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INDIA ENERGY FORUM

12th

NUCLEAR ENERGY CONCLAVE

Thursday, 2nd March, 2023 , Hotel SAMRAT, New Delhi

Theme

ROLE OF NUCLEAR ENERGY IN ACHIEVING A NET ZERO ENERGY MIX

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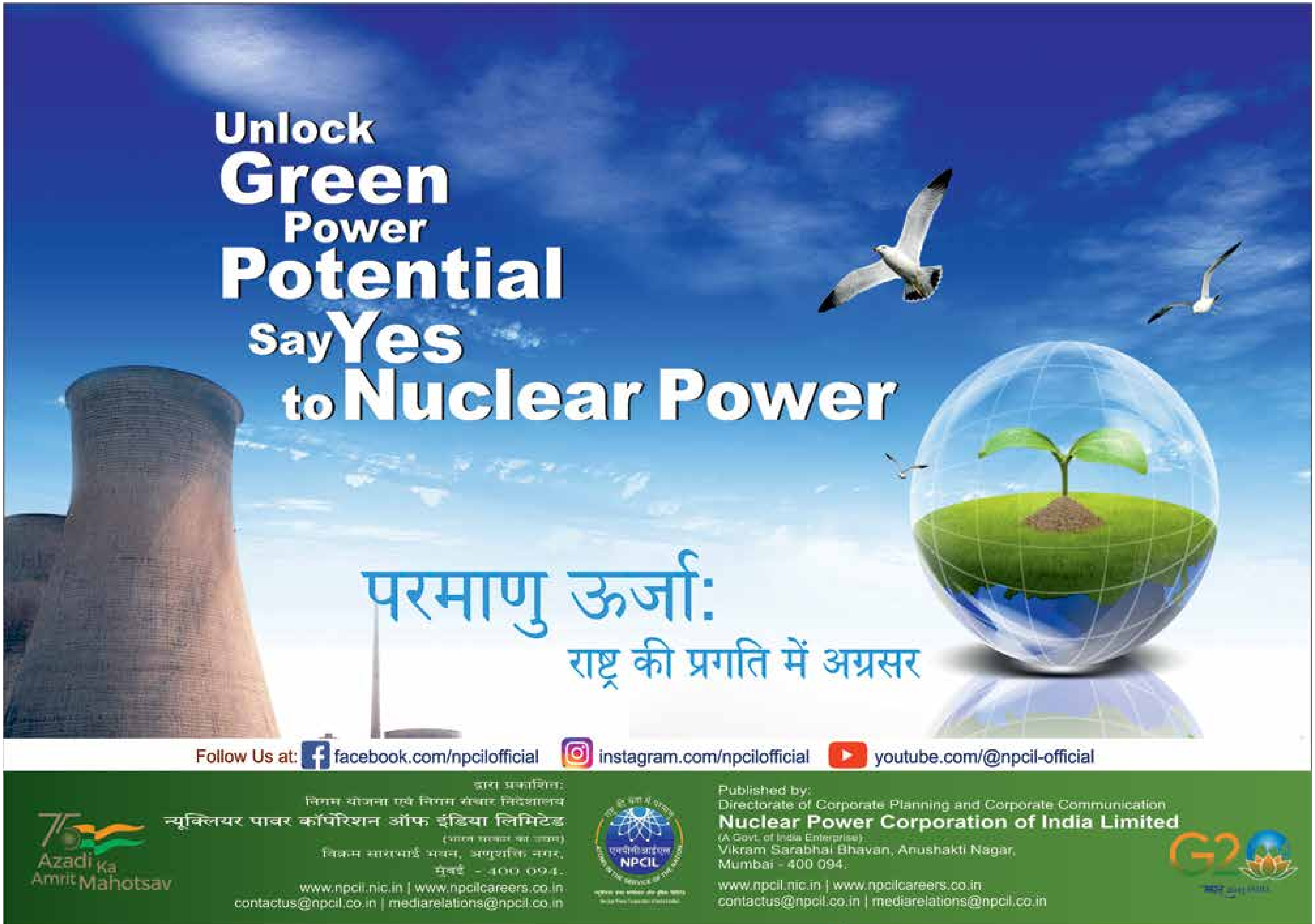

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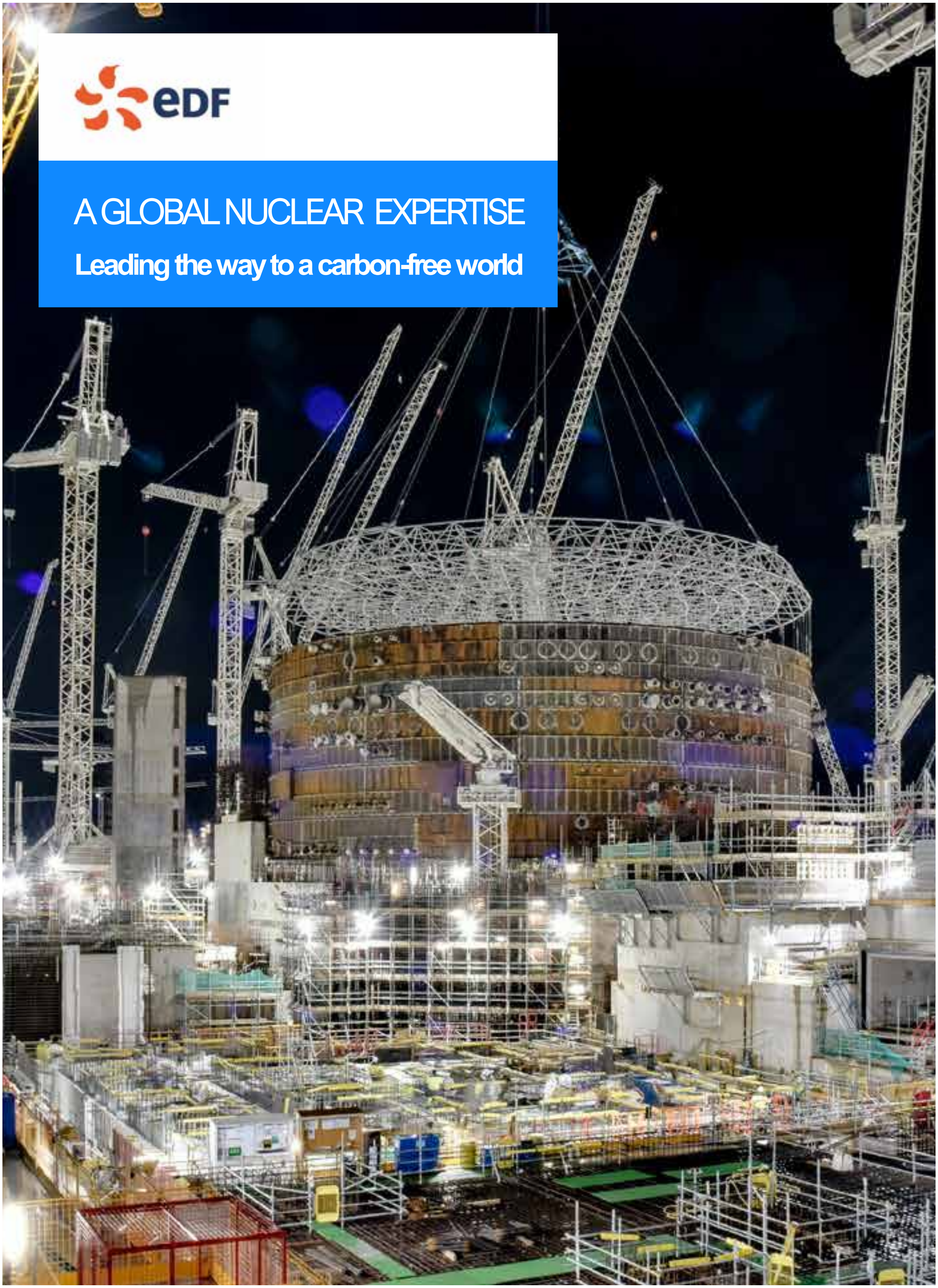

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PROGRAMME

9.00 a.m. to 9.30 a.m.	**:**	**Registration and Welcome Tea**
9:30 am to 11 am	**:**	**Inaugural Session**
9.30 to 9.35 am	:	Welcome Address by **Shri S M Mahajan,** Convenor, Nuclear Group, IEF
9.35 to 9.50 am	:	Setting the context by **Dr. R.B. Grover,** Chairman, Nuclear Group, IEF
9.50 to 10.05 am	:	Special Address by **Sh. Gurdeep Singh,** CMD, NTPC on "Accelerating the pace of Nuclear Power capacity addition"
10.05 to10.20 am	:	Presidential Address by **Sh. R.V. Shahi,** President IEF
10.20 to10.50 am	:	Keynote Address by Chief Guest **Sh. K.N. Vyas,** Secretary Department of Atomic Energy
10:50 to 10:55 am	:	Vote of Thanks by **Shri B. Bhambhani,** Secretary General, IEF
11:00 to 11:15 am	**:**	**Tea**
11:15 am to 1:15 pm	**:**	**Invited Presentations: Power Generation Capacity Build Up with Various Technologies**
Session Chair	:	**Sh. S.C. Chetal,** Former Mission Director- AUSC and Director- IGCAR

- "700 MW PHWR: Workhorse for Adding Nuclear Power Capacity in India", by **Sh. B.C. Pathak,** CMD, NPCIL.
- "Contribution of French LWRs in building up Nuclear Power Capacity in India", and "Design and Development of the SMR NUWARD", by **Mr. Stephane Salib,** Director, India Liaison Office, Jaitapur Project, EDF.
- Design & Developments of SMRs in India- **Dr AK Mohanty,** Director, BARC
- "Indo-French Civil Nuclear Partenership" **Mr. Thomas Mieusset,** Nuclear Counsellor, French Embassy

1:15 to 2:15 pm : Lunch

2:15 to 3:45 pm : **Panel Discussion: Equipment Manufacturing Capacity build up and Expectations from DAE for Atamnirbharta (self reliance)**

Session Chair : **Shri Ranjay Sharan,** Director (Projects), NPCIL

- **Shri Yatindra Mohan,** GM (NBG), BHEL
- **Shri Vikram Sehgal,** Sr. DGM (Design & Engg.) – Nuclear, L&T
- **Shri S K Joshi,** Assistant VP & Head Engg., Godrej & Boyce
- **Dr Komal Kapoor,** Chief Executive, Nuclear Fuel Complex
- **Ms Olga Lukerchik,** Chief Expert, ASE JSC (Engineering Div), Rosatom
- **Ms Minu Singh,** Mg Director, Nuvia India

3:45 to 4:00 pm : **Tea**

4:00 - 4:30 pm : **Valedictory Session**

: Valedictory Address by **Dr. Anil Kakodkar,** Chancellor, Homi Bhabha National Institute

: Summing up and major recommendations by **Sh. R.V. Shahi,** President IEF

: Vote of Thanks by **Sh. S.M. Mahajan,** Convenor, NG, IEF

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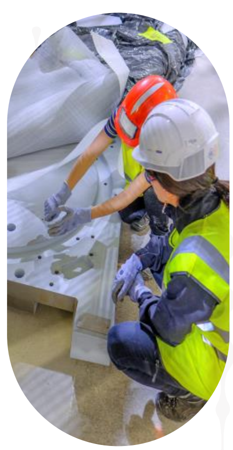

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Theme Paper on
Role of Nuclear Energy in Achieving a Net Zero Energy Mix

by

Shri S M Mahajan
Convenor, Nuclear Energy Group, IEF

With the increasing need to control greenhouse gas emissions, greater use of low-carbon emission electricity generation technologies has become necessary. India has set a goal of achieving a net zero-carbon energy mix by 2070. India's present per capita energy consumption is low and has to increase to meet its developmental needs. India thus faces twin challenges: to provide an increased amount of energy to develop, and simultaneously decarbonize its energy mix.

Globally, low-carbon energy sources having significant shares in the energy mix are hydro, nuclear, solar, and wind (onshore and offshore) and all are being used to produce electricity. Biomass is another source, but there are serious doubts among many scientists about its carbon-neutral credentials, especially when wood pellets are made by cutting down whole trees, rather than using waste products. It can take as much as a century for trees to grow enough to offset the carbon released. Groups of scientists have written open letters in this regard to world leaders (CRS report R41603, "Is bio-power carbon neutral?"). Transportation of biomass over long distances significantly lowers its EROI (The ratio of energy returned over energy invested) and makes its use questionable. The success of ongoing research to produce hydrogen from waste biomass will be a useful input for the de-carbonization of the energy mix.

The electricity generation potential of hydro and onshore wind sources in India is limited and so is the land that can be provided for setting up solar plants. The Government of India intends to develop 30 GW of offshore wind energy projects by 2030 and the first steps in this regard have already been initiated. However, its high cost is a constraint. A significant part of the increasing energy needs has to be, therefore, met by nuclear energy in India. Globally nuclear power is one of the largest sources of low-carbon electricity. In India, electricity generation by nuclear in 2021-22 was about 3% of the total generation and needs to be increased. India updated its Nationally Determined Contributions in August 2022 and is committed to achieving 50% cumulative electric power installed capacity from non-fossil fuel-based resources, and reducing the emissions intensity of its GDP by 45% by 2030.

India has to electrify its energy sector based on a mix of hydro, nuclear, solar, and wind, and it has to be done in a cost-effective manner. Academic studies as well as reports from countries with significant penetration of variable renewables indicate that the cost of electricity paid by consumers has increased and managing the grid has become a challenge. The cost of electricity at the generator end is different from the cost at the consumer end. The difference between the two is high when the generation is from intermittent sources as some means of storage have to be provided to manage intermittency. The generation of electricity by photovoltaic cells doesn't have any rotating inertia, which is necessary for short-term balancing. Also, the generation of electricity by PV doesn't provide any reactive power.

All these issues can be overcome and the cost at the consumer end can be made affordable if a significant share of electricity is provided by despatchable sources like hydro with storage, nuclear, or coal with carbon capture and use. Nuclear being an important option, India Energy Forum has organized this 12th Nuclear Conclave to discuss the stage of preparedness of our country with regard to increasing the share of nuclear in the energy mix.

The Department of Atomic Energy is pursuing an ambitious program to develop indigenous technologies for nuclear power generation and has set up a series of Pressurized Heavy Water Reactors (PHWRs). To speed up the program, India has taken up the construction of PHWRs in fleet mode. As an addition to the PHWR program, Light Water Reactors (LWRs) are also being set up. Now there are plans to design, develop and deploy SMRs as well. Bhabha Atomic Research Center continues to work on advanced technologies like Molten Salt Breeders and High-Temperature Reactors, and Indira Gandhi Center for Atomic research is working on Fast Breeder Reactors. The nuclear industry has high expectations from SMRs, and several groups around the globe are working to realize them.

The present installed capacity in the country is about 7 GW and the generation by nuclear power plants in the previous financial year was 47 TWh. The supply chain for setting up PHWRs is fully indigenous and uranium is available from indigenous sources as well as can be imported without any restrictions. NPCIL has designed and set up full-scope training simulators to train the operating staff. Enough capacity has been built in the country to provide trained manpower for constructing and operating PHWRs. The installed capacity based on PHWRs can be easily increased. India has an excellent manufacturing base and given the benefit of continuity of orders arising from fleet mode construction, it is our expectation that the Indian industry will not hesitate to invest in stepping up nuclear equipment manufacturing.

With the above background, the Conclave has been organized to cover all three options namely PHWRs, LWRs, and SMRs, being pursued currently by India. The talks will be delivered by representatives of the government, leading public sector undertakings, and some foreign companies. A panel discussion to deliberate on the readiness of the leading manufacturing industry to meet the needs of an expanded nuclear power program is also planned. Prospects of the Indo-French Civil Nuclear Partnership will also be projected.

It is hoped that the deliberations will go a long way in ramping up the nuclear power installed capacity.

Need for evaluation of near-term energy transition policies of India based on contributions to long-term decarbonization goals

Dr. R. B. Grover

Homi Bhabha National Institute, Mumbai 400 094, India

India faces twin challenges of meeting the rising energy demands of a developing economy and ensuring an economy-wide low-carbon transition to stay on track with its decarbonization goal leading to a net zero energy mix by 2070. As emissions from the use of fossil fuels remain the largest source of greenhouse gas emissions in the country, a massive restructuring of the energy sector is needed. This requires integrated planning across all sectors, and the harnessing of all low-carbon energy technologies and emission reduction mechanisms so that affordable and reliable energy is available to eve-ryone during the process of transition and after achiev-ing net zero. This article examines the future energy requirements and surveys a wide range of studies to make recommendations for policy formulation.

Keywords: Decarbonization, energy transition, net zero, policy formulation.

INDIA updated its Nationally Determined Contributions (NDCs) in August 2022 and has taken up an onerous target by committing to achieve net-zero carbon emissions in 2070. The country is also committed to achieving 50% cumulative electric power installed capacity from non-fossil fuel-based resources by 2030 with the help of the transfer of technology and low-cost international finance. Here, we review recent studies and developments to make recommendations for a policy formulation for the energy sector in India.

India must massively restructure its energy sector to meet the target of a net-zero energy mix. This has to proceed simultaneously with the growth of economy that can be achieved only with growth in per capita energy consumption. Carbon-free energy sources making a significant contribution to the energy mix in India as well as globally are hydro, nu-clear, solar and wind; and all of them are being used to generate electricity. Since fossil fuels are also used as or for producing feedstock for several industries like steel and fertilizer, in a net-zero scenario, one has to find a way to produce feedstock using electricity. Also, while electricity can be used for rail and road transport directly or using storage batteries, one must develop new energy vectors using electricity for aviation and shipping. New energy vectors might not be sufficient for all applications, for which the use of fossil fuels may have to be continued along with carbon capture and sequestration, a technology that is yet to be demonstrated at scale.

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Considering the options available, it is evident that there is a need for massive electrification using low-carbon energy forms, development and deployment of new zero- or low-carbon feedstock and energy vectors for sectors such as aviation, shipping and the production of chemicals where electrification alone will not be sufficient, and scale-up of carbon capture and sequestration technologies for residual emissions. One has to, therefore, rely on low-carbon sources for generating electricity and use electrolysers to produce hydrogen for use in industries, aviation, shipping, etc.

Aspirations of citizens are rising and they are looking for comfortable living conditions as demonstrated by variation in the daily load curve. The load curve in India normally had two peaks, one in the evening and one in the morning, with the evening peak being higher than the morning peak. This shape of the load curve is evolving. In winter, the morning peak is higher than the evening peak, and in summer, a peak in the afternoons has now evolved due to increasing air-conditioning load. This can be seen in Figure 1, where load curves for three different days are shown. Electricity is also needed for maintaining a cold chain for food and for the storage and distribution of pharmaceutical products.

Electricity requirement to achieve net zero

Data from the past decade indicate that the increase in per capita final energy consumption correlates well with an improvement in the composite metric called the human development index (HDI), the correlation being almost linear over the time frame from 2010 to 2019 (ref. 1). India's HDI in 2019 was 0.645, which puts it in the medium human development category. The country must aspire to reach a high HDI like 0.9, similar to what many G20 nations like Australia, Canada, France, Germany, Japan, South Korea, the UK and USA have already achieved.

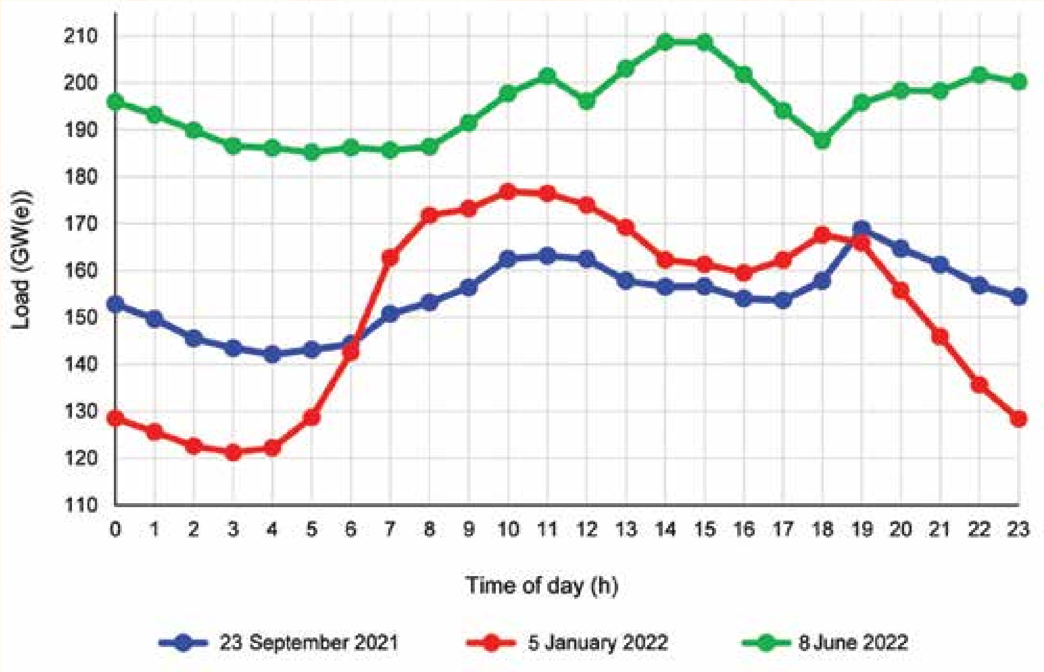

Figure 1. All-India load curves for three different days of the year chosen to convey a shift in the timing of occurrence of the peak load. Note: Based on data obtained from the International Energy Agency, available at https://iea.li/3Hmd90u (last accessed on 26 June 2022).

With this background, one has to estimate the target for the generation of electricity in a net-zero India in 2070. Estimates made by various agencies inform us that a massive increase in electricity generation is needed. Bhattacharyya et al.1 used the correlation between HDI and total final energy consumption to estimate electricity requirements. The study builds several scenarios and concludes that 'a bench-mark value for highly developed India's final energy consumption per capita per year can be taken as 16,000 kWh'. Assuming a population of 1.5 billion in 2070, it translates to a total generation of 24,000 billion kWh per annum. A part of it (about 60–70%) will be used as electricity and the rest for the generation of hydrogen by electrolysers. This estimate accounts for likely improvements in the efficiency of energy use, but one must note that the turnover of the existing stock to realize the benefits of efficiency improvement is a challenge for a price-sensitive market like India.

HDI data for 2021 have been just released and HDI for India has come down due to a decrease in longevity. India's HDI now is 0.633, while the world average is 0.732. The change in HDI does not in any way change the estimates made by Bhattacharyya *et al*.[1]. The estimates, such as by Grover[2,3] prior to the commitment made by India to achieve net zero by 2070, are now obsolete. Even after the goal of net zero was announced by the Government of India (GoI), some publications focus only on the power sector while developing future electricity demand. For example, Gulagi *et al.*[4] mention that the use of electricity demand for sec-tors such as heat, transport and industry was not considered by them in their study.

Technology development in the coming decades can make it possible to produce hydrogen using high-temperature heat from nuclear reactors or solar thermal power plants. Nevertheless, these have to be built to provide high-temperature heat. Another study that forecasts energy requirements similar to Bhattacharyya *et al*.[1], is by the Council on Energy, Environment and Water (CEEW), New Delhi[5]. Other studies have come up with estimates, but are based on optimistic assumptions like very low electricity – GDP elasticity[6], or using complex models with numerous assumptions as done by the Asia Society Policy Institute (ASPI), New York[7]. Optimistic assumptions in studies like that by ASPI have led to the prediction that there is no need to build any more coal-fired power plants, a prediction that has now been challenged by the post-pandemic electricity growth re-quirements[8]. Bhattacharyya *et al*.[1] have followed a simple and transparent approach with minimum assumptions.

The figure of 24,000 billion kWh per annum may be compared with the present electricity generation of about 1600 billion kWh from all sources. The compounded average growth rate (CAGR) of electricity generation for the decade 2010–11 to 2019–20 (i.e. the decade before the onset of the pandemic) was 5.17% (ref. 9). To achieve its target in 2070, India has to maintain this CAGR for growth in electricity generation for the next five decades, and also nurture all low-carbon electricity-generating technologies in order to achieve the target. As stated earlier, low-carbon electricity-generating technologies in India now making a significant contribution are hydro, nuclear, solar and wind.

Few publications related to India have projected the requirement of electricity generation to achieve high HDI. During discussions on the subject, one encounters several questions and reactions mentioning that the requirement of electricity generation in the country of about 24,000 billion kWh is too high. The first is to think of the correlation bet-ween HDI and final energy consumption as causation and start a discussion on the direction of causality. The second is to invoke the Indian tradition of frugality and suggest that we can do more with less. The third is to ignore the concept of life-cycle energy flows as embedded in the concept of EROI, the ratio of Energy Returned On (Energy) Invested, and opine that a lot can be achieved from agricultural residue, municipal solid waste, cow dung, etc. All these are important energy resources with positive externalities (including benefits for health and employment generation) associated with their use. However, they have low energy content per unit mass, and the energy required for their collection and transportation is disproportionately large. As a result, they have a low EROI. In certain cases where biomass is converted into pellets and transported over long distances, such as from the USA to the UK, EROI is close to one. Thus, their use will not make a substantial difference in the estimate of the target generation. Additionally, their carbon neutrality is difficult to verify. Broadly speaking, hydroelectricity has the highest EROI, nuclear and wind are next, and the EROI of solar photovoltaic (PV) sources varies depending on the technology deployed[10].

The World Energy Outlook analyses three different scenarios and forecasts a rising share of electricity in the global final energy consumption (FEC)[11]. In the scenario aiming to achieve net zero in 2050, it forecasts global electricity demand to increase from 24,700 TWh (20% of FEC) in 2021 to 62,159 TWh (52% of FEC) in 2050.

Meeting the target electricity requirements

Irrespective of the path followed to achieve the target gene-ration, one has to carefully examine the potential of various technology options to identify what the technology mix to provide the target generation would look like. The potential of renewable energy in India has been assessed by the Ministry of New and Renewable Energy (MNRE), GoI, as well as by academics. One optimistic estimate[12] accounts for all solar, wind, hydro, biomass, wave, marine currents, ocean thermal and tidal energy. According to this estimate, the total electricity generated could range from 1803.9 to 5854.6 billion kWh per annum, with the actual generation achieved somewhere between the two extremes. To arrive at solar potential, Sukhatme[12] assumed a range of areas devoted to the installation of solar PV plants resulting in a range of generation capacities (500–2000 GW). He also assumed a very large generation capacity based on wind, an estimate not accepted by GoI.

Estimates by Sukhatme[12] may be compared with those of Gulagi *et al.*[4], who assumed that 6% of the total land area in each of the Indian states could be covered by solar PV plants, resulting in an installed capacity potential of 14,223 GW. They assumed a wind-installed capacity potential of 1062 GW. However, they report that by 2050, only 3000 GW of PV and 410 GW of wind capacity will be exploited. MNRE estimated the total solar potential as 750 GW, wind as 300 GW at a hub height of 100 m, small hydro potential as 20 GW and bio-energy potential as 25 GW (ref. 13).

In any case, the total potential, even with technological developments in the coming decades, is not likely to reach anywhere close to the target generation. Therefore, one has to deploy other low-carbon sources, particularly nuclear.

To spur the growth of renewable energy, particularly solar and wind, the GoI has provided policy support and incentives like renewable purchase obligations, creating green energy corridors, waiving-off inter-state transmission charges, making available 100% foreign direct investment in wind and solar power projects, enabling accelerated depreciation on capital investments and concessional interest rates to finance these projects, etc. and results are visible. The PLI (production-linked incentives) scheme for solar cells and modules has been formulated to incentivize indigenous manufacturing. The only policy pronouncement in favour of nuclear is its inclusion in the non-fossil fuel-based portfolio.

The electricity demand grew steadily at about 4.1% annually during the last decade, and it is projected to grow by about 6% annually during the next decade8. The baseload capacity has to grow to meet the demand, but the narrative around and focus on renewable technologies created an impression that nothing more than renewable is needed. The result is power supply shortages in India, first during the winter of 2021 and then in the summer of 2022. This has now been understood and the Central Electricity Authority (CEA), GoI, has projected that apart from the under-construction coal-based capacity of 25 GW, the additional coal-based capacity required till 2031–32 may vary from 17 to around 28 GW (ref. 8).

Considering the importance of baseload capacity, as high-lighted by several studies summarized later in this article, the projection by CEA is not surprising. However, considering the target of net zero to be achieved by 2070, it is desirable that, to the extent possible, the baseload capacity is provided by nuclear rather than coal. Therefore, near-term policies must be formulated to enable the growth of nuclear-installed capacity in a sustained manner.

There are many other issues associated with the expan-sion of variable renewable energy (VRE) installed capacity and these are described in the following sections.

Integration of VRE in the grid

In addition to their overall potential being limited compared to the target demand of electricity in India, the inherent intermittency of solar and wind poses challenges when integrating them into the power grid. In an electrical system, demand and supply always have to match. An additional investment must be made in the electricity system when the supply is intermittent to match demand and supply. This could be in the form of systems to store electricity as in batteries or pumped hydro storage, using electrolysers to shape the demand, or by flexing generation from assets such as fossil fuel-fired generators or large hydro plants. All this is technically possible but adds to the cost of providing electricity to consumers. The cost becomes exorbitant when the level of penetration of renewables in the grid becomes high. This has been highlighted in several studies and also from experiences in the recent past. Here we review relevant studies that consider the necessity of having firm low-carbon electricity sources as a part of the electricity grid.

To start with, one needs clarity on the terminology used to refer to various generation sources. Building on the classification by Sepulveda et al.14 by integrating what has been left out, we present the following classification for low-carbon technologies.

(1) VRE resources: These include run-of-river hydropower, solar PV, concentrating solar power without storage and wind power.

(2) Storage, balancing and demand-shaping technologies: These technologies are key to integrating intermittent VRE and include short-duration energy storage as in Li-ion batteries, synchronous condensers, long-duration storage as in pumped hydro storage systems (PHS), demand-shaping technologies such as vehicle-to-grid technologies, deploying electrolysers for producing hydrogen and creating dispatchable load, or price-responsive demand-shaping by deploying smart meters, geographical aggregation by grid extension over a large area, etc. Technologies such as battery storage are energy-constrained, and their future role depends on steep price reductions and the continued availability of materials. The dispatchable load provided by hydro-gen electrolysers has good potential and provides green hydrogen, but price reduction is key to their large-scale deployment. All technologies in this category add to costs, but are necessary for large-scale deployment of VRE resources.

(3) Firm low-carbon resources: These technologies can meet demand during all seasons, over long durations, and some can even flex in response to demand. These include nuclear power plants (which may or may not be capable of flexible operation), hydroelectric plants with high-capacity reservoirs, coal and natural gas plants with carbon capture and storage (CCS) and capable of flexible operations, biomass and biogas fuelled plants and geothermal power. These plants provide power at all times, except when they are under maintenance and repair. The scheduled maintenance period of firm low-carbon plants is known well in advance.

Sepulveda et al.14 analysed two US regions, a northern system with modest renewable resource potential (New England) and a southern system having a significant renewable resource (Texas). The study concluded that firm low-carbon resources contributed to containing the overall cost of decarbonization even in regions with abundant renewable resources. It reported that 'in the absence of firm low-carbon resources, affordable decarbonization of the power sector would simultaneously require further steep reductions in the cost of VRE and battery storage technologies, significantly over-sizing installed capacity relative to peak demand, significantly greater demand flexibility, and expansion of long-distance transmission capacity connecting wide geographical regions.' The study did not model technologies capable of long-term storage, such as PHS that can moderate the cost of integrating VRE. It advocated greater public support for firm low-carbon sources.

The Nuclear Energy Agency has explained the issue of total costs (the sum of plant-level and grid-level costs) through a three-dimensional plot (Figure 2)15. The horizontal axis pointing left represents carbon constraint, while the horizontal axis pointing right represents the share of variable renewables. The blue line represents variation in the total cost when the carbon constraint is set at 50 g per kWh. The total cost is highest (125–150 USD/MWh) when the mix has only VRE and lowest (75–100 USD/MWh) when the mix has a mix of VRE and nuclear. When the carbon constraint is set at 1 g per kWh, the corresponding figures are 275–300 USD/MWh for only VRE and 75–100 USD/ kWh for a mix of VRE and nuclear.

The study by Cohen et al.16 focused on California, USA, and arrived at similar conclusions. Three groups were convened to model California's energy system and despite distinct approaches to the calculations, all the models concluded that 'solar and wind can't do the job'. The study referred to a large-scale weather pattern extending over large geographical areas and driving out solar and wind. It concluded, 'If wind and solar are pushed to do all the heavy lifting themselves, the system requires enormous excess generating capacity and storage (most of which is seldom used) to provide reliable electricity and completely drive out greenhouse emissions. The strategy is much more ex-pensive and demanding of land and infrastructure than other possible pathways'16. Finally, the study recommended developing clean firm power: 'Nuclear power can steadily provide very large amounts of energy in a small footprint'16.

The relationship between electricity supply and demand in low-carbon systems was analysed by the

International Energy Agency (IEA)17. The analysis revealed that due to the presence of VRE, multiple services are needed to provide electricity reliably and these include ‘meeting peak capacity requirements, keeping the power system stable during short-term disturbances, and having enough flexibility to ramp up and down in response to changes in supply or demand’17. The IEA study quantified the energy and service contribution of different technologies to maintain electricity

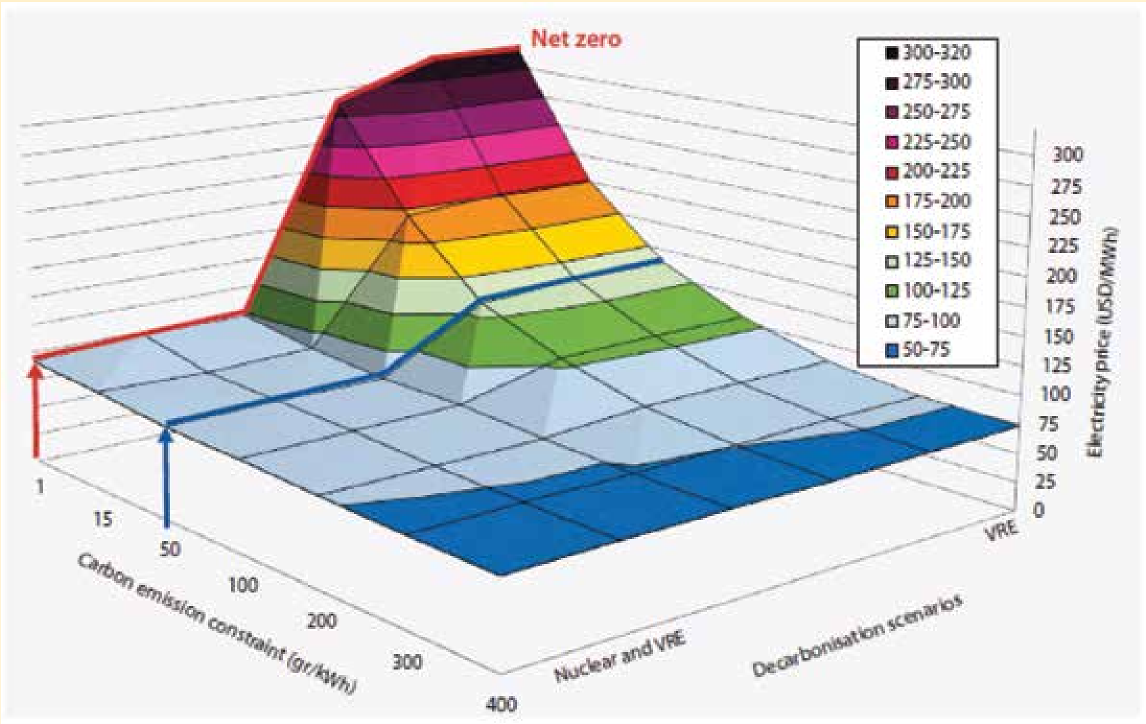

Figure 2. Total cost of different mixes of electricity (driving to net zero emissions). Note: The blue line represents variation in the total cost when the carbon constraint is set at 50 g/kWh. The total cost is highest (125–150 USD/MWh) when the mix has only variable renewable energy (VRE) and lowest (75–100 USD/MWh) when it has both VRE and nuclear sources. When the carbon constraint is set at 1 g/kWh, the corresponding figures are 275 to 300 USD/MWh for only VRE and 75 to 100 USD/kWh for a mix of VRE and nuclear. (Source: OECD/NEA (2022), Meeting Climate Change Targets: The Role of Nuclear Energy, https://www.oecd-nea.org/jcms/pl_69396/meeting-climate-change-targets-the-role-of-nculear-energy , reproduced with permission.)

security in China in Announced Pledges Scenarios, 2060 (ref. 17). While VRE majorly contributes to energy, contribution to system stability comes from firm power sources, namely nuclear and abated thermal. The contribution of VRE to even the peak capacity is much less than its contribution to energy. Using Monte Carlo assessments to simulate the power system under many possible conditions, they captured aspects like the amount of load not served or frequency of the unserved load. They concluded that ‘Maintaining operational security requires both system stability – supported by power system inertia and operating reserves – and the flexibility to ramp up and down to main-tain a balance between supply and demand’. VRE cannot provide system inertia, flexing or operating reserves (at all times).

Ancillary services in the electricity market

The Indian Electricity Grid Code (IEGC) is a regulation made by GoI. It defines ancillary services as 'the services necessary to support the power system (or grid) operation in maintaining power quality, reliability and security of the grid, e.g., active power support for load following, reactive power support, black start, etc.'. These consist of services required to maintain load-generation balance (frequency control), keep voltage and reactive power support, and maintain generation and transmission reserves18. The salience of these services has increased due to unbundling of the power sector, increased penetration of VRE and the aspiration of consumers who expect assured electricity sup-ply round the clock in all seasons. Before unbundling of the power sector, these services were provided by vertically integrated utilities along with energy. During the era of shortages, the tool used to maintain the load-generation balance was load-shedding.

Unbundling of the power sector has given the responsibility of providing ancillary services to the National Load Dispatch Centre, New Delhi and in the future, it will be passed on to the state load dispatch centres as well. Energy not supplied in 2020–21 and 2021–22 was only 0.4% (ref. 8). Therefore, one can state that India has achieved generation adequacy. However, the power supply continues to be unreliable, particularly in rural areas. It is due to problems mainly with the distribution network and inadequate paying capacity of the customer (or the subsidizing agency). From the point of view of generation, reserves of various kinds, such as spinning, high ramping, non-spinning, etc. must be maintained and kept ready for the disposal of the respective load dispatch centre. Since VRE generators are intermittent, do not supply reactive power and have no rotating inertia, the cost of providing ancillary services increases with increased penetration of VRE in the grid. CEA has now come up with draft guidelines for a resource adequacy planning framework and has identified the need for energy storage to manage the intermittency and variability of VRE sources19.

Ancillary services must be available on demand at different speeds and over timescales ranging from seconds to hours. Various generation and storage technologies have different minimum operational levels, and feasible rates and directions of ramping. They thus offer different kinds of ancillary services. Therefore, a generation mix of diverse low-carbon technologies along with energy storage capabilities can help alleviate the extent of ancillary services needed.

The role of hydrogen

Considering the role of hydrogen in sectoral decarbonization, estimates for its production are included in the forecasts of electricity requirements in India in 2070 by Bhattacharyya et al.1 as well as by CEEW5. The most important and early-use cases for low-carbon hydrogen are in the industries currently using natural gas-derived hydrogen, such as ammonia production for the fertilizer sector and chemical synthesis (such as methanol, etc.). The petroleum industry uses a large amount of hydrogen to remove sulphur from petroleum products like gasoline and diesel employing hydro-treatment-based desulphurization technologies. With the electrification of the transport sector directly or using battery electric vehicles, demand for diesel and gasoline will decrease in the long term, lowering hydrogen consumption in this sector. However, hydrogen and its derivatives like ammonia, methanol and other synthetic fuels would still be needed for emerging sectors where low-carbon alternatives do not exist or are techno-commercially unviable. Thus, hydrogen demand will rise in the approach to a net zero Indian economy.

It is estimated that about 30–40% of final energy consumption in net-zero India in 2070 may be in the form of low-carbon hydrogen (including production, transmission and distribution) in energy and industrial applications1. This implies a hydrogen requirement of about 120–150 million tonnes per annum by 2070, which is 20–25 times greater than the current consumption of 6 million tonnes per annum. Thus, the dedication of a significant portion of low-carbon electricity towards producing hydrogen will be needed. Hydrogen produced by the banking of VRE will not necessarily be green hydrogen. A diverse mix of all available low-carbon electricity generators will have to cater to the green hydrogen demand. There has been a recent initiative to convert Indian coal to hydrogen through gasification and a roadmap has also been issued in this context20, but a fossil fuel-dependent programme should only be an interim stra-tegy.

Carbon capture and storage technologies

The Indian electric power sector is heavily dependent on coal-based thermal power plants; about 70% of generated electricity in India today comes from them. The carbon emissions intensity of this electricity ranges from 900 to 1100 g CO_2-eq/kWh (e) (ref. 21). These are the largest contributors to India's overall GHG emissions every year. To move towards the target of net zero, CCS is essential for all new and existing thermal generating stations that have substantial useful life left as well as for new or upcoming projects and also in other industries such as steel and cement, which make use of coal or coke as part of their feedstock and energy requirements. However, an energy penalty (which may be a drop in plant thermal efficiency of 11–23% points) is associated with carbon capture in a thermal power plant22. Costs for carbon capture alone currently range from USD 50–180/tonne CO_2 captured, depending on technology, scale and concentration or partial pressure of CO_2 in the gas mixture being processed23.

Concluding remarks and recommendations for policy formulation

Harnessing low-carbon energy forms will enhance dependence on mining activities since new metals/ minerals like silicon, copper, nickel, lithium, manganese, cobalt, vanadium, titanium, platinum, palladium and others will be re-quired in massive quantities. India is not self-sufficient in many of these mineral resources and is still to deploy the technologies for indigenously producing solar PV panels, water electrolysers, grid-scale batteries, etc. at scale. How-ever, the country does have a high degree of supply security with respect to nuclear fuel for its existing and upcoming power reactors, ensured through international agreements24. Uranium can be stored for long durations to address any supply disruption. Domestic fuel fabrication facilities have already been established and can be expanded to meet increased demand. India also has significant domestic resources and extraction capabilities of other nuclear materials, such as zirconium. It has standardized and completely localized the entire manufacturing process for PHWRs, thus shielding the nuclear power programme from technology, currency, market, and supply-chain risks. So, a rapid increase in the deployment of nuclear-generating capacity is within reach for the country to attain net zero. India's programme for fleet-mode deployment of 700 MW(e) PHWRs indicates a long-term commitment to harnessing nuclear energy. It is one of the few countries to have explicitly included nuclear power in its arsenal of non-fossil energy sources for climate change mitigation as part of its NDCs. Policy support to ensure on-time, on-budget completion of projects (particularly those based on well-proven technologies like PHWRs) is needed so that the contribution of nuclear power towards climate action is fully realized.

India's massive energy demand and the simultaneous need to attain a net-zero economy require a structural shift in energy generation and utilization across all sectors. Energy use is not just electricity use – the entire energy system needs to transition to low-carbon alternatives. Certain sectors will require synthetic fuels and other energy carriers, such as hydrogen and its derivatives, whose production requires at least one electrochemical operation and hence electricity input. Electrification will be the cornerstone of the energy transition in most sectors. The electricity supply side needs an optimal blend of all low-carbon technologies. This mix should be determined by considering capital cost, dispatchability and reliability of generators, environmental footprints, resource utilization efficiency, climate resilience, contribution to energy security and affordability.

The estimated potential of renewables may get revised upwards in the light of technology improvements (e.g. commercial availability of higher-efficiency solar panels, use of bi-facial panels, taller wind turbines with larger rotor dimensions, etc.). Still considering their variability and resultant high system cost, nuclear and coal with CCS also need to be nurtured. An energy mix comprising all low-carbon technologies will have built-in diversity, which is a hedge against unforeseen disruptions. This requires clear policy articulation.

Based on our assessment, we recommend the following.

(i) Nurture all low-carbon technologies: Domestic ecosystems for all the required low-carbon technologies should be nurtured and sustained; indigenous supply chains for materials and components should be established; the required human resources for analysis, design, manufacture, operation and decommissioning should be developed; socio-economic–environmental consequences of the transition pathways should be analysed and any associated externalities must be fully appreciated and accounted for in the planning process.

(ii) Develop an all-round understanding of generation technologies as well as end-use technologies: To objectively understand environmental and sustainability characteristics and impacts of different energy generation, conversion and storage technologies, life cycle analyses must be carried out to support policy decisions. Energy benchmarking exercises are required to determine baseline energy consumption in different industries, and to track the effectiveness of energy efficiency and other decarbonization measures over time.

(iii) Provide a level playing field to all low-carbon tech-nologies: To align domestic and international financial flows with activities that contribute to net-zero initia-tives, many countries have developed green taxono-mies. Some countries have issued explicit statements outlining the share or role of nuclear in the energy mix to achieve a net zero. An initiative to prepare a green taxonomy is needed in India to ensure that all low-carbon technologies are provided with a level playing field.

(iv) Shape the load curve by deploying electrolysers: In addition to the generation of hydrogen, electrolysers should be positioned as a dispatchable load so that the must-run status given to nuclear can continue and there is a minimum need to curtail VRE even after its percentage share in the energy mix increases beyond the present values.

Reaching net zero is just one of the objectives, not the end. We also must ensure that resources are available for sustaining high electricity generation after 2070. Near-term policies have to be formulated to ensure that all technolo-gies needed for the long-term sustenance of electricity generation are nurtured and developed so that long-term decarbonization goals become achievable and sustainable.

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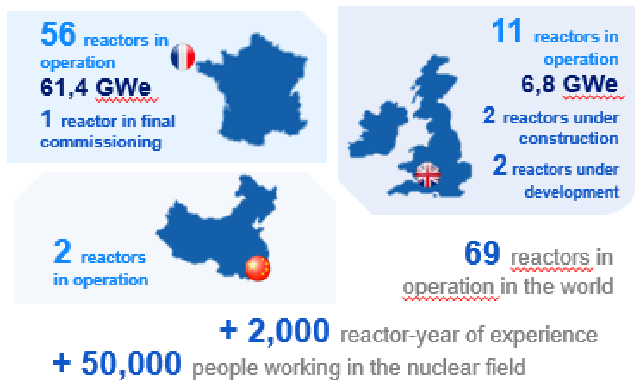

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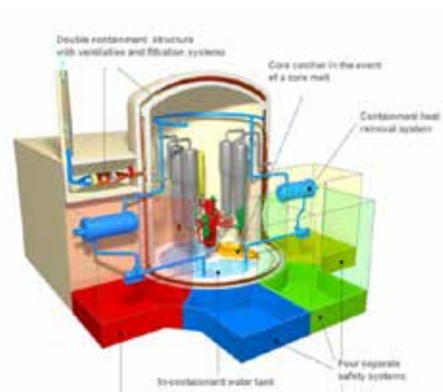

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Fuel assemblies in core	76

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- Improved **landscape** integration
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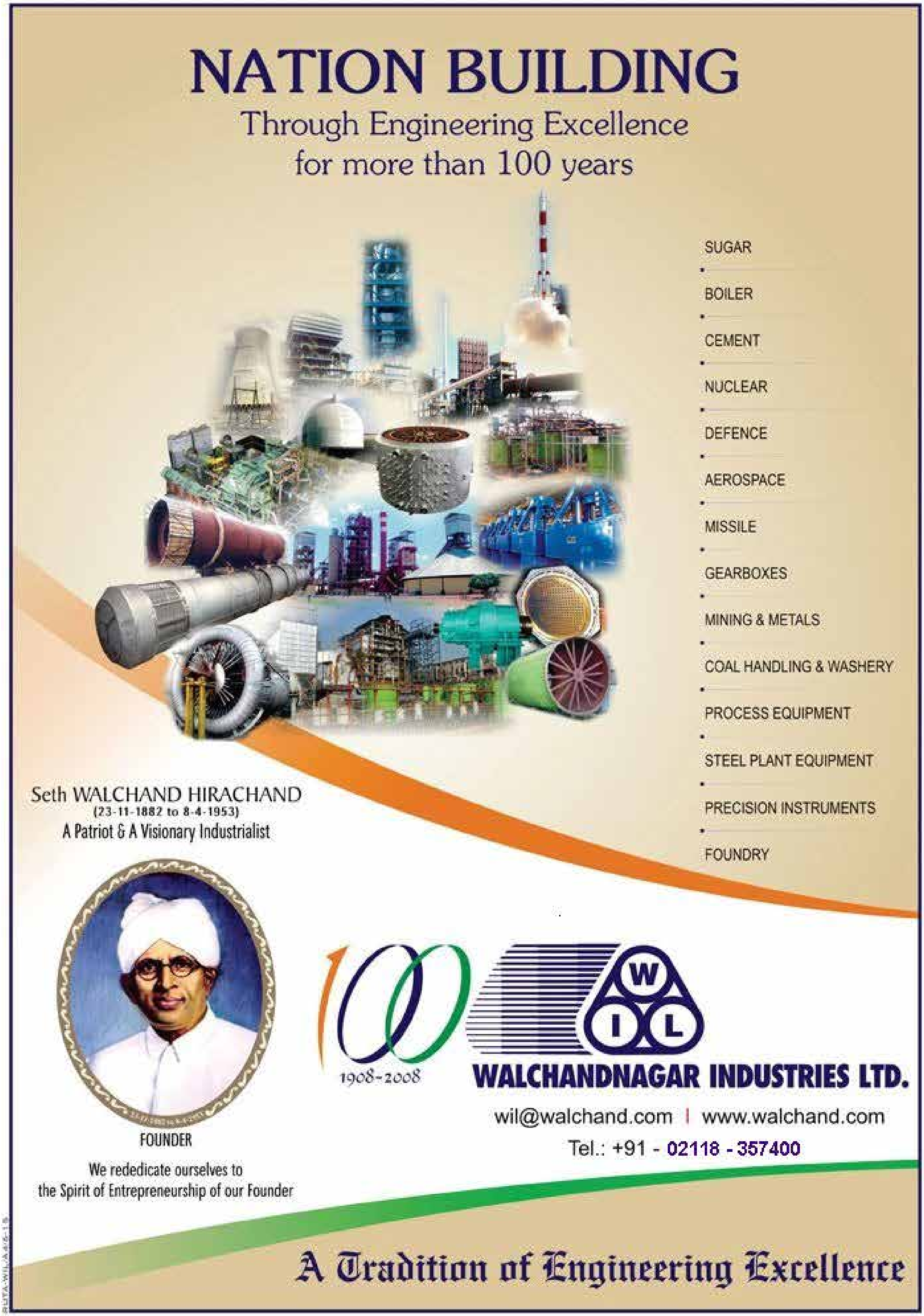
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Shri K.N. Vyas

Chairman, AEC and Secretary, DAE

Shri K.N. Vyas is a Mechanical Engineering Graduate of MS University, Vadodara and a graduate of the 22nd Batch of BARC Training School. Joining the Department in 1979, he commenced his career with forays into nuclear reactor fuel designs. In those early days of the oncoming computer age, he managed to gain substantial skills and proficiency in computer programming and developed programmes to carry out fuel performance analysis of nuclear fuels, which modeled fuel design aspects like irradiation swelling, fission gas generation and release, pellet-clad interaction, etc. The insights gained by these studies led to the design of the 7X7 cluster for BWR fuel having superior performance characteristics.

Subsequently, he went on to expand his repertoire, working in various projects on fuel analysis and design for the upcoming power reactors as well as towards design of novel fuels needed for strategic applications. He also gained expertise in thermal hydraulics and stress analysis and contributed towards analysis of critical reactor core components. As a fuel design engineer, he provided key inputs to fuel manufacturing units like Atomic Fuels Division and Nuclear Fuels Complex.

As a team member in Reactor Projects Group, he has played a crucial role in the completion of strategic projects executed by BARC. He has played an important role in indegnisation of special materials as well as several fabrication & test equipment used in fuel fabrication. His expertise was useful in evolving the design of Test Blanket Module and associated systems, planned to be installed at the ITER project, a fusion reactor under construction in France, by a multinational scientific consortium.

Shri K.N. Vyas is a recipient of several honours and awards such as the Indian Nuclear Society Outstanding Service Award, 2011, Homi Bhabha Science and Technology Award, 2006 and the Dr. N. Kondal Rao Memorial Award, 2017. He is a Fellow of Indian National Academy of Engineering, 2015.

His passion for tackling technological challenges has remained undiminished with age, as evidenced by his recent work in computational fluid dynamics studies of swirl flows in heat exchangers. These studies have led to superior understanding of heat transfer enhancements and in recognition of this excellent work carried out by him, he was awarded Master of Science (Engg) by the Homi Bhabha National Institute in the year 2016.

Shri K.N. Vyas is a strong team player and recognizes the importance of teamwork and collaboration in successfully implementing projects. He and his team have won several Group Achievement Awards in the years 2007, 2008, 2012 and 2013 in the field of design and development of critical reactor system equipment, as well as successful erection and commissioning of various reactor systems.

The leadership, insights and guiding hand provided by him as Director, Bhabha Atomic Research Centre since February 2016 has led to substantial progress in all aspects of basic and applied research in engineering, physical, chemical, biological and material sciences with a special thrust towards development of applications for societal benefits in the energy, health, food and agricultural sectors.

Shri Vyas is the Chairman of the Board of Governors of Tata Memorial Centre, Institute of Plasma Research, Homi Bhabha National Institute, University of Mumbai – DAE Centre for Excellence in Basic Sciences, Saha Institute of Nuclear Physics, National Institute of Science Education and Research, Institute of Physics and Harish-Chandra Research Institute. Shri Vyas is the Member of Management Council of Tata Institute of Fundamental Research and Co-Chairman in the Governing Body of Institute of Mathematical Sciences and

Shri K.N. Vyas assumed charge as Chairman, Atomic Energy Commission and Secretary, Department of Atomic Energy on September 20, 2018.

Dr. Anil Kakodkar

Chancellor, Homi Bhabha Institute

Anil Kakodkar joined the Bhabha Atomic Research Centre (BARC) in 1964, following the one year post graduate training in the then Atomic Energy Establishment. He became the Director of BARC in the year 1996 and was the Chairman, Atomic Energy Commission and Secretary to the Government of India, Department of Atomic Energy, during the years 2000 – 2009.He was DAE Homi Bhabha Chair Professor during Jan. 2010 – Jan. 2015 and INAE Satish Dhawan Chair of Engineering Eminence during Jan. 2015 to Jan. 2017. Currently he is Chancellor of Hoimi Bhabha National Institute.

Kakodkar obtained his BE (Mech. Engineering) degree from the Bombay University in 1963 and M.Sc. in the Experimental Stress Analysis from the Nottingham University in 1969.

Kakodkar has worked for the development of the atomic energy programme in India throughout his professional life and has been a key contributor to India's strategic programme. He was involved in the first successful Peaceful Nuclear Explosion Experiment that India conducted on May 18, 1974 at Pokhran. Later, he played a key role in the series of Nuclear Tests conducted during May 1998, again at Pokhran.

Kakodkar's leadership led to a significant boost to India's nuclear power programme notwithstanding. Kakodkar championed observer status for India at CERN (European Centre for Nuclear Research), partnership in the ITER (International Thermonuclear Experimental Reactor) project and exemption for nuclear trade from Nuclear Supplier's Group (NSG).

Notable also are his contributions to human resource development activities including establishment of National Institute of Science Education and Research, DAE-Mumbai University – Centre for Basic Sciences) and Homi Bhabha National Institute.

A committee under his Chairmanship worked out a detailed report for greater autonomy of IITs and taking them to world class level. Another Committee led by him has carried similar exercise in the context of NITs. He also led a committee set up by Government of Maharashtra to look at higher education in the

State. Another high-level committee under his Chairmanship has made comprehensive recommendations for improvement of safety on Indian Railways.

A TIFAC apex group led by him brought out a Technology Vision 2035. The document was released by Hon. Prime Minister of India during the Science Congress on January 3, 2016. Kakodkar was Chairman, Solar Energy Corporation in its formative stage. He was also Chairman of Inter University Centre for Astronomy and Astrophysics during 2006 to 2012, Chairman, Governing Board, Inter University Accelerator Centre, New Delhi, and Chairman, Board of Governors of the Indian Institute of Technology, Bombay during 2006-2015.

Kakodkar is a fellow of the Indian National Science Academy, Indian Academy of Science, National Academy of Science, India and Maharashtra Academy of Science. He was awarded with Padma Shri (1998), Padma Bhushan (1999) and Padma Vibhushan (2009) by the Government of India.

Shri R.V. Shahi

President IEF

Mr. R V Shahi was Secretary, Ministry of Power, Government of India, from 2002-07 which is the longest term served by any incumbent. In this position, he was responsible for policy initiatives and implementation for India's entire Power Sector (2,00,000 MW capacity) and over significant restructuring with the institution of the Electricity Act 2003, National Electricity Policy 2005 and National Tariff Policy 2006. Other major initiatives include 50,000 MW Hydro Power Initiative 2003, Accelerated Power Development and Reform Programme 2003, Setting up Bureau of Energy Efficiency 2003, Rural Electrification Policy 2005, Ultra Mega Power Policy 2006 and Merchant Power Policy 2006. Mr. Shahi is currently the Chairman of Energy Infratech Pvt. Ltd. and was formerly the Chairman and Managing Director (1994-2002) of professionally managed BSES Ltd (later taken over by Reliance Energy in 2004). He transformed BSES from a small distribution utility to a multi-unit fully integrated power utility having generation, transmission and distribution. At National Thermal Power Corporation (NTPC) from 1978-94, he was the General Manager in charge of Dadri Power Project; Executive Director in charge of Southern Region of NTPC, and Member on the Board of Directors of NTPC in-charge of Operations, R&D and Commercial functions. He has authored several books on the power sector, is a Fellow of the World Academy of Productivity Sciences, Institution of Engineers (India), International Institute of Electrical Engineers, and Indian National Academy of Engineering. He has been on the Boards of Xavier Management Institute Bhubaneshwar, IIM Lucknow, and Management Development Institute in Gurugram. Mr. Shahi is a graduate in mechanical engineering from the National Institute of Technology, Jamshedpur, post-graduate in Industrial Engineering, post graduate in Business Management (MBA), and a diploma in Advanced Industrial Management (Delft, Holland). Mr. Shahi is currently, as a consultant, is Sr. Energy Advisor for South Asia Regional Collaboration with the World Bank. President, India Energy Forum an Independent Think Tank, Distinguished Fellow and Chairman, South Asia Group on Energy (SAGE) in RIS.

Shri Gurdeep Singh

CMD, NTPC

Shri Gurdeep Singh, aged 53 years, is a Mechanical Engineer. He has more than three decades of experience in power generation sector. He started his career with NTPC Limited and has worked at various levels both in Indian and Multi-national Companies namely Powergen, CLP, IDFC, CESC and AES. He has worked in different areas of Power Sector ranging from business development, projects and operations.

Prior to joining NTPC, Shri Singh was Managing Director, Gujarat State Electricity Corporation Limited.

Shri Bhuwan Chandra Pathak

CMD, NPCIL

Shri. Bhuwan Chandra Pathak is a Mechanical Engineering graduate and began his career in 1986. He is recognized as a Distinguished Scientist of the Department of Atomic Energy.

He has a rich experience of over three decades in implementation of Nuclear Power Projects of various capacities of NPCIL starting from 220, 540, 700 to 1000 MWe of both PHWR and PWR technologies across the different sites in India. He held several key positions like Chief Construction Engineer, Project Director, Executive Director (Projects) before being appointed as Director (Projects) on NPCIL 's Board in July 2019. He has earned the reputation of a diligent and enterprising professional for his abilities to set benchmarks of outstanding achievements in his various assignments and leadership roles.

Shri. Pathak took over as CMD on 23rd February 2022. He believes in a governance philosophy that fuels progress, diversification and develops a synergy through alliances taking the organization to greater heights. He works to achieve highest standards of corporate governance building a well-defined and enforced structure that best aligns the business conduct with the objectives of the organization.

He takes keen interest in establishing and nurturing sound safety culture in NPCIL fleet and is an advocate of contributing towards neighbourhood development under the Corporate Social Responsibility.

He now looks ahead with optimism in contributing to India's goal of self-reliance in energy by leading the most ambitious nuclear power expansion programme of the country.

Dr. Ajit Kumar Mohanty

Director, BARC

Dr. Ajit Kumar Mohanty born in 1959 at Odisha is a well-known nuclear physicist, completed his bachelor's degree in 1979 from MPC College, Baripada and master's degree in Physics in 1981 from Ravenshaw College, Cuttack which was at that time under Utkal University, Bhubaneswar. Dr. Mohanty graduated from the 26th batch of the BARC Training School and joined Nuclear Physics Division of Bhabha Atomic Research Centre in 1983 and got his PhD degree from Bombay University later on. He has taken over as Director, BARC on 12th March 2019. Before his appointment as Director BARC, Dr. Mohanty has held the position of Director of Saha Institute of Nuclear Physics, Kolkata from June 2015 and Director of Physics Group, BARC from July 2018. During the past four decades, Dr. Mohanty has worked in several areas of nuclear physics covering collision energy from sub-Coulomb barrier to relativistic regime. It includes experiment using Pelletron accelerator at TIFR, PHENIX and CMS experiments at Brookhaven National Laboratory (BNL), USA and CERN, Geneva respectively.

Dr. Mohanty has held several honorary positions. To name a few, he served as Secretary and Member Secretary of BRNS Basic Science Committee from 2004-2010, General Secretary of India Physics Association (IPA) 2012-2016 and later on President of IPA 2018-2020, India-CMS Spokesperson (CMS Experiment at CERN Geneva) 2013-2015, Dean, Academic, Physical & Mathematical Sciences, BARC, Homi Bhabha National Institute. Dr. Mohanty has been recipient of several awards and recognitions during his illustrious career. Some of Dr. Mohanty's awards and recognitions are: Gold Medal in Graduation (1979, Radha Gobinda Trust, Mayurbhanj), Young Scientists Award of Indian Physical Society (IPS, Kolkata, 1988), Young Physicist Award by Indian National Science Academy (INSA, New Delhi 1991) and DAE Homi Bhabha Science & Technology Award (2001) by Department of Atomic Energy, Mumbai.

He was also conferred the CERN Scientific Associate position at CERN, Geneva from 2002-2004 and thereafter again from 2010- 2011. Dr. Mohanty is a fellow of National Academy of Sciences and Indian National Academy of Engineering.

Shri US Matharu

Director (Power & HR) Bharat Heavy Electricals Ltd.

Shri Upinder Singh Matharu was inducted as Director (Power) on the Board of Bharat Heavy Electricals Limited (BHEL) w.e.f. 21.03.2022. Shri Matharu is a 1984 batch Mechanical Engineering graduate from Thapar Institute of Engineering & Technology, Patiala. He holds post graduate degree in Business Administration (Marketing) besides being a Govt. certified Energy Manager and Auditor from Bureau of Energy Efficiency (BEE).

Shri Matharu joined BHEL in 1985 at Industrial Valves Plant (IVP), Goindwal when the plant was being set up. He has had a diverse and versatile experience spanning almost 37 years, working initially in manufacturing units at IVP and HPBP Tiruchirappalli and then in BHEL's Power Sector divisions including in Project Management function. Subsequently he headed Power Sector Eastern Region (PSER).

As Head of PSER, he has been responsible for execution of more than 8000 MW of thermal, hydro power projects in India and overseas besides FGD projects. During his tenure in Project Management, he was instrumental in developing and evolving various project management practices and systems of the Company, besides making significant contributions to the power sector capacity addition. During his stint in manufacturing units, he gained hands on experience in variegated functions including Sub-Contracting, Materials Management, Operation Planning & Control, Management Services, and was also actively involved from the inception of the manufacturing unit of IVP, Goindwal.

A soft-spoken person, he is widely known as a trustworthy professional having in-depth knowledge and experience of power sector ecosystem for speedy implementation of projects.

His extensive experience in manufacturing units and corporate functions have enabled him to assess the prospective changes in the business environment and contribute effectively in formulation of strategies for the growth of the Company.

Dr. Ravi B. Grover

Chairman, Nuclear Group, IEF

Ravi B. Grover is working as an Emeritus Professor at the Homi Bhabha National Institute (HBNI). He graduated from the Delhi College of Engineering, Delhi University, studied nuclear engineering in the Training School, and received a Ph.D. from the Indian Institute of Science. He was President of the Indian Society of Heat and Mass transfer during 2010-13. He has worked in the Bhabha Atomic Research Centre (BARC), the secretariat of the Department of Atomic Energy (DAE), and HBNI. Various positions held by him include Director, Knowledge Management Group, BARC; Director, Strategic Planning Group, DAE; and Principal Advisor, DAE. He superannuated from DAE in 2013 and occupied DAE Homi Bhabha Chair during 2013-18.

Working as a nuclear engineer in BARC, he specialized in nuclear reactor thermal hydraulics, process design, and process safety analysis. He participated in negotiations with other countries and international agencies leading to the resumption of international civil nuclear trade. He was the Sous-Sherpa of the Government of India for the Nuclear Security Summits held in 2010, 2012, 2014, and 2016.

He played a very significant role in conceptualizing and setting up HBNI and concurrent with other responsibilities, he was its Founder Director/ Vice-Chancellor during 2005-2016. DAE funds research in universities through the Board of Research in Nuclear Sciences (BRNS) and he has a long and continuing association with it. He is at present the chairman of BRNS.

He was conferred with a Padma Shri in 2014 and is a fellow of the Indian National Academy of Engineering, the Maharashtra Academy of Sciences, and the World Academy of Art and Science. He is a member of the Atomic Energy Commission since 2011.

Shri Ranjay Sharan

Director (Projects), NPCIL

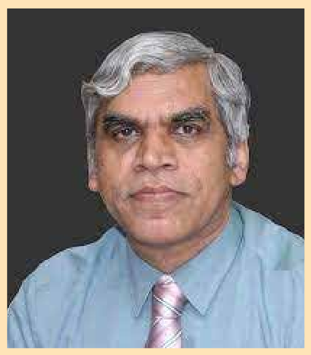
Shri Ranjay Sharan is a graduate in Mechanical Engineering and is an Outstanding Scientist (OS) of DAE. He belongs to 31st batch of BARC Training School. He is also a Master of Business Administration (MBA) with specialization in finance.

Presently, he is Director (Projects) of NPCIL. He is having 34 years of work experience in Mega Nuclear Power Plant construction & commissioning combined with experience of handling global project management issues.

He has to his credit completion of first of a kind Mega Nuclear Power PHWR Project of 2X540 MWe capacity at Tarapur (TAPP-3&4) with a saving of around 8% in Overall Project Cost coupled with substantial saving of time in Overall Project Schedule by completing the project in less than 5 years which was a world benchmark.

Recently he has completed construction of a first of kind 2X700 MWe Mega Nuclear Power PHWR Plant at Kakrapar (KAPP-3&4) by overcoming the challenges of post Fukushima design changes, contractual issues and COVID-19 pandemic.

Shri Sharan is a recipient of INS Medal award given by Hon'ble Prime Minister of India for his contribution in Project management at TAPP-3&4.



Shri S.C. Chetal

Former Mission Director- AUSC and Director- IGCAR

Shri S.C. Chetal, mechanical engineering graduate from Delhi College of Engineering. He was recently Mission Director of R&D Project for development of Advanced Ultra Super-critical (AUSC) technology for thermal power plants. He is a Fellow of the Indian National Academy of Engineering. He was the Director of Indira Gandhi Centre for Atomic Research. His long carrier spanning over 41 years in Atomic Energy had been associated with the fast reactors. He was the principal design engineer of the indigenously designed and built 500MW Prototype Fast Breeder Reactor. He has a rare expertise on design, materials and manufacturing. He had contributed to design and manufacturing of zirconium and titanium sponge plants. He has enhanced the capabilities of Indian industries for indigenous production of materials and manufacturing of mechanical components to stringent requirements. He is also currently contributing to the design and manufacturing of components for ITER project-an international project on nuclear fusion.

Dr. Komal Kapoor

Chief Executive, NFC

Dr. Komal Kapoor is the Chief Executive of Nuclear Fuel Complex (NFC) and the Chairman of NFC Board.

Dr. Kapoor is an Outstanding Scientist and a Metallurgical Engineer, joined the 33rd batch of BARC Training School, Mumbai in 1989. Subsequently, he was posted to NFC and served in various capacities for more than three decades. He has obtained Doctorate degree in Metallurgical Engineering and Materials Science from the Indian Institute of Technology (IIT), Mumbai. Dr. Kapoor is an Adjunct Professor in Homi Bhabha National Institute (HBNI), Mumbai and the Guest Faculty at the University of Hyderabad (UoH).

As Head of the three Nuclear Fuel Cycle Facilities, Dr. Kapoor is contributing significantly to the Indian Nuclear Power Program. He is responsible for setting up a large Greenfield Project at Kota, Rajasthan to meet the fuel requirements of upcoming Reactors in the Country.

Dr. Kapoor possesses extensive knowledge of nuclear fuel cycles and materials. His initiatives have resulted in improvement of quality standards and fuel performance in Nuclear Reactors and also consistent improvements of radiological safety.

Dr. Kapoor was instrumental in manufacture and supply of a variety of seamless tubes for the strategic applications of DAE and that of the Departments of Space and Defence. His research work has led to the development of several critical nuclear materials which are of great technical importance.

Dr. Kapoor is also responsible for numerous research collaborations with various national and international institutions in Nuclear Engineering. For his invaluable contributions in this field, Dr. Kapoor has been conferred with the several prominent Awards and Honours. He has to his credit over 100 Publications in National/International Journals of repute and Symposia.

Dr. Kapoor serves on the Boards of Uranium Corporation of India Limited (UCIL) and the Indian Rare Earths Limited (IREL).

Dr. Kapoor is the Life Member of the Indian Nuclear Society (INS), Indian Society for Non-destructive Testing (ISNT) and Indian Institute of Metals (IIM).

Mr. Stéphane SALIB

Director, India Liaison Office, Jaitapur Project, EDF.

Stéphane Salib has been working for the EDF Group since 2014.

He started first on corporate finance and strategy division, where he dealt with energy markets organization, worked on nuclear electricity tariff regulation, and monitored EDF group investments in some major infrastructure projects in nuclear and hydro power plants.

Then, in 2017, he joined the international nuclear division to manage tenders for nuclear new built projects. In particular, he oversaw the pricing and the financial integration of the Jaitapur offer.

Since 2022, Stéphane has relocated to Mumbai where he currently is the Deputy Director of the Jaitapur nuclear power project and ensures local coordination with various stakeholders as Director of EDF India Liaison Office in Mumbai.

Prior to joining EDF, Stéphane occupied several positions in the energy industry. Working successively in the oil refining industry on economics and industrial planning, then for highly intensive electricity consumers such as chemical, aluminum and steel industries to secure long term and competitive electricity supply contracts.

Stéphane holds a MSc in Engineering, a MSc in Economics and Corporate Finance and a Chartered Financial Analyst certification.

Mr. Thomas MIEUSSET

Nuclear Counsellor, French Embassy

Since September 2019, Thomas MIEUSSET is nuclear counsellor at the French Embassy in India.

Until Summer 2019, he was nuclear counsellor at the French Embassy in South Africa.

He was appointed to this position in 2016, following a year as senior executive at the international relations department of the French Alternative Energies and Atomic Energy Commission (CEA).

From 2010 to 2015, he was senior executive at the international relations department of the French nuclear regulatory body (ASN). He was in charge of bilateral relations with North America and several European countries. He was also the ASN's point of contact for the Multinational Design Evaluation Programme (MDEP), initiative of national regulatory bodies for the review of GEN III reactors (EPR, VVER…).

In 2001, he joined the French Alternative Energies and Atomic Energy Commission (CEA), serving as R&D engineer in the reactor studies department of the nuclear energy division. He contributed to the development and validation of a system code used for thermal hydraulics studies. He also contributed to the training and supervision of foreign staff in the framework of an associated laboratory with several countries.

He began his career in 1999 as deputy nuclear counsellor for nuclear affairs at the French Embassy in China.

Mr. Thomas MIEUSSET, 23 years of experience in the field of nuclear energy, holds a master degree in fluid mechanics and hydraulics.

Shri Yatindra Mohan

General Manager, Nuclear Business Group, Bharat Heavy Electricals Limited (BHEL)

Shri Yatindra Mohan is working as General Manager in Nuclear Business Group in Bharat Heavy Electricals Limited (BHEL).

Shri Mohan is a Mechanical Engineering graduate of 1991. He is looking after Marketing and Project Management aspect of Nuclear Business within BHEL.

He joined Heavy Electrical Equipment Plant at BHEL Haridwar in 1991. His earlier experiences include design and manufacturing of power plant equipment like Condenser, Heaters, Turbo-Generator and Steam Turbine. After vast experience of more than 17 years in design and manufacturing side, he was assigned the responsibility of Power Sector-Marketing in 2009. During his role as marketing executive, he worked on opportunities emerging in coal based Thermal Power Plants and Nuclear Power Plants.

As industry representative, he was involved in development of suitable insurance product for risk distribution arising out of CLND Act 2010 and Rules 2011. He played a key role in forging long term relationship with General Electric for Technology Transfer of 700 MWe Steam Turbines for Nuclear Power Projects in India. He also spearheaded the development of secondary cycle of 300 MWe Advanced Heavy Water Reactor (AHWR) based Nuclear Power Plants for 3rd Stage of Indian Nuclear Power Programme.

Ms. Minu Singh

Managing Director, Nuvia India

Minu Singh spearheads Nuvia India, the nuclear engineering, services and Products organization which is part of the Nuvia Group and Vinci - the world's largest Construction and Concessions Group. She as a part of The Nuvia group prides in working collaboratively with its customers at all stages of a nuclear facility's lifecycle: design, construction, operations, maintenance, decommissioning.

An experienced leader with broad technical and business background having expertise in strategic planning and partnership, International business development and developing new business lines. Committed to visionary leadership, development of high performance teams, transformational growth and outstanding business performance. She is electronics engineer graduate and Post Graduate Executive Management from SP JAIN Institute of Management & Research Mumbai.

She has had past extensive experience, where she has spent two decades in progressively larger positions in building and implementing business strategies primarily in Defence and Nuclear industry. She has extensive exposure in Project Management, Business Development, Financials Budgets, and P&L & ROCE.

Ms. Olga Lukerchik

Chief Expert, Supply Coordination Group of Kudankulam NPP, ASE JSC (Engineering Division of Rosatom)

Ms. Olga is a Power sector professional for last 20 years. She has managed Power Construction Regulatory compliances. She was working with Ministry of Energy and Construction.

Her current role in ASE is to develop Vendor supply chain for NP projects in India and augment localisation.

Shri Sameer Hajela

Associate Director (Reactor Safety & Analysis)

Nuclear Power Corporation of India Limited

Shri Sameer Hajela, a mechanical engineering graduate, joined NPCIL in 1989. Since then, he is working in the area of reactor safety. His expertise covers deterministic safety analysis, accident management, safety review and safety assessment.

His salient contributions include: Conceptualization and preparation of **Accident Management Program (AMP) for Indian PHWRs, a first of its kind activity undertaken in NPCIL; design and development of Symptom-Based Event Handling Scheme for PHWRs.**

As a utility representative, he is also involved in preparation and review of regulatory codes and guides. He has been associated with the **Convention on Nuclear Safety (CNS)** Peer Review. He was member of the national delegation in meetings attended by India, and also worked as Rapporteur and Coordinator for CNS meetings.

He has carried out various safety studies, viz. defence-in-depth based Plant State classification, Stress Test of Indian NPPs (post accidents at Fukushima NPP), NPCIL corporate nuclear safety policy, National Policy and Strategy for Safety of nuclear and radiation facilities, various Safety cases for safety enhancements.

Presently, as Associate Director, in the Directorate of Reactor Safety & Analysis, at NPCIL HQ, he is responsible for deterministic safety analysis and probabilistic safety assessment of PHWR based NPPs.

Shri S.K. Joshi

Asst Vice President – Engineering (Nuclear & Defence)
Godrej Precision Engineering

Godrej & Boyce Manufacturing Company Limited

Shri Joshi is Asst Vice President – Engineering (Nuclear & Defence).

Godrej Precision Engineering, Godrej & Boyce Manufacturing Company Ltd involved in manufacturing of Nuclear & Defence equipment.

Sh Joshi is Master of Financial Management (MFM) from Jamanalal Bajaj Institute of Management Studies, University of Mumbai, M.Tech. (Machine Design) from IIT- Chennai and B.E.(Mech) from WCE-Sangli (Maharashtra).

He has experience of overr 40 years at various levels in Design and Engineering in Machine tools, Nuclear and Defence domains. He has been involved in various first time new product developments in the country. Currently heading engineering function of the division including design, process planning and estimation.

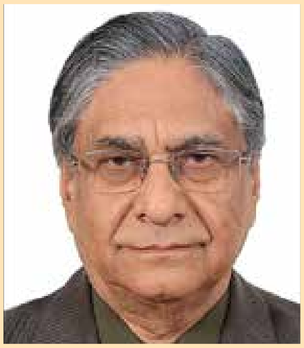
Shri Vikram Sehgal

Sr. DGM-Design & Engineering
Nuclear Equipment & Systems
Larsen & Toubro

Currently working with Larsen & Toubro, Heavy Engineering and has more than 24 Years of experience. I am a Mechanical Engineer & also worked with BARC on strategic projects. He is currently heading the Project Management & Engineering Department of Nuclear Equipment and Systems – L&T Heavy Engineering. His specializations are Design, Engineering, Materials, Analysis , Project Management and Manufacturing of Static Equipment's for LWR, PHWR & FBR for the Indian Nuclear Program. He is the core member for L&T's ASME Nuclear Certification and USNRC inspections and has vast experience in Nuclear Core Equipment's – Steam Generators, End Shield, Pressurizer, Heat Exchangers, End Fittings for NPP meeting International Codes like ASME Section III, KTA, RCC-M, RCC-MR.

Active member of India – International working group – Section III NB.

Vice Chair – International working group – NQA (Nuclear Quality Assurance).



Shri SM Mahajan

Convener, Nuclear Energy Group, IEF

Shri SM Mahajan is a Mechanical Engineer from DCE and M.Tech in Management & Systems from IIT, Delhi. He has attended Management Courses from Leeds University, Harward and IIM. He served in BHEL for 39 years in various capacities, functions and units before superannuating as Executive Director. He handled Manufacturing Technology Up-gradation, Investment Planning, Modernization of manufacturing facilities in various BHEL units, Engineering and R&D Co-ordination, Material management & operation management, He has been involved in manufacturing of nuclear power equipment in BHEL.

Post BHEL he continues to engage with the manufacturing industry guiding them in business development and manufacturing capabilities- in fabrication industry for Power, infrastructure and Aviation sectors. He has served as an Industry Expert with two banks for evaluation of Bank Investments and due diligence of the companies.

He is associated with Ministry of Electronics and IT as Expert in evaluation and recommendation of R&D proposals in area of Electronic System Development and for Electric Vehicles. He has guided several projects for successfully completion.

He is associated with many professional associations and was President of Indian Welding Society. He is Vice President of Asian Welding Federation : Executive Committee Member of Association of British Scholars.

About Organiser

India Energy Forum is a unique, independent, non-profit research organization and represents energy sector as a whole. It was set up in February 2001 and formally inaugurated in January 2002. The mission of IEF is to help evolve a National Energy Policy aimed at development of a sustainable and competitive energy sector in India. It is, probably, the only organization which championed the cause of TOTAL ENERGY – all forms of energy ranging from Coal, Power – Thermal & Hydro, Oil & Gas, Nuclear and Renewable from the beginning of its function. This feature of its functioning gave a distinctive advantage of taking an integrated look on the energy scene. In fact, IEF did frame an Energy Policy document which became an input to the Planning Commission's Integrated Energy Policy brought out in August 2006.

The Forum celebrated its 20th anniversary in June 2021.

Shri R V Shahi, Former Secretary, Ministry of Power, Government of India is the President of India Energy Forum. Earlier, Shri P S Bami, Former CMD, NTPC, was the Founder President of the Forum followed by Shri Anil Razdan, Former Secretary, Ministry of Power.

Its membership includes all the key players of the sector including NTPC, NHPC, Power Grid Corporation, Power Finance Corporation, Reliance Energy, Tata Power, ONGC, Indian Oil Corporation, Neyveli Lignite, Coal India, India Energy Exchange and over 120 highly respected energy experts.

Forum has concluded an MOU with International Solar Alliance to promote the development solar power projects not only in India but throughout the world.

It works closely with the main regional chambers and industry organizations including Bombay Chamber, Bengal Chamber, Madras Chamber, PHD Chamber, Observer Research Foundation, IRADE, INWEA, Indian Coal Forum, ORF, Federation of Indian Petroleum Industry, MGMI DC and ISMAA DC. Every year it organizes its flagship events viz, India Power Forum, Petro India, Renewable Energy Summit, Coal Summit/Roundtable Conference on Coal and Nuclear Energy Conclave.

Forum organizes webinars on critical issues of energy sector and monthly energy think tank meetings called "Urja Vichar Manch". It publishes a bimonthly journal TOTAL ENERGY which provides authentic information on the whole energy sector at one source. It also publishes research papers and monographs.

Board of Management 2023-24

<table>
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Shri R V Shahi
Former Secretary, Power &
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<tr><td colspan="2">PRESIDENT EMERITUS
Shri P.S. Bami
Former CMD, NTPC Ltd</td><td colspan="2">PAST PRESIDENT
Shri Anil Razdan
Former Secretary, Ministry of Power</td></tr>
<tr><td colspan="4">VICE PRESIDENTS</td></tr>
<tr><td colspan="2">Shri G.C. Mrig
Chairman, Vayunandana Power Ltd.</td><td colspan="2">Shri Rakesh Nath
Former Chairperson, CEA</td></tr>
<tr><td colspan="2">SECRETARY GENERAL
Shri B Bhambhani
Former ED, BHEL</td><td colspan="2">TREASURER
Dr V K Garg
Former CMD, PFC</td></tr>
<tr><td>NUCLEAR GROUP
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Emeritus Professor,
Homi Bhabha National Institute

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Shri S M Mahajan
Former ED, BHEL</td><td colspan="2">POWER GROUP
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Convenor : Shri A K Mishra
MD, e-Gateway
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Chairman: Shri Subhash Kumar
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Former Director, ONGC</td></tr>
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Advisor, ACB India Ltd &
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Shri S K Grover
Former GM (Fuels), NTPC</td><td>RENEWABLE & ENVIRONMENT GROUP
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Dr. Malti Goel
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Adani Transmission

Convenor:
Shri Sanjay Banga
President – T&D, TATA Power</td><td>ENERGY SECTOR REGULATIONS GROUP
Chairman:
Shri Rakesh Nath
Former Chairperson, CEA

Convenor:
Shri B P Singh Former Member, DERC and Former Director, NTPC</td></tr>
</table>

MEMBERS		
Dr Anil Kakodkar Former Chairman, AEC	**Shri Alok Perti** Former Secretary (Coal)	**Shri U Tripathi** Former DG, International Solar Alliance
Shri. S K Srivastava Former Secretary (Coal)	**Shri M A Pathan** Former CMD, IOCL	**Shri P S Bhattacharyya** Former CMD, CIL
Shri R S Dhillon Former CMD, PFC	**Shri Amarjit Singh, MBE** Founder SG, IEF	**Shri U Kumar** Former CMD, SECL/NCL
Shri K K Govil Former Director, PFC	**Shri V.P. Singh** Former ED, BHEL	**Shri A K Tooley** Former Director, WCL
Dr. Yashvir Bhalla Ex. Incharge (Western Region), BHEL	**Shri V.K. Sehgal** Former CMD, SECL	**Shri S C Dhingra** Former Member, UPERC
	Shri Atul Sobti Former CMD, BHEL and DG - SCOPE	

INDIA ENERGY FORUM

INDIA ENERGY FORUM

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Website: indiaenergyforum.org

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Core Business Activities

TEMA is a Leading Design & Manufacturer of Process Equipment like Shell & Tube Heat Exchangers, Screw Plug Heat Exchangers, Rod baffle Heat exchanger, Surface Condenser, HP/LP Feed water Heaters, Evaporator, Specialty Columns, Tubular Reactors Pressure Vessels. Tankages & Specialized custom built static equipment's at 3 manufacturing units in India namely TEMA-Achhad works, TEMA-Kherdi works & TEMA-Panoli works.

References in nuclear sector

- Condenser, Cyclone Separator, DW Column, Evaporator, Vessel, Reheater, & Scrubber column to BARC, India.
- Instrument Support Stand to NPCIL LWR project KKNPP-3&4.

Past contribution or participation to NPCIL projects / activities in India / upcoming and future associations in India (JV)

TEMA manufactured and is now supplying to BARC a variety of equipment, including condenser, cyclone separator, DW column, evaporator, vessels, reheaters, and scrubber column. The Instrument Support Stand (ISS) for NPCIL's LWR 1000 MWe reactor (KKNPP-3&4) are currently being manufactured & getting ready for dispatch. In addition, Purchase order for Manufacture & supply of distillation column assembly sets for NPCIL PHWR 700 MWe reactor (GHAVP-1to4 & Kaiga-5&6) is being awaited.

Particular solutions of interest to our company with foreign vendors or service providers

Supply of Equipment like Shell & Tube Heat Exchanger, Surface Condenser, HP/LP Feedwater Heaters, Deaerators, Steam Generator, Specialized static equipment & EPC works for Nuclear Power Projects In India & around the world.

Surface Condenser Under operation for 220 MW Combined cycle Power Plant.

HP & LP Heater Supplied to NTPC Solapur 2x660 MW Power Plant.


एनटीपीसी
NTPC
Azadi Ka Amrit Mahotsav
Transforming into a
"Sustainable Integrated Energy Company"
India's largest Power Company,
NTPC is venturing into
new business areas
like e-mobility,
Waste to Energy,
Power Distribution and
Green Hydrogen.
Green H2
TRASH
"Excellence in Corporate Social Responsibility"
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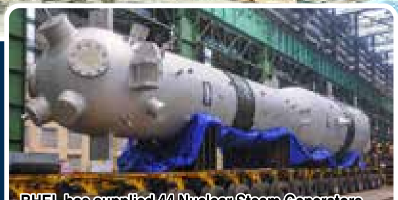
बी एच ई एल BHEL

When it comes to Nuclear Power Generation

WE DO IT ALL

Kaiga Atomic Power Station in Karnataka equipped with BHEL manufactured Turbine-Generator sets



BHEL has supplied 44 Nuclear Steam Generators

Stage-1 of 2x540 MW, Tarapur Atomic Power Station, Maharashtra commissioned by BHEL for NPCIL

- **BHEL is the only company involved in all the three stages of India's nuclear power programme**
- **BHEL is the only indigenous supplier of nuclear turbines in the country**
- **On the secondary side, BHEL supplied power equipment accounts for 74% of the country's installed nuclear power capacity under the indigenous Nuclear Power Programme**

भारत हेवी इलेक्ट्रिकल्स लिमिटेड
Bharat Heavy Electricals Limited

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www.bhel.com

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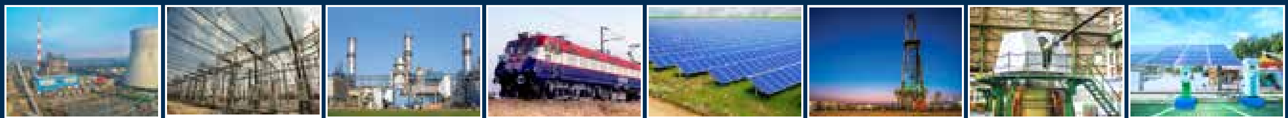

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