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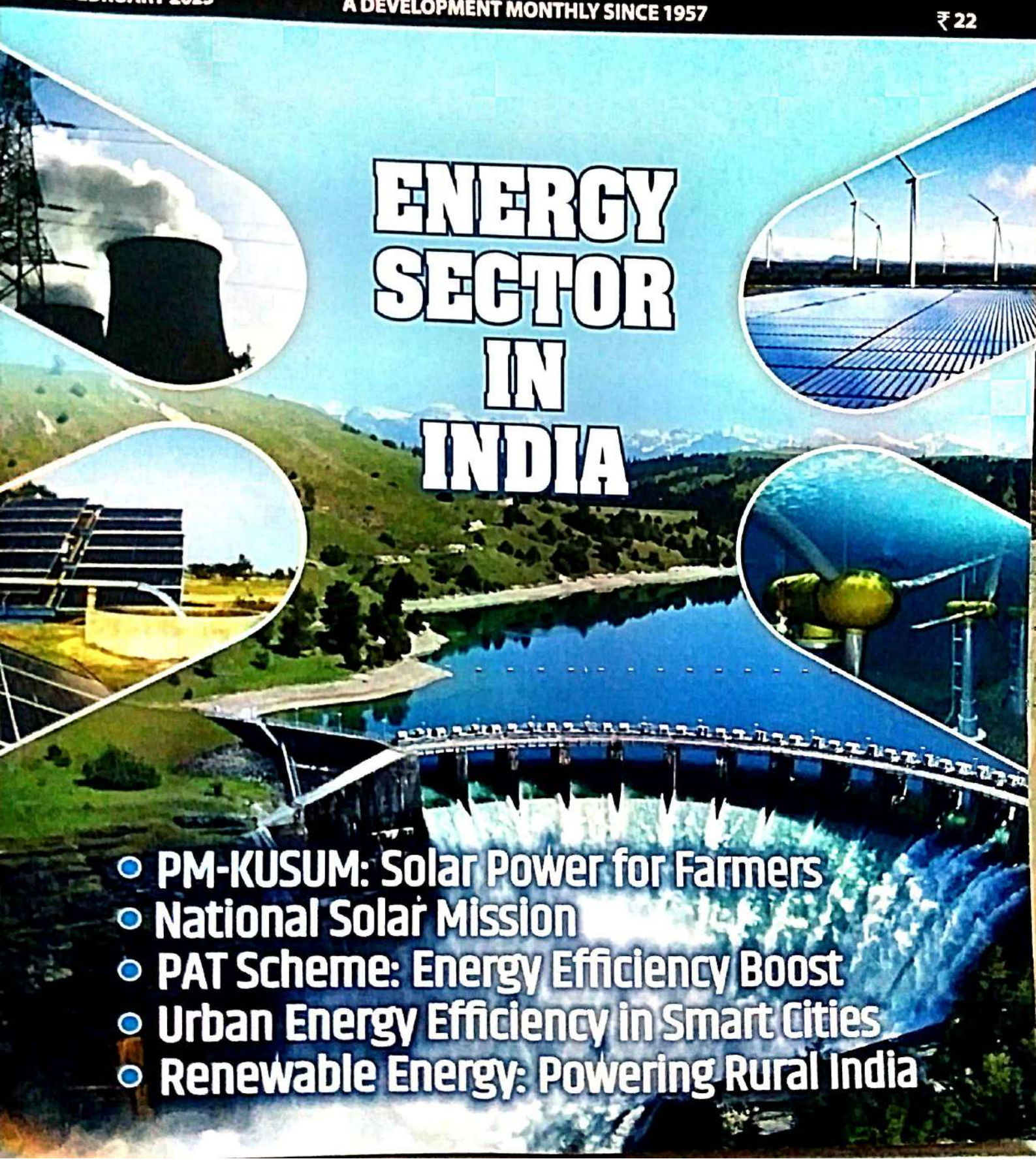

ENERGY SECTOR IN INDIA

- PM-KUSUM: Solar Power for Farmers
- National Solar Mission
- PAT Scheme: Energy Efficiency Boost
- Urban Energy Efficiency in Smart Cities
- Renewable Energy: Powering Rural India

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Let noble thoughts come to us from all sides.
Rig Veda

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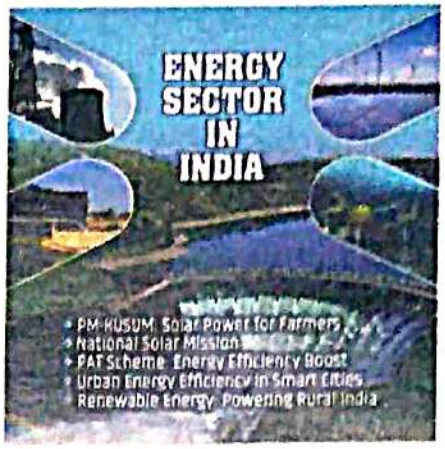
Empowering India's Future



As we step into 2025, India's renewable energy sector has achieved a remarkable milestone, with 27 GW of renewable energy capacity added in 2024. The country's solar energy capacity has reached an impressive 94.17 GW, while wind energy capacity stands at 47.96 GW. The *Pradhan Mantri Sangha Mitra Bio-Gas Yojana* (PMSGMBY) has also seen significant success, with 7 lakh installations in just 10 months, averaging 70,000 installations per month.

This progress is a testament to India's commitment to achieving its ambitious goal of 500 GW of non-fossil fuel energy by 2030, as outlined in the *'Panchamrit'* goals set by the Prime Minister. The *Panchamrit*, a five-point plan, aims to increase non-fossil energy capacity to 500 GW by 2030, meet 50 per cent of the country's energy requirements through renewable energy by 2030, reduce carbon emissions by 1 billion tons by 2030, reduce the carbon intensity of the economy by less than 45 per cent by 2030, and achieve net-zero emissions by 2070.

The addition of nearly 15 GW of renewable energy capacity between April and November 2024 is almost double the 7.57 GW added during the same period in the previous year, demonstrating the country's rapid progress in the renewable energy sector. The country crossed the 200 GW milestone of total installed renewable energy capacity in September 2024 and has further increased its total installed non-fossil fuel capacity to 214 GW in November 2024, representing a 14 per cent increase compared to the same period last year.

The *PM Surya Ghar: Muft Bijli Yojana* has already shown remarkable impact, with 6.3 lakh installations completed in just nine months, resulting in an impressive monthly installation rate of 70,000. The scheme offers a subsidy of up to 40 per cent to households, making renewable energy more affordable and accessible. The government has also set a target of achieving 1 crore solar installations by March 2027, which is expected to add 30 GW of solar capacity through rooftop installations in the residential sector.

The Government of India's vision of a *Viksit Bharat*, or a developed India, is closely tied to the development of the energy sector. As the country strives to achieve its goal of becoming a developed nation, the energy sector will need to keep pace with the growing demands of a rapidly industrialising economy. This will require a concerted effort to increase the share of renewable energy in the energy mix, improve energy efficiency, and reduce greenhouse gas emissions.

India has also been at the forefront of global efforts to combat climate change, and has made significant strides in achieving the Paris Agreement goals. The country's commitment to reducing its carbon footprint and transitioning to a low-carbon economy is a testament to its resolve to address the global challenge of climate change, and its determination to play a leadership role in the transition to a sustainable and equitable energy system.

The current issue of Yojana features articles from renowned subject-matter experts and specialists in their respective domains, who share their insights and perspectives on the energy sector in India. In an effort to provide a comprehensive understanding of the sector, these experts delve into the various aspects of energy development, including renewable energy, energy efficiency, and sustainability. Their contributions are a testament to the importance of the energy sector in achieving the goal of a *Viksit Bharat*, and highlight the need for a coordinated approach to energy development that balances economic, social, and environmental considerations. □

PM-KUSUM: Empowering Farmers with Solar Energy Solutions

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Agriculture has been the focus of India's development planning because of its vital role in providing food and nutrition to consumers and sustaining the livelihoods of those involved in agricultural supply chains. The *Pradhan Mantri Kisan Urja Suraksha Evam Utthaan Mahabhiyan* (PM-KUSUM) was launched by the Union Ministry of New and Renewable Energy (MNRE) in March 2019. Currently, there are approximately 5,02,000 solar pumps in the country, which prevent the release of 1.02 million tonnes of CO_2 into the atmosphere in a year. The integration of solar energy into agricultural practices offers multifaceted benefits that extend beyond farm income enhancement.

Agriculture has been the focus of India's development planning because of its vital role in providing food and nutrition to consumers and sustaining the livelihoods of those involved in agricultural supply chains, from production to final consumption. Since the beginning of the Green Revolution in the mid-1960s, food grain production increased from 72.35 million tonnes in 1965-66 to 332.30 million tonnes in 2023-24. Progress in non-food grain crops, including horticultural crops, sugarcane, and cotton, has also been quite impressive. The country is now self-sufficient in most food and non-food commodities.

Agricultural development strategies have relied on improved crop genetics, agrochemicals, and water for irrigation. Irrigation plays a vital role in boosting crop yields and making agriculture more resilient to climate change. The irrigation landscape has evolved and expanded over time. The area under irrigation has grown significantly from 19 per cent of the net cultivated land in

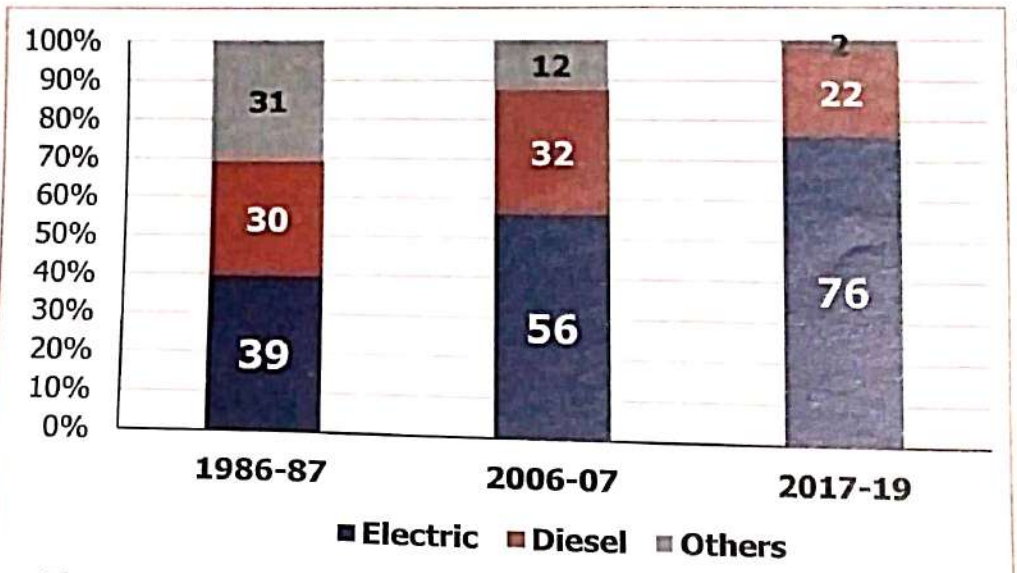


Figure 1 : Changes in composition of energy use for irrigation

1960-61 to 56 per cent in 2022-23, nearly tripling in coverage. However, this expansion has been characterised by an increasing reliance on underground water sources. The proportion of irrigated area using groundwater has risen from 30 per cent to 63 per cent.

There is a close relationship between the expansion of groundwater irrigation and energy use. As agriculture progressed, the landscape of energy changed drastically from animate to inanimate sources, especially electricity, partly because of its subsidised provision that enabled farmers to economically exploit groundwater resources to enhance food production (Figure 1). The number of groundwater extracting devices (GEDs) has increased manifold, from a mere 0.6 million in 1982-83 to 219 million in 2017-19, leading to a significant increase in energy consumption in agriculture.

The increasing energy consumption has been accompanied by a change in its composition from diesel to electricity owing to improvements in power infrastructure, provision of subsidised electricity, and rising prices of diesel (Figure 1). Currently, more than three-quarters of the GEDs operate on electricity and 22 per cent on diesel. Subsidised electricity, while beneficial for farmers, inadvertently encourages excessive utilisation of groundwater resources. Farmers frequently extract water in excess of crop requirements, which threatens long-term water security and imposes an additional subsidy. Furthermore, the environmental impact of energy consumption is substantial. The combined use of non-renewable electricity and diesel in agriculture contributes significantly to carbon emissions, accounting for 8-11 per cent of the country's total carbon output. This amounts to an annual emission of 45-62 million tonnes of carbon.

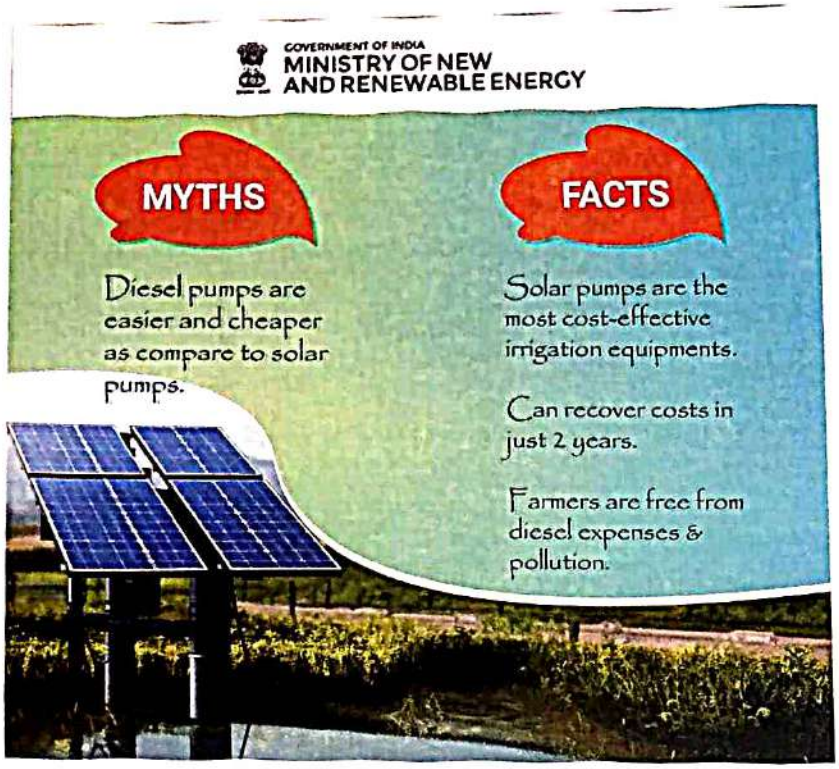
As non-renewable resources continue to deplete, their extraction and use have become increasingly costly both economically and environmentally. The shift towards renewable energy sources, particularly solar energy for irrigation pumps, is a strategic response. Solar-powered irrigation offers numerous advantages over traditional diesel or electric pumps, including a reliable and cost-effective alternative for irrigation, lower operational costs, reduced dependence on fossil fuels, and mitigation of climate change.

The *Pradhan Mantri Kisan Urja Suraksha Evam Utthaan Mahabhiyan* (PM-KUSUM) was launched by the Union Ministry of New and Renewable Energy (MNRE) in March 2019. Regarded as one of the world's largest initiatives of its kind, PM-KUSUM aims to integrate solar energy into agriculture by encouraging its adoption as a substitute for electric and diesel power sources. It has three main objectives: creating decentralised solar power installations, switching out diesel-powered agricultural pumps for solar-powered ones, and converting the existing grid-connected agricultural pumps to solar energy.

The PM-KUSUM aims to establish 34.8 gigawatts (GW) of solar capacity by March 2026 through three components. Component-A targets installing a solar capacity of 10 GW by setting up solar energy-based power plants with capacities ranging from 500 kW to 2 MW; Component-B targets the installation of 1.4 million standalone solar-powered irrigation pumps in the areas where grid supply is not available; and Component-C targets solarisation of 3.5 million grid-connected agricultural pumps, including feeders. As of

Table 1 : Salient features of PM-KUSUM

Aspect	PM-KUSUM
Coverage	All India
Year of Initiation	March 2019
Architecture/ Institutional set-up	• **Two tier** • **National Level:** Screening Committee under the chairmanship of Secretary, MNRE • **State level:** State Implementing Agency (SIA)
Planning	• SIA assesses the demand of solar pumps and submits the proposal to MNRE. • MNRE after the approval from Screening Committee sanctions and allocates the number of pumps to SIA • SIA installs pumps through empaneled vendors, and monitors the progress till at least five years
Nodal Department	• **National level**: MNRE • **State level**: DISCOMS/ State specific Renewable Energy Development Agency/ Agriculture department/Any other department identified by the state government
Beneficiaries	• Individual farmers/SHGs/JLGs forming groups of farmers/Co-operatives/ Panchayats/FPO, WUA.
Financial assistance (Subsidy)	**Component B&C:** • 60 per cent of the benchmark or tender cost whichever is less, in all states except North Eastern states, J&K, Himachal Pradesh, Uttarakhand, Lakshadweep and A&N Islands where subsidy assistance is 80 per cent. • In case the state government provides top up subsidy, farmers' share can be reduced. • Priority is given to marginal and small farmers, and those with micro-irrigation system
Ceiling	• Central Financial Assistance (CFA) is restricted to 7.5 Hp pumps. However, more than 7.5 Hp pumps may be allowed without CFA. • CFA is available for pumps up to 15 Hp capacity in J&K, Ladakh, Uttarakhand, Himachal Pradesh, and the A&N and Lakshadweep Islands, as well as for cluster/ community irrigation projects in high water table areas.
Funding pattern	**Component B&C:** • 100 per cent central government assistance for all UTs • 50:50: Central & state government sharing for all other states (60 per cent subsidy of benchmark cost) • 62.5: 37.5: Central & state government sharing for all other states in NE & Himalayan states, Lakshadweep and A&N Islands (80 per cent subsidy of benchmark cost) • Farmers share: 20 per cent in special category states and 40 per cent in other states. • Bank finance may be available upto 10 per cent to 30 per cent of farmers' share.
Installation and maintenance	• Empaneled vendors are responsible for design, supply, installation and commissioning of solar agricultural pumps under the close real-time monitoring of SIA. • Annual maintenance charges for a period of 5 years, including insurance coverage for the installed system against natural calamity and theft.
Convergence possibility	• The guidelines of PM-KUSUM encourage convergence with PDMC. New solar pumps shall not be installed in dark zones. Existing pumps in dark zones can be replaced with solar provided they use micro-irrigation techniques to save water.



30 September 2024, progress includes the installation of 298.33 MW of solar capacity, 0.5 million standalone solar pumps, 37,271 individual grid-connected pumps, and feeder-level solar power facilities. Table 1 outlines the key aspects of PM-KUSUM.

Extending beyond the obvious advantages of reduced electricity and diesel consumption, the use of solar energy to pump groundwater for irrigation has several other benefits for farmers. These pumps are known for their user-friendly operation, minimal supervision requirements, and low maintenance requirements, making them attractive options for farmers. A study conducted in Rajasthan by Gupta (2019) reveals that while the solarisation of irrigation pumps leads to an increase in groundwater consumption, it simultaneously results in substantial savings in electricity and diesel. This shift from non-renewable to renewable energy has a positive impact on farm income through an increase in cropping intensity, changes in cropping patterns, and a reduction in production costs.

Further evidence from Andhra Pradesh and Chhattisgarh demonstrates the potential of solar-powered irrigation pumps to enhance farm income. The implementation of grid-connected solar pumps with energy buyback arrangements has shown promising results. In Gujarat, this approach could lead to a 40 per cent reduction in energy consumption for irrigation while providing farmers with an additional source of income. The grid-connected solar pumps have the potential to become a lucrative 'crop' for farmers, offering economic benefits to governments and environmental benefits to society. The multifaceted benefits of solar-powered irrigation pumps, including reduced resource consumption and supplementary income generation, underscore their significance in promoting sustainable and profitable farming practices.

Currently, there are approximately 5,02,000 solar pumps in the country, which prevent the release of 1.02 million tonnes of CO_2 into the atmosphere in a year. If all the existing 21.3 million electric and diesel-operated GEDs are switched over to solar power, it could result in a staggering reduction of up to 45 million tonnes of CO_2 emissions annually. The transition to solar-powered irrigation systems is a crucial step towards more environmentally friendly and energy-efficient agriculture.

The adoption of solar energy for irrigation enhances economic accessibility to irrigation, alleviates the subsidy burden on governments, and contributes to decarbonisation; its current adoption rate is only 2.64 per cent. This low adoption rate indicates barriers to the widespread implementation of solar-powered irrigation systems, which may include initial investment costs, lack of awareness, technical challenges, and policy-related issues.

The high upfront investment required for the installation of solar pumps is a significant barrier. The benchmark cost for a 7.5 Hp solar pump system is fixed at Rs 349 thousand under PM-KUSUM. The scheme provides for a subsidy of 60 per cent, and managing the remaining Rs 140 thousand is a big deal for farmers, especially marginal farmers owning upto one hectare of land, who comprise over 70 per cent of the total farm households. Meeting the initial amount from

savings is challenging for them and can significantly influence their decision to adopt solar pumps. Although a portion of this can be obtained from commercial banks, farmers encounter significant challenges in accessing credit, and financial institutions are reluctant to provide services because of higher transaction costs. Innovative financing solutions are crucial for addressing this challenge. Affordable financing arrangements, such as low-interest loans, extended repayment periods, or pay-as-you-save models, could make solar pump systems more accessible to a broader range of farmers. Additionally, public-private partnerships or community-based ownership models could help distribute the costs and risks associated with solar pump adoption.

Electricity subsidies for groundwater irrigation pose a further challenge. While subsidies alleviate financial constraints for farmers, free or heavily subsidised electricity provides farmers with little economic motivation to adopt more sustainable alternatives, such as solar-powered irrigation systems. Rationalising electricity subsidies and redirecting funds for solar power energy could be game changers. Gradually reducing electricity subsidies and simultaneously financially supporting solar pumps can encourage farmers to transition to cleaner energy sources.

Although solar pumps offer a clean and affordable irrigation solution, there is an apprehension that the zero marginal cost associated with solar energy may lead to over-extraction of groundwater resources, negatively impacting their long-term sustainability. To mitigate this risk, it is crucial to promote solar pumps in conjunction with water-saving technologies such as micro-irrigation systems and digital irrigation scheduling devices. The existing PM-KUSUM guidelines encourage this convergence; the implementation often falls short due to a lack of institutional mechanisms. In most states, solar pumps and micro-irrigation technologies are promoted separately under different schemes, managed by different agencies, hindering effective integration of these complementary technologies. To address this issue, there is a pressing need for restructuring and convergence of institutional arrangements at various levels of implementation. This integrated approach would not only enhance the efficiency

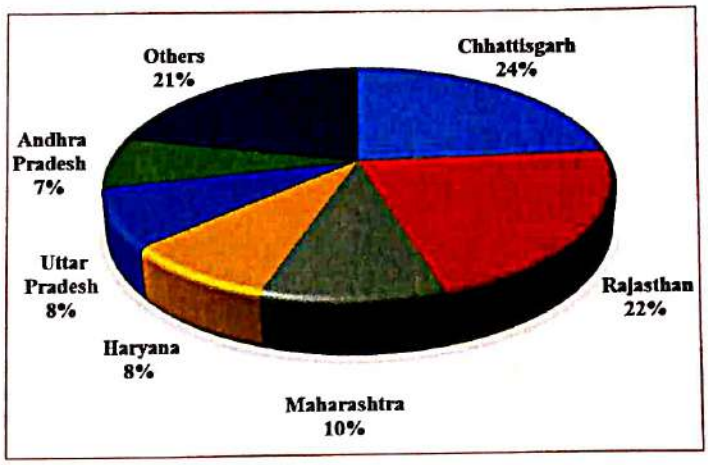


Figure 2 : Distribution of solar pumps across states, 2022-23

of water use in agriculture but also contribute to the long-term viability of groundwater-dependent ecosystems and communities.

There is significant regional variation in the solarisation of irrigation pumps. Approximately two-thirds of solar pumps are installed in six states: Chhattisgarh, Rajasthan, Maharashtra, Haryana, Uttar Pradesh, and Andhra Pradesh (Figure 2). This uneven distribution highlights the potential influence of state-specific policies, agricultural practices, climatic conditions, and economic factors on the adoption of solar-powered irrigation systems. Understanding the reasons behind the success of solar pump adoption in these states could provide valuable insights for promoting the wider adoption of solar energy.

The integration of solar energy into agricultural practices offers multifaceted benefits that extend beyond farm income enhancement. This reduces farmers' reliance on costly fossil fuels and lowers operational expenses, thereby enabling them to allocate more resources to other agricultural activities. Moreover, as a consistent and reliable source of energy, it mitigates the risks associated with power outages or fuel shortages. From an environmental perspective, the widespread adoption of solar energy can substantially contribute to reducing carbon emissions and mitigating climate change.

(The co-authors of this article, SK Srivastava and Prabhat Kishore are associated with the ICAR-National Institute of Agricultural Economics and Policy Research (NIAP), New Delhi.) ❑

The National Solar Mission: Progress, Challenges, and the Path for Renewable Energy by 2030

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India has emerged as one of the fastest-growing nations in the renewable energy sector under the banner of the National Solar Mission. The National Solar Mission aims to establish India as a global leader in solar energy. With significant growth in solar power capacity and various policy initiatives, the mission supports sustainable growth and energy security. Key programs like *PM-KUSUM* and *PM-Surya Ghar: Muft Bijli Yojana* boost renewable energy production and empower farmers. The 'Make in India' campaign and the Production Linked Incentive (PLI) Scheme promote domestic solar manufacturing. Despite challenges, collaborative efforts are paving the way for a sustainable future in solar energy.

The National Solar Mission is a major initiative of the Government of India and state governments aiming to promote ecologically sustainable growth while addressing India's energy security challenges. The Mission's objective is to establish India as a global leader in solar energy by creating the policy conditions for its large-scale diffusion across the country as quickly as possible.

The mission aims to focus on setting up an enabling environment for solar technology penetration in the country. It adopted a three-phase approach with evaluation of progress, review of capacity, and targets for subsequent phases based on emerging cost and technology trends. Phase-1 (2010-13), Phase-2 (2013-17) and Phase-3 (2017-22) had a cumulative target of 20,000 MW of grid-connected and 2000 MW for off-grid solar capacity by 2022. However, in 2015 the government upscaled the target of renewable energy capacity to 175 GW by the year 2022, which included 100 GW from solar, 60 GW from wind, 10 GW from bio power, and 5 GW from small hydropower. The targets were to be achieved through an enabling policy framework,

large-scale deployment goals, aggressive research and development, and domestic production of crucial raw materials, components and products.

The government has taken various policy initiatives to promote solar energy adoption. These included financial incentives, subsidies and tax benefits for solar projects and manufacturers. Solar energy in India is experiencing significant growth and becoming a crucial component of the country's energy mix. India has expanded its solar power capacity significantly in the preceding years.

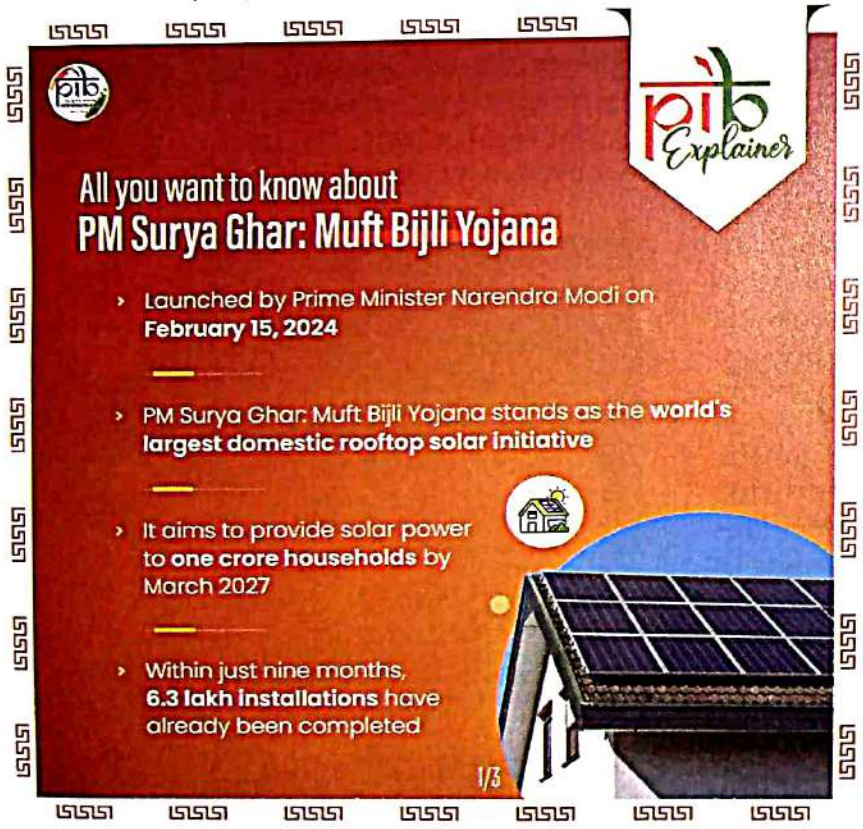
Solar energy has created a visible impact in the energy scenario in India. Potential share of energy mix is now coming from solar energy. As per the Ministry of New and Renewable Energy's (MNRE) Physical Achievements data, the installed cumulative renewable energy capacities as of 30 November 2024 stand at 158.55 GW (wind power—47.96 MW, solar—94.17, small hydro—5.08 biomass bagasse cogeneration—9.81, biomass non-bagasse cogeneration—0.92, waste-to-power—0.25 and waste-to-energy off-grid—0.36, total 158.55 MW). Installed capacity addition of solar power during the current financial year from 01 April 2024 to 30 November 2024 is 12,354.21 MW.

Millions of people in rural areas have benefitted by adopting solar power. They are meeting cooking and lighting needs in an environmentally friendly manner and creating opportunities for economic activities at the village level. It supports the government's agenda of sustainable growth and becoming an integral part of the solution to meet the nation's energy needs and helping in energy security.

The National Solar Mission has gained critical importance in India's National Action Plan on Climate Change (NAPCC) in promoting ecologically sustainable growth and addressing energy security. It is helping in realising the Nationally Determined Contribution (NDC) target to reduce the emission intensity of its GDP by 45 per cent from 2005 levels by 2030.

The solar growth of India has primarily been driven by competitive auctions for solar projects. The auction allowed developers to bid for tariffs, resulting in record-low solar power prices, making solar energy increasingly cost competitive with conventional sources.

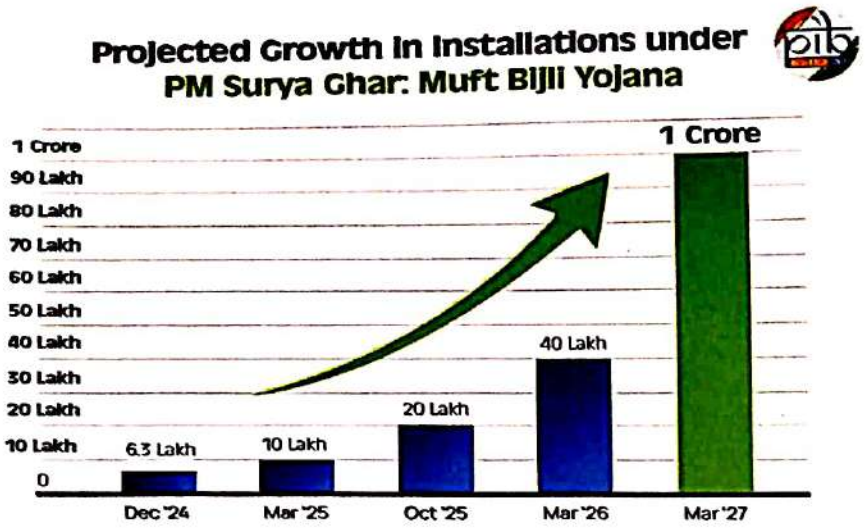
India, along with France, spearheading the solar initiative for countries lying between the tropics under the banner of the International Solar Alliance (ISA), aims to collaborate and promote solar energy adoption globally.



The country is advancing towards a sustainable energy future with initiatives like the *PM-KUSUM* scheme and *PM-Surya Ghar: Muft Bijli Yojana*. These programs aspire to boost renewable energy production, enhance energy access, and empower farmers while reducing dependency on fossil fuels. The government has taken various key steps in this regard.

PM-KUSUM scheme

The *Pradhan Mantri Kisan Urja Suraksha Evam Uthaan Maha Abhiyan (PM-KUSUM)* scheme is for de-dieselisation of the farm sector and enhancing the income of farmers. Under the scheme, a central government subsidy of up to 50 per cent of the total cost is given for the installation of stand-alone solar pumps and also for the solarisation of existing



grid-connected agricultural pumps. Further, farmers can also install grid-connected solar power plants up to 2 MW under the scheme on their barren/ fallow land and sell electricity to local DISCOM at a tariff determined by the state regulator. This scheme aims to add solar capacity of about 34,800 MW by March 2026 with the total central financial support of Rs 34,422 crores.

PM Surya Ghar: Muft Bijli Yojana (PMSG: MBY)

The world's largest domestic rooftop solar scheme, PMSG: MBY targets one crore solar installations by March 2027 with an outlay of Rs 75,021 crore. In nine months of its initiation since February 2024, 6.3 lakh installations have been achieved. This marks a tenfold increase in monthly installations compared to the average of 7000 per month prior to the launch of this scheme, which reflects that the scheme is on a fast track for accelerated growth, paving the way for a sustainable future in rooftop solar energy. Extensive awareness campaigns, simplified consumer processes, addressing regulatory barriers, expansion of the vendor base, and affordable financing options all have greatly contributed to the enhanced growth. By November 2024, a subsidy of over Rs 3100 crores had been disbursed to more than four lakh consumers under the scheme. With an average of 67,000 households receiving subsidies monthly, the scheme demonstrates operational robustness.

Solar manufacturing & PLI Scheme

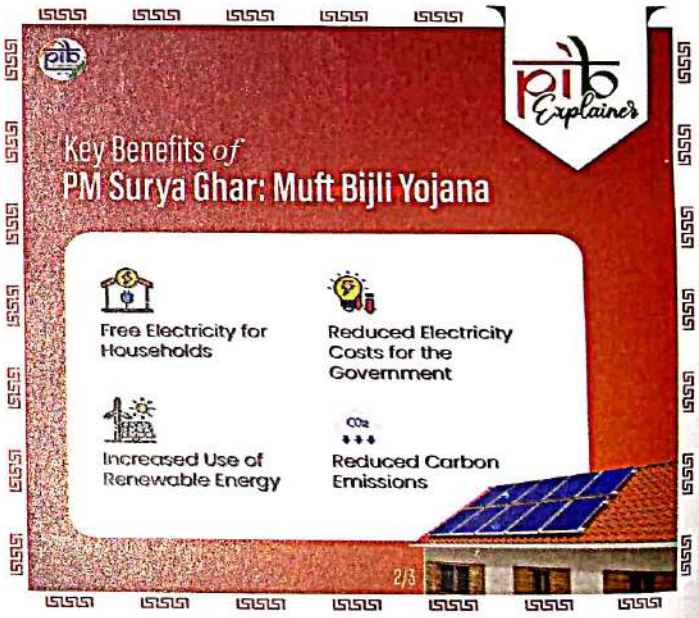
There has been a great emphasis by the Government on the 'Make in India' campaign to promote domestic solar manufacturing to reduce dependency on imports and create a self-sufficient solar ecosystem. The Government of India has introduced the Production Linked Incentive (PLI) Scheme with an outlay of Rs. 24,000 crores for the National Program on High Efficiency Solar PV (Photovoltaic modules). The scheme aims to build an ecosystem for manufacturing of high efficiency solar PV modules in India and thus reduce import dependence in renewable energy.

Development of Solar Parks and Ultra-Mega Solar Power Projects Scheme

Development of Solar Parks and Ultra-Mega Solar Power Projects Scheme was launched in December 2014 with an objective to facilitate the solar project developers to set up projects hassle-free and expeditiously. The scheme aims to establish at least 25 solar parks with a cumulative capacity of 40 GW by 31 March 2026 and to speed up the installation of grid-connected solar power projects for electricity generation on a large scale.

Global Renewable Energy Investment Meets

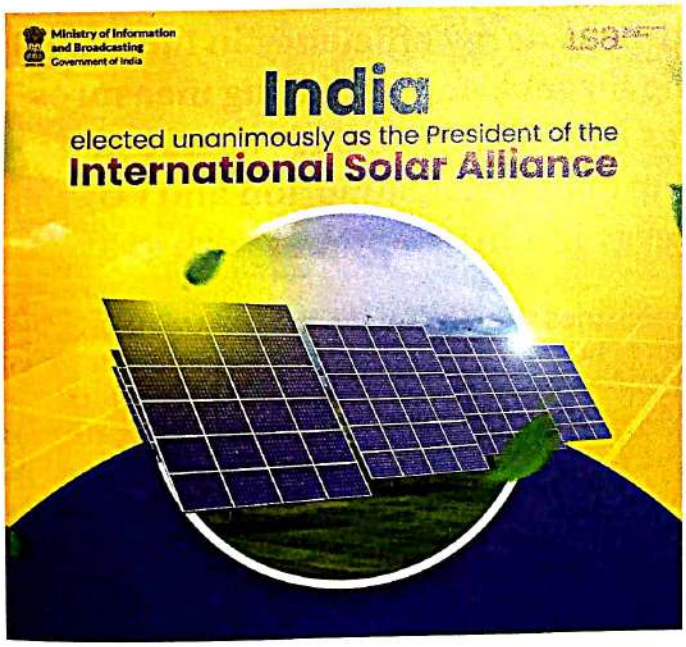
For bringing together global investors, innovators and policymakers with the aim to accelerate the development and deployment of renewable energy solutions across the nation, the RE-INVEST meets are being organised by the government since 2015. During 4th Global

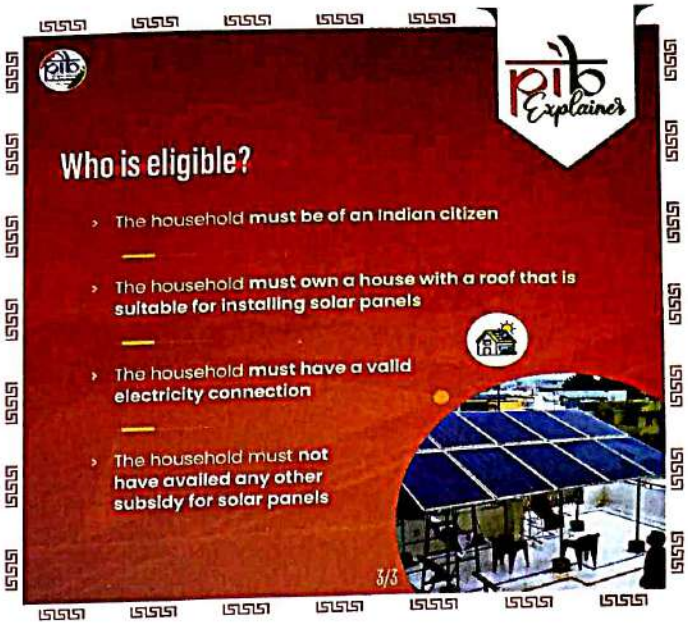


RE-INVEST meet held in Gandhinagar, a commitment of Rs 32.45 lakh crore worth of investment in the solar power sector has been made, which is expected to generate employment for 82 lakh persons. The states also pledged their commitments to add capacities of renewable energy plants, with Gujarat striving for an additional 128.60 GW, followed by Andhra Pradesh with 72.60 GW and Maharashtra with 62.73 GW by 2030.

Challenges

The progress has been quite significant despite various challenges of policy implementation at different levels, land acquisition for large solar parks, and grid integration and stability. Land acquisition, transmission infrastructure, power purchase agreements, energy storage and other critical factors are affecting the sector. To expedite progress in the renewable energy sector, concerted collaborative efforts among all stakeholders are needed to address the challenges. Challenges, particularly in transmission and energy storage practical solutions, need to be addressed as a priority. The policies that are simple, clear and implementable are going to help the sector. In the 4th RE-INVEST held in September 2024, the commitments have been made for amounts over Rs 32 lakh crore and 540 GW of renewable energy projects. These commitments can be translated into reality through concerted collaboration among industry players, government bodies, and financial institutions.





Path for 2030

It is critical for the development of solar power in the country that the overall quality and reliability of solar products are ensured so that the products meet the highest standards. Policies of states are also going to be critical in achieving the government of India's renewable energy targets. Making efforts to simplify the regulatory process and ensure that India remains at the forefront of global clean energy development, prioritising solar PV cell manufacturing in India and reducing reliance on imports, lays a strong foundation for India's clean energy future. It supports the growth of the solar power industry, generates economic opportunities, and makes a meaningful contribution to the country's climate goals. Collective experience and wisdom are critical on the part of key government leaders, industry experts and stakeholders to develop strategies for achieving India's ambitious target.

Greener And More Sustainable Future for All

The National Solar Mission reflects an aspirational appetite for sustainability and innovation, redefining the nation's energy landscape. By channelling ambition into actionable targets, India is on an accelerated growth track to reduce the country's dependence on fossil fuels, combat climate change, and provide sustainable energy solutions to meet its growing power demands, demonstrating the power of bold vision and collective effort. As the country leads change, it inspires a global pursuit of a cleaner, greener future. ❑

The Perform, Achieve, and Trade (PAT) Scheme

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India's ambitious national goals under the *Viksit Bharat* and *Atmanirbhar Bharat* programmes focus on continuous economic growth and alleviating equity and poverty issues. Energy, being the most important element driving economic growth, faces challenges like increasing demand, climate change, and pollution. The PAT mechanism under the National Mission for Enhanced Energy Efficiency aims to improve energy efficiency in industrial sectors. It involves setting energy-saving targets, implementing measures, and trading Energy Saving Certificates (ESCerts). The PAT scheme has shown significant success in reducing energy consumption and CO_2 emissions, contributing to India's energy intensity and net-zero goals.

India has set ambitious national goals for overall human development under the *Viksit Bharat* and *Atmanirbhar Bharat* programmes. A key aspect of these programmes is continuous economic growth concomitant with the alleviation of issues related to equity and poverty. Globally, energy is the single most important element that drives economic growth in key sectors such as industries, electricity generation, transportation, and buildings. Energy production from fossil fuels has been the mainstay for most of the twentieth century; however, challenges such as ever-increasing energy demand, climate change, pollution, and access to fossil fuel resources have begun a process of shifting energy production towards non-fossil sources such as solar, wind, hydro, and nuclear. India has crossed 200 GW

in installed capacity of renewable energy (RE), accounting for about 46 per cent of the total installed capacity. As part of its commitments to the United Nations Framework Convention on Climate Change, India has also set goals such as reducing the energy intensity of its economy by 45 per cent by 2030 compared to 2005 levels and achieving net-zero emissions by 2070.

The demand for energy in view of India's predicted economic growth for the next several decades implies that electricity generation and energy usage will continue to grow, exacerbating the challenges of climate change and pollution. The two key levers that can accelerate the growth of energy supply while tackling climate change and the surging demand are RE and Energy Efficiency (EE). EE implies that the efficiency of energy usage must be constantly measured and analysed, and effective measures deployed to reduce energy waste. This will help in reducing the overall energy demand. India has enacted the Energy Conservation Act, 2022, which provides the legal framework for designing and implementing EE measures in key energy-intensive sectors such as industries, buildings, and transportation.

Anecdotally, readers will be familiar with the transition in lighting from incandescent lamps to CFLs and now to LED lamps. These transitions to more energy-efficient forms of lighting have resulted in enormous energy savings in India's national demand while reducing the electricity bills of the consumer. Such transitions highlight the multidimensional benefits of EE measures since they reduce CO_2 and air pollution emissions at power plants and the economic cost of installing additional power plants, all the while financially benefitting the consumer.

The industry sector is a major component of India's energy consumption, and the consumption from the sector is expected to rise for the next several decades as demand for steel, cement, and other products will be driven by economic growth. Iron and steel and cement are examples of energy-intensive sectors, along with other sectors such as pulp and paper, textiles, fertilisers, aluminium, chlor-alkali, refineries, railways, power distribution, thermal power generation, buildings, and MSMEs. Many industrial plants in India are among the most energy efficient in the world, but each sector has plants that are lagging because of various factors, including technology, vintage, the process used, and financial access. It was envisioned that a mechanism be evolved to enable industries to accelerate EE transitions while addressing the multidimensional technical, economic, and competitiveness issues involved.

The PAT Design Framework

The National Mission for Enhanced Energy Efficiency under the Prime Minister's National Action Plan for Climate Change (NAPCC) lists the Perform, Achieve, and Trade (PAT) mechanism for driving EE improvements in industrial and allied sectors.

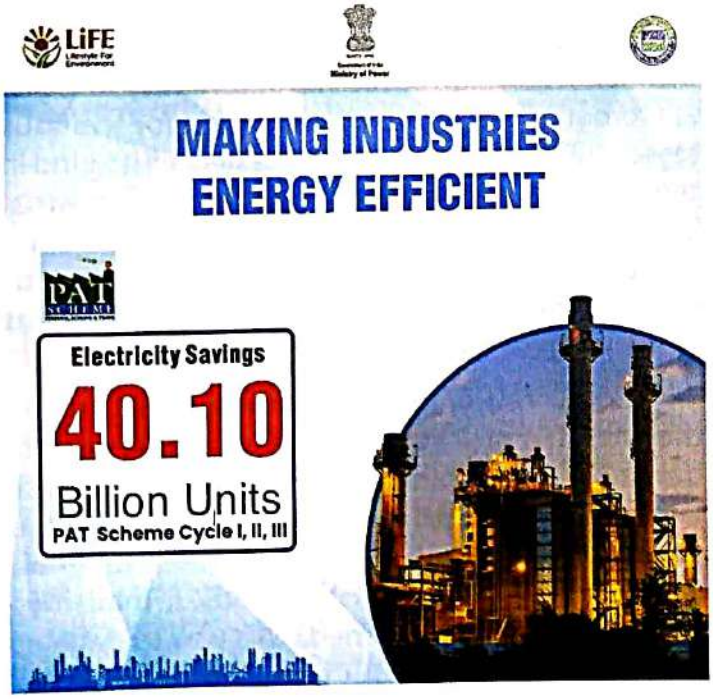
The PAT mechanism enables the design and implementation of EE goals in several energy-intensive industries in a graded and phased manner. The design of such an ambitious industrial EE programme was challenging for various reasons. This mechanism was the first-of-its-kind in the world, involving many of the largest industrial plants in India, with a diversity of manufacturing processes and products and a deep, rigorous study of the technical and economic dimensions of the programme.

The Bureau of Energy Efficiency (BEE) under the Ministry of Power is the lead agency that designed and implemented PAT. The approach taken by the BEE to design and implement this programme was consultative. It entailed numerous workshops with all industrial bodies, ministries, and stakeholders concerned. This was to develop a robust mechanism with technical and financial

frameworks that would work given the nature, scale, and scope of the programme.

The first step involved the identification of designated consumers (DCs), which are industrial plants that would mandatorily participate in PAT. Such DCs would then be analysed by accredited energy auditors to compute the specific energy consumption (SEC) of that DC, which is the energy used to produce one unit of a product (such as a tonne of cement or steel). This baseline SEC number would be computed for all DCs and used as the SEC at the start of a PAT cycle. An SEC reduction target would be issued for each DC based on how its baseline SEC compares with the sector average and leaders.

Technical studies were conducted for each sector to model various processes, sub-processes, unit operations, mass and energy balances, variability factors, and input and product characterisation. These were accompanied by plant visits for data collection and validation. Sample energy economic audits were used to generate EE measures available for specific DCs in each sector to understand the technology options and economic parameters such as rate of return and payback period. Consultations with financial institutions enabled the availability of funds to DCs to implement EE measures, which might involve large investments with larger payback periods. These studies helped develop the technical, financial, and market-trading frameworks, which



are integrated into PAT to ease the implementation process of such a large industrial EE programme.

A PAT consultation document was prepared and circulated to all DCs and stakeholders before the first cycle of PAT. This document is evolving, with feedback and analyses from each PAT cycle.

The DC would have to analyse, prioritise, and implement a set of EE measures in its processes, which would entail a financial investment and resultant energy savings every year. Each DC would evaluate a suite of recommended EE measures from the energy audit study and decide, based on various financial parameters, the EE measures that could be applied within the overall design of the specific plant. Typically, each DC would have a suite of available EE measures ranging from a large number of small investment in small SEC per cent reduction measures to a smaller number of large investment in larger SEC per cent reduction measures.

A PAT cycle is typically three years, at the end of which the DC's SEC would be recomputed. The achieved SEC would then be compared with the DC's target SEC. If the DC exceeded this target, energy savings certificates (ESCerts) would be issued proportional to the amount of excess energy saved. These ESCerts could be used by the DC to offset future SEC targets in the next PAT cycle or sold to a DC that needed to purchase these ESCerts to compensate for the shortfall in achieving its SEC targets. This market option was added to address the asymmetry in DCs' SECs and provide flexibility to DCs to adjust to their specific technical and economic situations so that they could time their investments better given the huge investments and technical and logistic issues involved in making many of the larger process-related changes to existing plants.

Each energy-intensive sector has a large, diverse set of technical and economic factors that need to be considered before measuring baselines, assigning SEC reduction targets, and estimating achieved SEC numbers. This intra-sector diversity includes the scale of production, use of raw material type and quality, process technology at each unit operation within the plant, the vintage of various technology and equipment, operation and maintenance practices, and variability of the output product within the same plant from the

Table 1: Target Energy Savings and % Energy Intensity (SEC) Reduction; NHR: Net Heat Rate

Sector	Baseline SEC, toe/ton product	%SEC Reduction	Target SEC, toe/ton of product	Target Energy Savings, Mtoe	Number of DCs
Aluminium	2.005	5.354	1.897	0.456	10
Cement	0.088	4.793	0.084	0.816	85
Chlor-Alkali	0.393	6.138	0.369	0.054	22
Fertiliser	1.375	2.775	1.337	0.478	29
Iron and Steel	0.549	5.863	0.517	1.485	67
Pulp and Paper	0.656	0.656	0.622	0.118	31
Textiles	0.227	0.227	0.215	0.094	90
Industry Total	**0.230**	**5.486**	**0.217**	**3.501**	**334**
	Baseline NHR (kCal/kWh)	%NHR Reduction	Target NHR (kCal/kWh)		
Thermal Power Plants	2775.56	2.149	2715.919	3.359	144
TOTAL				**6.86**	**478**

baseline year to the target year. For example, raw material input has high variability in the pulp and paper, fertiliser, and textile sectors; process and technology vary widely in aluminium, iron and steel, among others; final product output varies in the iron and steel, textile, and cement sectors; and vintage and capacity utilisation vary across all sectors.

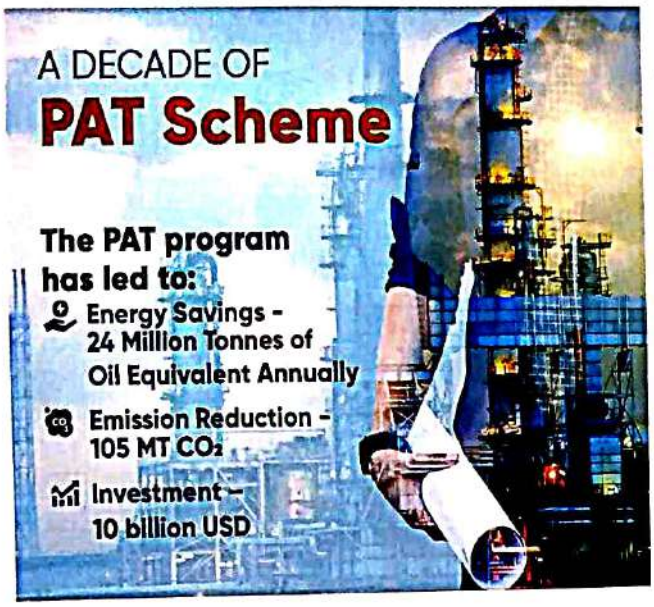
As a case study, we examine the iron and steel sector to understand the challenges faced by the sector, which have an impact on the SEC of a DC. The raw material quality varies from plant to plant, given that iron ore mines have variable characteristics of ore. There is high moisture content and a high alumina and silica ratio in the raw material. Coal, typically of Indian origin, has high ash content even after washing. Low availability of coking coal, a need for import of higher-grade coal, albeit at a higher cost, increased risk of supply chains, and a lack of scrap recovery and import infrastructure are some of the issues that impact SEC at any plant in addition to the plant-specific challenges listed in the previous paragraph.

Some of the EE measures available are to improve the quality of coal, coke, and raw materials using sinter and pellet plants. Waste heat recovery systems are useful for the utilisation of waste heat energy, moisture reduction in coal and raw materials, and power generation. Utilising RE for specific processes and plant and housing colony operations is another attractive EE measure. Various EE technologies, such as variable frequency drives for industrial fans, blowers, and motors, can bring energy savings with lower payback periods. A shift in the process flow of the plant can bring larger benefits at a higher initial investment. Increasing scrap utilisation and the car scrapping framework recently introduced in India can significantly increase the amount of steel scrap available for recycling in steel plants and reduce SEC.

PAT Cycle Performance

PAT cycle I was set up with 478 DCs, and the total energy savings target was 6.86 million tonnes of oil equivalent (MTOE) apportioned to each industrial sector, as shown in the table-1.

PAT cycle I (2012–2015) exceeded targets and saved 8.67 MTOE, translating to reductions of approximately 31 million tonnes of CO_2 based on BEE and other reports. Cycle II from 2016 to 2019 saved about 14.08 MTOE, and subsequent cycles have added new sectors and DCs. PAT cycles V and VI had energy savings targets of 0.5130 MTOE and 1.277 MTOE, with 110 and 135 DCs participating in each cycle, respectively. PAT cycle VII is ongoing



between 2022–23 and 2024–25, involving 509 DCs with an overall energy savings target of 6.627 MTOE.

The PAT mechanism has had a considerable impact on improving the EE of industrial plants, which results in a reduction of CO_2 emissions and energy usage, as well as unlocking investments for improving the technology and processes at various industrial and building sites. This has been made possible through the collaborative and consultative efforts of the BEE and other stakeholders, all working towards a common goal. The framework includes both technical and economic initiatives, along with a growing number of accredited and certified energy auditors and managers that the BEE has developed over the past decade and beyond. These energy auditors and managers are the backbone of the system whose success depends on the measurement, reporting, and verification of the energy audits of each DC, followed by random sample checks of the energy audit.

PAT Lessons and Way Forward

While PAT design and implementation have been a successful flagship beginning for India's industrial EE journey, it must be continuously improved and tuned based on careful techno-economic analysis and feedback. This evolutionary growth will be critical for the programme to contribute as a powerful engine of India's development journey goals, such as *Viksit Bharat* and *Atmanirbhar Bharat*.

1. ESCert trading: In most of the cycles of PAT, a majority of the DCs exceeded their targets and obtained ESCerts that needed to be traded at the approved exchanges in the country with other DCs or banked for use in future PAT cycles. The trading exchange data suggests that the buyer demand was much smaller than the supply of ESCerts, leading to low prices. A price floor and ceiling are dynamically needed based on the demand and supply data at any designated trading window.
2. Target setting: The setting of energy savings targets needs careful analysis of technical and economic parameters to result in a more balanced market of ESCerts, which can lead to prices that better reflect the weighted average cost of EE improvement measures within sectors.
3. Widening and deepening of sectors: For PAT to contribute strongly to India's energy intensity and net-zero goals, it has to continuously transform into a more robust mechanism that can accommodate more sectors and eventually all of the Indian industry, including MSMEs.
4. Buildings sector: The buildings sector is projected by most estimates to be one of the largest consumers of embodied and operational energy, and this provides an excellent opportunity to integrate EE from the design stage of each building through PAT and other mechanisms, which can mandate EE while providing auditing, technical, and financial initiatives to enable stakeholders to move in the direction of EE buildings.
5. Carbon Credit Trading System (CCTS): The Government of India adopted the CCTS recently, and this would provide another framework for PAT to play a complementary role in enabling a roadmap for net-zero and decarbonisation transition for the Indian economy. □

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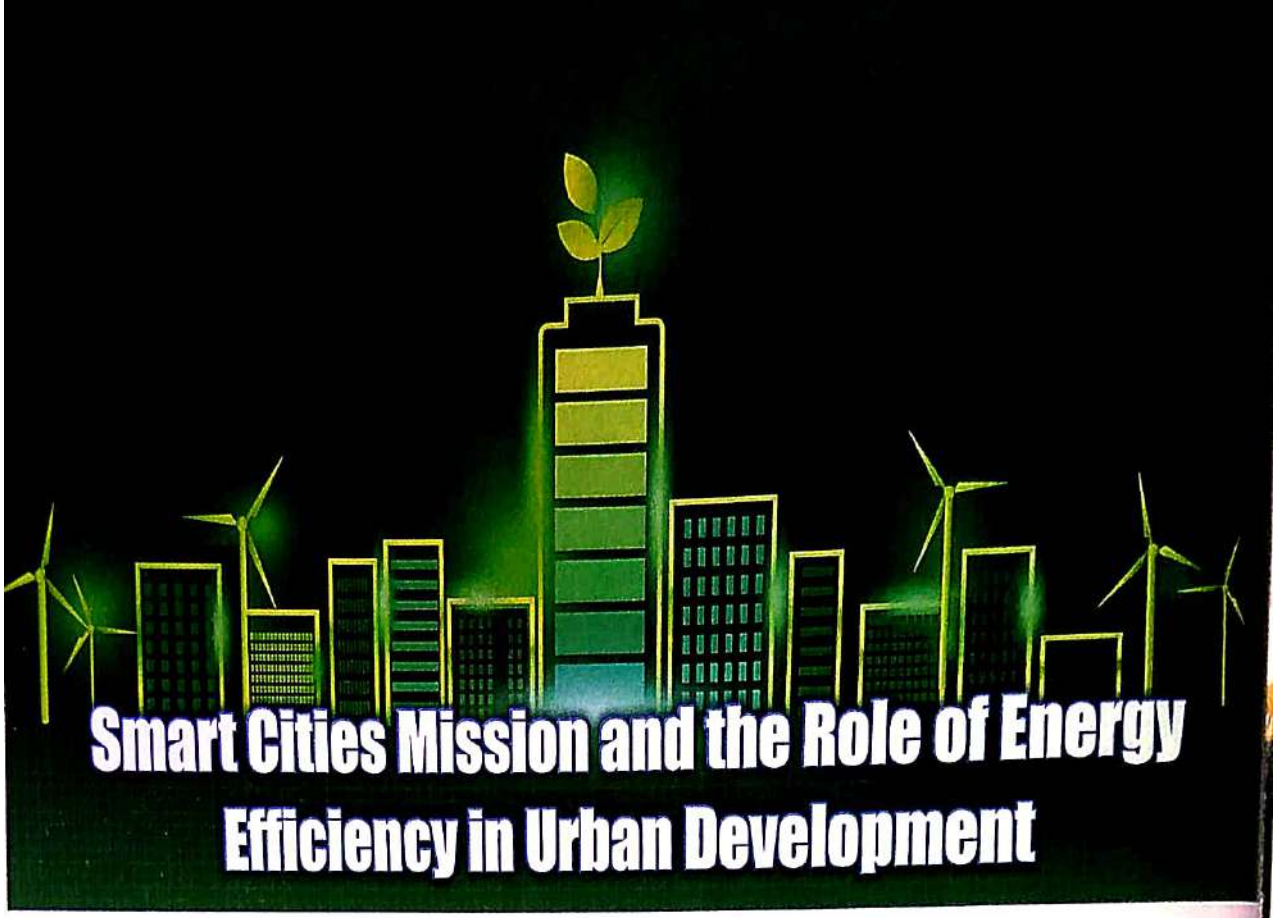

Smart Cities Mission and the Role of Energy Efficiency in Urban Development

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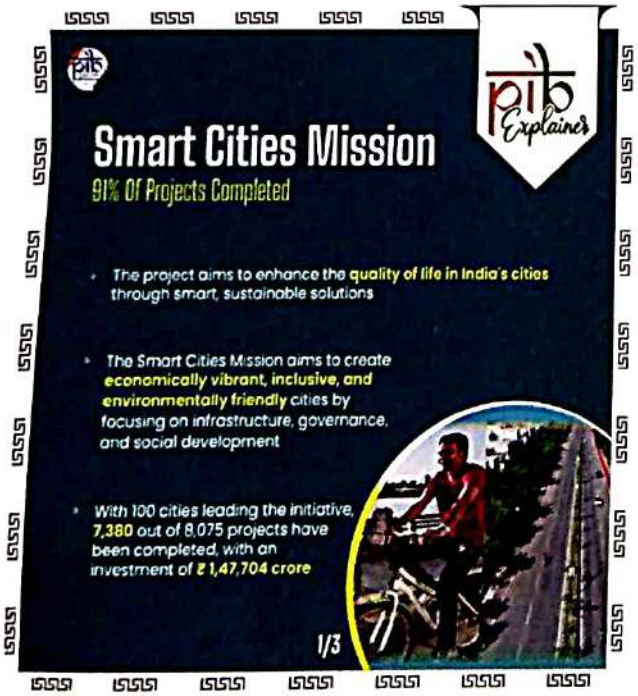
India's Smart Cities Mission (SCM), launched in 2015, seeks to integrate infrastructure and technology for effective urban growth. Cities account for 50–60% of global GHG emissions, raising the need for a low-carbon economy through efficient energy supply and consumption. Effective waste management relies on energy efficiency, which reduces heavy energy consumption during collection, processing, and disposal of waste. The shift from conventional frameworks such as the Energy Conservation Act (2001) towards greater industry- and consumer-oriented programs, reflects an evolving trajectory of energy efficiency focused policy paradigm. Taking cognisance of energy efficiency measures addressed through the SCM, there is a need to upscale these across cities in India.

Cities account for 50–60% of global GHG (Greenhouse Gas) emissions, raising the need for a low-carbon economy through efficient energy supply and consumption. Urbanisation contributes to making India the third-largest energy consumer, with 80 per cent of the energy generation from conventional sources. The coal-based energy generation contributes to around 70 per cent of emissions. To ensure affordability and accessibility in urban networks, the government has been promoting integration of energy-efficient practices. India's Nationally Determined Contributions (NDC) and Long-Term Low-Emissions Development Strategy (LT-LEDS) focus on building climate-resilient and energy-efficient urban infrastructure. Energy efficiency, a cornerstone of the smart city framework, enhances a city's smartness through robust information and communication systems (ICT), minimising household costs, reducing pressure on utilities by balancing energy demand and supply while minimising emissions

and strengthening climate resilience.

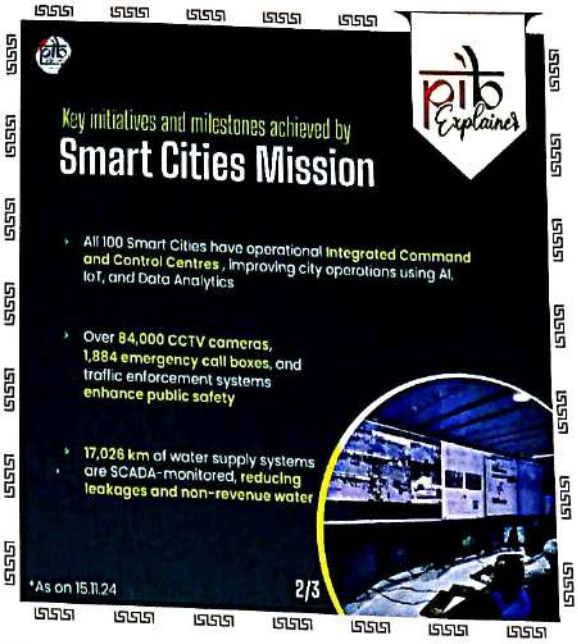
Power demand in India is expected to double by 2030 due to the country's rapid economic expansion and urbanisation. The capacity of DISCOMs (Distribution Companies) to deliver reliable and affordable power to cities while sustaining their financial stability is an ever-increasing challenge. The propelling demand necessitates capacity expansion, thereby exerting additional financial stress on utilities and negative externalities on the environment. Energy-efficient techniques are critical towards minimising consumption, enhancing distribution processes, and transforming consumer behaviour in an economically viable and environmentally sustainable manner. India's Smart Cities Mission (SCM), launched in 2015, seeks to integrate infrastructure and technology for effective urban growth. SCM had been aiming to improve the quality of life in cities through affordable housing, sustainable mobility, waste management, dependable power and water. The mission has raised the emphasis on energy efficiency to ensure sustainable resource usage and lower the expenses and emissions. The ecosystem-based adaptation initiatives and green infrastructure development further complement the energy demand management in cities. Smart and sustainable urbanisation in India demands energy efficiency-centered strategies for optimising resources, reducing costs, and enhancing 'smartness' in cities across four key sectors, identified through research and consultations:



Energy-efficient buildings: The building sector, undergoing phenomenal growth, accounts for more than a third of the country's energy consumption, and it is estimated that around 40 per cent of the building stock that shall exist over the next two decades is yet to be constructed. Currently this is and shall continue to be high-density construction for both commercial and residential buildings in and around the metropolitan and smart cities in the coming years. The energy demand for ageing building stock as well as for new construction needs to be optimised. Technological advancements in energy efficiency are crucial for optimising the energy consumption of building infrastructure, including hospitals (which account for 14 per cent of the country's energy use). Retrofitting of existing buildings, including healthcare facilities, with energy-efficient systems for HVAC (Heating, Ventilation, and Air Conditioning), lighting, water supply, and waste management, and application of energy-efficient appliances for uses such as air filtration, can significantly reduce energy consumption. Through targeted policies under the National Program for Climate Change and Human Health (NPCCHH), hospitals can prioritise energy efficiency, ensuring sustainable operations and aligning with broader climate resilience goals.

This urgently requires capacity enhancement of existing and new cadre of professionals. Leveraging efficient systems and renewable energy under the national climate-health program, can reduce operating costs, enhance sustainability, and ensure climate-resilient, future-ready public health infrastructure. Under the SCM, around 525 projects have been established across the smart cities, focused on energy and green buildings area with emphasis on improving energy efficiency and using renewable energy sources. Enhanced focus on green public procurement in the building sector shall further assist in lowering the energy footprint. Green building standards, such as GRIHA (Green Rating for Integrated Habitat Assessment) and LEED (Leadership in Energy and Environmental Design), ensure energy efficient sustainable construction practices. All such initiatives need to be scaled up for adaptation across cities.

Energy-efficient water management: The CSCAF 2.0 (Climate Smart Cities Assessment Framework) has introduced the 'Energy Efficient



Water Supply' indicator to guide cities in reducing energy consumption, GHG emissions, and costs while promoting sustainable, efficient, and profitable urban water systems. Sustainable water management initiatives can be strengthened through a focus on energy efficiency by technological interventions such as integrating SCADA (Supervisory Control and Data Acquisition) automation, optimising pumping systems with Variable Frequency Drives (VFDs). In smart cities it is vital to enhance energy efficiency in water management by initiatives such as regular energy audits, integrating renewable energy sources like solar and micro-hydro, retrofitting dilapidated water supply infrastructure and applying hydraulic modelling. Further, techniques such as real-time monitoring and decision support systems for demand management and for reducing non-revenue water (NRW), bulk metering for precise water accounting, and pressure management to minimise energy and water losses shall help in establishing efficient water supply networks and strengthening the water-energy nexus. The rising demand for treated water entails incorporation of digital solutions through usage of IoT, AI and ML technologies.

Energy-efficient waste management: Effective waste management relies on energy efficiency, which reduces heavy energy consumption during collection, processing, and disposal of waste. Technologies like IoT, sensor-based mechanisms, GPS navigation, RFID (Radio Frequency Identification), and data management optimise collection as urban waste generation rises 5 per cent annually along with a 3-3.5 per cent urban population growth to reach 436 MMT by 2050. The AI technologies, when combined with chemical analysis, can improve waste pyrolysis. AI integrated in waste logistics can reduce transportation distance and optimise the energy consumption required in transportation. Mechanical biological treatment and refuse-derived fuel (RDF) systems in waste treatment facilities ensure the safe disposal of hazardous waste. Waste can be turned into energy while lowering costs with methods like sanitary and bioreactor landfills and solar integration. Compared to creating new materials, recycling and reusing commodities like steel, wood, and concrete from construction and demolition waste greatly reduces energy requirements. During construction, source reduction techniques like modular design and careful material planning reduce energy consumption and waste production thereby promoting energy-efficient waste management in cities.

Energy-efficient Transportation: The transportation industry in India is the third-largest emitter of greenhouse gases, consuming 94 MTOE (18 per cent of energy use) and contributing 14 per cent of energy-related CO_2 emissions. An integrated, sustainable transportation ecosystem is produced by cooperative multimodal networks and renewable energy projects, such as

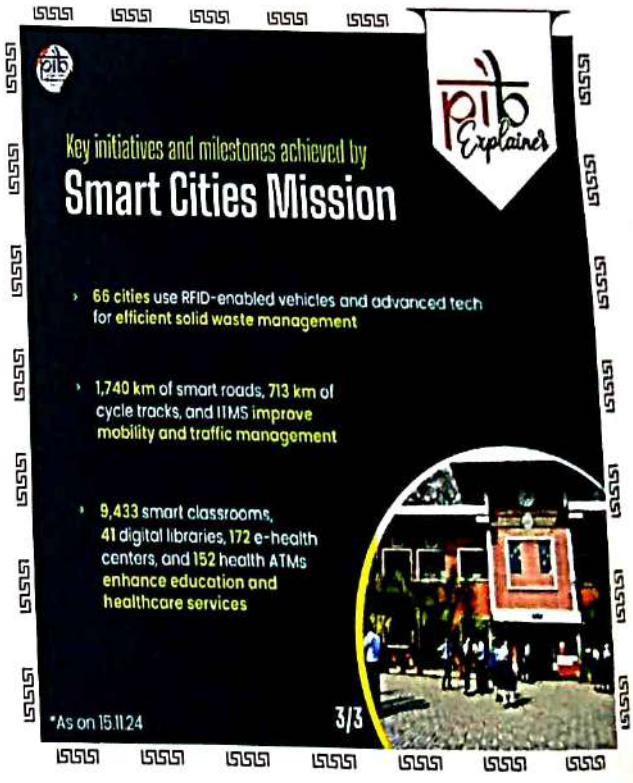


Table 1: Transforming policy environment with direct & indirect contribution to energy efficiency in cities

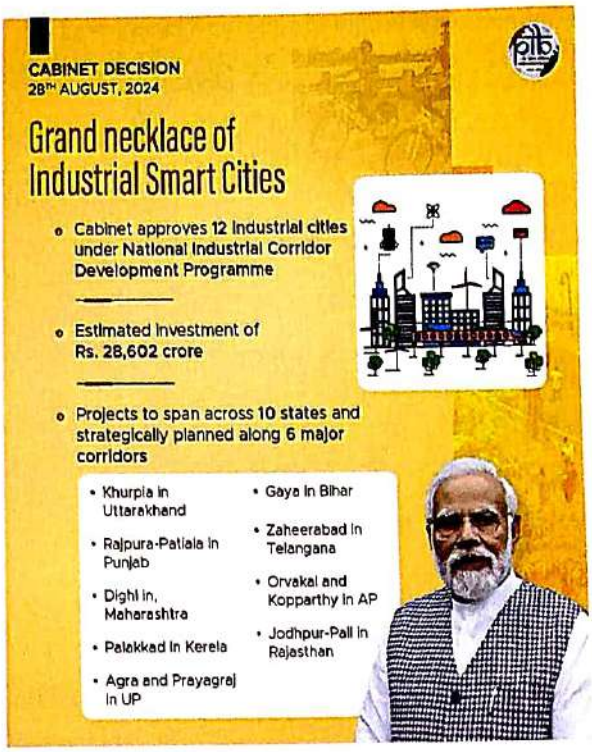
Policy/Programme	Year	Emphasis
Energy Conservation Act (EC Act)	2001, Amended 2010	Establish energy efficiency standards, promote energy conservation, regulate high energy-use industries.
National Mission on Enhanced Energy Efficiency (NMEEE)	2010	Enhance industrial energy efficiency through Perform, Achieve & Trade (PAT), and financial instruments like Energy Savings Certificates.
National Mission for Sustainable Habitat (NMSH)	2010	Promote sustainable urban development, energy-efficient buildings, and urban waste management.
National Solar Mission (NSM)	2010	Scale up solar power generation with targets for grid-connected and off-grid solar installations.
Perform, Achieve, and Trade (PAT) Scheme	2012	Market-based mechanism for enhancing energy efficiency in industries
National Electric Mobility Mission Plan (NEMMP)	2013	Development and promotion of electric vehicles that contribute to net zero emissions by reducing vehicular pollution
Smart Cities Mission (SCM)	2015	Foster energy-efficient, sustainable urban development with integrated technologies and green infrastructure.
National Smart Grid Mission	2015	Modernises India's power distribution network using smart grids and enables grid decarbonisation for net zero carbon goals.
Unnat Jyoti by Affordable LEDs for All (UJALA)	2015	Encourages the production and use of energy-saving LED lights and appliances. Lowers the amount of electricity used in homes and businesses.
Energy Conservation Building Code (ECBC)	2017 (Updated)	Sets energy efficiency standards for commercial buildings to boost climate resilience in Urban Development.
Draft National Energy Policy (NEP)	2017	Provide universal energy access, reduce fossil fuel dependency, and promote low-carbon development.
Draft National Cooling Action Plan (NCAP)	2018	Manage cooling demand, reduce carbon footprint, and increase energy-efficient cooling technologies.
National Program for Climate Change & Human Health (NPCCHH)	2019	Ensuring environmentally sustainable and climate-resilient health services
Steel Scrap Recycling Policy (SSRP)	2019	Promotes the use of scrap steel in manufacturing to lessen the emissions and effects of mining. Encourages the steel sector to use sustainable manufacturing practices.

solar-powered infrastructure. Energy-efficient urban mobility incorporates cutting-edge technologies and creative methods. Emissions are decreased by improved public transportation, non-motorised modes, and electric cars with robust charging infrastructure. Traffic operations can be optimised using artificial intelligence and big data analytics that enable energy efficiency by reducing the energy demand for sustainable urban freight. Drones, ridesharing, adaptive traffic systems, and autonomous delivery vehicles can all increase productivity while contributing to a reduction in energy consumption.

Trajectory of Policy and Regulatory Framework

Integrating energy-efficient solutions across various sectors in cities is catered to by various national policies and programs. A few key policy initiatives influencing the present course of energy efficiency in Indian cities are presented in Table 1.

The shift from conventional frameworks such as the Energy Conservation Act (2001) towards



greater industry- and consumer-oriented programs reflects an evolving trajectory of energy efficiency focused policy paradigm. The trajectory showcases increasing emphasis on aligning energy efficiency dimensions with overarching goals of sustainability, climate resilience, and low-carbon development in cities.

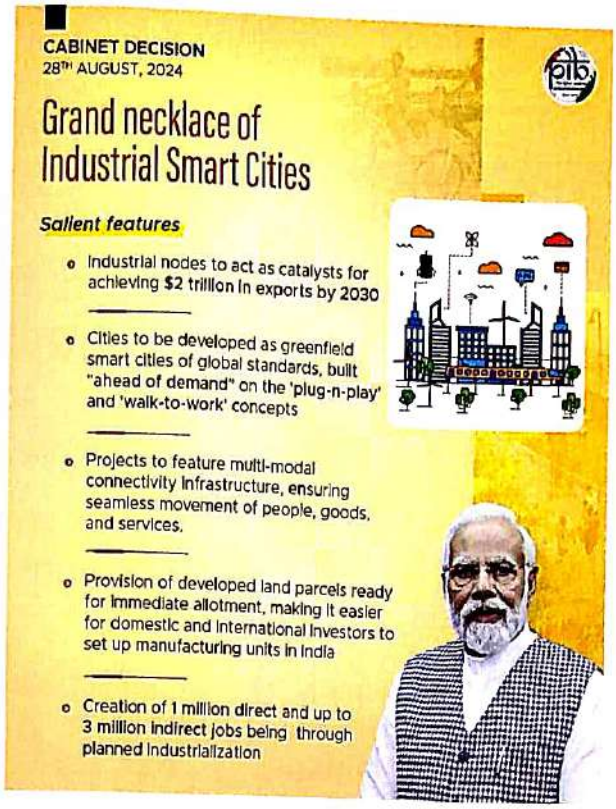
Harnessing momentum for the way forward

To minimise the emission intensity through the urban development sector, India is progressively focusing on energy demand management, enhancing renewable energy capacity and maximising energy efficiency. A systems approach shall assist in providing impetus to the efforts towards energy efficiency, particularly in the high-potential areas in smart cities through greater emphasis on a few critical overarching dimensions:

Co-production of knowledge for policy and governance: A co-production approach needs to be adopted for the establishment of ever-evolving knowledge system for energy efficiency in smart cities through engagement of key stakeholders such as think tanks, academic and research institutions, technology innovation hubs, NGOs and CBOs (Community-Based Organisations), the business sector, regulatory and statutory bodies, public utility providers, international organisations and funding agencies, and urban planning and development organisations. The targets of national initiatives like NAPCC, and NMEEE need to be explicitly integrated and addressed in city & regional master plans. Enabling a conducive policy ecosystem pertaining to sourcing and procurement of renewable energy by local government utilities and strengthening institutional capacity of urban local bodies shall assist in effective decentralised governance for energy management. Inter-sectoral coordination needs to be significantly strengthened to overcome barriers and streamline integration and collaboration across key stakeholders mandated to manage energy-intensive sectors of smart cities.

Cutting-edge technologies for energy efficiency: The widespread adoption and upscaling of energy-efficient and clean energy projects, supported through various schemes by the Department of Science & Technology (DST), Government of India, Bureau of Energy Efficiency (BEE), and Ministry of New & Renewable Energy (MNRE), Government of India, shall strengthen the research ecosystem, necessary for technological advancement. This will help reduce import and capital costs, enhance revenue streams for smart energy companies, and drive the development of cutting-edge technologies like smart grids, advanced energy storage, blockchain energy trading, IoT-enabled sensors, AI-driven predictive systems, renewable energy integration, Geographic Information System and Global Positioning System-integrated public utility systems and district energy systems. This shall also provide impetus for widespread adoption for energy efficiency in sector-specific technologies such as waste-to-energy solutions, Building Integrated Photovoltaics (BIPV), Building Automation and Control Systems (BACS), EV infrastructure, smart lighting, soft sensing for wastewater treatment, and advanced metering.

Strategic financing for energy management: The financial instruments for scaling up energy efficiency in urban development entail innovative and blended financing mechanisms to address funding challenges and foster smart energy initiatives. National programs like the National Mission for Enhanced Energy Efficiency (NMEEE) can be hybridised with instruments such as Energy Efficiency Financing Platform (EEFP), Venture Capital Fund for Energy Efficiency (VCFEE), the Partial Risk Guarantee Fund for Energy Efficiency (PRGFEE)



and Green Growth Equity Fund (GGEF) that shall incentivise investments and reduce financial risks by harnessing public and private capital for projects relating to renewable energy and clean transportation. Financial tools like green bonds that enable cities to raise funds for sustainable energy projects and market-based mechanisms such as the Perform, Achieve, and Trade (PAT) scheme need to be revisited and strengthened towards upscaling into high-energy-consuming sectors. Strengthening these mechanisms through strategic domestic and international collaborations shall further enable cities to leverage resources for prompt adoption of energy-efficient practices spanning from smart grids to advanced energy storage systems.

Targeting performance measurements: Defined performance targets, benchmarks and outputs are necessary for the effective execution of policies. These could include both action-oriented (such as facility upgrades and awareness campaigns) and quantitative targets (such as energy usage, percentage renewable energy deployment, and GHG emission reduction) at the city level. Creation of energy-efficient assets must be guaranteed by a long-term performance structure (including robust database management, MIS, and sector-specific annual reports) that assigns accountability for goal-setting, tracking, and reporting on a continual basis.

Taking cognisance of energy efficiency measures addressed through the SCM, there is a need to upscale these across cities in India. Through enabling policy and regulatory environments, the integration of advanced technologies, and innovative financing mechanisms, India can accelerate transitioning towards energy-efficient smart cities. ❑

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Scope & Opportunities for Renewable Energy in Rural India

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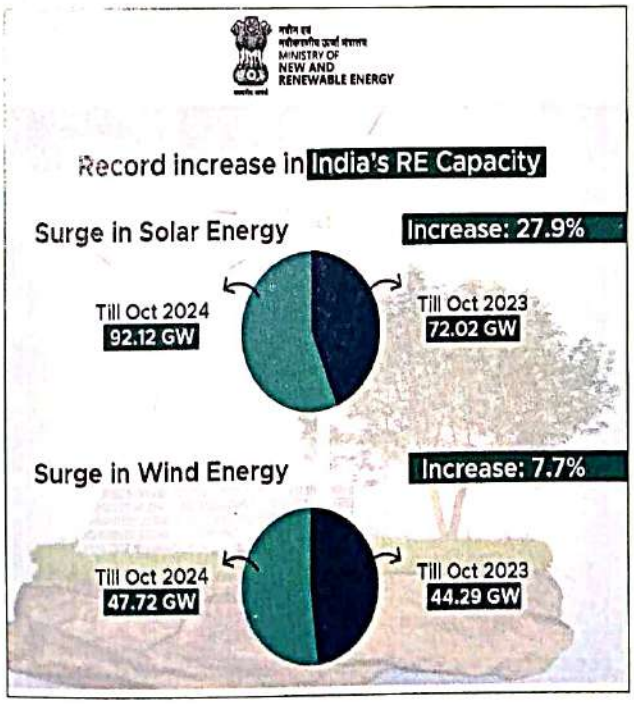
India's renewable energy capacity grew by 165 per cent in 10 years, rising from 76.38 GW in 2014 to 203.1 GW in 2024. The rural population accounts for about 67 per cent of the total population and 37 per cent of its GDP. The government has identified energy as a priority sector, with an overall allocation of Rs 68,769 crores. The *Pradhan Mantri Surya Ghar: Muft Bijli Yojana* was launched to install rooftop solar plants in 1 crore households, providing up to 300 units of free electricity per month. The Central Government has strongly supported solar power, with special emphasis on incentivising distributed solar power. The National Green Hydrogen Mission targets 5 million metric tonnes of annual Green Hydrogen production capacity by 2030.

Today's world is fighting a war that is bigger and more severe than any war fought in the past, and that is the fight against pollution and depletion of natural resources in every context, be it quantity or quality. Amongst all the major problems being faced, usage and implementation of renewable energy (RE) is the best and most suitable alternative. India is adopting ambitious goals for deploying solutions such as clean hydrogen, energy storage, carbon capture and sustainable aviation fuels. It is heartening to note that India's renewable energy capacity grew by 165 per cent in 10 years, rising from 76.38 Gigawatts in 2014 to 203.1 Gigawatts in 2024, accounting for 46.3 per cent of the country's total installed capacity.

The rural population accounts for about 67 per cent of the total population and 37 per cent of its GDP. While the overall Indian economy is expected to grow in excess of 7 per cent—the fastest amongst large global economies- rural India still lags behind substantially. The primary hindrance to growth in rural productivity and subsequent economic growth is the lack of basic infrastructure such as electricity, clean water and sanitation. Nearly 300 million people in rural India lack access to grid-connected power, promoting use of archaic sources of energy such as kerosene, diesel, wood-fired *chulhas*, etc. which not only results in huge government subsidies, but also substantial health and environmental hazards.

Solar power offers an opportunity to bridge the massive infrastructure gap and improve the social, economic, environment and health indicators. Solar power has been around for a while; historically high costs have necessitated it to be driven by philanthropic capital or government subsidy, thus limiting its scope. However, with a drop in capital cost of nearly 70 per cent over the last few years, solar energy has now become commercially mainstream, thus attracting private capital and entrepreneurs. This truly makes solar power the much-awaited solution for the millions living without electricity. The Central Government, under the leadership of Prime Minister Narendra Modi, has strongly supported solar power. As part of the government's vision of 'Electricity for All' the Centre has placed special emphasis on incentivising distributed solar power, having already sanctioned 4,604 distributed solar projects in rural areas to power 4,745 villages/ hamlets.



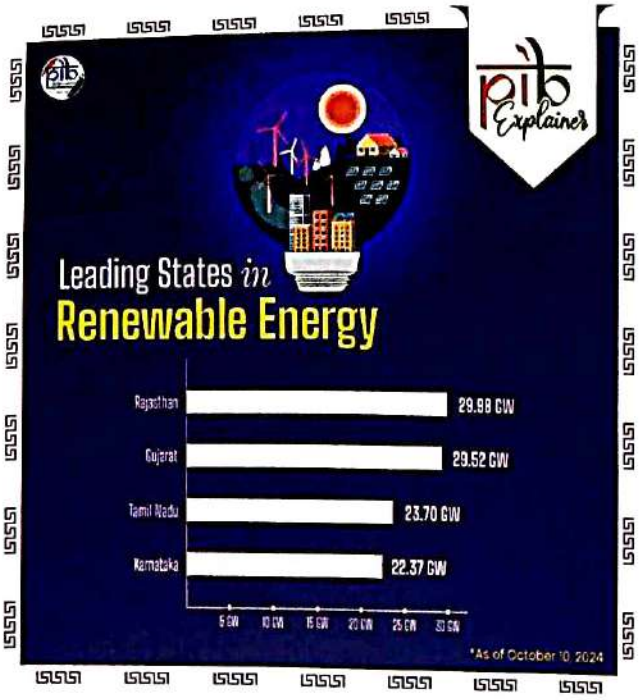
Why Solar Energy?

There is a huge scope of promoting the use of solar energy throughout India, especially the rural areas for the following reasons:-

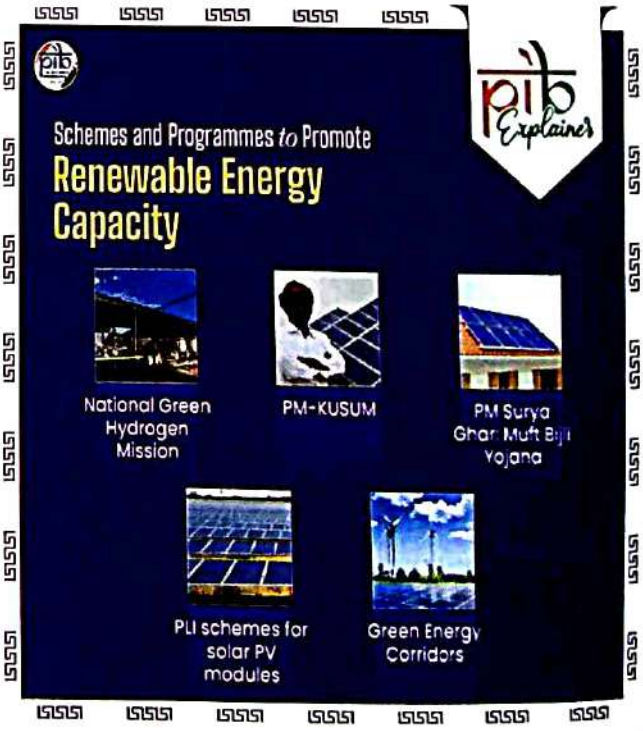
- To promote the use of sustainable, economic and least-cost decentralised electrification solutions for areas not feasible for grid connection/extension in partnership with the local government units, semi-private and private sectors.
- The modular nature of solar power makes it easy to deploy for multiple rural applications, impacting key facets of rural population, such as productivity, safety, health benefits, access to clean water, heating solution and livelihood. Solar lighting, for example, not only provides a high-quality solution to improve rural productivity, but also substantially reduces health hazards by enabling replacement of kerosene lamps. Even 4-5 hours of additional lighting can improve productivity and income of rural households.
- Another important application is solar powered agriculture pumps, which have the potential to substantially improve productivity of Indian farmers. The agricultural sector needs proper irrigation facilities to reap proper benefits. Most of the farmers use pumps that are connected to the grid, while majority of them run on diesel and other fossil fuels which leads to almost 20 per cent of the installed power in India. The government has launched various schemes to promote the installation of grid-connected solar power plants and solar pumps.
- Clean water remains a big challenge in rural India, since water treatment requires power. Solar energy is finding important applications in this field also.

The Government of India has implemented a range of following measures and initiatives aimed at promoting and accelerating RE capacity across the nation:-

- Permitting Foreign Direct Investment (FDI) up to 100 per cent under the automatic route



- National Green Hydrogen Mission, 2023: The mission targets to achieve about 5 million metric tonnes (MMT) of annual Green Hydrogen production capacity by 2030.
- Waiver of Inter State Transmission System (ISTS) charges for inter-state sale of solar and wind power for projects to be commissioned by 30th June 2025, green hydrogen projects until December 2030; and offshore wind projects until December 2032.
- Setting up of Ultra Mega Renewable Energy Parks to provide land and transmission to RE developers on a plug-and-play basis.
- Schemes such as *Pradhan Mantri Kisan Urja Suraksha evam Utthaan Maha Abhiyan* (PM-KUSUM), Solar Rooftop Phase II, 12000 MW CPSU Scheme Phase II, etc.
- *PM Surya Ghar: Muft Bijli Yojana*: Aimed to install rooftop solar plants in one crore households with a total financial outlay of Rs 75,021 crore and to be implemented until FY27.
- Laying of new transmission lines and creating new substation capacity under the Green Energy Corridor Scheme for evacuation of renewable power.
- Setting up of Project Development Cell for attracting and facilitating investments.
- Standard Bidding Guidelines for tariff-based competitive bidding process for procurement of Power from Grid-Connected Solar PV and Wind Projects.
- Government has issued orders that power shall be dispatched against Letter of Credit (LC) or advance payment to ensure timely payment by distribution licensees to RE generators.
- A Project Development Cell has been established to attract and facilitate investments in the renewable sector.
- Ultra Mega Renewable Energy Parks are being set up to provide land and transmission for large-scale renewable energy projects.
- Cabinet approval for a Viability Gap Funding scheme for offshore wind energy projects, facilitating the installation and commissioning of 1 GW of offshore wind energy capacity along the coasts of Gujarat and Tamil Nadu.
- The 'National Repowering and Life Extension Policy for Wind Power Projects, 2023' has been released.
- Strategy for Establishment of Offshore Wind Energy Projects outlines a bidding trajectory of 37 GW by 2030.
- Offshore Wind Energy Lease Rules, 2023, notified to regulate the grant of leases for offshore wind energy development.
- Procedure for Uniform Renewable Energy Tariff (URET) established.
- Standard & Labelling (S&L) programs for Solar

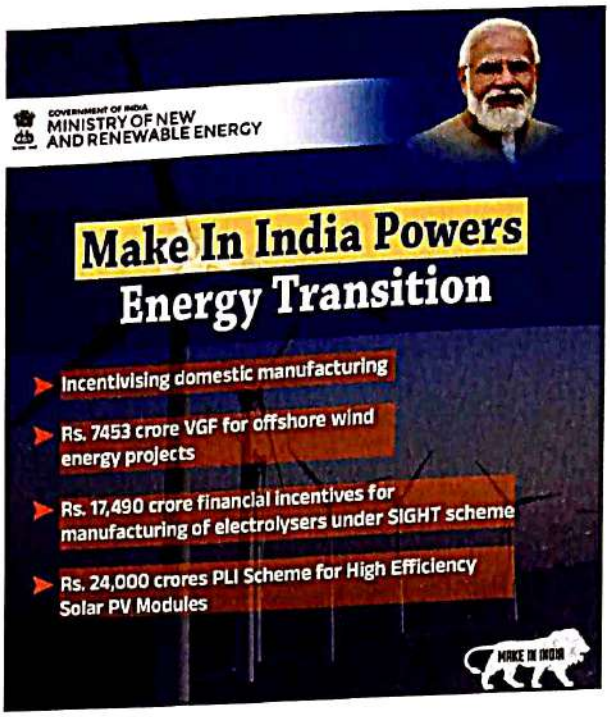


Photovoltaic modules and grid-connected solar inverters launched.

- A transmission plan has been prepared to augment transmission infrastructure until 2030.
- Electricity (Late Payment Surcharge and Related Matters) Rules notified.
- Green Energy Open Access Rules 2022 issued to promote renewable energy.
- Launched the Green Term Ahead Market (GTAM) to facilitate the sale of renewable energy power through exchanges.

While having a look at the Union Budget 2024-25, we find the government has identified energy as a priority sector, with an overall allocation of an estimated Rs 68,769 crores. The budget emphasises the development of new strategies for strengthening the transition to RE sources and promoting energy security in terms of 'accessibility, affordability, and availability.' The growth of nuclear energy in the form of small modular reactors has been emphasised, with the government planning to make it a significant portion of the energy mix for *Viksit Bharat*. To facilitate this, the government plans to partner with the private sector to set up Bharat Small Reactors and aims to enhance the research and development of Bharat Small Modular Reactors and newer nuclear technologies.

However, RE sector of India is also facing varied challenges: The material and natural resource, primarily land, costs to generate one unit of electricity are substantially higher for RE compared to the generation of one unit of electricity from fossil fuels. Another hindering factor is Land acquisition: Identification of land with RE potential, its conversion, decision on land lease rent, and various clearances take time. Despite the numerous benefits provided by the government for solar power solutions such as subsidies, direct and indirect tax benefits, there is a lack of trust for performance among the consumers. Because of the lack of technical expertise and intellectual property with Indian companies, the efficiency and the quality of solar panels produced by the Indian brands is not able to compete with its global counterparts. Another major issue is of dust in our environment. Even a single grain of sand can affect the performance of a solar PV cell/module. These challenges have had an overtly deep impact on



the abilities of Indian Solar Panel Manufacturers. Due to Intermittency (Renewable sources are not constant; they fluctuate based on weather conditions) and grid balancing challenge (sudden surges or drops in RE generation can strain the grid). Birds and bats might collide with wind turbines, especially during migration seasons. Also, a large amount of water is needed for hydrogen production. Since most DISCOMS are bound by Power Purchase Agreement for thermal power, their capacity to procure solar-based power is reduced, thus affecting the overall Renewable purchase obligations targets. Although, the growth of nuclear energy in the form of small modular reactors has been emphasised by the government, estimates by Now Solar, an India-focused renewable energy advisory and management organisation, indicate that small modular nuclear reactors are expected to be the costliest source of power and are unlikely to be available before 2030. Although a bold initiative aimed at expanding the nuclear energy component in the energy mix of India, questions regarding its economic viability remain unanswered. Over the years, nuclear policies have predominantly centred on large nuclear reactors, with no initiatives in place to foster demand and create a level playing field for new market entrants. Additionally, some nuclear reactors are under International Atomic Energy Agency (IAEA) safeguards due to their use of imported uranium. Without policies to stimulate market demand, this initiative risks becoming another failure. Programmes and schemes aimed

at gradually phasing out fossil fuels such as the harnessing of wind energy and the integration of compressed biogas into the natural gas need attention. The focus on nuclear energy also raises questions on the potential sidelining of such projects in the future.

In line with the interim budget announcement, the *Pradhan Mantri Surya Ghar: Muft Bijli Yojana* was launched to install rooftop solar plants in 1 crore households, providing up to 300 units of free electricity per month. This scheme has seen significant interest, with over 1.28 crore registrations and 14 lakh applications, but the applications received account for only about 11 per cent of total registrations, largely because the final approval for installing solar rooftops lies with the respective state electricity boards. The capacity of solar plants depends on the transformer capacity of the area, making it challenging for state electricity boards to approve the applications. The state electricity boards, with their existing grid capacity, may not be able to approve the installations until there is an upgrade in the grid infrastructure.

To sum up, India's renewable energy journey has reached a significant milestone, marked by the impressive achievement of over 200 GW of installed capacity. This accomplishment is a testament to the nation's commitment to a sustainable energy future, driven by a diverse array of renewable sources, including solar, wind, hydro, and bioenergy. The proactive initiatives, such as the National Green Hydrogen Mission, *PM-KUSUM*, *PM Surya Ghar*, and the PLI schemes for solar PV modules underscore the government's strategic focus on enhancing energy generation capacity while reducing reliance on fossil fuels. With ambitious targets set for the future, including a goal of 500 GW from non-fossil sources by 2030, India is well-positioned to emerge as a global leader in renewable energy, contributing to environmental sustainability, energy security and rural prosperity. These ongoing efforts reflect a holistic approach to building a greener economy, ensuring that India not only meets its energy needs but also addresses the pressing challenges of climate change and resource conservation. ❑

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Green Hydrogen: India's Path to a Sustainable Energy Future

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India's National Green Hydrogen Mission (NGHM) aims to establish India as a global hub for Green Hydrogen production, usage, and export, advancing the country's energy self-sufficiency through clean energy solutions. The Mission targets a production capacity of at least 5 Million Metric Tonnes (MMT) of Green Hydrogen annually by 2030, with potential growth to 10 MMT per year as export markets expand. The Mission will significantly decarbonise key industrial sectors and lay the groundwork for similar transitions in emerging sectors like steel, shipping, energy storage, and long-haul mobility. Green Hydrogen initiatives are expected to avert around 50 MMT of CO_2 emissions annually, contributing to India's energy independence and Net Zero goals. The initial funding for the Mission is Rs 19,744 crore, allocated as Rs 17,490 crore for the SIGHT programme, Rs 1,466 crore for pilot projects, Rs 400 crore for R&D, and Rs 388 crore for other components. Through government interventions and a phased, collaborative approach, the Mission will accelerate the development of Green Hydrogen technologies, reduce production costs, and create economies of scale.

India, that is *Bharat*, has long been committed to sustainable development, earning global recognition for its climate goals. Having surpassed its Paris Agreement targets, the nation is now focused on achieving energy independence by 2047 and reaching Net Zero emissions by 2070. A critical component of this vision is Green Hydrogen—an innovative, clean energy solution that has the potential to revolutionise India's energy landscape and position it as a global leader in renewable energy production.

With one of the world's fastest-growing renewable energy sectors, India's abundant renewable resources offer a unique opportunity to meet domestic energy needs and supply Green Hydrogen to global markets. The National Green Hydrogen Mission is a comprehensive initiative designed to build a robust Green Hydrogen ecosystem in India, addressing the emerging sector's opportunities and challenges.

The global transition to clean energy is accelerating as nations work to combat climate change, ensure energy security, and foster economic growth. As other countries push forward with their renewable energy ambitions, India's leadership in this space is becoming increasingly significant. Green Hydrogen, produced from renewable sources like solar and wind, holds vast potential to decarbonise hard-to-abate sectors such as industry, transport, and power generation while creating sustainable economic and employment opportunities. Through the National Green Hydrogen Mission, India not only contributes to global sustainability but also paves the way for a cleaner, greener, and more energy-secure future.

Advancing Energy Independence and Sustainable Development

India aims to achieve Net Zero emissions by 2070, with energy demand projected to grow by 25 per cent by 2030. Currently, over 40 per cent of its primary energy is imported, necessitating a transition to renewable energy and reduced reliance on fossil fuels. Green Hydrogen, produced from renewable energy, can play a key role in reducing carbon emissions and improving energy self-sufficiency. It can replace fossil fuels in industries such as petroleum refining, steel production, and fertilisers, and be used in hydrogen-fuelled long-haul transport, including automobiles and ships. Additionally, it has the potential to meet energy needs in remote regions.

Countries worldwide are scaling up Green Hydrogen production, using government funding and policy support to enhance R&D, manufacturing, and infrastructure. The growing demand for Green Hydrogen, driven by the global shift towards Net Zero and disruptions in fossil fuel supply chains, presents a significant opportunity for India to capitalise on its renewable energy resources and become a leading producer and exporter of Green Hydrogen and its derivatives like Green Ammonia and Green Methanol.

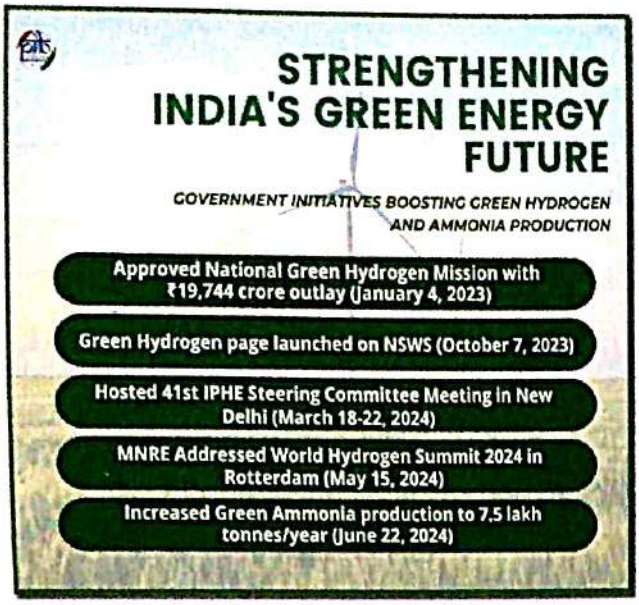
Despite challenges such as high costs and a lack of harmonised standards, technological advancements and falling costs of renewable energy and electrolysers indicate that Green Hydrogen will soon become cost-competitive across various sectors. The National Green Hydrogen Mission will accelerate India's efforts in achieving a low-carbon, self-reliant economy, aligning with global trends in technology, policy, and regulation.

The rapid scaling of renewable energy and electrolyser capacity is essential for cost efficiency, while the development of infrastructure for delivery, storage, and transportation will be critical. International cooperation will play a vital role in supporting India's efforts. The Ministry of New and Renewable Energy leads the Mission's coordination through a collaborative approach involving various ministries.

Objectives of National Green Hydrogen Mission (NGHM)

Launched in January 2023, the primary goal of the National Green Hydrogen Mission (NGHM) is to establish India as a global hub for Green Hydrogen production, usage, and export, advancing the country's energy self-sufficiency through clean energy solutions. This ambitious initiative will help decarbonise India's economy, reduce dependence on fossil fuel imports, and position India as a leader in Green Hydrogen technology and markets, contributing to the global clean energy transition.

To achieve these objectives, the Mission targets a production capacity of at least 5 Million Metric Tonnes (MMT) of Green Hydrogen annually by 2030, with potential growth to 10 MMT per



year as export markets expand. The Mission will encourage the replacement of fossil fuels and feedstocks with renewable alternatives derived from Green Hydrogen. This includes substituting fossil-based hydrogen in ammonia production, petroleum refining, and city gas distribution systems; producing steel with Green Hydrogen, and using Green Hydrogen-based synthetic fuels, such as Green Ammonia and Green Methanol, in sectors like mobility, shipping, and aviation. Furthermore, the Mission aims to position India as a global leader in electrolyser manufacturing and other Green Hydrogen technologies.

Scaling Green Hydrogen Production: Leveraging Renewable Resources and Innovative Technologies

India currently consumes about 5 MMT of Hydrogen annually, primarily sourced from fossil fuels through steam reforming of natural gas and naphtha, referred to as Grey Hydrogen. Some Hydrogen is also produced as a by-product in the chlor-alkali industry or via electrolysis using grid electricity. Recent pilot projects have focused on producing Green Hydrogen through water electrolysis using renewable electricity and biomass through thermochemical and biochemical methods. The National Green Hydrogen Mission aims to scale up these technologies to make Green Hydrogen affordable and widely accessible by reducing costs related to electrolysers, renewable energy inputs, water supply, storage, distribution, and infrastructure.

India's extensive experience in renewable energy, coupled with policy frameworks that reduce solar and wind power costs, will further support the reduction of renewable energy costs for electrolysis-based projects. To meet production goals, the Mission proposes increasing electrolyser capacity, boosting domestic production to reduce imports and enhance global competitiveness.

Additionally, innovative decentralised models, such as rooftop solar and small hydro plants, will be explored for Green Hydrogen production, reducing transportation needs and optimising land and water use. The Mission will also focus on decentralised systems for long-haul mobility, with hydrogen refuelling stations connected to renewable energy plants.

For India's islands, decentralised Green Hydrogen production will support local energy needs and regional development. Infrastructure for storing and delivering Green Hydrogen and its derivatives, including export facilities and pipelines, will be developed, with collaborative projects like Hydrogen Hubs.

Targeted interventions are expected to make Green Hydrogen competitive with Grey Hydrogen in the near future. Finally, biomass-based Green Hydrogen production, with scalable technological pathways such as biomass gasification and biogas reforming, will be a key focus of the Mission, reducing costs through pilot projects and enhanced biomass supply chains.

Phased Implementation: Laying the Foundation for Green Hydrogen Growth and Expansion

Given the emerging nature of the Green Hydrogen sector and its rapidly evolving landscape, the National Green Hydrogen Mission will be implemented in phases. The initial phase will focus on deploying Green Hydrogen in existing hydrogen-oriented sectors while establishing the foundation for R&D, regulations, and pilot projects. The later phase will expand into new sectors, building on the progress of earlier efforts.

PHASE I (2022-23 to 2025-26)

Phase I prioritises creating demand for Green Hydrogen and boosting domestic electrolyser manufacturing capacity. Incentives will be introduced to promote indigenisation and increase Green Hydrogen production and adoption, with a focus on the refinery, fertiliser, and city gas sectors to drive new investments. This phase will also set the

stage for the green transformation of hard-to-abate sectors, with pilot projects in steel production, long-haul mobility, and shipping. Simultaneously, regulations and standards will be developed to support sector growth and align with international norms. The efforts in Phase I will help reduce costs and prepare for wider deployment in Phase II.

PHASE II (2026-27 to 2029-30)

By Phase II, Green Hydrogen is expected to become cost-competitive with fossil fuel alternatives in the refinery and fertiliser sectors, enabling accelerated production growth. Commercial-scale Green Hydrogen projects may be launched in steel, mobility, and shipping, depending on cost evolution and market demand. Pilot projects in sectors like railways and aviation will also be initiated. In Phase II, R&D efforts will be expanded, driving further technological advancements and deeper decarbonisation across all sectors.

Coordinated Efforts: A Multi-Ministry Strategy for NGHM's Success

The success of the National Green Hydrogen Mission will require coordinated efforts across multiple ministries, departments, and institutions at both the central and state levels. The Ministry of New and Renewable Energy (MNRE) to lead the Mission, formulating financial incentives for Green Hydrogen production, utilisation, and export while driving renewable energy and Green Hydrogen capacity deployment, supporting R&D, and fostering international collaborations. The Ministry of Power (MoP) will develop cost-effective renewable energy policies and work with state governments and distribution companies for Green Hydrogen production. The Ministry of Petroleum and Natural Gas (MoPNG) will facilitate the adoption of Green Hydrogen in refineries and city gas distribution, designing new projects to replace fossil fuels.

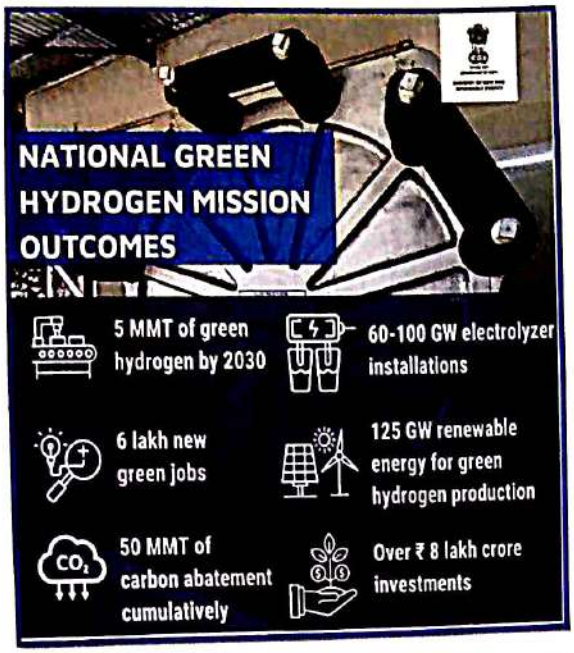
The Ministry of Chemicals and Fertilisers to encourage domestic Green Ammonia-based fertilisers, reducing dependence on imports. The Ministry of Road Transport and Highways (MoRTH) to drive Green Hydrogen adoption in heavy vehicles and long-haul transport, supporting infrastructure and technology development. The Ministry of Steel will focus on Green Hydrogen adoption in steel production, facilitating pilot projects for green steel. The Ministry of Ports, Shipping and Waterways (MoPSW) will establish infrastructure for Green Hydrogen exports, including refuelling facilities for hydrogen-powered ships. The Ministry of Finance will explore financial frameworks to promote Green Hydrogen, while the Ministry of Commerce & Industry will ease business processes and attract investments.

The Ministry of Railways to transition to Green Hydrogen in operations and establish necessary standards. Regulatory standards for the safe scaling of Green Hydrogen projects will be developed by MNRE in collaboration with relevant agencies. Scientific departments, including MNRE and the Office of the Principal Scientific Advisor, will lead R&D efforts, partnering with the private sector. The Ministry of External Affairs (MEA) will facilitate global partnerships to support the Green Hydrogen ecosystem. The Ministry of Skill Development and Entrepreneurship will create skill programs for the sector, while the Ministry of Education will incorporate hydrogen technologies into curricula. State governments will be crucial in implementing policies and infrastructure to support Green Hydrogen projects and manufacturing, positioning themselves as leaders in the sector.

Key Components of NGHM: A Comprehensive Strategy for Implementation

The National Green Hydrogen Mission (NGHM) adopts a comprehensive strategy to drive India's green hydrogen transition, focusing on demand creation, ecosystem development, and policy support. By leveraging its renewable energy potential, India aims to capture 10 per cent of the global green hydrogen market by 2030, with targeted efforts to boost both export and domestic demand. Green hydrogen will replace grey hydrogen in sectors like refining and fertilisers, with annual consumption targets ensuring market growth. Monitoring systems, competitive bidding for procurement and legal frameworks will ensure compliance and cost-effectiveness.

Strategic initiatives such as the Strategic Interventions for Green Hydrogen Transition (SIGHT) will provide financial incentives to scale production and manufacturing of electrolysers. Pilot projects across sectors—steel, transport, and shipping—will accelerate technology adoption, with hydrogen highways, refueling hubs, and green ammonia bunkers supporting large-scale deployment. Green



hydrogen hubs will consolidate infrastructure and promote economies of scale, while policies will streamline land acquisition, facilitate renewable energy integration, and encourage green finance.

A robust regulatory framework will ensure safety, quality, and interoperability, aligning with international standards. R&D programs will drive innovation across production, storage, and application, supported by public-private partnerships. Skill development initiatives will build a specialised workforce, and public awareness campaigns will foster broader adoption. International cooperation will further catalyse growth, positioning India as a global leader in green hydrogen, paving the way for decarbonisation, energy security, and economic growth.

Effective Risk Management Strategies

Achieving the objectives of the National Green Hydrogen Mission requires continuous monitoring and flexibility for adjustments. The Governance Framework will oversee risk identification, classification, and timely action, making necessary policy revisions to manage potential risks. The Mission aims to minimise risks using a combination of financial and non-financial tools, with regular stakeholder consultations ensuring timely mitigation strategies. Key risks and their corresponding mitigation strategies include:

a. **Strategic Risks:** To address potential supply chain disruptions in critical inputs, the Mission will diversify supply chains to ensure stability and continuity in the Green Hydrogen sector.

b. **Technological Risks**: A technology-agnostic funding approach will be adopted to support various R&D initiatives and pilot projects. Collaborations among industry, academia, and startups will foster adaptability to emerging technologies and mitigate potential disruptions.

c. **Operational/Project Risks**: Challenges such as water and land availability, as well as safety concerns, will be managed by optimising production plant locations, encouraging states to create land banks, and enforcing stringent safety standards and regulations.

d. **Financial and Market Risks**: The Mission will address factors such as sustainable demand, affordable renewable energy, electrolyser availability, infrastructure costs, and accessible credit. Key efforts will focus on stimulating demand, planning renewable energy capacity, promoting domestic manufacturing, scaling up infrastructure, and securing funding through risk-sharing frameworks, foreign direct investment (FDI), bond markets, and multilateral financial assistance.

Comprehensive Governance Structure for the successful execution of the National Green Hydrogen Mission

The successful implementation of the National Green Hydrogen Mission requires coordinated efforts across Central and state governments, industry, institutions, and other stakeholders. A flexible, results-driven governance structure will guide the Mission, with an Empowered Group (EG), chaired by the Cabinet Secretary and including senior officials from key Ministries, overseeing activities, monitoring progress, suggesting policy changes, and approving necessary adjustments. Experts from industry and relevant sectors may also be included in the EG.

The EG will manage the overall implementation, propose changes to activities, recommend fiscal, monetary, or regulatory actions, and resolve any issues related to the Mission's provisions. It will ensure the Mission aligns with other Government of India initiatives related to Hydrogen, fostering collaboration and avoiding duplication. Sub-committees of experts may be created to support its functions, with the EG monitoring project performance for scaling potential.

A National Green Hydrogen Advisory Group, chaired by the Principal Scientific Advisor to the GoI, will advise the EG on science and technology aspects. The group will conduct gap analyses, set performance and cost targets, recommend R&D roadmaps, and evaluate proposals for financial support. The Ministry of New and Renewable Energy (MNRE) will serve as the nodal Ministry, overseeing policy formulation and implementation to scale up Green Hydrogen production, with Line Ministries supporting uptake in relevant sectors, guided by the EG. The Mission Secretariat, based in MNRE, will manage day-to-day operations and be led by a Mission Director, who will also serve as the EG Secretary. The Secretariat will handle policy development, including guidelines, incentives, and funding for pilot projects, and monitor sector risks while managing the program's budget.

A National Portal will be established to manage project applications, approvals, fund disbursements, monitoring, and stakeholder engagement, evolving as the Mission progresses. Other Ministries and Departments will implement Green Hydrogen projects in their respective sectors, with dedicated Green Hydrogen cells coordinating efforts under the EG's guidance. Existing institutions such as MoPNG, DST, ISRO, and MoRTH will be leveraged for implementation, testing, standardisation, and R&D activities, optimising resource utilisation.

NGHM: Transformative Economic and Environmental Outcomes

The Mission is expected to drive broad economic benefits by decarbonising key sectors such as industry, mobility, and energy, reducing reliance on imported fossil fuels, fostering domestic manufacturing, generating employment across the Green Hydrogen value chain, and advancing technological innovation in India.

The Mission aims to establish a large-scale Green Hydrogen ecosystem, targeting a production capacity of 5 MMT per year, accompanied by a renewable energy capacity of approximately 125 GW. With growing international partnerships, this capacity could expand to 10 MMT per year.

This ecosystem will generate substantial investments and employment while reducing energy import costs. By 2030, the targeted Green Hydrogen capacity could attract over Rs 8 lakh crore in investments and create over 6 lakh jobs. The Mission will significantly decarbonise key industrial sectors and lay the groundwork for similar transitions in emerging sectors like steel, shipping, energy storage, and long-haul mobility. Green Hydrogen initiatives are expected to avert around 50 MMT of CO_2 emissions annually, contributing to India's energy independence and Net Zero goals.

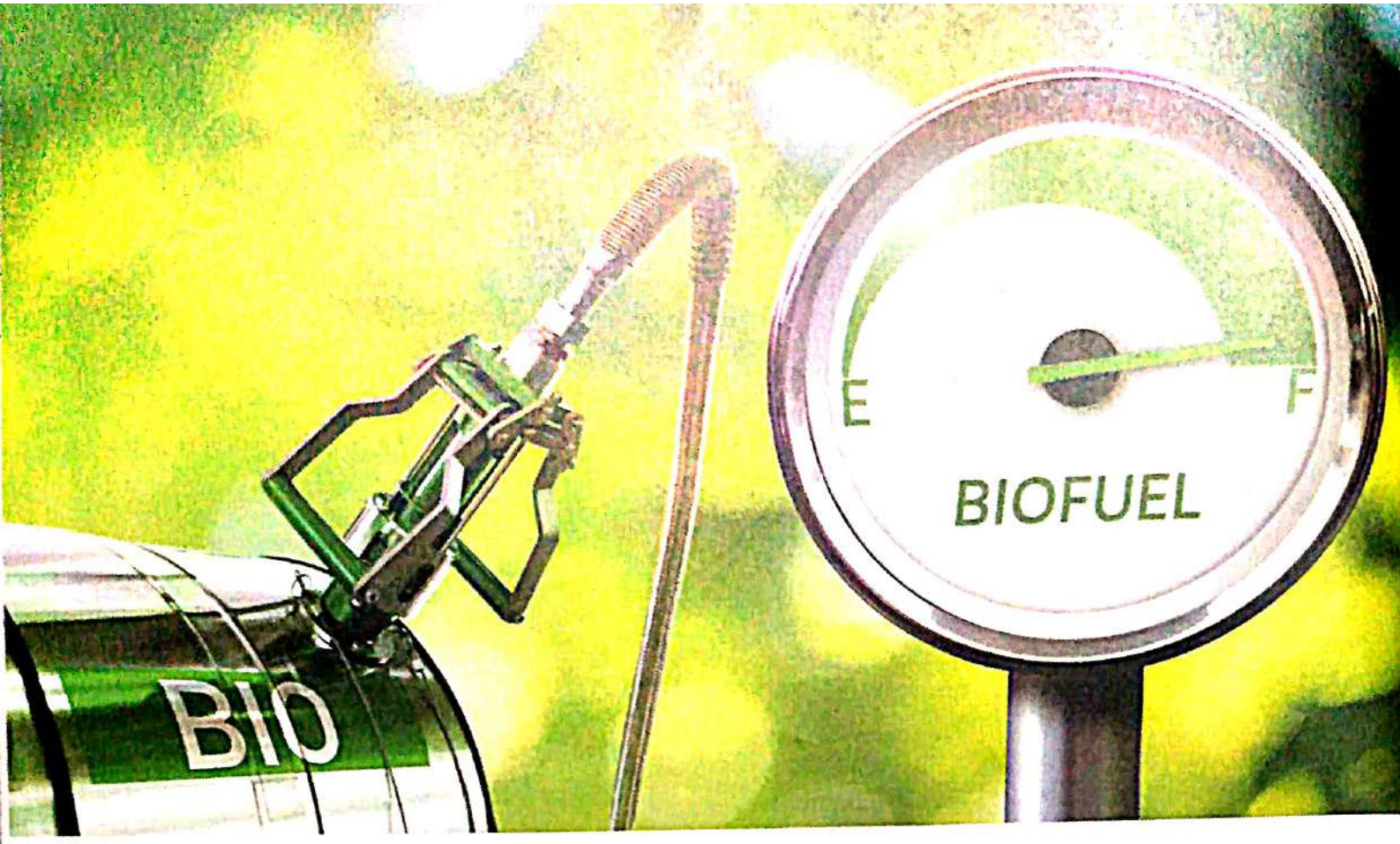
Strategic Financial Outlay to Propel NGHM's Success

Financing for the Mission will require both public and private investment, with government support aimed at de-risking private sector participation. Investments will focus on developing Hydrogen production projects, retrofitting for Green Hydrogen and Green Ammonia use, and supporting associated activities like software, testing, and maintenance. This approach will create a multiplier effect, accelerating Green Hydrogen production, uptake, and exports.

The initial funding for the Mission is Rs 19,744 crore, allocated as Rs 17,490 crore for the SIGHT programme, Rs 1,466 crore for pilot projects, Rs 400 crore for R&D, and Rs 388 crore for other components. MNRE will define implementation guidelines for each component.

Conclusion

Green Hydrogen is a cornerstone of India's strategy for a sustainable energy future, essential for decarbonising hard-to-abate sectors. The National Green Hydrogen Mission is poised to build a robust Green Hydrogen ecosystem that fosters innovation, attracts investment, and drives economic growth. Through government interventions and a phased, collaborative approach, the Mission will accelerate the development of Green Hydrogen technologies, reduce production costs, and create economies of scale. By tapping into India's vast renewable energy potential, the Mission aims to establish the country as a global leader in Green Hydrogen production and export, advancing energy self-sufficiency while mitigating climate change. As the Mission unfolds, it will decarbonise critical sectors, reduce reliance on fossil fuel imports, and generate millions of green jobs, marking a transformative shift towards a Net Zero future. Through this ambitious effort, India is not only advancing its own energy transition but also contributing significantly to the global clean energy revolution. ❑



Biofuels as Promising Substitute for high Carbon Energy Source

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The demand for energy is rising, but fossil fuels are no longer viable. Wind and solar power have become significant in India's renewable energy portfolio. Biofuels, derived from renewable biomass, offer a strategic advantage for sustainable development and energy security. The National Policy on Biofuels (NPB) 2018 aims to augment biofuel generation and build a sustainable ecosystem. Jatropha curcas is identified as a key non-edible feedstock for biodiesel production. Access to affordable and clean energy is essential for health, development, and well-being.

"Nature Runs on Sunlight.

Nature uses only the energy it needs.

Nature fits form to function.

Nature recycles everything.

Nature rewards cooperation.

Nature banks on Diversity.

Nature demands local expertise.

Nature curbs exercises from within.

Nature taps the power of limits."

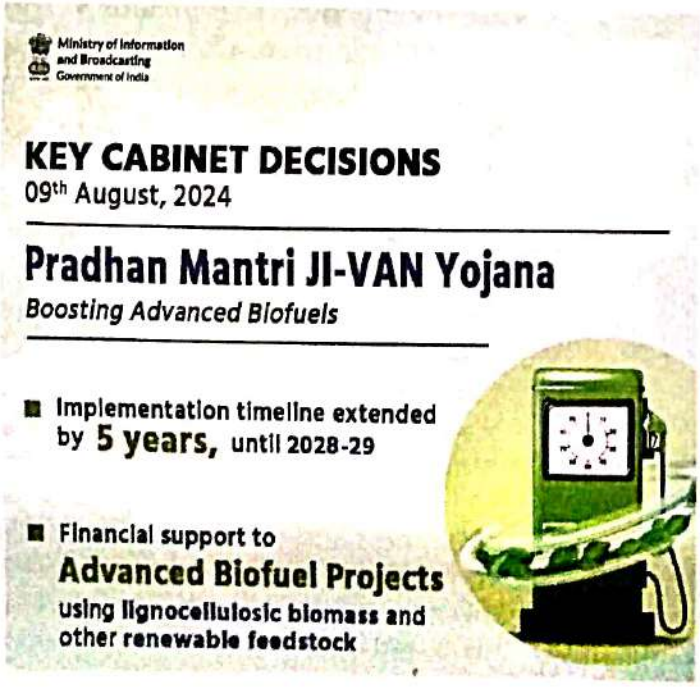
Benyus, J (1997).

The demand for energy is rising, but the supply of the same can no longer be fossil fuels. Wind energy has emerged as a symbol of India's transition to cleaner and more ecologically friendly power generation. Solar power generation has improved rural energy access in India to a large extent in recent decades. The exponential increase in solar installation and its becoming a dominant force in the energy sector has attracted its place as a significant

one in the renewable portfolio of the country.

Rising developmental activities and, at the same time, rising populations attract equally rising energy demands. However, the source of conventional energy that the world depends on presently is causing more harm than good. Hence, alternative sources of energy that help mitigate and adapt to the challenges of climate change, biodiversity loss and pollution are areas that need serious attention. If biodiversity conservation, adapting to climate change, and the control of pollution are the ways for well-being of all the nations and people, alternate energy that departs from the polluting and global warming conventional fuels has to be discarded, and alternatives have to be found out and sustainably exploited and used. Energy plays a necessary role in the economic growth of any country, and the current energy supplies in the world are unsustainable from environmental, economic, and societal standpoints. Nations all over the world have initiated the use of alternative sources of energy so that the energy, livelihood and health are secured besides mitigating the global warming gases like carbon dioxide and methane, etc.

In a large and developing country like India, which is equally vulnerable to energy insecurity, climate change, large population, ill health, and poverty, the demands for energy and the challenges of the supply of the same are becoming enormous. India needs to generate more energy. In this regard, biofuels have emerged as an ideal choice to meet these requirements. Huge investments in research and subsidies for production are the rule in most of the developed countries.



India started its biofuel initiative in 2003. This initiative differs from that of the other nations in its choice of raw material for biofuel production—molasses for bioethanol and nonedible oil for biodiesel. Cyclicality of sugar, molasses, and ethanol production resulted in a fuel ethanol program that suffered from inconsistent production and supply. Availability of molasses, high cost, availability of land, choice of non-native crops, yield, and market price have been major impediments to biodiesel implementation. However, a coherent, consistent, and committed policy with long-term vision can sustain India's biofuel effort. This will provide energy security, economic growth, and prosperity and ensure a higher quality of life for India. Ministry of Petroleum and Natural Gas envisages that the Government of India emphasises realising energy security of the country by reducing import dependence on fossil fuels. The growing concern about the import dependence of fossil fuels in tandem with environmental pollution issues has driven the need for alternative fuels that have superior environmental benefits and are economically competitive with fossil fuels. This has prompted a strategic role for biofuels in the Indian energy basket. Sources of biofuel, such as agriculture and forest residue, Municipal Solid Waste (MSW), cow dung, etc., when properly used, will reduce dependence on imports of crude oil, achieve foreign exchange savings, provide better remuneration for the farmers with a view to double their income, address growing environmental issues owing to the use of fossil fuels and burning of biomass/ waste, address challenges of waste management/agri-residue management in line with the Swachh Bharat Abhiyan, and promote the 'Make in India' campaign.

Besides being a necessity for the developmental activities, household energy is increasingly vital for maintaining good health. Cheap, low-cost and fair household energy is a prerequisite for many of the developing countries, including India. However, unaffordable and inadequate household energy presents adverse consequences that are amplified by poverty and a changing climate. To date, the connections between energy, socioeconomic disadvantage, and well-being are generally underappreciated, and household

energy connection with climate change is under-researched. Availability of a large surplus of biomass and other waste available in the country, energy recovery from these resources is a viable solution in many aspects. Biofuel is unique as it provides several social and environmental benefits apart from providing clean fuels.

Our civilisation is a practical model on fossil fuels. Fossil fuels are necessary for all the activities today, including the food we eat. Finding the alternative of fossil fuels, tapping the hydro-electricals and biomasses will go a long way. Biomass fuels, hydrogen fuels, solar powers and windmills adorning the vehicles, factories, homes and all the institutions will be challenges that demand our attention. Elaborate and extensive damming of the rivers for hydroelectricity shall cause unprecedented environmental and social conflicts. It would again lead into the production of a totally new nature. Wars will be fought not only between the countries but also within the nation itself over the issues of the sites of installing the hydropower potential sites just like the wars that happened on the sites of oil sources. Hence, our surest way to reduce the differences and to allow the coexistence of all of us is to allow the coexistence of different sources of energy alternatives as well as conventional sources and technologies with newer insights and innovations so that the coexistence of them takes care of the sustainable development and inheriting a safe and a secure future. The need for the conservation and maintenance of the diverse sources of energy in our country also arises from the fact that the newer sources and mode of production established and developed in some institutions and regions are not well adapted to the other regions. The sources and mode of production of energy that look good in some places may not work well in some other places. Hence, designing technologies for the diversity and affordability or accessibility is said to be more difficult than sending satellites. The introduction of expensive solar cookers, solar lamps, and hydrogen fuels where there is no infrastructure for repairing is an uphill task. In this respect, biofuels may be more useful.

Till the 18th century the major source of energy was the solar power captured by plant biomass. Though solar energy is the 'mother' of all other forms of renewable energy, the primary source of food energy for all multicellular organisms is biomass. The energy needed to till the land and do the agriculture came from the food consumed by animals or laborers. The energy to make grasses into food came from wood. India, being one of the fastest growing major economies in the world, our development objectives need to be focused on economic growth, equity and human well-being. Renewable energy resources are indigenous, non-polluting and virtually inexhaustible and our country is endowed with abundant renewable energy resources. Hence the use of renewable resources should be promoted and accelerated in all possible ways. Our energy security would be susceptible to all wrongs if alternative fuels are developed and promoted based on indigenously produced renewable feedstock. Biofuels shall surely bring a ray of hope in providing energy security. Availability of a large surplus of biomass and other waste available in the country, energy recovery from these resources is a viable solution in many aspects. Biofuel is unique as it

SOME FACTS ABOUT BIOFUELS

Biofuels	Liquid or gaseous fuels produced from biomass resources and used in place of, or in addition to, diesel, petrol or other fossil fuels for transport, stationary, portable and other applications;
Biomass resources	The biodegradable fraction of products, wastes and residues from agriculture, forestry and related industries as well as the biodegradable fraction of industrial and municipal wastes.
Bio-ethanol	Ethanol produced from biomass such as sugar-containing materials, like sugarcane, sugar beet, sweet sorghum, etc.; starch-containing materials such as corn, cassava, algae, etc.; and cellulosic materials such as bagasse, wood waste, agricultural and forestry residues, etc.
Biodiesel	A methyl or ethyl ester of fatty acids produced from vegetable oils, both edible and non-edible, or animal fat of diesel quality.

provides several social and environmental benefits apart from providing clean fuels.

Alternative fuels, as a substitute to the 'traditional' fuel, are expected to yield significant energy security and environmental benefits to nations. Coined in the late 1980s, biofuels are renewable fuels generally derived from biomass and primarily used for motive, thermal and power generation, with quality specifications in accordance with the International Standards. They are majorly derived from agricultural crops such as corn, soybeans and sugarcane, or from biomass resources such as agricultural, wood, animal and municipal wastes. These are also considered to be the first-generation biofuels. The two most common biofuels used in the transport sector, i.e., ethanol and biodiesel, are ecofriendly and can be used as substitutes for gasoline and diesel or are blended with them so that greenhouse gas emissions can be reduced and thus help in the improvement of ambient air and water quality.

As the biofuels are derived from renewable bio-mass resources and, therefore, provide a strategic advantage to promote sustainable development and to supplement conventional energy sources in meeting the rapidly increasing requirements for transportation fuels associated with high economic growth, as well as in meeting the energy needs of India's vast rural population. Biofuels can increasingly satisfy these energy needs in an environmentally benign and cost-effective manner and help reduce dependence on malignant imports of fossil fuels and thereby provide a higher degree of national energy security. Energy security and environmental concerns have been strongly responsible for the growth of biofuels around the globe. A good number of market mechanisms, incentives, and subsidies have already accelerated this growth by putting an end to the initial inertia. Developing countries are promoting the growth of the biofuels with an additional view that biofuels are the potential means to stimulate rural development and create opportunities for jobs.

Many developed countries pursue aggressive policies for encouraging the production and use of biofuels. There are strong apprehensions that as more and more land is brought under biofuel crops, food prices would increase substantially, affecting poor consumers, particularly those from low-income net food-importing countries. However, the use of the biofuels and the way India is promoting biofuels is different from the current international approaches so that the promotion of biofuels does not lead to food insecurity. In India biofuels are based on non-food feedstock to be raised on degraded or wastelands that are not suited to agriculture. The use of biofuels in India is not new. Jatropha oil has been in use in rural areas for quite a few decades in diesel generators and engines. Jatropha seed oil can be used without refining directly in the diesel engines.

Considering all the options available among nonedible tree-bearing oil (TBO) seeds, Jatropha curcas L. has been identified as the most suitable seed. Seeds from the Jatropha curcas plant are used for the production of bio-fuels, a crucial part of India's plan to attain energy sustainability. Jatropha has the unique potential, provided proper incentives

and directions are formulated and implemented by the stakeholders, including the farmers, scientists and policymakers. The total requirement of the biodiesel in our country is projected today to be very high. With the positive and increasingly successful performance of the domestic automobile industry, which is catching up with the global competitors, the market for biodiesel is emerging. This indicates that the total coverage of the land of our country as of today by the fuel-yielding plants, which stands at 5000 km² is going to be increased and made more efficient and farmer friendly. Having said that, the active participation of local communities and private entrepreneurs can sustain the programme only in the short term. Hence, a good long-term strategy at our disposal must be our priority. Considering the potential of biodiesel production in India, there is an urgent need to undertake research by the public sector and private partners and incentivise the local farmers, restoration practitioners and all the stockholders to achieve a higher yield of feedstock.

Jatropha curcas farming

Some interesting features of Jatropha as a viable option for biofuels are:

1. Jatropha can be grown in arid zones (20 cm rainfall) as well as in higher rainfall zones and even on land with thin soil cover.
2. It is a quick-yielding species and can grow well in degraded landscapes.
3. It can be a good plantation material for eco-restoration in all types of wastelands.
4. It is highly resistant to pests and diseases.
5. It attracts pollinators like honey bees, which in turn will be useful for apiculture and honey production.
6. It can sequester atmospheric carbon and assists in the process of building up total soil carbon.
7. The seed cakes made from jatropha are good manure as they are rich in nitrogen.
8. It adapts easily in low-fertility soil, and alkalinity does not affect it much.

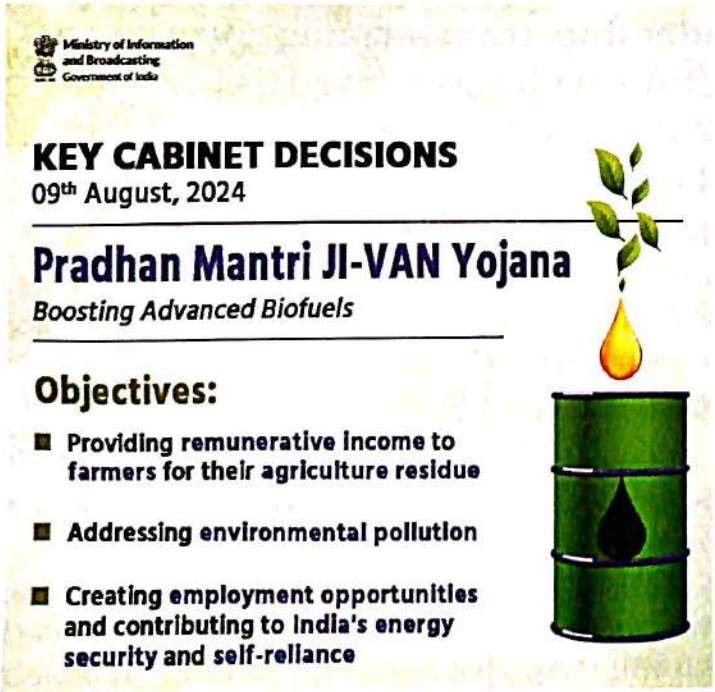
The National Policy on Biofuels (NPB) 2018 was adopted in India to augment the generation of biofuels and to build a sustainable biofuel ecosystem. According to the 'National Biofuel Policy,' the Government of India aims to meet 20 per cent of the country's diesel demand with fuel derived from plants. This will require setting aside 140,000 square kilometres of land—a momentous task and a momentous opportunity. The government presently is implementing an ethanol-blending program and considering initiatives in the form of mandates for biodiesel. Such strategies, accompanied by the rising population and growing energy demand from the transport sector, make the biofuel market a promising field of opportunities. The Biodiesel Blending Programme (BBP) got affected due to a lack of sufficient feedstock coupled with an 18 per cent Goods and Services Tax (GST) effective from 1 July 2017. The policy's objective is to reduce the import of petroleum products by fostering domestic biofuel production. The NPB got amended in 2022 and advanced the deadline to reach the blending target of 20 per cent bioethanol in petrol from 2030 to 2025-26. The amendment also envisages making additional feedstocks eligible for the production of biofuels. The higher funding and incentives will play a good role in catching the potentials of biofuels in India.

Promoting the use and making the public aware of the use and the growth of the biofuels shall surely make the provisions for the lowering of environmental loads. This will indeed be very efficient. The effects of the use of biofuels shall also surely include the reduction in the emission of the harmful greenhouse gases and thereby be helpful in reducing the global warming. Biodiesel, being nontoxic, emits less carbon monoxide and 100 per

cent less sulphur dioxide emissions with no unburnt hydrocarbons; it will be an attractive source of energy for polluted cities.

The planning and the implementation of low-carbon development in the transport sector in the developing countries and the world at large is a paramount task for every government in every country today. In the present globalised world, transportation and the transport sectors play a pivotal role in the macro- as well as microeconomical activities. Transport plays a very important role in the survival of the nations and the continents. From developmental activities to disaster management, transport plays a big role. And at the same time transport and transportation activities require and shall require a major share of the energy produce. Hence developing countries in order to efficiently conduct their activities must rely on low carbon, cheaper, easily accessible and available sources of energy that can be used, exploited, and generated sustainably. The Indian roads and the ports today are becoming great global attractants that attract investments from outside and inside alike.

The prospect of biofuels as a transport alternative fuel is promising. The transport sector occupies one of the largest energy-consuming sectors in every country of the world. A part of this energy demand, if it is supplied by the ecofriendly biofuels, much of the problem of pollution, such as acid rainfall, harmful tropospheric ozone formation, and release of the global-warming gases, shall be reduced.



Challenges of biofuels in the striving to explore further:

1. Intensive research and development to standardise and increase the efficiency of the biofuels.
2. Proper transfer and induction of newer technologies regarding the biofuel production.
3. Mainstreaming the importance, acceptance and adoption of the biofuels.
4. Cooperative work must be promoted between the farmers and growers as institutions, both educational and financial.
5. Sustainable production of the high-quality biofuel feedstocks through intense and active local communities.
6. Proper utilisation of the end products.
7. Special creation of the grants for undergoing research in the locally available resources for the production of the biofuels.
8. Strict maintenance of the achievable high standard and quality. This must be strictly enforced, implemented and audited in a timely manner.
9. Participation from all the states and,
10. Awareness and capacity building must be given a good share of priority, as until and unless people are not aware of the importance and significance the sustainability of the process, project and propagation will not last long.

Human welfare and energy have this obligatory relationship now. And there is no bias in terms of the energy need. We must move or should be intelligent enough to have basic energy as a fundamental right of all of us. To have a clean environment, better sanitation, better health, and a well-secured and well-informed society, the primary requirement has always been easily assessable, affordable and equitably distributed energy. No energy, no food and no health and no development. We need practical and sustainable solutions for the energy demands to be met. Shrinking crude oil, warming globe and increasing energy demands may surely be adapted, provided we seek and promote organic solutions for a systemic resolution of issues. ❑

(The co-author, Abhishek, is a Doctoral student (PhD) in Energy Management at Technische Universität Berlin (TU-Berlin), Berlin, Germany; and the co-author Prof Anjali Priyadarshani is from the Department of Zoology, Kirori Mal College, University of Delhi.)

PRAGATI: Driving India's Development With Purpose

NEW INDIA SAMACHAR RESEARCH TEAM

A recent study titled 'From Gridlock to Growth: How Leadership Drives India's PRAGATI Ecosystem,' explores the remarkable success of the PRAGATI initiative. Launched on 25 March 2015, PRAGATI embodies the 'Minimum Government, Maximum Governance' approach. India's PRAGATI initiative exemplifies Digital-First Leadership, transforming governance aspirations into tangible outcomes. PRAGATI has reviewed 340 stalled projects worth Rs 17.05 lakh crore ($205 billion) since its launch. Prime Minister Narendra Modi's leadership of PRAGATI meetings underscores its importance as a flagship government initiative.

A recent study titled ***'From Gridlock to Growth: How Leadership Drives India's PRAGATI Ecosystem,'*** published by **Oxford University's Saïd Business School** and the **Gates Foundation**, explores the remarkable success of the PRAGATI (Pro-Active Governance and Timely Implementation) initiative.

It asserts that decisive leadership and innovative governance have revolutionised infrastructure delivery in India, setting a global benchmark for developing nations tackling similar challenges.

Background

Launched on **25 March 2015**, PRAGATI embodies the '**Minimum Government, Maximum Governance**' approach.

The program champions **collaboration**, **transparency**, and **technology** to fast-track India's growth story while ensuring excellence in project

management.

Enhanced efficiency via PRAGATI reinforces the RBI and NIPFP's research findings that **every rupee spent on infrastructure generates a 2.5-3.5 rupee GDP gain, showcasing its transformative impact.**

India's PRAGATI initiative exemplifies Digital-First Leadership, transforming governance aspirations into tangible outcomes by integrating multiple platforms like *PARIVESH*, *PM Gati Shakti*, and the Project Management Group (PMG).

The learnings from the SWAGAT (State-Wide Attention on Grievances by Application of Technology) initiative, known for real-time citizen-centric grievance resolution (launched in 2003), have evolved into PRAGATI's broader focus on nation-building, setting precedence for accountability and transparency.

Key Achievements of PRAGATI

1. **Unblocking Progress:** PRAGATI has reviewed **340 stalled projects worth Rs 17.05 lakh crore ($205 billion)** since its launch nine years ago till June 2023.
2. **Delays Minimised:** Structured monthly reviews and advanced digital tools under PRAGATI have drastically reduced project timelines, **transforming delays of 3 to 20 years into completion within months.**
3. **Environmental Approvals** take just **70-75 days** instead of 600
4. Central approvals for forest clearances plummet to **20-29 days from 300 earlier**.
5. **Effectiveness of CPGRAMS:** average resolution time cut to 20 days by 2023, from 32 days in 2014.
6. **Systematic Improvements:** average issuance time for passports was cut **to 7 days in 2023, from 16 days in 2014.**

Striking Outcomes Witnessed Under PRAGATI For The Following Projects

- **Bogibeel Rail and Road Bridge:** Completed in 3 years after over ***two decades of*** **delays.**
- **Jammu-Srinagar Baramulla Rail Link:** On track for completion by 2025, overcoming years of stagnation.
- **Navi Mumbai Airport:** Resolving **15+ years** of land acquisition hurdles, set for launch by December 2024.
- **Bengaluru Metro Rail, Karnataka:** Timely review expedited land acquisition for Phase 1, enabling the 42 km, 40-station metro to transform urban mobility and improve air quality since 2017.
- **Haridaspur-Paradeep Rail Connection, Odisha:** Resolved funding and investor-contractor deadlocks **by granting the Ministry of Shipping equity,** expediting land acquisitions, clearances, and coordination, leading to the rail line's inauguration in 2020.
- **Dahisar-Surat Section, National Highway 8, Maharashtra & Gujarat:** By 2014, a project that was stalled started witnessing significant progress after 2017 PRAGATI's review, allowing the service road to be built with safeguards for wildlife and compensation agreements for landowners.
- **Varanasi-Aurangabad Section, National Highway 2, UP & Bihar:** only 20% of the road widening was completed in the initial five years due to antiquated land records challenges. The projects found a better pace and progress after the PRAGATI review. The project is now set for completion later this year.
- ***Jal Jeevan Mission*:** tap water access for rural HHs increased from 17% in 2019 to 74% in Feb 2024.

National Leadership In Action

Prime Minister Narendra Modi's leadership of PRAGATI meetings underscores its importance as a flagship government initiative. He ensured swift course corrections and effective governance.

Such foresight has ensured that ***PRAGATI went beyond infrastructure development; it drives social upliftment and fosters sustainable innovation, benefiting all stakeholders across the length and breadth*** of the nation.

PM, with his impeccable reputation for effective governance, drives policies into actionable results by assigning senior officials to ground sites to get real-time updates.

Another example of effective governance can be seen in his directive to provide mobile towers

in all uncovered villages within a financial year, accelerating connectivity in remote areas.

It has revolutionised India's bureaucracy, supporting it to realise its full potential and shifting from a system of delays and inefficiency to one of transparency, real-time communication, and rapid execution.

It becomes a powerful example of cooperative federalism, where the Central and state governments work together for shared goals, overcoming political differences.

PRAGATI: The Influencer For Other Government Schemes

The outstanding success of PRAGATI also accelerated technology usage in many other crucial flagship schemes, which enabled the nation to reap better outcomes for the budget allocated.

These include:

- ***The Swachh Bharat Mission:*** *12 crore toilets and WoW villages excel in rural sanitation.*
- ***The Jal Jeevan Mission:*** *tap water access for rural HHs increased from 17% in 2019 to 74% in Feb 2024.*
- **The Saubhagya Scheme:** attained universal electrification
- **The Vibrant Villages Programme (VVP):** 46 Northeast villages transformed into India's *'First Villages'*.
- **MoHUA's Light House Projects:** innovation with digitised tech—1,100 houses built in 12 months in a single city, with projects active in six cities nationwide.
- **The *SVAMITVA* initiative: drone** tech-enabled legal land ownership records render security to rural residents.

Why It's a Global Benchmark for Governance?

As a beacon of the new era of governance in India, this platform has broken the glass ceiling of government accountability and reshaped outdated perceptions of pre-2014 bureaucracy.

It has fostered a culture of transparency and responsiveness across the government machinery.

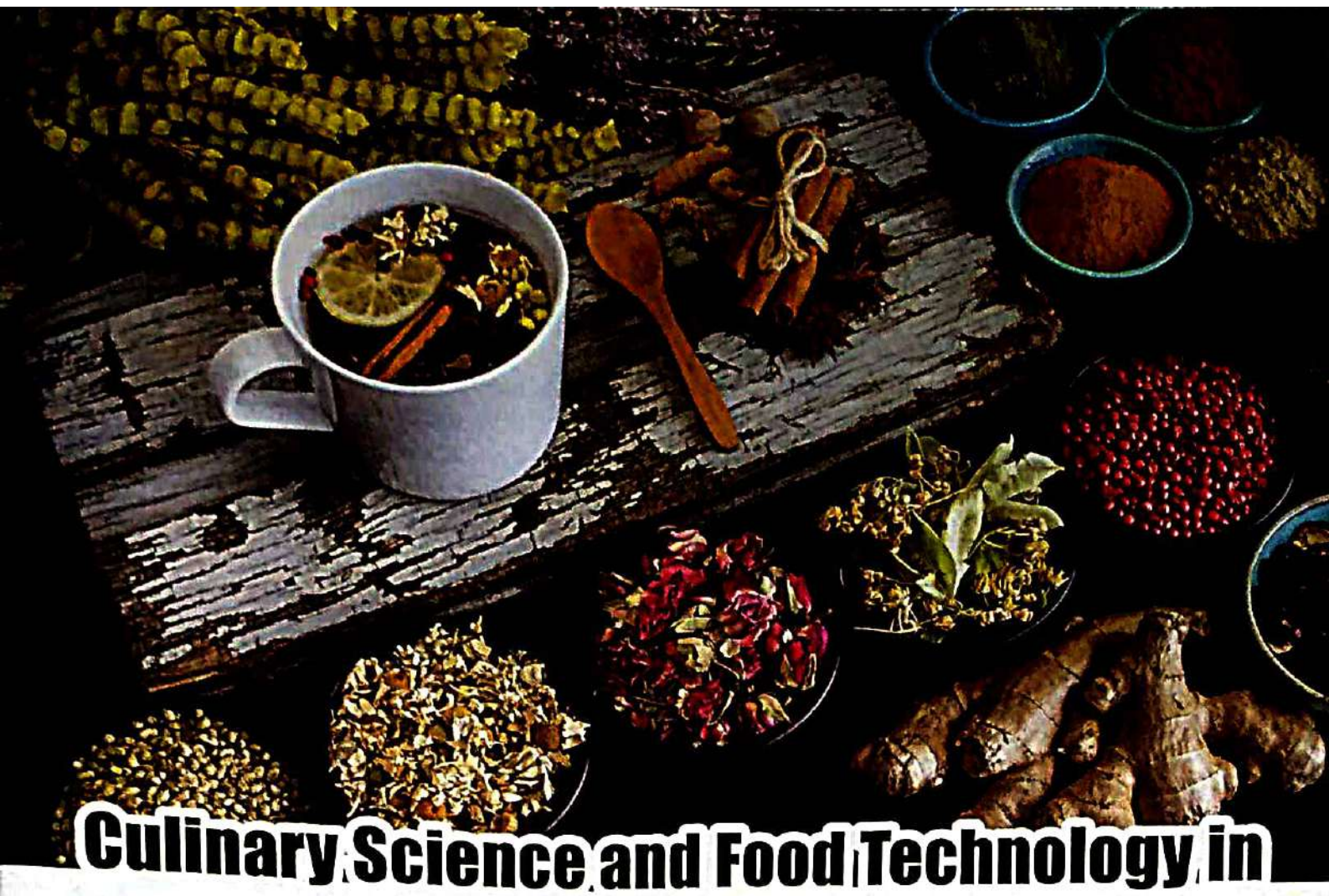
For instance, the Oxford report identifies that tech-driven transparency through drone feeds and GPS tracking delivers real-time data that facilitates quick decision-making, allowing officials to address issues proactively.

Digital dashboard usage across projects of diverse sectors such as roads, power, railways, and aviation demonstrates how integrated technology can enhance project oversight.

By combating corruption, PRAGATI cuts through red tape and reduces opportunities for misuse, ensuring that resources are allocated efficiently.

Public inputs that were crucial were fed back via a robust feedback loop that shapes high-level decision-making, enabling citizens to influence governance directly and ensuring that their needs are addressed in policy formulation.

Overall, undoubtedly, it can be inferred that digital tools and the steadfast resolve of decisive leadership are essential preconditions for impactful change, as exemplified by India's PRAGATI initiative. ❑



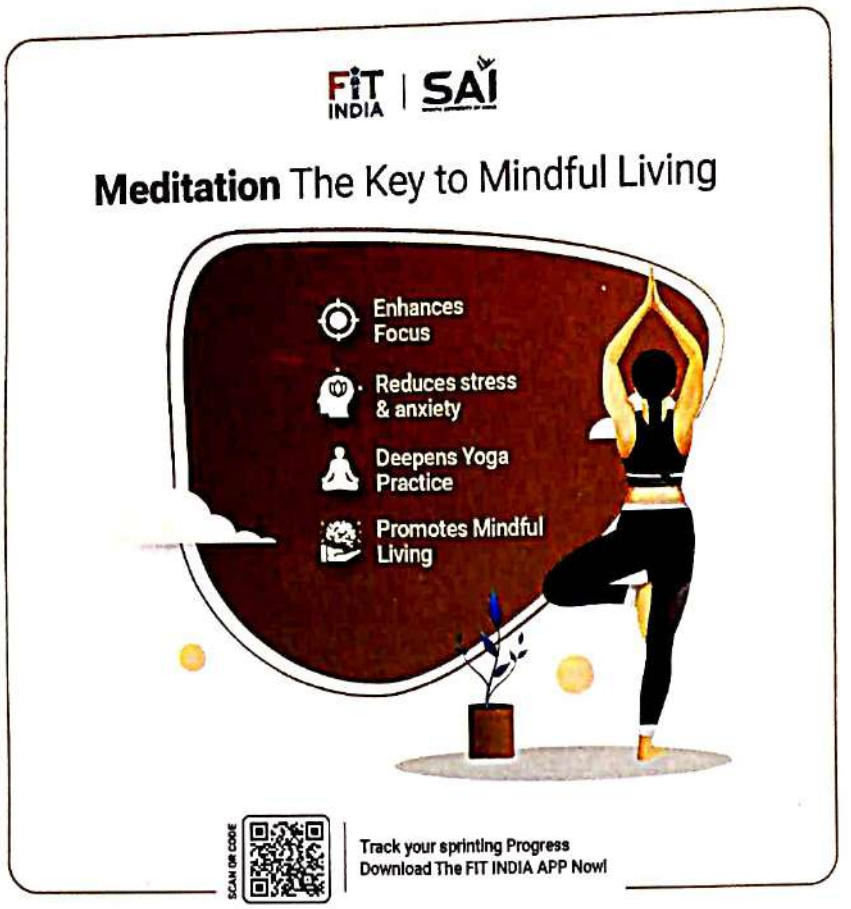
Culinary Science and Food Technology in Ancient India: Insights from Pākaśāstra

PROF K SURYANARAYANA | The author is the Director, Department of Research and Publications, National Sanskrit University, Tirupati, Andhra Pradesh. Email: suryakorada@nsktu.org

This article explores the rich tradition of *Pākaśāstra*, highlighting its socio-cultural, medicinal, religious, and spiritual dimensions. It delves into the overlap of food discourses in Hindu life, the significance of dietetics and culinary art, and the impact of cooking utensils and plant-based leaves on health. The study emphasises the importance of pure and regulated eating habits, as mentioned in ancient texts like the *Srimad Bhagavad Gita* and *Caraka Samhita*. Modern research corroborates these traditional concepts, underscoring the need for further exploration of *Pākaśāstra* to understand its relevance today.

In Indian tradition, food is considered medicine, and the way food is prepared, combined, and consumed is believed to have a profound effect on one's physical and mental health. The *Kasyapasamhita* says:

सर्वभूतानामाहारः स्थितिकारणम्।
न त्वाहाराद्दतेऽस्त्यन्यत् प्राणिनां प्राणधारणम्॥
न चाहारसमंकिञ्चिद्भैषज्यमुपलभ्यते।
शक्यतेऽप्यन्नमात्रेण नरः कर्तुं निरामयः॥
भेषजेनोपपन्नोऽपि निराहारो न शक्यते।
तस्माद्भिषग्भिराहारो महाभैषज्यमुच्य॥



"Sustenance of living beings is dependent on food. There is nothing other than food that supports the life of living beings. There is no medicine that is comparable to food. It is possible to free a man of ailments solely through diet. On the contrary, one cannot free a man of ailments even through medication if diet is ignored. It is therefore rightly said by physicians that food is the greatest medicine."

Three food discourses overlap within a Hindu's life: ontological and experiential concerned with the cultural sphere and worldly life, therapeutic, connected with the sphere of healing and happiness and transcending the first two, aiming for self-control and salvation.

The Sanskrit sources of ancient India indicate eminent contributions in the field of dietetics (*Pathyāpathyanirṇaya*) and in the science and art of cooking (*Pākaśāstra* and *Pākakalā*). Culinary art can be defined as the art of cooking. This art, supplemented with a strong foundation of the science of dietetics, makes the Indian tradition of cooking more systematic. Thus dietetics and culinary art bear certain areas in common. Dietetics (*Pathyāpathyanirṇaya*) is defined as the application of the science of nutrition to the human being in health and disease.

There are published texts and many manuscripts are available that deal with culinary science and dietetics in ancient India.

Though *Pākaśāstra* is not one of the *aṣṭāṅga* (eight branches) of Ayurvedic system of medicine as described in the *Carakasamhita*, however, it is supported by the Ayurvedic theories and concepts. The Ayurvedic approach to health and disease is threefold: drug, diet, and lifestyle (*aushada, ahara* and *vihara*). The diet has a 1/3rd role in managing disease and maintaining health. Hence, dietary descriptions are spread all through the clinical branches of Ayurveda. Thus, food being an important subject for both Ayurveda and *Pākaśāstra*, it is natural that ideas and concepts from *Pākaśāstra* are found in Ayurvedic works and vice versa. Cakrapanidatta, in his *Ayurvedadipika*, a commentary on *Caraka Samhita*, quotes many verses from Nala's *Pākadarpaṇa*, an independent work on *Pākaśāstra*.

In this article, some important culinary points on this less explored Sanskrit studies are briefly presented. These include text sources of *Pākasāstra*, types of food, food classification, the effects of serving cooked food on various (plant-based) leaves, the impact of food on body and mind, etc.

Text sources of *Pākaśāstra*

Below are mentioned some published works and manuscripts on Culinary science:

पाकदर्पणः, प्रयोगपारिजातः, क्षेमकुतूहलम्, भोजनकुतूहलम्, वैद्यकशब्दसिन्धुः, हृदयदीपः, व्यञ्जनवर्गः, पाकाधिकारः, तक्रविधिः, भीमभोजनकुतूहलम्, रुचिवधूगलरत्नमाला, ताम्बूलकल्पसङ्ग्रहः, पाकाधिकरणः, वस्तुगुणागुणः, पाकावलिः, अन्नपानविधिः, तक्रपानविधिः।

The following encyclopaedic works also contain chapters on culinary art :

- अर्थशास्त्र
- मानसोल्लास
- शुक्रनीति
- शिवतत्वरत्नाकर

(other sources of *Pākaśāstra* are mentioned at the end of the article.)

Types of food

Below are some of the important foods that are listed in ancient texts related to culinary science.

- Grains (*dhānyāḥ* - धान्याः)
- Vegetables (*śākāḥ* - शाकाः)
- Spices (*elādayaḥ* - एलादयः)
- Milk and milk products (*kṣīraprakaraṇam* - क्षीरप्रकरणम्)
- Oils (*tailaprakaraṇam* - तैलप्रकरणम्)
- Sugarcane and its products (*ikṣuprakaraṇam* - इक्षुप्रकरणम्)
- Honey (*madhu/mākṣika* – मधु- माक्षिक)
- Liquors (*madyam*- मद्यम्)
- Meat (*māmsam* - मांसम्)
- Water (*jalam* - जलम्)
- Fruits

Though the details related to above-listed foods are not in this article's scope, it is hereby being impressed upon the readers the wisdom of our ancestors, for example, in identifying eight varieties of honey as mentioned:

माक्षिकं भ्रामरं क्षौद्रं पौतिकं छात्रलं तथा।

आर्घ्यमौद्दालकं दालमित्यष्टौ मधुजातयः ॥

mākṣika, bhrāmara, kṣaudra, pautika, chātraka, ārghya, auddālaka and dāla. Of these, *mākṣika* is defined as :

नानापुष्परसाहाराः कपिला नवमक्षिकाः।

याः स्थूलास्ताभिरुत्पन्नं मधु माक्षिकमुच्यते ॥

The honey that is secreted by young, large bees that are tawny in colour and collect nectar from different flowers is called *mākṣika.*

The qualities of a good cook

It is clearly mentioned in the verses below from *Kshemakutuhalam*, the qualities of a good

Dining Vessels and their Effect

Vessels used for food	Dietetic effects
Haima (utensil made of gold)	alleviates aggravation of all doṣa and improves sight *pathya, doṣahṛt* and *dṛṣṭikṛt*
Raupya (utensil made of silver)	*cākṣuṣya* (improves sight) and *pittahṛt* and *kaphavātahṛt* (alleviates aggravation of all three *doṣa*)
Kāmsya (utensils made of bell-metal)	*buddhiprada* (sharpen intellect), *rucya* (improves appetite) and *raktapittaprasādana* (clears the blood and bile).
Paittala (utensil made of brass)	*vātakṛt* (aggravates vāta), *rūkṣa* (astrigent), *uṣṇa* (hot), *kṛmikaphapraṇut* (destroys worms and alleviates aggravation of *kapha*).
āyasa and *kācapātra* (utensil made of iron and glass)	*balya* (imparts strength) and *śothapāṇḍuharaṃ* (treats swelling and jaundice).
Mṛnmaya (earthen vessel)	*śrīnivāraṇam* (removes affluence)
Dārūdbhava (wooden vessel)	*rucida* (improves appetite) and *śleṣmakārī* (aggravates *kapha*)
Sphaṭika (crystal) and vaidurya vessels	*pavitra* (pure) and *śitalaṃ* (cooling)

cook in cleanly preparing tasty dishes and it is astonishing to know how scientific the ancient cooks were -

पितृपैतामहो दक्षः शास्त्रज्ञो मिष्टपाचकः ।

शैचयुक्तोऽथ भक्ता सूपकारः स शस्यते ॥४७॥

A cook who has inherited his profession from his father and his grandfather, adept in his job, well-versed in his science, capable of preparing savoury dishes, clean and faithful is fit for praise.

सूदकारपतिस्तत्र प्रायो वैद्यगुणान्वितः ।

तत्रत्यजनतत्त्वज्ञस्तत्प्रशासनतत्परः ॥५०॥

Regarding the chef, it is mentioned that he should possess the qualities of a physician. He should be aware of the nature of the men working there (in the kitchen) and able to direct them.

Food in relation to modes of existence (*Gunas*)

The *Srimad Bhagavad Gita* mentions three types of food, namely *sattvic*, *rajasik* and *tamasik* foods.

आयुःसत्त्वबलारोग्यसुखप्रीतिविवर्धनाः ।

रस्याः स्निग्धाः स्थिरा हृद्या आहाराः सात्त्विकप्रियाः ॥17.8 ॥

The foods that increase life, purity, strength, health, joy and cheerfulness (good appetite), which are savoury and oleaginous, substantial and agreeable, are dear to the *Sattvic* (pure) people.

कट्वम्ललवणात्युष्णतीक्ष्णरूक्षविदाहिनः ।

आहारा राजसस्येष्टा दुःखशोकामयप्रदाः ॥17.9 ॥

The foods that are bitter, sour, saline, excessively hot, pungent, dry and burning are liked by the *Rajasic* and are productive of pain, grief and disease.

यातयामं गतरसं पूति पर्युषितं च यत् ।

उच्छिष्टमपि चामेध्यं भोजनं तामसप्रियम् ॥17.10 ॥

That which is stale, tasteless, putrid, rotten, refuse and impure, is the food liked by the *Tamasic*.

The theme of food is used as a metaphor for any worldly temptation binding the self to the *samsara* but also represents the means to restrain one's own appetites and advance spiritually and ethically towards liberation.

Utensils used for cooking

Different metallic vessels used for cooking are described in the culinary texts. The vessels are made of gold (*haima*), silver (*raupya*), bell-metal (*kāmsya*), brass (*paittala*) and iron (*āyasa*) and their dietetic effects are also described. Apart from these, the author mentions the vessels made of glass (*kācapātra*), earthen vessel (*mrnmayapātra*), wooden vessel (*dārūdbhava*), crystal (*sphatika*) and *vaiḍurya* also.

दोषहृत् दृष्टिकृत् पथ्यं हैमं भोजनभाजनम्/

रौप्यं भवति चाक्षुष्यं पित्तहृत् कफवातहृत् ॥

काम्स्यं बुद्धिप्रदं रुच्यं रक्तपित्तप्रसादनम्/

पैत्तलं वातकृद्रूक्षम् उष्णम् कृमिकफप्रणुत् ॥

आयसे काचपात्रे च भोजनं सिद्धिकारकम्/

शोथपाण्डुहरं बाल्यं कामलापहम् उत्तमम् ॥

शैलजे मृन्मये पात्रे भोजनं श्रीनिवारणम्/

दारूद्भवे विशेषेणरुचिदं श्लेष्मकारी च ॥

Leaf Types (for serving food)	Dietetic effects
Ramabhāpatra (plantain leaf)	*hṛdya, rucya, vṛṣya* and *balāgnida* (pleasant, improves appetite, aphrodisiac, strengthens body and stimulates the digestive fire)
Palāśapatra (butea frondosa)	*kaphavātaṃpīnasaghna, rucya and bṛmhaṇa* (alleviates phlegm and *vāta*, cures *pīnasa*, improves taste and promotes health).
Hastikarṇipatra(coral tree leaf)	*kṣāra, pathya, usna and katuka*(acidic, hot and pungent in taste).*kaphaghnam* (alleviates *kapha*), *jvaraśātanam* (treats fever)
arkapatra (madder plant leaf)	*krmighna* and *pittakṛt* (kills worms and aggravates bile)
erandapatra (castoroil plant leaf)	*hanyat paramacākṣusyam* (greatly beneficial for the eyes) *laghu dipanapacanam* (light and stimulates the digestive fire). *vataghna, krmighna* and *pittakṛt* (alleviates vāta, kills worms and aggravates bile)
Kṣiravṛkṣapatra (peepal tree leaf)	*tṛṣṇā dāhāsrapittanut* (removes thirst, burning sensation and bleeding disorders)
Pāṭalapatra	*pāṇḍuśothaśvāsasomarogaghnam* (cures jaundice, inflammatory swelling, dyspnoea and polyuria)
Ketakipatra (screw pine leaf)	*manohara, rucikara, laghu* and *cakṣusya* (pleasing, tasty, light and beneficial to the eyes)
kumudapatra, raktotpalapatra and *utpala patra* (white water- lilly leaf, red lotus leaf and blue lotus leaf)	*nindita, śīta, rūkṣa*, (scorned, cool, pungent) *vrsya, klamahara* and *yātrārthināṃ abhihita* (aphrodisiac, removes weariness and suitable for travellers)

पवित्रं शितलं पात्रघटितं स्फटिकेन यत्/
काचेन रचितं तद्वत्तथा वैडुर्यसम्भवम्॥

The author also denotes that a vessel for storing water must be made of copper. In its absence, an earthen vessel is preferable—

जलपात्रम् तु ताम्रस्य तद् अभावे मृदो हितम्॥

Research on the use of different cooking utensils and their effect on health has been a subject of experimental study in recent times. eg. "*Study of Elements Released from various Cooking Utensils after heating on Cooking Utensisl of Aluminum, Stainless Steel, Titanium-coated Stainless Steel and Teflon and their Potential Health Hazards*" by Manogari Sianturi et al. The paper mentions that Metals in food have a dual function because they are essential nutritional elements but can also be toxic when present at high concentrations. The majority of metals have a significant effect on human health. Various metals such as copper, iron, manganese, zinc, calcium, magnesium, potassium and sodium are essential elements. Although small levels of some metals are very important for vital functions in the human body, excessive intake of these metals can cause health problems. The paper makes an in-depth study of the vessels made of select metals and their impact on health.

Impact of Serving cooked food on plant-based leaves

रम्भापत्रेऽशनम् हृद्यं रुच्यं वृष्यं बलाग्निदम्।
विषश्रमानिलाम्रेषु हितं पाण्डौ न शस्यते॥

पालाशपत्ले च मरुत्-श्लेष्मगुल्मोदरप्रणुत्।

कफवातम्पीनसघ्नं रुच्यं श्रेष्ठं च बृम्हणम्॥

क्षारोष्णकटुकं जन्तु कफघ्नं ज्वरशातनम्।

शितिताज्वरहृत् पथ्यं हस्तिकर्ण्या तु भोजनम्॥

अर्कपत्ले भृशं रुक्षं कृमिघ्नम् पित्तकृत् परम्।

गुल्मशूलविषश्वासपाण्डुकुष्ठकफानिलान्॥

हन्यात् परमचाक्षुष्यं लघु दीपनपाचनम्।

एरण्डपत्लं वातघ्नं क्रिमिघ्नं पित्तकृत्परम्॥

पत्लेषु क्षीरवृक्षाणां तृष्णादाहास्रपित्तनुत्।

पाण्डुशोथश्वाससोमरोगघ्नं पाटलाशनम्॥

सर्वग्रन्थिविनाशाय केतकीपत्लभोजनम्।

मनोहरं रुचिकरं चक्षुष्यं भोजनं

यात्रार्थिनामभिहितं वृष्यं क्लमहरं परम्।

नलिने कुमुदे रक्तोत्पले वाथोत्पले दले॥

भोजनं निन्दितं शीतं रुक्षं दौर्भाग्यमग्निनुत्।

Ill-effects of improperly cooked food

It has been shown that there are eight imperfections (अन्नेऽष्टदोषाणां सम्भवः) in cooked rice if not cooked according to the rules:

जीवनं जीविनामन्नमृतूक्तं विधिपाचितम्।

तदेवाविधिना भुक्तं परिणामे विषोपमम्॥५१॥

Food is the life of living beings if eaten as per seasonal rules and if cooked according to rules. If eaten contrary to rules, it turns out to be poison-like.

विद्यते ह्यष्टदोषो हि प्रत्यक्षेण प्रमादतः।

के ते दोषाः सदाविष्टाः प्रत्यक्षेण बलीयसा॥४१॥

ये ते तदाश्रिताः दोषा असृतः पिच्छिलोऽशुचिः॥४२॥

क्वथितः शुष्कतो दग्धो विरूपो नर्त्तुजस्तथा॥४३॥

The imperfections of cooked rice are; *asrta* (soured due to non-separation of starch); *picchila* (sticky), *asuci* (uncleaned), *kvathita* (boiled much more), *śuska* (lessened liquidity), *dagdha* (overcooked), *virūpa* (discoloured), *anartuja* (occurred in against the season).

असृतान्न लक्षणं तद्दोषश्च अस्स्रावितयवागुं यदन्नमसृतमुच्यते।

तदन्नं येन भुक्तं चेत् तस्य व्याधिकरं भवेत्॥४८॥

"The food, whose starch is not expelled out, becomes, sour and is called *asṛta-anna* (unpoured off superfluous water), whosoever eats such type of food, suffers from diseases".

Impact of food upon body and mind

Food can impact human mind and personality immensely. This is clearly mentioned in the *Upanishads* and *Srimad Bhagavad Gita*.

आहारशुद्धौ सत्त्वशुद्धिः सत्त्वशुद्धौ ध्रुवा स्मृतिः।

स्मृतिलाभे सर्वग्रन्थीनां विप्रमोक्षः।

If one eats pure food, one's mind becomes pure. Purity of mind results in perseverance of memory. Perseverance of memory leads to higher level of consciousness, resulting in freedom from bondages.

युक्ताहारविहारस्य युक्तचेष्टस्य कर्मसु।

युक्तस्वप्नावबोधस्य योगो भवति दुःखहा॥ (Bg 6.17)

He who is regulated in his habits of eating, sleeping, recreation and work can mitigate all material pains by practicing the yoga system.

In *Caraka Samhita* it is strikingly mentioned that a person can be free of diseases by eating limited quantities of healthy food.

कोऽरुक् ! कोऽरुक! कोऽरुक्! मितभुक्, हितभुक्, ऋतभुक्! सोऽरुक्, सोऽरुक्, सोऽरुक्।

Who is free of disease? He who eats minimal, healthy and well earned, he is free of disease

Conclusion

This brief survey of *Pākaśāstra* highlighting some important aspects of culinary science includes the socio-cultural, medicinal, religious and spiritual dimensions of food in Indian tradition. Further, it is necessary that the concepts and ideas mentioned in the traditional texts, such as impact of utensils for cooking and serving cooked foods on plant-based leaves are corroborated with modern experimental methods to authenticate the information.

In conclusion, it is necessary to perform a detailed research on this less-explored area of Sanskrit studies '*Pākaśāstra*' to gain an understanding of its relevance in present times. Further, linguistic archaeology must be studied in depth to understand further, on the history of food. □