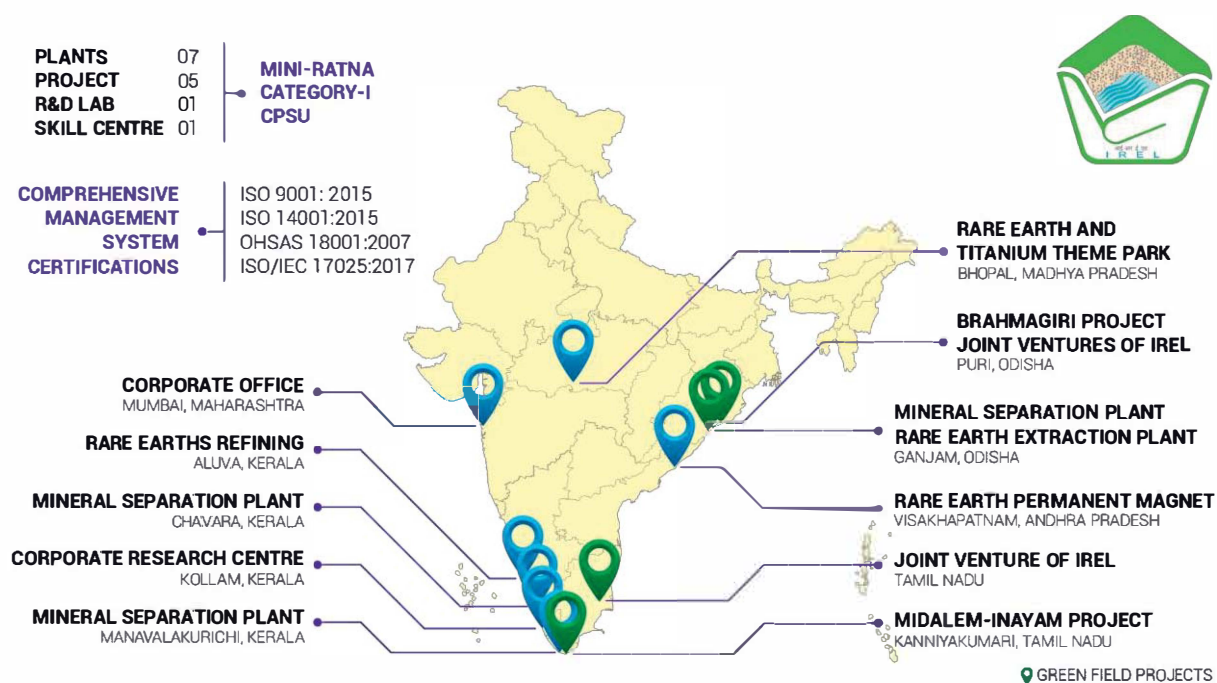


Position of IREL in Indian Atomic Energy Programme

The operating units of the company are located at Chavara, Kerala; Manavalakurichi, Tamil Nadu; Chatrapur, Odisha and Aluva, Kerala. The Corporate Office is located at Mumbai.

IREL's vision for the Amrit Kaal targets are in coherence with DAE's vision plan of 2047 which would be evolving out of the proposed Chintan shivir, i.e., making the country self-reliant by sustained supply of:

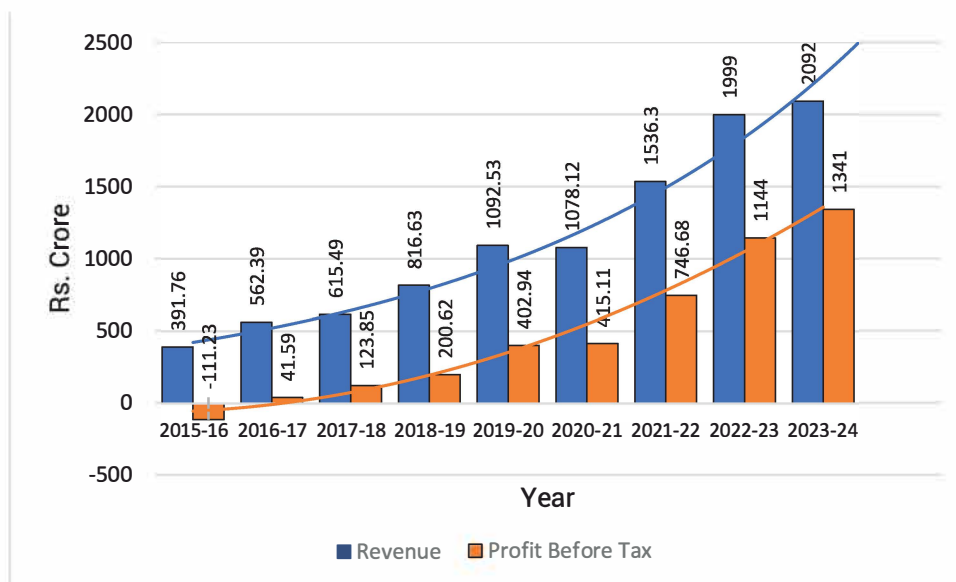
- i. Zircon to NFC for the Nuclear Power Program.
- ii. Thorium for the Third stage Nuclear Power Program
- iii. Strategic Rare Earths and Rare Earth Permanent Magnets (Samarium-Cobalt) to DAE.
- iv. Rare Earths to downstream industries involved in the initiatives taken towards Green & Clean Energy.



IREL Overview

7.1 Performance

The performance of IREL has seen considerable growth in the last nine years growing sustainably at a CAGR of about 30%. The Company has grown over 5.3 times during the period and has obtained "Excellent" MoU rating over the last six years consistently.



The total Dividend paid over the last ten years has surpassed the initial equity infused by more than 14 times. Issued 400% equity bonus shares raising the paid-up equity capital to Rs. 345.46 crore from Rs. 86.37 crore.

7.2 Achievement in Rare Earth Sector

During the period, IREL has established a Rare Earth Extraction Plant in Odisha for extraction of Rare Earths in the form of Mixed Rare Earth Concentrate from a prescribed substance. The NGADU produced during the process is supplied to DAE while Thorium is stored in engineered trenches for future use in the Atomic Power Program of the Country. A facility has also been established for refining the Mixed Rare Earth Concentrate to produce Refined Separated High Pure Rare Earths.

IREL has also set up a Rare Earth Permanent Magnet Plant in BARC Campus, Vizag for the production of Samarium-Cobalt magnets from Indian Rare Earth resources for use by DAE and Defence Sectors.



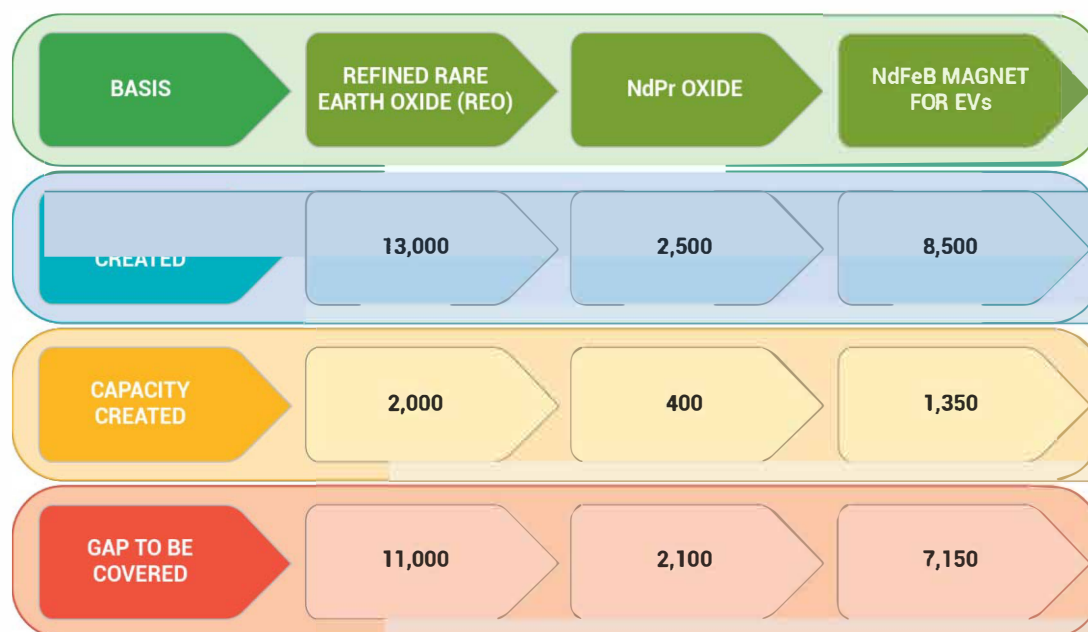
Rare Earth Permanent Magnet Plant at Visakhapatnam, Andhra Pradesh dedicated to the nation by the Honourable Prime Minister Shri Narendra Modi, May 2023



Rare Earth Permanent Magnet Plant and the Products, Visakhapatnam, Andhra Pradesh

Further, a Rare Earth Metal and Titanium Theme Park has been established in Bhopal for setting up of Mini-Plants to demonstrate production of metals of Lanthanum, Cerium, Neodymium; recovery of Rare Earths from end-of-life magnets; production of LED/ Lamp phosphors and demonstration of Kroll process.

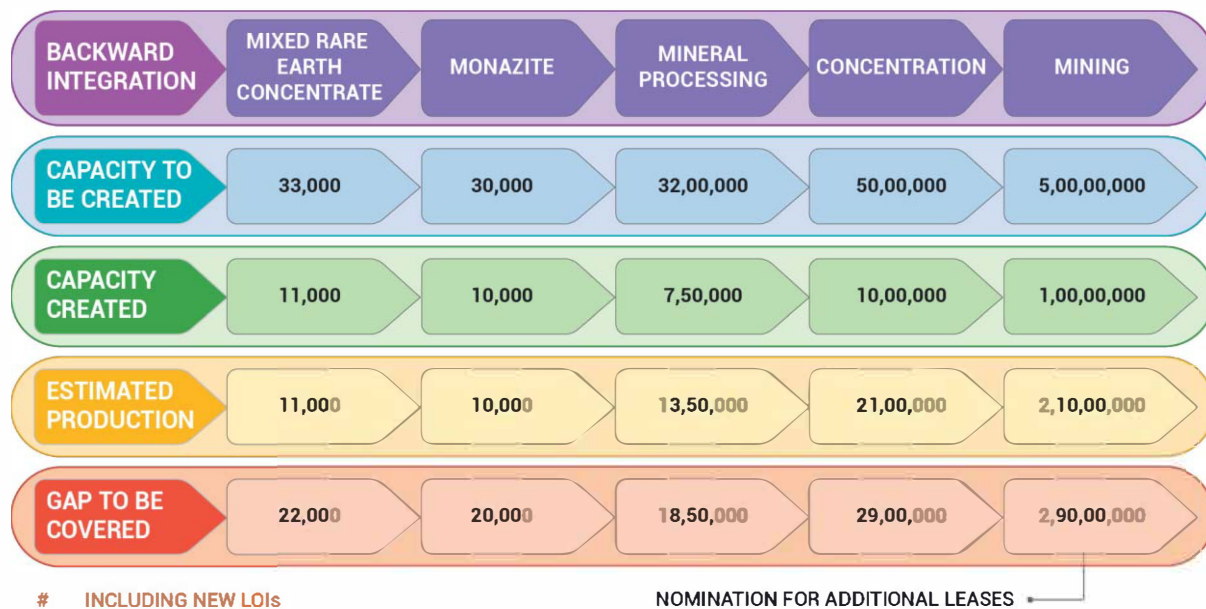
Vision @ 2047 – Rare Earths



ALL VALUES IN TONNES

Rare Earths Need Statement

For Rare Earths, the Vision Target bestowed on IREL is production of 13,000 tons of Rare Earth Oxides (REO) in the backdrop of Energy Transition aspirations of the Government, which would suffice production of about 8,500 tons of NdFeB magnet for the Clean Energy Initiatives.



IREL Pre-Requisites

IREL has recently obtained three Letter of Intent (LoI) from Government of Odisha and Tamil Nadu.



New Project Initiatives

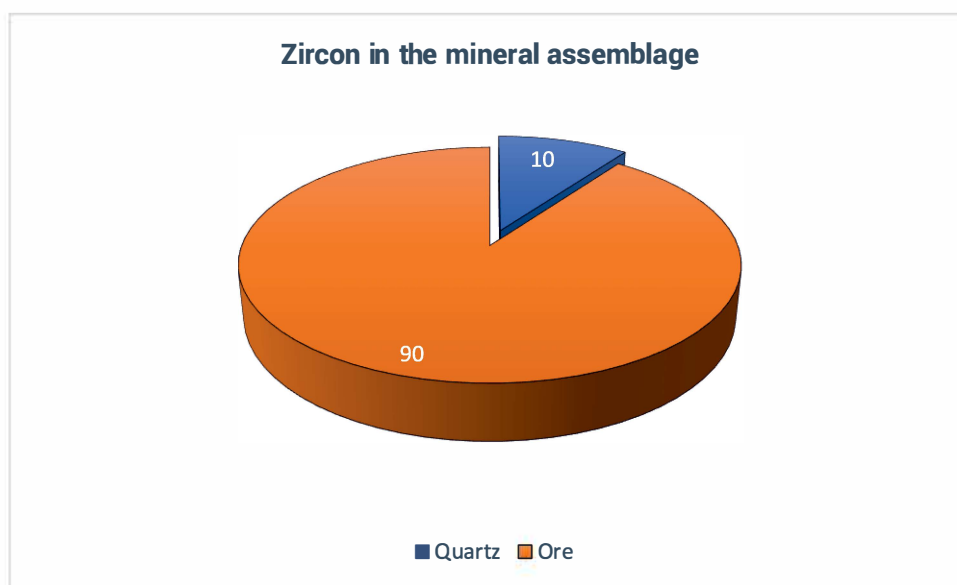
Pre-project activities towards obtaining statutory clearances are underway after which the mines will be operationalized. However, to meet the Vision target additional resources in the form of Mining Leases need to be awarded to IREL. The annual mining capacity from these deposits need to be to the tune of 29 million tons per annum. Considering the quantum of

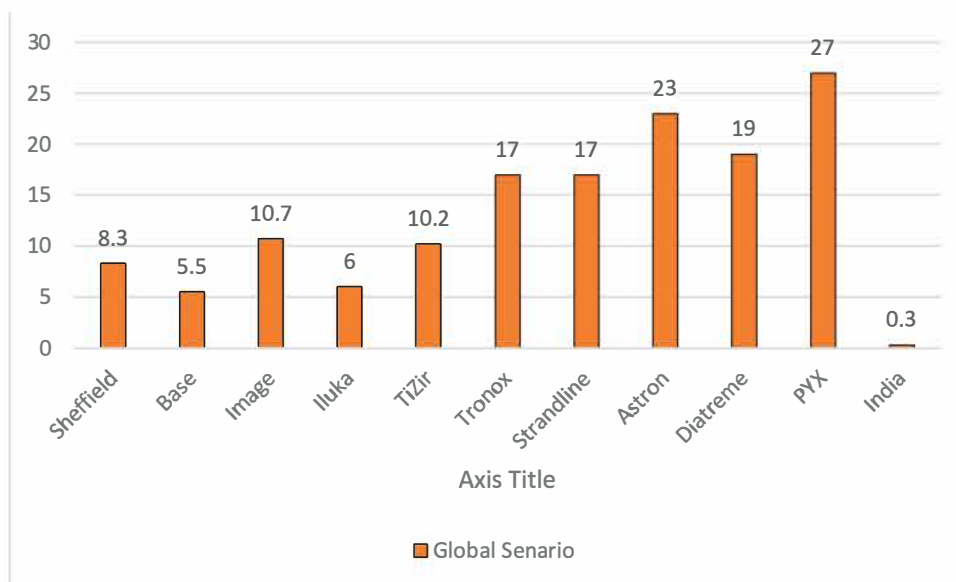
mining to the done, the new leases need to be in different geographies from environment sustainability point of view.

Further, IREL has received directives from the Government of India for co-operation on Rare Earths with Vietnam, Oman and Sri Lanka for which discussions are on at various levels.

7.3 Vision @ 2047 – Zircon

The availability of Zircon in the mineral assemblage in the southern deposits is between 0.5-0.8% while that in eastern deposits is to the tune of 0.20-0.25%. While meeting the Vision target of DAE for Rare Earths, about 32,000 tons of Zircon will be produced of which about 5,000 tons of the grade required by NFC will be set aside. The exact requirement will be worked out in consultation with NFC.





7.4 Vision @ 2047 – Mid-Stream industries in Rare Earths Sector

Rare Earths are considered a niche material since it improves the performance of core/functional material when added in small quantities. However, this sector is presently absent in the Country due to inverted pricing dynamics. IREL is working closely with DAE/ Government of India to incentivize the aspiring mid-stream industries. Once the same fructifies, the mid-stream sector which deals with converting Rare Earth oxides to metal/ alloy will develop thereby increasing consumption of the niche product within the Country.

7.5 Vision @ 2047 – Technology Demonstration Plant

To meet the requirement of the Department, BARC is developing technology for production of Titanium Sponge and NdFeB Magnets. Once scalable technology is developed, IREL based on funding support from the Government will establish Technology Demonstration cum Production Plant for the production of Titanium Sponge and NdFeB magnets for their requirement in strategic sector.

Availability of Nuclear Fuel (domestic as well as imported) for power projects

In respect of domestic uranium, while modest uranium reserves in the country have been discovered and exploration is on to cover the entire country, with due challenges in establishing mines and extracting the ores.

In respect of imported uranium, the demand for global uranium is expected to grow significantly as, in addition to existing countries having nuclear power planning expansions, several more countries are considering, planning or starting nuclear power programmes, particularly in view of its clean credentials and climate change concerns. With the increase in demand, the prices of uranium are expected to increase over time in the next two decades leading to 2047.

As per IAEA Red Book 2022, reserve, production, demand etc. for nuclear fuel are given below:

Uranium Reserve

(as of 1 January 2021, tonnes U, rounded to nearest 100 tonnes^{a)})

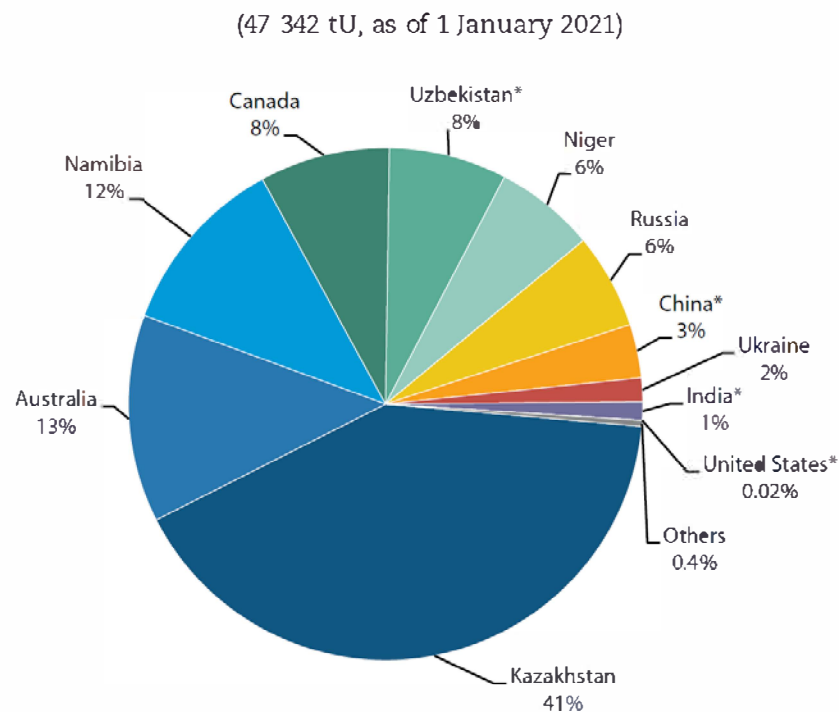
Resource category	2019	2021	Change ^(a)	% change
Identified (total)				
<USD 260/kgU	8 070 400	7 917 500	-152 900	-1.9
<USD 130/kgU	6 147 800	6 078 500	-69 300	-1.1
<USD 80/kgU	2 007 600	1 990 800	-16 800	-0.8
<USD 40/kgU ^(b)	1 080 500	775 900	-304 600	-28.2
RAR				
<USD 260/kgU	4 723 700	4 688 300	-35 400	-0.7
<USD 130/kgU	3 791 700	3 814 500	22 800	0.6
<USD 80/kgU	1 243 900	1 211 300	-32 600	-2.6
<USD 40/kgU ^(b)	744 500	457 200	-287 300	-38.6
Inferred resources				
<USD 260/kgU	3 346 400	3 229 200	-117 200	-3.5
<USD 130/kgU	2 355 700	2 263 900	-91 800	-3.9
<USD 80/kgU	763 600	779 600	16 000	2.1
<USD 40/kgU ^(b)	335 900	318 700	-17 200	-5.1

^{a)} Note that tonnes U values in this table are rounded to the nearest 100 tonnes, independently, at the country and cost range level. Therefore, these cost range totals do not exactly match totals for these cost ranges as shown in other tables relating to uranium resources in this report. (a) Changes might not equal differences between 2019 and 2021 because of independent rounding. (b) Resources in the cost category of <USD 40/kgU and <USD 80/kgU should be regarded with some caution since some countries do not report low-cost resource estimates, mainly for confidentiality concerns, whereas other countries that have never, or not recently, hosted uranium mining may be underestimating mining costs.

Source: IAEA - Red Book 2022

7.6 Uranium Production

In 2020, 17 countries produced uranium, with the global total amounting to 47342 tU.



* NEA/IAEA estimate.

7.7 Uranium Requirement

The world Annual requirements by 2040 are given below:

(tonnes U per year)

Region	2020	2025 low	2025 high	2030 low	2030 high	2035 low	2035 high	2040 low	2040 high
Africa	294	304	304	304	304	688	1 392	1 232	1 872
Central and South America	619	560	576	784	784	720	1 056	1 120	1 712
East Asia	16 039	17 408	20 080	19 824	27 056	20 176	33 248	22 560	41 296
Europe (non-EU)	9 244	7 328	7 904	7 904	9 376	8 272	11 232	9 008	14 880
European Union	12 942	15 440	15 584	14 368	15 456	13 696	16 736	12 592	19 360
Middle East, Central and South Asia	1 945	2 816	3 200	3 808	5 728	5 408	8 448	6 032	9 888
North America	19 031	15 552	17 872	13 968	17 888	11 584	18 048	10 336	18 464
Pacific	0	0	0	0	0	0	0	0	0
South Eastern Asia	0	0	0	0	0	0	0	160	800
World Total	60 114	59 408	65 520	60 960	76 592	60 544	90 160	63 040	108 272

* NEA/IAEA estimate.

7.8 Conclusion and way forward

Addressing these challenges and going ahead with the growth as planned will enable actualise the Vision Amrit Kaal and achieving the goals of Viksit Bharat by 2047 & energy transition to Net Zero by 2070. Strong coordination teams involving the union and state governments along with PSU to be established for the entire life cycle of then plants. Improving project management practices to complete projects on time and adopting innovative solutions for reducing gestation period are necessary. Faster development of new technologies by R&D units would enable PSUs to launch them in the commercial domain. Enhanced public outreach by PSUs would ensure genuine apprehensions of stakeholders addressing in a simple, understandable and credible manner. Evolving financing and business models for meeting the funding requirements of the massive expansion programme would be necessary, particularly tapping of private capital.



परमाणु ऊर्जा विभाग
DEPARTMENT OF ATOMIC ENERGY