Achieving 500 GW of renewable energy capacity by 2030

An industry perspective

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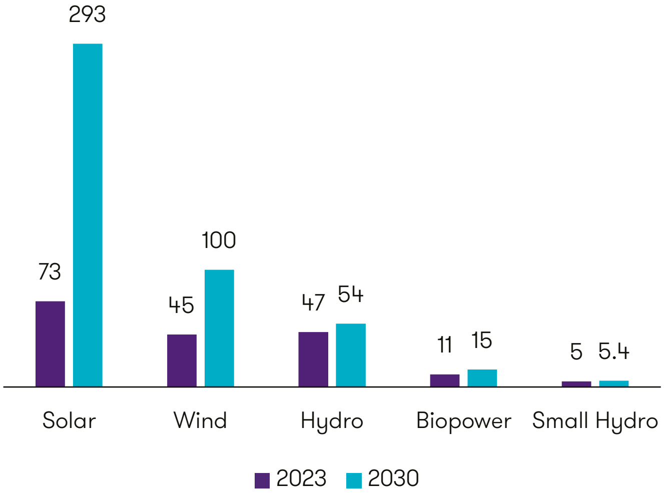
Executive summary

India is the world's third largest carbon emitter[1] and has committed to a monumental journey towards achieving net zero emissions by 2070. Since the Paris Agreement in 2015, India has made significant strides in reducing emissions intensity by 33-35% by 2030[2]. The country has set an enhanced target at the COP26 of 500 GW of non-fossil fuel-based energy by 2030[3]. This has been a key pledge under the Panchamrit. As of December 2023, India ranks 4th globally for the total renewable power capacity additions[4] with combined installed renewable energy capacity of ~180 GW[5]. With the aim of achieving a 500 GW capacity by 2030, it is anticipated that renewables will make up approximately 50% of the total installed capacity. Solar and wind power are leading the way, while coal energy production has seen more modest growth. The chart below illustrates the projected growth of renewable energy sources by 2030[6].

RE Installed capacity in FY 2023 vs Projected in FY 2030



The Ministry of Power released the National Electricity Plan (NEP) for the period 2022-32, which predicts the peak electricity demand and energy requirement in India. The NEP expects the share of non-fossil-based capacity to increase to 57.4% by 2026-27 and potentially rise further to 68.4% by 2031-32. In pursuit of this ambitious objective, the government has introduced a myriad of key policies encompassing support for the creation of ultra-mega and mega solar parks, the implementation of a carbon credit trading scheme, renewable purchase obligations (RPOs), renewable generation obligations (RGOs), production linked incentive (PLI) schemes, and Green Energy Corridor, among others.

Aligned with a strong focus on green energy and the integration of renewable sources, the government is actively reinforcing the transmission network to fulfill the 'Power for All' initiative. Ongoing state-led transmission schemes aim to seamlessly incorporate renewable energy generation, projecting a 4% CAGR expansion of the Indian transmission network from 2023 to 2028, requiring an investment of over ~INR 1,78,500 crore. Concurrently, the government is prioritising digital technologies such as advanced metering infrastructure and distribution automation to enhance operational efficiency. Meeting India's ambitious wind and solar capacity goals necessitates a substantial investment of USD 223 billion between 2022 and 2029, alongside an extra USD26 billion for battery storage projects.

1. www.weforum.org/agenda/2023/01/india-holds-the-key-to-hitting-global-climate-change-targets-here-s-why/
2. pib.gov.in/PressReleaseIframePage.aspx?PRID=1847812#:~:text=The%202015%20NDC%20comprised%20eight,of%202.5%20to%203%20billion
3. pib.gov.in/PressReleasePage.aspx?PRID=1881484
4. www.investindia.gov.in/sector/renewable-energy
5. mnre.gov.in/physical-progress/
6. cea.nic.in/wp-content/uploads/irp/2023/05/Optimal_mix_report__2029_30_Version_2.0__For_Uploading.pdf

USD 633bn

Investment opportunity in RE till FY 2030

USD 100bn

Energy efficient investment potential by FY 2030

USD 224bn

Thermal, T&D expansion modernisation by FY 2030

The private sector is taking a leading role in India's energy transition, particularly in renewable power generation, energy storage, green hydrogen, and electric mobility. Major private sector power producers have set ambitious renewable energy targets and investments. The government has awarded a 6 GW capacity for solar PV manufacturing to three private sector companies, encouraging local manufacturing. Private players have also announced significant battery manufacturing capacity, and the private sector is dominating government auctions for green hydrogen and electrolyzers. Private sector-led manufacturing is crucial for India's renewable energy goals and sustainable future.

Several emerging technologies, including offshore wind, biofuels, agri photovoltaics (AgriPV), and floating solar, are gaining prominence as strategies to augment the share of renewable energy in the overall energy mix, showcasing immense potential with ambitious targets and innovative solutions.

The offshore wind sector aims to harness the power of the seas. The Indian government has introduced the National Offshore Wind Energy Policy, which includes guidelines for assessment studies and surveys. This model has three approaches: Model-A (VGF Model), Model-B (Non-VGF with exclusivity over seabed) and Model-C (Non-VGF without exclusivity). However, infrastructure gaps, complex regulations, and financial constraints pose hurdles. The government's response includes model-based development plans, financial incentives, and talent skilling programmes, paving the way for a brighter future.

Biofuels not only contribute to energy security but also empower rural communities and reduce carbon footprint, thus biofuels hold immense potential. The Indian government has made amendments to its National Policy on Biofuels to support domestic biofuels production. The policy includes an accelerated national E-20 mandate, aiming to increase ethanol production capacity in India. The amendments allow for the conversion of excess cereal grains for ethanol production and permit additional feedstocks for biofuel production.
|The government is encouraging sugar mills and distilleries to produce ethanol under the Ethanol Blending Programme. Biodiesel, advanced biofuels, and waste-to-energy solutions require further attention to overcome technical, financial, and regulatory barriers. Recommendations such as R&D support, sustainable feedstock promotion, and diverse business models aim to unlock their full potential.

AgriPV technology seamlessly integrates solar panels within agricultural land, offering a win-win scenario. Farmers enjoy increased income from both crop cultivation and solar energy generation. However, balancing agricultural needs, managing initial costs, and developing effective business models remain key challenges. Pilot programmes, clear regulations, green financing, and capacity building programmes are crucial to pave the way for its widespread adoption.

Floating solar is also emerging as a land-efficient solution, as it harnesses the power of the sun from water bodies such as reservoirs. Lowering evaporation and maintaining cooler water temperatures are additional benefits. While promising, challenges such as cost burden, environmental impact, and technical hurdles require innovative solutions. Recommendations focus on cost reduction strategies, environmental stewardship, data-driven site selection, and technological advancements to ensure its smooth sailing.

According to the International Energy Agency (IEA) Bioenergy Report 2022, modern bioenergy is the largest source of renewable energy globally, accounting for 55% of renewable energy and over 6% of the global energy supply. About 32% of the total primary energy use in India is still derived from biomass and more than 70% of the country's population depends on it for its energy needs. Organic waste can be used for energy generation through grid-connected biogas plants, compressed biogas for transportation, industrial co-digestion and decentralised energy needs. Copenhagen, Stockholm and Pitten are successful examples of cities utilising biogas for sustainable energy solutions. The National Bioenergy Programme aims to promote the use of bioenergy with an allocated budget of INR 858 crore for Phase-I for sustainable energy recovery. The programme encompasses three sub-schemes - waste to energy programme, biomass programme, and biogas programme.

In the context of the imperative for grid resilience and emergency preparedness, generating and storing green hydrogen and energy storage becomes a necessity for the transition to a sustainable and dependable energy future. As technology progresses and investments in storage solutions grow, battery storage stands out as a pivotal technology to fortify grids against challenges associated with renewable energy integration. With capabilities encompassing backup power, micro-grid functions, frequency control, voltage support, and black start services, battery storage plays a crucial role in enabling the power system to endure and recover from disruptions caused by natural disasters, cyberattacks, or other unforeseen events. Furthermore, it contributes to reducing the impacts of emergencies by alleviating peak demand, congestion, losses on the transmission and distribution network, and by optimising the utilisation of renewable energy sources.

India's ambitious 500 GW renewable energy goal necessitates significant scaling up of battery storage capacity. The National Electricity Plan (NEP) estimates India's battery storage requirement to the tune of 41.65 GW/208 GWh by 2030, with potential for additional expansion. The government has rolled out various policy measures such as PLI scheme for Advanced Chmeistry Cells (ACC), introducing energy storage obligations in the RPO, notified bidding guidelines for the procurement and utilisation of BESS, and waiver of ISTS charges for the BESS projects commissioned till June 2025.

Green hydrogen and green ammonia have the potential to revolutionise India's efforts to decarbonise hard to abate sectors. The government is committed to establishing a green hydrogen production capacity of at least 5 million metric tonnes per annum (MMTPA) by 2030, supported by robust policy measures, including the Green Hydrogen Policy and the National Green Hydrogen Mission. Striving to position itself as a global leader in green hydrogen production, the government aims to curtail carbon emissions, reduce dependence on fossil fuels, and foster economic growth through the National Green Hydrogen Mission, which is allocated a financial budget of USD 2.4 billion (INR 197 billion). While challenges remain, such as high production costs and limited infrastructure, green hydrogen and green ammonia are expected to contribute significantly to India's 500 GW target.

Chairman's address

It is with a profound sense of responsibility and anticipation that I present to you this comprehensive report, 'Achieving 500 GW of Renewable Energy Capacity by 2030 – An Industry Perspective', prepared by Grant Thornton Bharat.

Today, the energy industry finds itself at the heart of a global transformation. The collective aspiration for a sustainable future is no longer a distant dream but a near-term commitment. The urgency to address climate change has taken center stage, with renewable energy as its pivot. The ambitious target of achieving 500 gigawatts (GW) of renewable energy underscores India's commitment to move towards a more sustainable future and to fight climate change even more aggressively.

During the last 10 years, with various policy initiatives and support from the GOI (government of India), the power sector has undergone transformative changes. We now have power surplus and distribution utilities. Most power companies, whether they are in the private sector or in the public sector, are moving towards profitable growth path. The industry has witnessed an exponential growth in the last few years, driven by innovation and a relentless quest for sustainability through governmental support and policy push. The plunge in the costs of renewable technologies, combined with supportive policies and a growing acceptance of clean energy, has been pivotal in this upsurge. We have also seen a significant scale-up in the deployment of various forms of renewable energy, from wind and solar to bioenergy and hydropower, pointing to a diversifying energy mix that is both resilient and reliable.

Reaching 500 GW by 2030 requires a compounded annual growth rate of around 20% from 180 GW at present. It mandates a collaborative effort among governments, industry players, the financial community, and civil society. This report is a culmination of insights from across these spheres.

In his recent interviews, the Minister of Power and New and Renewable Energy indicated that besides 180 GW of RE capacity already installed, 130 GW of RE capacity is under various stages of implementation and another 70 GW is under bidding. This very clearly indicates that the target set by the GOI to achieve 500 GW of RE capacity by 2030 is imminently achievable, and it is quite possible that this target may be surpassed earlier.

As we delve into the industry vantage point, we confront the twin imperatives of scalability and sustainability. Our analysis suggests that the road to 500 GW is paved with innovation in areas such as grid integration, energy storage, and demand-side efficiencies. Advancements in flexible power generation and next-generation renewable technologies can be accelerated. The integration of decentralised systems, energy storage, green hydrogen, smart grids, and IoT-based solutions will be instrumental in creating a resilient energy infrastructure capable of withstanding the variable nature of renewable power generation. Capital mobilisation is another pillar that will fortify our journey. A conducive investment climate that promotes certainty and minimises risk is key to attracting the investments required. We emphasise the need for innovative financing mechanisms that blend public and private capital, de-risk investments, and tap into the potential of green bonds and climate finance.

Policy initiatives, market design, and regulatory frameworks keep evolving to foster a fertile environment for renewable energy investments. The PLI scheme brought in by the GOI has reduced our dependence on imports - both in solar panel and battery storage.

Equally significant is the social dimension of our transition. The report acknowledges that the shift to renewable energy is not just about power generation; it is about empowering communities, generating employment, and spurring socio-economic development. We must ensure that this transition is just and inclusive, leaving no one behind. To conclude, the path to achieving 500 GW of renewable energy capacity by 2030 is exhilarating and full of new opportunities. This report does not shy away from the enormity of the challenge, but instead chooses to focus on the vast landscape of possibilities. It is a blueprint for innovation, and ultimately, a gesture of commitment to a greener, cleaner, and more sustainable future.

As we unveil this report, we do so with the confidence that the industry is poised to take on this challenge. The collective efforts, experiences, and wisdom encapsulated in these pages are not just a testament to the potential of renewable energy but also a reaffirmation to innovate, collaborate, and excel.

I invite you all to engage with the insights and recommendations of this report.

With best wishes,

K S Popli
Secretary General, India Energy Forum
Former CMD, IREDA

1 Introduction

As India has set an ambitious target of becoming energy independent by 2047 and achieving net zero by 2070, the government of India is committed to set up 50% of cumulative power generation from non-fossil fuel based energy resources by 2030. India made commitment to become carbon neutral by 2070 and five commitments as *Panchamrit* at COP26[7].

The five commitments made at the global conference were:

NON-FOSSIL FUEL-BASED ENERGY

500 GW by 2030
~280 GW from Solar

ENERGY FROM RE

50% by 2030

CARBON EMISSION REDUCTION

Reduction of 1bn tonne by the year 2030

CARBON INTENSITY REDUCTION

45% by 2030

NET ZERO

Achieve net zero emissions by the year 2070

Energy demand growing at an annual rate of +6%

Energy demand projected to increase 50% from 2019 to 2030

To attain this objective, increasing the utilisation of domestically sourced renewable energy stands as the cornerstone of India's energy transition. Fulfilling these ambitious commitments necessitates extensive decarbonisation efforts on a monumental scale. To meet India's new 2030 goals, the nation must install an additional 320 gigawatts (GW) of non-fossil fuel energy capacity within this decade. India has experienced the swiftest growth rate in renewable energy capacity expansion among all major economies in the last seven years[8]. It will need to substantially ramp up the addition of renewable capacity, aiming for an average annual increase of around 45 to 46 GW of non-fossil fuel energy capacity to achieve the targets.

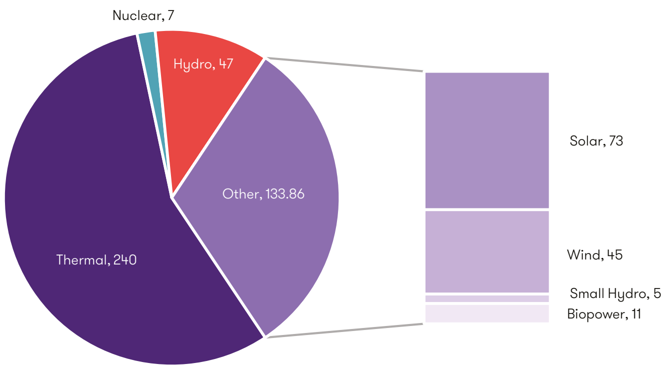
Renewable energy landscape in India

India, ranking as the world's third-largest carbon emitter[9], has embarked on a significant endeavour towards attaining net zero emissions by 2070. Since the adoption of the Paris Agreement in 2015, India has made notable progress in decreasing emissions' intensity by 33-35% by 2030[10]. India acknowledges the crucial role of renewable energy in stimulating both economic development and environmental preservation. The renewable energy capacity in India has steadily grown, reaching a combined installed capacity of 180.79 GW as of December 2023, encompassing various sources such as large hydropower. Leading this transition is solar power, with an installed capacity of 73.3 GW, closely followed by wind power at 45.7 GW[11]. Other contributors to the renewable energy mix include biomass, small hydropower, and waste-to-energy. There are plans for further expansion, driven by the ambitious target of achieving 500 GW of renewable energy capacity by 2030.

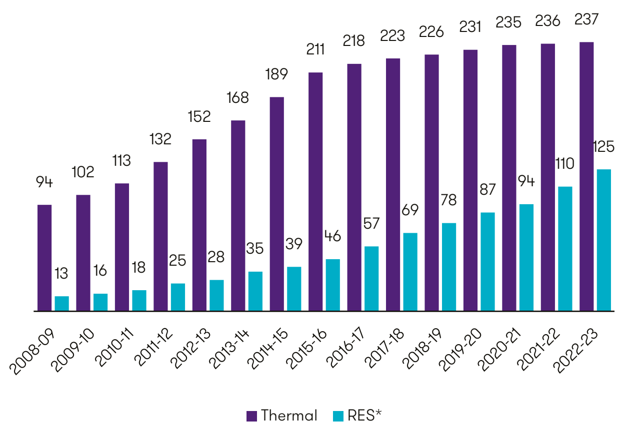
7. pib.gov.in/PressReleasePage.aspx?PRID=1795071
8. pib.gov.in/PressReleseDetail.aspx?PRID=1785808
9. www.weforum.org/agenda/2023/01/india-holds-the-key-to-hitting-global-climate-change-targets-here-s-why/
10. pib.gov.in/PressReleaseIframePage.aspx?PRID=1847812
11. mnre.gov.in/physical-progress/

New operational challenges will emerge as the proportion of renewable energy in electricity generation rapidly increases from its current level of approximately 10%. This stems from the inherent characteristics of renewables, where electricity generation depends on factors such as sunlight and wind, resulting in variability and intermittency. It is imperative to optimise the utilisation of renewable energy while ensuring the stability of the grid and meeting demand in real time. There is a growing global consensus on efficiently managing power systems to maintain grid security and stability, incorporating integrated resource planning for increased renewable integration. India can leverage this understanding and customise it to facilitate a smooth transition. Continuous system planning and simulation studies will be necessary to assess the evolving requirements for ancillary services and storage.

All India Installed capacity (in GW) as on Dec'23



Trend of Installed capacity-Thermal vs RES (GW)



Souce: CEA, Growth of Electricity Sector in India
*RES includes Small Hydro Project (≤ 25 MW)

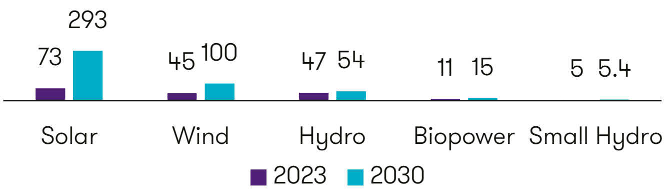
While thermal power capacity steadily climbed from the early 2000s to FY 2017, its growth has significantly slowed in recent years. This shift aligns with the government's increasing push for renewable energy sources, as shown above.

12. www.mospi.gov.in/sites/default/files/publication_reports/Energy_Statistics_2023/EnergyStatisticsIndia2023.pdf

As per forecasts by the Central Electricity Authority (CEA), reaching the milestone of 500 GW in non-fossil fuel energy, as announced in Glasgow, could potentially be attained by aggregating around 435 GW from wind, solar, and other renewable energy (RE) sources, 61 GW from large hydro, and 19 GW from nuclear energy (CEA, 2020). The attainment of 500 GW in non-fossil fuel capacity, alongside achieving 50% generation from renewables, appears not only achievable but likely economically feasible as well. Nonetheless, meeting these objectives poses considerable challenges. Among the primary obstacles is the imperative to enhance the flexibility of generation sources and the deployment of large-scale energy storage capabilities. These enhancements are essential to ensure the seamless operation of the grid, fully exploit RE capacity, and concurrently satisfy demand consistently on a 24X7 basis with a high level of reliability. A heightened emphasis on boosting decentralised generation from renewable sources would facilitate this transition and, over time, prove to be cost-effective.

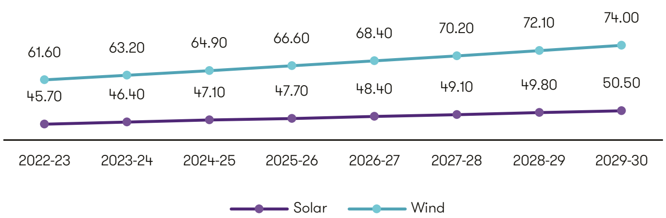
Considering the target of 500 GW capacity by 2030, renewables is expected to contribute close to 50% of the overall installed capacity. The chart given below captures the growth of renewable energy sources systems by 2030.

RE Installed capacity in FY 2023 vs Projected in FY 2030



The National Electricity Plan 2022 paints a picture of increasing capital costs for both solar and wind power projects in India. By 2029-30, the installation cost per megawatt (MW) is expected to reach Rs 50.5 million for solar and Rs 74 million for wind. However, despite the rising costs, both sectors are projected to experience growth.

Capital Cost Projections (INR Million/MW)



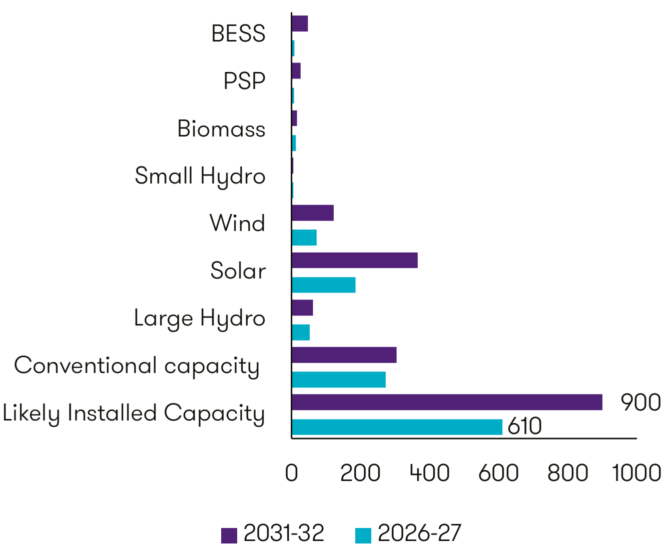
As per the Energy Statistics India 2023 report[12], clean energy sources, including hydro, nuclear, and other renewables, exhibited the most substantial growth (6.83% CAGR) in commercial energy production from 2012-13 to 2021-22. Conversely, overall commercial energy production saw a growth rate of 2.62% (CAGR) during this timeframe. In contrast, coal energy production experienced a more moderate CAGR growth of 3.8% and accounted for 73% of total commercial energy production in 2021-22.

Impact of government initiatives and policies

The Electric Act of 2003 mandates the central government to periodically issue both a national energy policy and tariff policy. Furthermore, in alignment with the national energy policy, the central government is required to release a national electricity plan every five years. In March 2023, the Ministry of Power (MoP) revealed the National Electricity Plan ((NEP) (Vol-I Generation)[13], which encompasses the period from 2022 to 2032. As per the NEP document, the projected all India peak electricity demand and electrical energy requirement are estimated at 277.2 GW and 1907.8 BU for 2026-27, and 366.4 GW and 2473.8 BU for 2031-32, respectively, based on the 20th Electric Power Survey (EPS) demand projections[14]. These forecasts take into account various factors such as increased adoption of electric vehicles, installations of solar rooftops, production of green hydrogen, and the implementation of the Saubhagya scheme.

Based on generation planning studies carried out under the purview of preparation of the National Electricity Plan for the period of 2022-27 and 2031-32, the likely Installed capacity for the year 2026-27 is 610 GW and 900 GW, respectively. The detailed breakup is as follows:

Forecasts for FY 27 & FY 32 in GW



The projected installed capacity for 2026-27 and 2031-32, as determined from generation planning studies within the National Electricity Plan framework, stands at 610 GW and 900 GW, respectively. These estimates are in line with the nation's goal of attaining a non-fossil-based installed capacity of about 500 GW by 2029-30. The NEP foresees the proportion of non-fossil-based capacity to climb to 57.4% by the end of 2026-27, potentially increasing further to 68.4% by the end of 2031-32, up from approximately 42.5% as of April 2023.

Key policy developments affecting renewable energy (RE) development in India

Carbon Credit Trading Scheme, 2023[15]

The primary objective of the Carbon Credit Trading Scheme is to establish a robust platform for the trading of carbon credits. These credits represent quantified units of emissions reduction, removal, or avoidance, with each credit equivalent to one metric ton of carbon dioxide equivalent (tCO2e). Such credits may be traded within the country's industries and entities to control the emissions of greenhouse gases. The scheme intends to encourage obligated entities to minimise their carbon footprint by reducing emissions.

Development of ultra-mega and mega solar parks[16]

The initiative aims to assist states/union territories in establishing solar parks across various locations nationwide, facilitating the development of essential infrastructure for solar power projects. These solar parks offer pre-developed land with necessary clearances, transmission systems, water access, road connections, communication networks, and more. The scheme expedites the installation of grid-connected solar power projects to enable large-scale electricity generation. To date, the government has approved 50 solar parks with a combined capacity of 37,990 MW in 12 states throughout the country. Of these approvals, 11 solar parks with a total capacity of 8,521 MW have been fully completed, while 7 solar parks with a collective capacity of 3,985 MW are partially completed. Within these parks, solar projects totalling 10,237 MW have been developed. The Solar Park Scheme is currently scheduled to run until 31 March 2026, with solar parks required to have a capacity of 500 MW or more. However, consideration is given to smaller parks in areas where acquiring contiguous land is challenging due to difficult terrain or a severe shortage of non-agricultural land.

National portal for rooftop solar[17]

MNRE has introduced a 'National Portal (NP)' designed specifically for registering applications under the simplified procedure. The entire process, from submitting applications to disbursing subsidies/CFA, will be conducted online exclusively through this portal.

13. pib.gov.in/PressReleaseIframePage.aspx?PRID=1928750
14. cea.nic.in/wp-content/uploads/ps___lf/2022/11/20th_EPS____Report___Final___16.11.2022.pdf
15. dnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2023/10/2023100519l4289922.pdf
16. mnre.gov.in/development-of-solar-parks-and-ultra-mega-solarpowerprojects/#:~:text=These%20parks%20are%20proposed%20to,up%20of%20solar%20power%20projects.
17. www.solarrooftop.gov.in/

Revised CFA for Rooftop Solar Programme Phase-II[18]

The Ministry of New and Renewable Energy has approved updated benchmarks for Central Financial Assistance (CFA) as part of Phase-II of the Rooftop Solar Programme. These modifications, effective immediately, are intended to enhance backing for grid connected rooftop solar photovoltaic systems. The revised CFA rates differ depending on the project's capacity and category.

- For individual household projects, the rates are fixed at INR 18,000/kW for capacities ranging from 1-3 kW in general, and INR 20,000/kW for the same capacities in special category states.
- Projects exceeding 3-10 kW now have revised rates of INR 9,000/kW (General) and INR 10,000/kW (Special category states).
- Resident Welfare Associations/Group Housing Societies (RWA/GHS) and common facilities up to 500 kW have a revised CFA of INR 9,000/kW (General) and INR 10,000/kW (Special category states).

These updated CFAs will be applicable to all upcoming bids and those closing after 15 days from the issuance of the revised rates. The adjustments are aimed at rationalising financial assistance based on project characteristics, ensuring fair distribution and support for renewable energy endeavours.

Competitive bidding guidelines

The Indian government has introduced guidelines for tariff-based competitive bidding processes, ensuring fairness and standardisation in the procurement of grid-connected solar, wind, hybrid, and real-time continuous (RTC) projects.

RTC tender by Solar Energy Corporation of India

To address intermittency in RE projects, the Solar Energy Corporation of India (SECI) issued a tender for 2.5GW of RTC power from RE projects[19], aiming to counterbalance high-cost power with cheaper RE sources. A subsequent tender in September 2022 reinvigorated the remaining 2.25GW.

Captive generating plants

Captive generating plants, producing electricity primarily for personal use, benefit from exemptions, provided certain criteria are met. The Appellate Tribunal for Electricity (APTEL) has ruled that the proportionality requirement is waived if the plant is established by a special purpose vehicle (SPV).

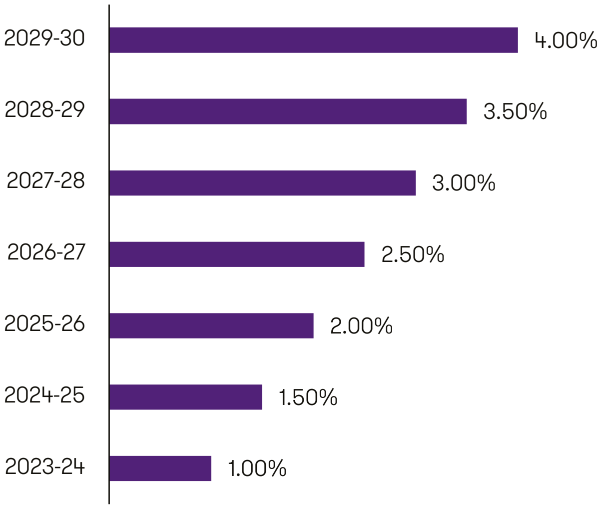
Renewable purchase obligations (RPO)

State electricity regulatory commissions mandate a percentage of electricity to be sourced from RE. The NEP projects an increase in non-fossil-based capacity, reaching 68.4% by 2031-32. The MoP defined new RPO targets, hydro power obligations (HPO), energy storage obligations (ESO), and other RPO beyond 2021.

RPO obligations till 2030

	Wind*	HPO (from LHP including SHPs)**	Other RPO***
2022-23	0.81	0.35	23.44
2023-24	1.6	0.66	24.81
2024-25	2.46	1.08	26.37
2025-26	3.36	1.48	28.17
2026-27	4.29	1.80	29.86
2027-28	5.23	2.15	31.43
2028-29	6.16	2.51	32.69
2029-30	6.94	2.82	33.57

Energy storage obligation (Storage on energy basis)**



*Shall be met only by energy produced by WPPs commissioned after 31 March 2022
** shall be met only by energy produced by LHPs including PSPs commissioned after 8 March 2019
***met from any other source than wind and HPO
****percentage of total energy consumed shall be solar/ wind along with/ through storage

Renewable generation obligations (RGO)

Coal-fired thermal power plants commissioned after 1 April 2023 face increased renewable purchase obligations, rising to at least 40% of their coal power capacity, and different targets based on their operational dates. The policy encourages coal plants to generate renewable energy or enter agreements to procure an equivalent amount.

For instance, for plants commissioned between 1 April 2023 and 31 March 2025, there are two options:

- Either establish 40% renewable power capacity
- Procure and supply renewable energy equivalent to such capacity by April 2025

18. solarrooftop.gov.in/pdf/CFA%20structure2024.pdf
19. www.seci.co.in/whats-new-detail/2348

Electric vehicles

India is progressively adopting policies for electric vehicles, with initiatives like Delhi's goal of one in every four vehicles sold by 2024 being electric. NITI Aayog emphasises the need for increased investment to expedite India's transition to electric mobility.

Production-linked incentive scheme (Tranche II) under 'National Programme on High Efficiency Solar PV Modules' [20]

The government has awarded a combined capacity of 39,600 MW for domestic solar PV module manufacturing to 11 companies, with a total investment of INR 14,007 crores under the production linked incentive scheme for high efficiency solar PV modules (Tranche-II). It is anticipated that manufacturing facilities with a capacity of 7,400 MW will commence operations by October 2024, followed by 16,800 MW by April 2025, and the remaining 15,400 MW by April 2026. This initiative, Tranche-II, is projected to attract an investment of INR 93,041 crore and is expected to create a total of 101,487 jobs, with 35,010 in direct employment and 66,477 in indirect employment.

Green Energy Corridor[21]

As of 31 December 2022, a total of 8759 circuit kilometres (ckm) of intra-state transmission lines have been built, and intrastate substations with a capacity of 19868 MVA have been energised. The second phase of the Intra-State Transmission System Green Energy Corridor Scheme (InSTS GEC-II), sanctioned on 6 January 2022, has prompted the states of Gujarat, Himachal Pradesh, Karnataka, Kerala, Rajasthan, Tamil Nadu, and Uttar Pradesh to initiate the tendering process for projects aimed at evacuating 20 GW of renewable energy capacity.

Energy storage

The government acknowledges the need for market mechanisms and innovative economic models for energy storage technology adoption. Initiatives include the legal status designation for energy storage systems (ESS), energy storage obligation trajectory till 2029-30, waiver of ISTS charges on hydro pumped storage projects and BESS projects, and revised schemes for flexibility in generation and scheduling.

The following initiatives have been taken to promote growth of energy storage technologies:

- Legal status for energy storage systems (ESS) has been issued by the Ministry of Power (MoP) on 29 January 2022, wherein ESS has been designated as a power system element that can be utilised as a generator, transmission or distribution element.
- Energy storage obligation trajectory till 2029-30 has been notified by the Ministry of Power vide order dated 22 July 2022.
- Waiver of ISTS charges on hydro pumped storage projects (PSP) and BESS projects, commissioned up to 30 June 2025, has been provided vide order dated 23 November 2021. The waiver shall be applicable for a period of 25 years for Hydro PSP and for a period of 12 years for BESS, or for a period subsequently notified for future projects by the central government from the date of commissioning of the power plant.
- Revised scheme for flexibility in generation and scheduling of thermal/hydro power stations through bundling with renewable energy and storage power has been notified vide order dated 12 April 2022.
- Bidding guidelines for Battery Energy Storage Systems (BESS) have been notified by MoP vide resolution dated 10 March 2022.

These policies collectively underscore India's commitment to advancing renewable energy, electric mobility, and energy storage technologies, contributing to a sustainable and resilient energy future.

20. cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2023/10/20231005855129127.pdf
21. cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2023/08/2023080211.pdf

Some key declarations from the budget by GOI

India is investing USD 67 billion over the next six years in the energy sector, including refineries and natural gas network expansion - Declaration in India Energy Week by PM Modi

Union budget 2024-25

- INR 10,000 crore in 2024-25 for grid-based solar power scheme, compared to Rs 4,757 crore in 2023-24, as per revised estimates.
- Wind power was allocated INR 930 crore in 2024-25 compared to INR 916 crore in 2023-24.
- Rooftop solarisation: 10 million houses to be brought under rooftop solar scheme and provided 300 units of free electricity each month.
- Viability gap funding will be provided for offshore wind energy for an initial capacity of 1 gigawatts (GW).
- Coal gasification and liquefaction of 100 tonnes capacity to be set up by 2030.
- National Green Hydrogen Mission allocated INR 600 crore in 2024-25, compared to INR 100 crore in 2023-24.
- The Union Ministry of Environment, Forests, and Climate Change's (MoEFCC) budget estimate raised to INR 3,265.53 crore from INR 3,079.4 crore in 2023-24.
- The Union Ministry of New and Renewable Energy's (MNRE) budget estimate increased to INR 12,850 crore from INR 10,222 crore last year.
- Phased mandatory blending of compressed biogas (CBG) with compressed natural gas (CNG) for transportation and piped natural gas or PNG for domestic purposes will be mandated.

Union budget 2023-24

- Green growth was identified as one of the nodes in the SAPTARISHI (7 priorities).
- Pumped storage projects received a push with a detailed framework to be formulated.
- Union Budget 2023-24 envisions to create sustainable cities of tomorrow. To translate this, states and cities will be encouraged to undertake urban planning reforms and actions to transform our cities into 'sustainable cities of tomorrow.'
- USD1.02 billion (INR 8,300 crore) central sector support for ISTS infrastructure for 13 GW renewable energy from Ladakh was announced.

Infrastructure-wise grid readiness to embrace 500 GW by 2030

In line with the government's commitment to 'Power for All', demonstrated through initiatives such as the 'Saubhagya Yojana', and a heightened focus on green energy production, the renewable energy sector in the nation, along with its transmission and distribution infrastructure, is experiencing a transformative phase of expansion. As new generation facilities, primarily driven by renewable sources, come online, there is a renewed emphasis on enhancing the country's transmission network. This is aimed at both enhancing network efficiency and addressing the intermittent nature of renewable energy sources. Moreover, the government is actively pursuing the adoption of digital technologies and smart grid solutions, such as advanced metering infrastructure, distribution automation, and demand response systems, to enhance the operational efficiency of the grid, reduce losses, and facilitate better management of energy resources. To meet the escalating demands for electricity evacuation, the Indian transmission network (comprising lines of 110 kV and above) will need to expand at a compound annual growth rate (CAGR) of approximately 4% between 2023 and 2028, necessitating an investment of over approximately INR 1,78,500 crore during this period.

Within the National Infrastructure Pipeline (NIP), the energy sector has been designated the largest portion (24%) of the anticipated total capital expenditure. The emphasis is on renewable energy endeavours, with a projected allocation of INR 9.3 lakhs crore spanning over 250 opportunities. The government's objective is to elevate India's renewable energy capacity to 450 GW by 2030, necessitating substantial investments in the infrastructure for generation, transmission, and distribution. To facilitate the integration of renewable energy into the current transmission grid, the government intends to establish green energy corridors and renewable energy management centres. This initiative aims to enhance network efficiency and mitigate the intermittent nature of renewable energy sources (RES). Under the NIP, the generation, transmission, and distribution sectors are slated to receive an approximate total investment of INR 14 lakhs crore[22]. With the addition of new generation capacities from both renewable and non-renewable sources, the focus for the transmission and distribution sectors will be on advancing high-voltage transmission corridors, constructing substations, and improving last-mile connectivity to ensure uninterrupted and seamless power delivery.

22. indiainvestmentgrid.gov.in/opportunities/

With regards to GoI's target for establishing 50% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030, the following additional initiatives have been taken toward the integration of renewable power in the grid[23]:

- Transmission schemes for the integration of 66.5GW renewable generation in states like Rajasthan, Gujarat, Maharashtra, Madhya Pradesh, Karnataka, Andhra Pradesh and Tamil Nadu have been planned and are under various stages of implementation.
- About 55.08 GW of renewable potential has been identified in Rajasthan, Gujarat, Himachal Pradesh and Ladakh, for which planning of transmission system has been carried out and the implementation of the same would be taken up.
- About 33.35 GW of renewable generations can be integrated into the ISTS grid through margins at various existing/under construction ISTS S/s.
- For the remaining capacity addition, SECI has preliminarily identified 181.5GW potential renewable energy zones in 8 states viz. Andhra Pradesh, Karnataka, Telangana, Rajasthan, Maharashtra, Madhya Pradesh and offshore wind at Gujarat and Tamil Nadu with various hybrid and solar locations planned with storage (BESS of 43.6GW).
- About 51,000 ckm of transmission lines and 4,33,500 MVA of transformation capacity is expected to be added in the ISTS network at an estimated cost of about INR 2,44,000 Cr. These transmission schemes include various high capacity 765kV and 400kV EHVAC transmission lines and ±800kV & ±350kV HVDC lines.

Financial backing to support RE capacity integration

India's renewable energy sector presents attractive prospects for investors, with the government rolling out various financial instruments such as green bonds, infrastructure investment trusts (InvITs), and viability gap funding (VGF) to entice them. Furthermore, tax incentives and exemptions on customs duties for renewable energy equipment add to the appeal. Nevertheless, persistent challenges remain in the form of regulatory ambiguities, lengthy approval procedures, and currency fluctuations continue to pose concerns for foreign investors.

Estimates indicate that India needs a substantial USD 223 billion annually from 2022 to 2029[24] to meet its renewable energy integration targets. This significant investment encompasses grid expansion and enhancement, energy storage solutions, and financing for renewable energy projects themselves. Although India has made progress in mobilising domestic funds, attracting international investments is vital to bridging the funding shortfall.

23. powermin.gov.in/en/content/500gw-nonfossil-fuel-target
24. www.powerfoundation.org.in/publications.php
25. www.powerfoundation.org.in/publications.php

India's aspiration to reach a 500 GW RE installed power capacity by 2030 poses a significant hurdle, requiring more than just a boost in generation capabilities. It calls for a resilient and flexible grid infrastructure. This evolution goes beyond simple hardware enhancements; it requires a strategic revamp to guarantee the smooth integration of various energy sources and effective power distribution across a sprawling and ever-changing terrain. Few estimates on investment needs are as cited below:

- **Investment needs:** India needs USD 223 billion of investment from 2022 to 2029 to meet its wind and solar capacity targets. This is three times the investment flows into new-build wind and solar from 2014 to 2021. An additional USD 26 billion would be required for battery storage projects[25].
- **Investments in transmission and distribution grid (2020-29):** Investments in the grid are primarily motivated by the need to expand generation capacity, update aging infrastructure, and improve grid intelligence and reliability. As a result, estimates suggest that between 2020 and 2029, around USD 175 billion will be necessary for upgrading the transmission and distribution grid[26]. This funding is essential to accommodate new capacity additions and strengthen the current network.
- **Funding sources:** Renewable project developers have raised debt from several different sources, such as banks, non-banking finance companies, bonds, and multilateral agencies. Equity investments have come from a diverse set of investors, such as pension funds, oil and gas companies, and infrastructure investment trusts.
- **Policy incentives:** India has implemented various policy incentives to support renewable energy deployment, such as accelerated depreciation, viability gap funding, payment security mechanisms, and tax benefits. The government has also announced new targets to reduce emission intensity and achieve net-zero by 2070.

Investment potential[27]

- **USD 633bn** Investment opportunity in RE till FY 2030
- **USD 100bn** Energy efficient investment potential by FY 2030
- **USD 224bn** Thermal, T&D expansion modernisation by FY 2030

Significant investment would include green hydrogen, e-mobility, decarbonisation technologies such as CCUS, smart meters, digitisation, and energy storage value chains. The journey towards 500 GW of renewable energy is not just about numbers; it's about India's future. By addressing the financial hurdles through strategic reforms, innovative solutions, and international partnerships, India can secure the capital needed to integrate its clean energy future and emerge as a global leader in the green energy race.

26. www.powerfoundation.org.in/publications.php
27. www.powerfoundation.org.in/publications.php

Foreseen challenges inhibiting accelerated RE growth

The transition to a net-zero future is a challenging yet feasible task. India's commitment to amplify its renewable capacity demonstrates its resolve to align economic development with climate action objectives. Harnessing the potential of alternative energy sources marks a significant step towards achieving this commitment. The nation's success in achieving net-zero emissions will not only be momentous for India but will significantly influence global endeavours towards a sustainable future. Thus, India's journey highlights the indispensable role of alternative energy in paving a sustainable, prosperous, and net-zero path for nations worldwide. India's commitment to a clean energy future hinge on the accelerated growth of renewables.

Few major challenges are as discussed below:

Intermittency and variability

Solar and wind power, the primary RE sources in India, are inherently intermittent and variable, depending on weather conditions. This unpredictability poses a challenge for grid operators who need to maintain a balance between electricity supply and demand.

- Impact on grid stability: The fluctuating output of RE sources can cause voltage and frequency fluctuations, potentially destabilising the grid and leading to power outages.

Forecasting and scheduling: Accurate forecasting of RE generation is crucial for grid operators to plan and schedule dispatch of conventional power plants to compensate for RE variability.

Grid infrastructure and management

The Indian power grid, designed for conventional power plants, faces challenges in accommodating the large-scale integration of RE sources.

- Transmission bottlenecks: The existing transmission infrastructure may not be adequate to handle the increased power flow from RE-rich regions to demand centers, leading to congestion and curtailment of RE generation.
- Grid flexibility and control: Grid operators need enhanced flexibility and control mechanisms to manage the variability of RE sources and maintain grid stability.

Land acquisition and environmental concerns

Large-scale RE projects require significant land acquisition, which can raise concerns over land use, displacement of communities, and environmental impacts.

- Land availability and acquisition: Securing suitable land for RE projects can be challenging due to competing land uses, ownership issues, and regulatory hurdles.
- Environmental impact assessments: Proper environmental impact assessments and mitigation measures are necessary to address concerns over habitat loss, biodiversity impacts, and visual impacts of RE projects.

Storage solutions and demand-side management:

The intermittent nature of RE sources necessitates energy storage solutions to store excess RE generation and provide a reliable power supply during periods of low RE output.

- Energy storage technologies: Investments in battery storage technologies, pumped hydro storage, and other innovative storage solutions are needed to complement RE integration.
- Demand-side management: Demand-side management strategies, such as load shifting and demand response programmes, can help balance RE variability and reduce peak demand.

Policy and regulatory framework

A comprehensive policy and regulatory framework is essential to facilitate RE integration and address market distortions.

- Renewable purchase obligations: Renewable purchase obligations (RPOs) mandate a certain percentage of electricity procurement from RE sources, but may need adjustments to ensure grid stability.
- Pricing and market mechanisms: Appropriate pricing mechanisms and market reforms are needed to incentivise RE integration while ensuring grid stability and fair competition.

Technological advancements and innovation

Continuous research and development in RE technologies and grid management systems are crucial for addressing integration challenges.

- Grid modernisation: Investments in smart grid technologies, advanced forecasting tools, and real-time monitoring systems can enhance grid flexibility and stability.
- RE technology advancements: Research into grid-friendly RE technologies, such as hybrid systems and distributed generation, can improve integration and reduce variability.

Financial viability and investment

Ensuring the financial viability of RE projects and attracting investments is crucial for large-scale RE integration.

- Cost competitiveness: While RE costs have declined significantly, ensuring cost competitiveness with conventional sources is essential for sustained growth.
- Investment incentives: Government incentives, such as subsidies, tax breaks, and risk mitigation measures, can encourage private sector investment in RE projects.

Stakeholder collaboration and public awareness

Effective collaboration among stakeholders, including government agencies, power utilities, RE developers, and communities, is crucial for successful RE integration.

- Policy coordination and implementation: Coordinated policy formulation and implementation across central and state governments can streamline RE integration efforts.
- Public awareness and acceptance: Educating the public about the benefits and challenges of RE integration can foster support and address concerns over land use and environmental impacts.

Integrating RE sources into the Indian grid presents a multifaceted challenge that requires a holistic approach. Addressing grid infrastructure, storage solutions, policy frameworks, technological advancements, financial viability, and stakeholder collaboration is essential to achieve India's ambitious RE targets and transition to a sustainable energy future.

2 Developers’ and manufacturers’ plan and perspective

Role of achieving supply chain resilience for sustainable growth

India's aspirations for economic growth are intricately linked to the robustness of its supply chains. In an increasingly volatile global landscape marked by natural disasters and geopolitical tensions, the importance of having a resilient and adaptable supply chain cannot be overstated. It is not only a competitive advantage but also a prerequisite for sustainable development. Therefore, achieving supply chain resilience is of paramount importance for India's energy security, sustainability, affordability, and pursuit of net-zero emissions.

The critical role of attaining supply chain resilience for sustainable growth encompasses several key aspects:

- **Reducing import dependence and vulnerabilities:** By developing local manufacturing capacities and promoting innovation in renewable energy technologies and essential components, India can reduce its reliance on imports. This proactive approach helps mitigate risks associated with supply disruptions, price fluctuations, and geopolitical uncertainties. Additionally, it contributes to conserving foreign exchange, creating employment opportunities, and enhancing India's competitiveness globally.
- **Bridging the sustainability-affordability gap:** Through encouraging domestic value addition and ensuring adherence to quality standards in renewable energy technologies, India can bridge the gap between sustainability and affordability. This strategy facilitates the widespread adoption of clean energy sources, enabling India to meet its climate commitments, reduce carbon emissions, and improve environmental and social outcomes.
- **Leveraging domestic demand and export potential:** By capitalising on strong domestic demand and government support for renewable energy deployment, India can attract investments and foster innovation in the sector. Moreover, positioning itself as a global hub for renewable energy manufacturing and trade allows India to tap into export opportunities, access new markets, and explore diverse avenues for growth.
- **Driving innovation and technological advancement:** Prioritising research and development, fostering collaborations, and investing in skill development within the renewable energy sector can propel innovation and technological advancement in India. This proactive approach supports the creation of indigenous and tailored solutions, strengthens intellectual property rights, and provides India with a competitive edge globally.

In conclusion, a resilient supply chain is fundamental for building a robust and sustainable foundation for India's long-term growth. By prioritising resilience, India can safeguard its economic future, preserve its environment, and empower its people, thereby shaping a more prosperous and sustainable tomorrow.

Solar module manufacturing

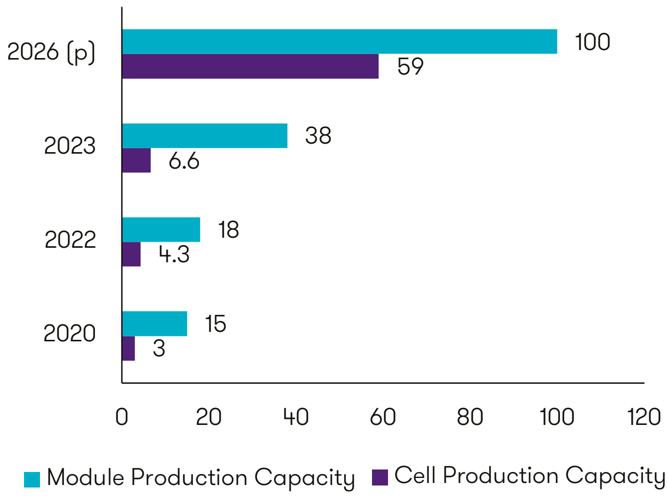
The Indian module manufacturing market has also grown in recent years. It has been competing at the global level in terms of technology, quality, costs, etc. Indian module manufactures have been able to turn around products that are high in quality and performance and have been able to quickly adopt latest technological developments with focus on quality and reliability. The PLI initiative stands as a pivotal force propelling the expansion of the entire photovoltaic (PV) manufacturing landscape in India. In addition to bolstering the infrastructure across all facets of PV manufacturing, spanning from polysilicon production to module assembly, it will concurrently foster the growth of a complementary market. As a result of the combined impact of both phases of the PLI programme, it is anticipated that the scheme will directly increase module capacity by 51.6 GW and integrated polysilicon-to-module capacity in India by a minimum of 27.4 GW.

Also, post restrictions in the US for China, the developers are enthusiastic in buying modules from Indian players than their Chinese counterparts. Indian modules are very well accepted in the US market even when they are 5% expensive than the Chinese modules and are considered as a credible option for the US. Due to this, the export has also gone up by 60-70%. Indian manufacturers are finding their way in the global markets and their performance is showing excellent results.

Post restrictions, the incentives offered by the US to manufacturers and developers are attracting investment opportunities in the US. The Indian module manufacturers are planning to set up factories in the US and there is a great opportunity for Indian module manufacturers and its mix of Make in India for the US and Made in the US for US. India has also been supplying cells to module manufacturers in the US. There is much demand coming from the US and India has not been able to fulfil that demand. With the availability of the latest technology and improved supply chain, the cells being manufactured in India or are going to be manufactured will also have the best quality. Also, the manufacturers feel that India will have equally high-quality wafers, cells and modules.

Marching ahead, India will not have issues with respect to the quality of modules and is hopeful that we will have more than 100 GW of module manufacturing with best-in-class quality and performance.

Growth of domestic PV manufacturing capacity in GW



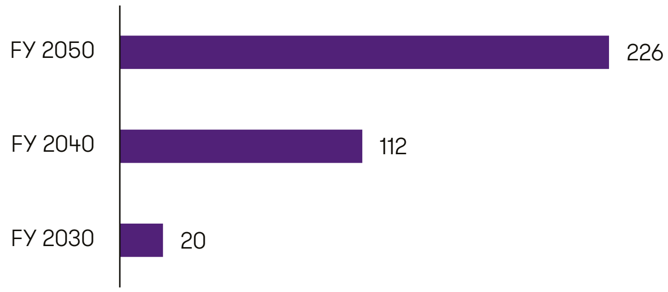
Electrolyser manufacturing

India's ambitious goal of producing 5 million metric tonnes (MMT) of hydrogen by 2030, with an allocation of USD 2.36 billion (INR 197.4 billion), is in accordance with the objectives of the National Green Hydrogen Mission. The pursuit of leadership in electrolyser manufacturing is crucial for nurturing India's green hydrogen ecosystem and transitioning towards a cleaner energy economy. The production-linked incentives (PLI) provided under the SIGHT programme act as a catalyst, capitalising on India's competitive advantages in labour and cost structures.

According to the estimates of the NITI Aayog and a RMI study, India's domestic market for electrolysers could reach 226 GW, which translates to USD 31 billion by 2050[28]. The shorter-term demand by 2030 is estimated to be 20 GW.

As per a cost analysis conducted by IRENA, as reported in the NITI Aayog report, approximately 50% of the total cost for both PEM and alkaline electrolysers is attributed to the stack. Another significant portion of the total system cost of electrolysers is allocated to the power supply, representing an additional 20%-30% of the system cost. When further examining the cost structure, it becomes evident that around 80% of the cost comprises the stack, power supply, and water circulation system. In scenarios where seawater is utilised for green hydrogen production, the costs associated with water desalination and purification are incorporated into the total cost of green hydrogen production. Regarding electrolysers, PEM technology involves rare-earth metals and precious metals such as gold and platinum, leading to a higher share of material costs. Conversely, alkaline electrolysers, leveraging readily available nickel and boasting a simpler design incur costs that are approximately 50%-60% lower than those of PEM electrolysers, as indicated by the NITI Aayog report.

Estimated Indian electrolyser demand (GWe)



Market development

- India announces bidders for the country's first GH2 manufacturing subsidies[29]: Fourteen companies, including Acme Cleantech, Avaada GreenH2, Bharat Petroleum Corp, CESC, Greenko ZeroC, JSW Energy, Reliance Industries, Sembcorp Green Hydrogen, and Torrent Power, have submitted bids for incentives under India's Green Hydrogen Mission. These H2 subsidies will only last for three years, capped at INR 50 per kilogram from the first year of production, INR 40 the second, and INR 30 in the third.
- However, when it comes to the second funding opportunity, designated for biomass-based production pathways of up to 40,000 tonnes annually, only one bid has been submitted, and it comes from the state-owned Bharat Petroleum, with a modest offer of 2,000 tonnes per year.

28. www.niti.gov.in/sites/default/files/202206/Harnessing_Green_Hydrogen_V21_DIGITAL_29062022.pdf
29. www.seci.co.in/Upload/New/638382530784581869.pdf

- On the other hand, the electrolyser tender aims to support an annual manufacturing capacity of 1,500 MW and has attracted 21 bids, totalling 3,428.5 MW, more than double the intended capacity. This auction presents a potentially more lucrative opportunity for companies, spanning five years with initial support set at a maximum of INR 4,440 per kilowatt of capacity sold, gradually decreasing to INR 1,480.
- Leading contenders for the electrolyser manufacturing capacity include NuTech, Green H2 Network India, Hygenco, Matrix Gas and Renewable (Gensol), C Doctor and Co., L&T Electrolyser, and Adani New Industries.
- Nonetheless, all applicants for electrolyser manufacturing subsidies must commit to allocating 50% of their subsidised annual sales towards domestic installations.

Furthermore, companies are required to incorporate a measure of 'local value addition' to maintain the supply chain within India. This entails a percentage calculation based on the disparity between the sale value of the electrolyser and the value of imports, ensuring a minimum proportion of the electrolyser's sales value is derived from locally sourced materials.

Potential of a regional hydrogen supply chain, equipment manufacturing and services hub in India

As per the 'Hydrogen Equipment Manufacturing and Services' report by the Indian Hydrogen Alliance (IH2A), the potential market for domestically manufactured hydrogen equipment in India is projected to reach USD 45-50 billion by 2030[29]. This assessment encompasses various components of hydrogen production plant equipment, such as electrolysers and balance-of-plant equipment, intended for deployment both within India and for export to the Asia, Middle East, and Africa regions. By positioning India as a central supply chain hub for forthcoming green hydrogen projects, this initiative is anticipated to generate approximately 162,000 direct and indirect job opportunities. Within the estimated market valuation of USD 45-50 billion, electrolyser stacks account for 34%, the balance of plant equipment comprises 62%, and specialist engineering services constitute 4%. This underscores the potential for India to capitalise on its competitive edge in manufacturing and engineering design, thereby establishing itself as a regional hub for hydrogen plant equipment supply chain activities.

The hydrogen equipment manufacturing and services estimate by IH2A comprises of:

- The domestic market for hydrogen production plant equipment in India is estimated to reach 9 bn[31], based on a conservative projection. This estimation is derived from an anticipated deployment of 135 domestic plants by 2030, with an annual electrolyser capacity of 6.8 GW, yielding and supplying at least 1 million metric tonnes of green hydrogen for domestic industrial use. These 135 green hydrogen projects are expected to vary in scale, ranging from 10 MW to 100 MW, utilising different electrolyser technologies across diverse end-use configurations, including industrial applications, fertiliser production, and heavy-duty transport. The deployment of the balance of plant equipment, encompassing compressors, storage tanks, transformers, rectifiers, liquefaction units, air separation units, dispensing units, power systems, sensors and instrumentation, and pipeline/evacuation infrastructure, is also accounted for. An optimistic perspective would entail an additional 3.4 GW of electrolyser capacity, contributing an extra USD 4.5 billion to the domestic market within the same timeframe.
- The potential for regional exports of hydrogen equipment is estimated to be valued at a minimum of USD 34 billion. This encompasses the exportation of locally manufactured electrolysers and balance of plant equipment to approximately 540 projects across the Asia-Pacific (APAC), Middle East, and Africa regions.
- Additionally, exports of specialist engineering design, engineering, procurement, and construction (EPC) services are projected to amount to at least USD 2 billion, calculated based on a 5% operating expenditure (OPEX) ratio on investments in deployed project capital expenditures (CAPEX). This export potential is expected to generate around 162,000 direct and indirect job opportunities as a result of fostering the hydrogen economy in India.

30. ih2a.com/workgroup-1-hydrogen-production-and-electrolyser-fuel-cell-manufacturing/
31. ih2a.com/wp-content/uploads/2023/10/IH2A-India-Green-Hydrogen-Equipment-and-Services-Market-Opportunity-2030-White-Paper-Oct-2023.pdf

Private sector initiatives in RE manufacturing

The private sector is poised to assume a pivotal role in propelling India's energy transition, particularly in the realms of renewable power generation, energy storage, green hydrogen, biofuels, and electric mobility. Currently, private sector entities are driving the expansion of supply, marking a transition from the initial dominance of public sector entities. Major private sector power producers, such as the Adani Group, Jindal, and Tata Power, renowned for their significant coal holdings, have announced ambitious targets for renewable energy alongside corresponding investment plans.

- In 2021, the Indian government allocated a 6 GW capacity for solar PV manufacturing under production-linked incentives (PLI)[32], encompassing the entire value chain from polysilicon to modules. The Indian Renewable Energy Development Agency (IREDA) was entrusted with executing this initiative. Three private sector companies were awarded a combined capacity of 6 GW for fully integrated (Polysilicon-Module) manufacturing, involving an estimated investment of INR 4,455 crore. Notably, all three awardees hailed from the private sector.
- India's PLI scheme for Advance Chemistry Cells (ACC) aims to bolster local manufacturing, targeting 50 GWh capacity[33] for lithium-ion battery (LIB) cells while reducing import dependence. The scheme mandates a 60% domestic value addition within five years of commercial operations. Furthermore, private sector entities have announced approximately 95 GWh of battery manufacturing capacity, currently in various stages of development.
- Moreover, the results of the Solar Energy Corporation of India's (SECI) inaugural subsidy auctions for green hydrogen and electrolysers predominantly favoured private sector entities. Notably, seven of the winning bidders were private conglomerates[34].

Leading conglomerates are divesting from traditional fossil fuel portfolios and actively pursuing ambitious renewable energy targets. Government incentives such as PLI schemes are driving this transition, attracting substantial private investments primarily focused on local manufacturing across solar PV, batteries, and green hydrogen. Furthermore, private entities are emerging as key players in recent government auctions, consolidating their leadership in shaping India's clean energy future. This decisive shift towards private sector-led manufacturing underscores its critical role in advancing India's renewable energy aspirations and ensuring a sustainable future.

32. mnre.gov.in/production-linked-incentive-pli/
33. pib.gov.in/PressReleaseIframePage.aspx?PRID=1999072
34. www.seci.co.in/Upload/New/638404110109579816.pdf

Regulatory framework to support RE manufacturing

In 2021, the government announced import duties, constituted a pre-approved list of modules for usage in projects, and announced a manufacturing-linked subsidy scheme. In March 2021, the MNRE announced a basic customs duty (BCD) of 25% on imported solar cells and 40% on imported solar modules from April 2022. The MNRE released the first Approved List of Models and Manufacturers (ALMM) for solar modules in 2021. As per government orders, nearly all projects to be set up in India must use only the modules included in the ALMM list.

While India's solar manufacturing sector has seen a slow growth, domestic manufacturers have an opportunity to aggressively expand their presence and benefit from a favourable policy landscape. The years 2020 and 2021 saw large-scale supply chain disruptions and global shortages in polysilicon and other raw materials, which have led to a 40% increase in the price of imported solar modules.

The Indian government supports sustainable growth in the solar PV manufacturing industry by promoting both demand and supply of domestic PV products. Initiatives such as PM-KUSUM and CPSU Scheme boost demand with domestic module requirements. Meanwhile, schemes like the PLI provide financial assistance to manufacturers to enhance supply.

Measures to emerge as export hub in RE manufacturing

As India strides towards clean energy leadership, ambitions to become a global hub for renewable energy (RE) manufacturing are taking centre stage. However, achieving this goal requires addressing several critical aspects:

Bolstering manufacturing competitiveness

- Invest in R&D and innovation: Foster indigenous technology development and attract global tech partnerships to bridge the gap with established players.
- Skill development: Upskill the workforce for advanced manufacturing processes, ensuring a talent pool for export-oriented production.

Enhancing ease of doing business

- Streamline regulatory processes: Simplify approvals for land acquisition, environmental clearances, and export procedures.
- Improve infrastructure: Upgrade ports, roads, and logistics networks to efficiently handle large-scale production and export movement.
- Reduce bureaucratic hurdles: Ensure transparency and timely approvals to attract foreign investments and partnerships.

Building quality and brand recognition

- Implement stringent quality standards: Adhere to international benchmarks for RE components and products to gain global trust.
- Promote collaboration: Encourage joint ventures and partnerships with established international brands to leverage their expertise and market access.

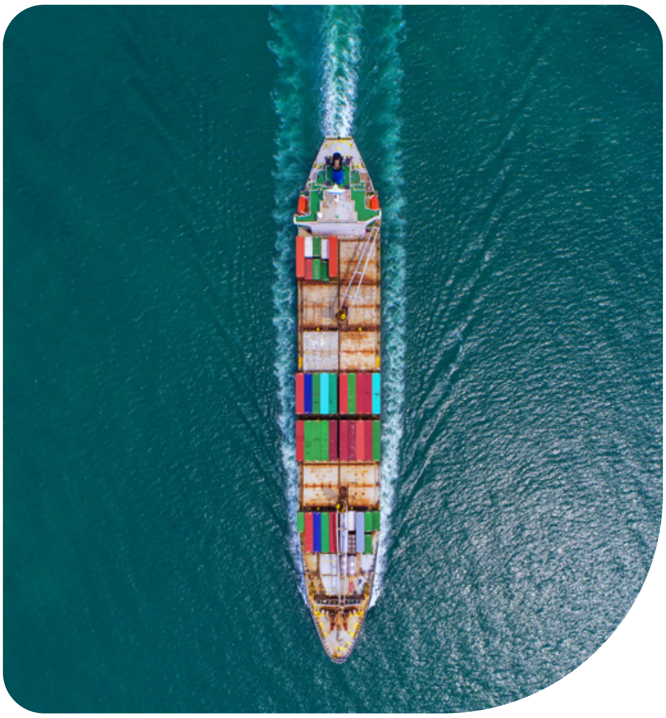
Others

- Technology development fund: To match the quality at the global level and players producing top-con and moving to heterojunctions cells and modules, India needs to invest huge on R&D and technological developments. For this, India needs separate technology development funds. The technology gap has drastically narrowed.
- Formation of independent bodies: Form a body that continuously works on future technologies and continuously tracks down the development at the global level.
- Long term and firm policy stability: India should come up with a long term and firm policy that instils confidence in the manufacturers to ramp up their capacity. A visibility in the long term will provide them with sustainable business. The solar sector is growing at a considerable rate, and the manufacturing sector is also seeing a huge investment coming in, and to protect that investment where investors see the businesses that are sustainable, there is a need for policy stability.

  Policy stability will also help manufacturers in their business planning and allocate their capital in R&D, expansion, etc. This will help in bringing clarity to manufacturers whether to invest in wafer manufacturing, plant or cell manufacturing, or setting up module manufacturing.
- Fostering R&D: In terms, the Council of Scientific & Industrial Research (CSIR) laboratory has already launched a policy and has chosen two laboratories, i.e., CSIR Chandigarh and CSIR Central Electronics Engineering Research Institute (CSIR-CEERI), Pilani. The CSIR will soon invite industry partners to carry out R&D in the right direction. The government is very well intended towards R&D and is doing its best possible for the intervention.
- Apart from the above, for the PLI scheme, there is a high entry barrier for the players who want to invest in manufacturing. There should be a policy measure that supports the business to enter into it. And barriers should be toned down. Also, there should not be any flip flop in the policy.
- Strengthening export opportunities: Another way to boost manufacturing and export could be to provide financing from the prescribed bank or state at a 3-4% interest cost. Like in the case of Germany, if someone imports machines from the country, the manufacturer gets financing at low interest rates, thereby giving jobs and other benefits in that particular factory. So, instead of giving a straight subsidy, they are making their product cost competitive. This could help in developing the ecosystem.

  In the Indian context, EXIM bank has previously supported Indian companies in a similar manner and supported Indian companies in doing projects in India and as well as in other countries. But there could be improvement in terms of considering more countries and considering not just those tenders where PPAs are given to specific entities. In case power is given directly to the government, even if it is done through any public sector undertaking, support should also be available in that case. Such models will increase the project visibility holistically and accelerate the development.

The outlook for India's PV manufacturing sector appears promising. In the coming two to three years, as India achieves self-sufficiency, it should shift its attention towards broadening its presence in international markets and positioning its PV products as competitive alternatives to China, emphasising quality and price. Meanwhile, maintaining stable policies is imperative to uphold investor confidence within the market. By implementing these crucial measures, India can unlock its potential as a global RE manufacturing powerhouse. A combination of policy support, infrastructure improvement, quality focus, strategic partnerships, and proactive trade initiatives will not only boost exports but also propel India towards a cleaner and more sustainable future.



3 Support of new and emergent technologies to achieve 500 GW

In order to achieve a monumental milestone of 500 GW renewable energy capacity, new and emergent technologies are posed to play a pivotal role in this ambitious endeavour. Embracing cutting-edge innovations such as advanced solar photovoltaics, offshore wind, energy storage solutions, biofuels and green hydrogen production holds the key to realising this goal. These technologies offer enhanced efficiency, scalability, and sustainability, propelling India towards a cleaner and greener energy future. By fostering research, development, and deployment of these new technologies, India can accelerate its transition to renewable energy, mitigate climate change impacts, and pave the way for a more resilient and prosperous future.

Offshore wind

In 2015, the government of India introduced the 'National Offshore Wind Energy Policy'[35], establishing a framework for the development of the offshore wind sector in the country. Following the policy notification, the government has issued the 'Guidelines for Offshore Wind Power Assessment Studies and Surveys' through the National Institute of Wind Energy. These guidelines enable private investors to conduct assessments of offshore wind resources. Additionally, the government is currently conducting offshore wind resource assessments and related studies in identified locations off the coast of Gujarat and Tamil Nadu. The objective is to validate the offshore wind resource potential in these areas. To further support offshore wind development, the Ministry has established a committee to create a roadmap for the country's existing and upcoming offshore wind projects.

The government has allowed foreign direct investment (FDI) of up to 100% through the automatic route for renewable energy projects[36], including offshore wind energy projects. This decision aims to attract foreign investors and promote the growth of the country's offshore wind sector.

In a strategy paper published on 26 September 2023[37], the MNRE proposed three models for the development of offshore wind energy projects:

Model-A (VGF model)

This approach will be followed for demarcated offshore wind zones for which MNRE/NIWE has carried out or proposed to carry out detailed studies/surveys. Presently, a part of identified Zone B3 (365 Sq.km) equivalent to 0.5 GW off the coast of Gujarat and 0.5 GW equivalent site off the TN coast will be considered in phase-1 of this model. The MNRE, through its implementing agencies, will come up with bids for procurement of offshore wind power capacity under this model. Necessary central financial assistance, such as viability gap funding (VGF), will be available to achieve a predetermined power tariff.

Model-B (Non-VGF but with exclusivity over seabed during the study/survey period)

This approach will be followed for sites identified by the NIWE. Proposed offshore wind sites demarcated within identified zones will be allocated for a fixed period on a lease basis through single-stage, two-envelope bidding. Project development will be carried out by the prospective developer in these sites without any central financial assistance (CFA). The power generated from such projects will be either used for:

- Captive consumption under open-access mechanism or
- Sold to any entity through a bilateral power purchase agreement or
- Sold through power exchanges

The government may also call for bids for procurement of power for DISCOMs based on tariff after two years. Benefits, such as provision of power evacuation infrastructure from the offshore pooling delivery point, waiver of transmission charge and additional surcharge, renewable energy credits with multipliers, carbon credit benefits, etc., as determined by GOI/state governments from time to time will be applicable.

35. pib.gov.in/newsite/PrintRelease.aspx?relid=126755
36. www.investindia.gov.in/sector/renewable-energy
37. mnre.gov.in/off-shore-wind/

Model-C (Non-VGF and without exclusivity over seabed during the study/ survey period)

In this model, the developer may identify any offshore wind site within the EEZ excluding the sites considered under Model-A and Model-B. They will also undertake studies and surveys. The government will come up with bids for project development/ allocation of the seabed. The bidding may include any one of the following methods:

- Bidding on lease/allocation fee or revenue sharing in case of projects for captive consumption/third party sale/sale through exchange under open access mechanism.
- Tariff-based competitive bidding in case of power procurement by DISCOMs or the central government or state governments.
- Any other transparent bidding mechanism identified by the government.

Key challenges

- **Infrastructure deficit:** India lacks specialised vessels, ports, and transportation infrastructure tailored for offshore wind installations and maintenance. This drives up costs and delays projects.
- **Uncharted territory:** Comprehensive environmental and social impact assessments (ESIAs) are crucial for understanding the potential effects of offshore wind farms on marine ecosystems and coastal communities. However, such assessments for large-scale projects remain limited in India.
- **Regulatory labyrinth:** The current regulatory framework lacks clarity and consistency for offshore wind development. Issues such as permitting, grid access, and tariff determination remain ambiguous, deterring potential investors.
- **Financial currents:** Offshore wind projects carry a hefty price tag, making them less competitive compared to established sources such as onshore wind or coal. Without adequate financial incentives or risk-mitigation mechanisms, attracting investments becomes challenging.
- **Talent tides:** India needs to nurture a workforce skilled in offshore wind development, operation, and maintenance. This includes engineers, technicians, and specialists across various disciplines.

Recommendations

- **Building the harbour:** Invest in port upgrades and specialised vessels capable of handling offshore wind installations. Consider public-private partnerships to accelerate infrastructure development.
- **Navigating with care:** Conduct rigorous and transparent ESIAs that adhere to international best practices and address stakeholder concerns. This foster trust and paves the way for sustainable development.
- **Charting a clear course:** Develop a comprehensive and streamlined regulatory framework that clarifies permitting processes, grid access procedures, and tariff determination. Align with international standards to attract global expertise and financing.
- **Weathering the financial storm:** Implement attractive financial incentives, such as tax breaks, grants, or feed-in tariffs, to bridge the cost gap between offshore and onshore wind. Explore innovative financing models and risk-sharing mechanisms.
- **Riding the waves of change:** Invest in skilling and training programmes to create a robust talent pool with expertise in offshore wind development, operation, and maintenance. Partner with academic institutions and industry leaders to bridge this critical gap.

Case study

Lhyfe's ground-breaking offshore green hydrogen production venture[38]

Sealhyfe marks a pioneering initiative in offshore hydrogen production, a collaborative effort by Lhyfe and its partners, harnessing renewable energy from a floating wind turbine. The core setup features a 1 MW electrolyser situated on the WAVEGEM, a compact floating platform spanning less than 200 square meters. Capable of generating up to 400 kilograms of hydrogen daily, this innovative system is strategically positioned 20 kms from the shore and is exclusively powered by the FLOATGEN floating wind turbine.

Phase 01

Inaugural testing

The initial phase involved testing the system at the Quai des Frégates, Port of Saint-Nazaire, over an eight-month period from September 2022 to May 2023. The system underwent rigorous testing at the Quai des Frégates, Port of Saint-Nazaire, spanning eight months from September 2022 to May 2023. This included benchmarking tests to record platform behaviour, technology optimisation for offshore conditions, and the development of remote management solutions through software and algorithms. These trials at the quay allowed Lhyfe to enhance technology performance and ensure minimal maintenance interventions at sea.

Phase 02

Commencement of offshore production

The system was transported 20 kms off the coast of Le Croisic, France, and remarkably restarted, becoming operational within a mere 48 hours.

Phase 03

Advancing to the next stage

Lhyfe revealed that the HOPE project secured 20 million euros in funding, enabling the construction of a 10 MW offshore hydrogen production plant. This facility will have the capacity to produce 4 tonnes of green hydrogen daily at sea. The produced green hydrogen will be transported ashore through pipelines, then compressed and delivered to customers, marking a significant stride in sustainable offshore hydrogen production.

38. www.lhyfe.com/press/lhyfe-announces-that-sealhyfe-the-worlds-first-offshore-hydrogen-production-pilot-produces-its-first-kilos-of-green-hydrogen-in-the-atlantic-ocean/

Biofuels

Biofuels have already been acknowledged as one of the most feasible solutions to the diminishing fossil fuels reserves, along with many key advantages such as cost benefits, empowering rural economy, and reducing carbon footprint. In addition to reducing dependence on fossil fuels, biofuels also serve as a catalyst to strengthen the economy by reducing government expenditure on fossil fuel imports, increasing farmers' income by turning them from food producers to fuel producers, supporting new businesses, mainly start-ups, and achieving energy security and energy independence as well. At this juncture, it is encouraging to see the Indian government providing much-needed assistance to production of biofuels. Due to the government's efforts, the country achieved the target of 10% ethanol blending in 2022 and saved as much as INR 53,894 crore[39] in forex outgo from 10% blending besides benefiting the farmers. Buoyed by this, the centre has already advanced the target of 20% ethanol blending in petrol 2030 to 2025[40], which is promising.

India's Biofuel Policy 2018

The Indian government has made key amendments to its 2018 National Policy on Biofuels to support greater domestic biofuels production. The policy includes an accelerated national E-20 mandate from 2030 to 2025, which aims to increase the capacity of ethanol production in India from 7 billion litres (BL) in 2021 to 15 BL in 2025. The National Biofuel Coordination Committee, which consists of 14 different ministries, amended the policy to allow conversion of excess cereal grains for ethanol under the EBP programme. The amended policy permits additional feedstocks for biofuel production. The revisions allow for the manufacturing of ethanol from corn (maize), food grains, including broken rice, wheat, non-suitable grains for human use, and other non-food sources (2G). Other additions to the policy include the domestic production and sale of flexible-fuel vehicles (FFV), and the promotion of domestic biofuel production of biofuels through special economic zones and export-oriented units under the Make in India campaign.

To achieve the E-20 target by the end of the Indian financial year 2024/2025 (ESY), the government is encouraging sugar mills and stand-alone distilleries to divert surplus sugar and derivatives and procure excess grains from the Food Corporation of India (FCI) to produce ethanol under the Ethanol Blending Programme (EBP).

Excluding union territories, oil marketing companies (OMCs) are responsible for nationwide blending of ethanol into gasoline. The Cabinet Committee of Economic Affairs (CCEA) has approved the government's **Pradhan Mantri JI-VAN Yojana**[41], which provides 'viability gap funding' to 2G bioethanol manufacturing projects to increase ethanol production for blending[42]. The EBP has established an organised and regulated domestic marketplace where ethanol produced by sugar mills or standalone distilleries can enter into long-term agreements to sell ethanol to the OMCs at fixed rates. This initiative aims to prevent scattered ethanol diversion from mills for localised purchasing and provides safe purchasing alternatives, secure transportation costs, and timely payments to safeguard mills. As of November 2022, OMCs have invested USD 91 million (INR 7.5 billion) to enhance their ethanol storage capacity, totalling 344 million litres. This provides ethanol storage for a 20-day turnaround period at their depots, as reported by the Ministry of Petroleum and Natural Gas (MoPNG). Furthermore, the government's financial assistance programme to sugar mills for ethanol production increased by 54% in Indian Fiscal Year (IFY) 2023/2024, compared to IFY 2022/2023.

Biodiesel policy

India maintains an ambitious diesel blending goal (on-road use) target of 5% with biodiesel by 2030. According to the Indian government, the national average blend rate has marginally increased from 0.07% in 2022 to 0.10% in 2023[43]. India's biodiesel production is primarily produced from animal fats, limited quantities of non-edible oils, UCO, and imported palm oil and palm stearin. Biodiesel utilisation in India remains exceptionally low due to import limitations, a lack of an organised supply chain, and excessive costs and non-availability of feedstocks. Approximately 3 MMT of UCO are produced annually, but a lack of stable procurement mechanisms results in limited uptake. Around 80% of biodiesel production expenses stem from feedstock procurement.

Other biofuels: Drop-in-fuels, bio-CNG, bio-Hydrogen, bio-methanol, Di-Methyl-Ether

On 2 November 2022, the Ministry of New and Renewable Energy (MNRE) extended its National Bioenergy Programme from IFY 2021/2022 to 2025/2026, to focus on three areas, notably waste to energy, biomass, and biogas . On 15 December 2022, the Indian government announced various initiatives for establishing domestic bio-compressed natural gas (CNG) plants, including via the Sustainable Alternative Towards Affordable Transportation programme (SATAT), which has the goal to establish 5,000 bio-CNG operations to produce a cumulative 15 MMT of bio-CNG by IFY 2023/2024[45].

First launched in 2018, the goal of SATAT is enhancing the application of various biomass feedstocks, including municipal

39. mopng.gov.in/files/uploads/BPCL_Ethanol_Booklet_2023.pdf
40. pib.gov.in/PressReleasePage.aspx?PRID=1984975#:~:text=The%20Government%20has%20achieved%20the,the%20target%20of%20November%2C%202022.
41. pib.gov.in/PressReleasePage.aspx?PRID=1843441
42. Funding provided to support infrastructure projects is considered economically justified but lacks financial viability
43. Remarks by Nirmala Sitharaman: Union Budget 2023-2024, Government of India, February 1, 2023
44. "MNRE Notifies National Bio Energy Programme." MNRE
45. "Establishment of Bio-CNG Plants." Press Information Bureau,

solid waste, press mud and agricultural residues (bio-manure). The compressed biogas would be sold at OMC fuel stations as a green transport fuel alternative. According to MoPNG, 38 compressed biogas plants have been commissioned with an installed capacity of 125 million metric tonnes[46].

The Ministry of Science and Technology has invested in technologies to scale enhanced biofuels production, including biohydrogen, biobutanol, and synthetic hydrocarbons[47]. The Department of Biotechnology-Indian Oil Corporation Center established the first pilot programme to produce biodiesel using carbon dioxide through 'high value' lipids technology[48]. The laboratory is also producing biohydrogen using sugars derived from various biomass sources through anaerobic fermentation.

Key challenges

The biofuel sector in India has significant potential to contribute to the country's energy security, reduce its carbon footprint, and create jobs. However, there are few challenges that need to be addressed to bring about holistic growth.

Technical challenges

- **Technology development:** The development of advanced biofuel technologies, such as second-generation biofuels and waste-to-energy conversion, is still in its early stages in India. This limits the commercialisation of these technologies and the production of sustainable biofuels
- **Feedstock availability:** The availability of sustainable feedstock is critical for the growth of the biofuel sector in India. However, competing land uses and the diversion of food crops for biofuel production pose challenges to feedstock security.
- **Conversion efficiency:** The conversion efficiency of biofuel production processes is relatively low, leading to higher costs and lower yields.
- **Quality control:** Establishing and enforcing quality standards for biofuels is essential to ensuring their performance and safety. However, limited testing facilities and weak enforcement mechanisms pose challenges to quality control in India.

Financial challenges

- **High investment costs:** The upfront investment costs for biofuel projects are high, especially for second-generation biofuels and waste-to-energy projects. This can deter potential investors and hinder the development of the sector.
- **Lack of subsidies and incentives**: Government subsidies and incentives are essential to make biofuels competitive with conventional fuels. However, the current level of support in India is inadequate.
- **Price volatility:** The prices of agricultural feedstocks and biofuels are volatile, making it difficult for biofuel producers to plan and operate their businesses profitably.
- **Limited market access:** The market for biofuels in India is still limited, due to factors such as consumer awareness, lack of infrastructure, and blending mandates.

Regulatory challenges

- **Complex regulatory framework:** The regulatory framework for the biofuel sector in India is complex and fragmented. This can create uncertainty for investors and make it difficult to navigate the regulatory landscape.
- **Delayed approvals:** The approval process for biofuel projects can be lengthy and cumbersome, delaying project implementation.
- **Limited enforcement:** Weak enforcement of existing regulations can lead to unfair competition and discourage investment in the sector.
- **Lack of coordination:** There is a lack of coordination among different government agencies involved in the biofuel sector. This can lead to policy inconsistencies and delays in implementation.

By addressing the technical, financial, and regulatory challenges, India can accelerate the growth of the biofuel sector and achieve its ambitious biofuel targets. Few recommendations proposed are as follows:

Recommendations

- **Support research and development in advanced biofuel technologies:** The government should support research and development in advanced biofuel technologies, such as second-generation biofuels and waste-to-energy conversion. This will help to reduce the cost of biofuel production and improve its competitiveness.
- **Promote sustainable feedstock production:** The government should promote the production of sustainable feedstocks for biofuels, such as non-food crops and agricultural residues. This will help to address concerns about food security and land use.
- **Develop and enforce quality standards:** The government should develop and enforce quality standards for biofuels to ensure their performance and safety. This will boost consumer confidence in biofuels and promote their adoption.
- Increase the use of non-food biofuels such as jatropha, palm oil, and coconut oil.
- Develop a robust supply chain management system to ensure efficient transportation and distribution of biofuels.
- Encourage the use of advanced biofuels such as cellulosic ethanol and algal oil.
- Promote the development of biofuel production facilities in various parts of India.
- Collaborate with international organisations to gain access to advanced biofuel technologies and best practices.

46. "38 CBG/Biogas Plants with Installed Capacity of 225 MT per annum Commissioned", ICN Bureau
47. See: Scientific Decision Units, Department of Biotechnology, Ministry of Science and Technology
48. The process separates chemical production from commodity feedstocks and converts carbon dioxide into acetic acid and the later to lipids (algal oil) including omega 3-fatty acids and biodiesel.

Agri Photovoltaics (AgriPV)

Agri PV technology integrates solar panels within agricultural settings, offering a dual-purpose approach that enhances land productivity, and is emerging as a win-win for India's energy and food security. By optimising land use, Agri PV offers advantages such as increased farmer income, reduced land pressure and improved water conservation. The dual use of land allows for additional income through both crop cultivation and solar energy production. This co-existence benefits rural communities by diversifying revenue streams and promoting energy self-sufficiency.

Key challenges

- **Balancing agricultural needs:** Ensuring compatibility with farming practices and avoiding adverse impacts on crop yields is crucial.
- **Initial infrastructure costs:** Setting up Agri PV projects can be expensive (approximately between 1.3 to 2 times), requiring supportive policies and financing mechanisms.
- Financing and support: Commercial adoption requires government support to overcome initial high costs. Concessional green financing tied to clearly defined standards would incentivise developers and encourage wider adoption. This will allow entrepreneurs to focus on projects eligible for support and maximise the impact of government initiatives.
- **Business model mismatch:** Current Agri PV projects focus on technical aspects, overlooking crucial business model development. Aligning the incentives of farmers (land access) and developers (power generation) remains a significant challenge. States need to actively test diverse business models, integrating farmer perspectives and considering different local contexts.
- **Regulatory ambiguity:** Existing land-use and tax regulations do not adequately support agri PV. The lack of consistent standards and definitions creates confusion and discourages potential investors. Establishing clear regulations alongside streamlined land-use permits would significantly improve the environment for project development.
- **Capacity building gap:** Both farmers and developers need capacity building to navigate the nuances of agri PV systems. Training programmes focusing on operation, maintenance, and financial considerations can empower stakeholders and facilitate seamless project implementation.

Recommendations

- **Pilot diverse business models:** Encourage states to explore innovative approaches, prioritising farmer involvement and local context.
- **Streamline regulations and define standards:** Develop clear and consistent regulations alongside standardised definitions for agri PV projects, promoting transparency and attracting investment.
- **Offer green financing solutions:** Implement concessional financing schemes linked to established standards, incentivising project development and reducing initial cost barriers.
- **Invest in capacity building:** Enhance capacity-building programmes for both farmers and developers, empowering them to manage and profit from agri PV opportunities.

Floating solar

Floating solar, deploying panels on water bodies such as reservoirs and lakes, offers exciting possibilities for India's clean energy landscape. This innovative approach addresses the challenge of land scarcity for large-scale solar installations while offering additional benefits, such as efficient land use, reduced evaporation and cooler water temperatures. This technology is gaining traction globally as a sustainable and space-efficient solution to harness solar energy, providing an innovative pathway toward cleaner and more resilient energy systems.

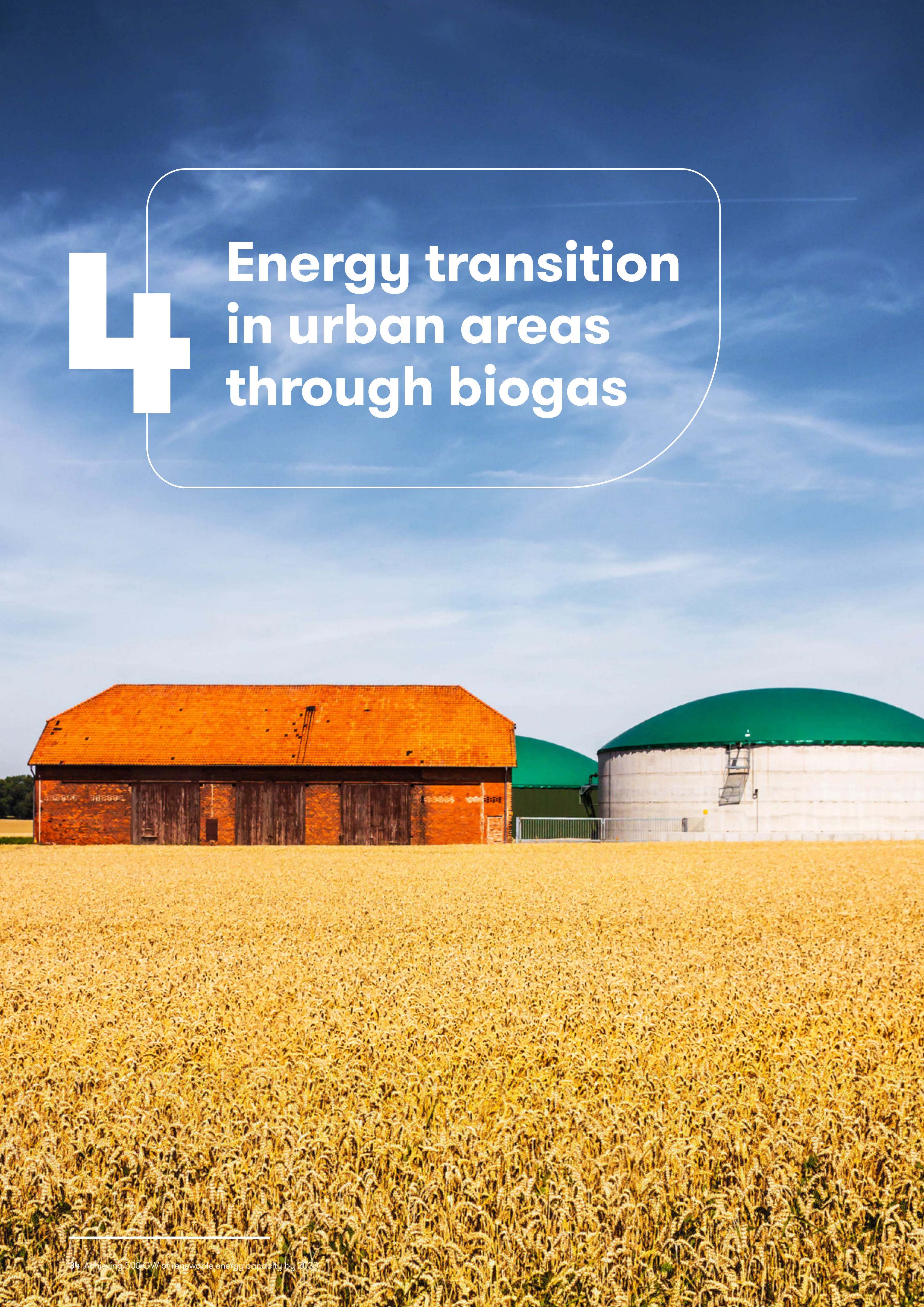
Key challenges

- **Cost burden:** High upfront costs and specialised maintenance raise the price tag. Innovative financing and cost-efficient materials are key to smooth sailing.
- **Environmental balancing act:** Balancing energy generation with ecosystem protection is crucial. Eco-friendly platforms, thorough impact assessments, and sustainable materials are the anchors for responsible deployment.
- **Site selection dilemma:** Finding the perfect watery home depends on depth, waves, wind, and existing activity. Detailed data analysis and stakeholder collaboration chart the course for optimal location.
- **Technical hurdles:** Weatherproof platforms and robust electrical systems are essential to withstanding the aquatic elements. Innovation and expertise are the lifeboats for overcoming these technical challenges.

Recommendations

- **Cost reduction strategies:** Invest in innovative materials, streamlined installation, and smart financing models to bridge the cost gap.
- **Environmental stewardship:** Prioritise rigorous impact assessments, eco-friendly platform designs, and responsible material choices.
- **Data-driven site selection:** Invest in detailed data analysis and stakeholder collaboration to optimise location feasibility and minimise environmental impact.
- **Tech innovation and collaboration:** Encourage research and development for weatherproof platforms, robust anchoring systems, and resilient materials.

4 Energy transition in urban areas through biogas



According to the International Energy Agency (IEA) Bioenergy Report 2022, modern bioenergy is the largest source of renewable energy globally, accounting for 55%[49] of renewable energy and over 6% of the global energy supply. About 32% of the total primary energy use in India is still derived from biomass and more than 70%[50] of the country's population depends on it for its energy needs.

The current combined installed capacity of bioenergy and waste to energy in the country is given as 10.84 GW[51] as on 31 December 2023, whereas the projected installed capacity of biomass energy is 14.5 GW by 2030. The total estimated energy generation potential from urban and industrial organic waste in India is approximately 5.69 GW. To support a greater number of projects and promote ease of doing business in the country, the MNRE expanded the bio-energy programme by bringing all three separate schemes under one umbrella programme viz. the National Bioenergy Programme (NBP). The programme has a budget outlay of INR 1,715 crore and is to be implemented in two phases.

Avenues for integration of biogas with urban energy infrastructure

There are different types of wastes that are generated from our daily or industrial activities, such as organic waste, e-waste, hazardous waste, inert waste, etc. However, organic waste has a significant portion in overall waste generation in the industrial/ urban/ agricultural sector, and therefore, it can be used for energy generation. The organic fraction of waste can be further classified as non-biodegradable and biodegradable organic waste. As urban centres strive for sustainable energy solutions, the integration of biogas presents diverse opportunities across multiple facets of energy infrastructure. By exploring these diverse avenues for biogas integration, Indian cities can unlock the potential of this clean energy source for their energy needs. Few avenues of integration are as listed below:

- **Grid-connected biogas plants:** Urban waste holds immense potential for generating clean energy through grid-connected biogas plants. These large-scale facilities process organic waste, producing biogas that can be converted into electricity and fed directly into the power grid. This not only contributes to renewable energy goals but also reduces reliance on fossil fuels, lowering greenhouse gas emissions and improving air quality in urban areas.
- **Biogas for transportation:** Compressed biogas (CBG) derived from organic waste provides a sustainable alternative to fossil fuels for powering urban transport systems. It can be used in buses, taxis, and commercial vehicles, reducing dependence on imported oil and mitigating particulate matter emissions.
- **Industrial co-digestion:** Industrial waste often contains organic materials suitable for co-digestion alongside municipal waste in biogas plants. This collaborative approach increases biogas yields, optimises waste management for industries and provides them with cleaner energy options.
- **Biogas for decentralised energy needs:** Smaller-scale biogas plants can be set up in individual buildings, communities, or institutions, catering to their specific energy needs. This decentralised approach reduces reliance on the centralised grid, promotes energy independence, and utilises local waste resources effectively.

Biogas in action: Successful implementations

Many countries have recognised the potential of biogas and have implemented initiatives to promote its use:

Copenhagen, Denmark

Copenhagen, renowned for its commitment to sustainability, has successfully implemented biogas as part of its urban energy mix. At the Biogas Park in Avedøre, Copenhagen[52], the sewage sludge from Copenhagen is treated at the Biofos' wastewater treatment plant and processed through anaerobic digestion to produce biogas. The biogas produced from sewage sludge is then cleaned in HOFOR's biogas upgrading plant supplied by Ammongas, where the CO2 is separated from the CH4, creating clean biomethane ready for grid injection. Meanwhile, using excess wind energy an electrolyser creates hydrogen for Electrochaea's methanation plant. By combining the now separated CO2 from the upgrading plant, with the hydrogen created from excess wind energy, Electrochaea's methanation plant creates additional biomethane, which together with the biomethane from upgrading, is injected into the natural gas grid, thereby replacing natural gas with green biomethane for the Copenhagen households, transport, factories, and heat and power. Thus, Copenhagen supplies their own gas via the Avedøre Biogas Park.

49. www.iea.org/energy-system/renewables/bioenergy
50. sansad.in/getFile/lsscommittee/Energy/17_Energy_41.pdf?source=loksabhadocs
51. cea.nic.in/wp-content/uploads/installed/2023/12/IC_31_Dec_2023.pdf
52. www.energy-community.org/dam/jcr:b6f793b6-85c1-447c-a803-baa936bf02bc/Avedore_ENG.pdf

Stockholm, Sweden

Stockholm, another frontrunner in sustainable urban development, has embraced biogas as an integral part of its public transport system[53]. The city operates a fleet of buses powered by biomethane produced from sewage sludge and food waste. Storstockholm's Lokaltrafik (Greater Stockholm Local Transport, SL) has invested heavily in new biogas-powered articulated buses, but also in a new filling point at the Söderhallen bus depot. The biogas with which the buses are refuelled comes through a direct line from the nearby sewage treatment plant in Henriksdal. The projects have received support from Klimp and is a good example of the switch from fossil fuel to biofuel, where the environmental and financial effects benefit both transport providers and travellers.

Pitten, Austria

In Pitten, Austria, 450,000 tonnes of paper and board are produced annually on 2 paper machines. Due to the focus on sustainability, recycling waste streams from the industry via the anaerobic digestion of wastewater. W.Hamburger has used recycled paper for decades as a raw material for the production of various paper and board products. In accordance with environmental regulations and additionally to gain a competitive business advantage, different stages of wastewater treatment are installed. In Pitten, W.Hamburger operates its own wastewater treatment plant to clean wastewater volumes of 6,000 m^3 per day. After a mechanical cleaning stage, four anaerobic reactors with a total volume of 3,500 m^3 generate approximately 17,600 Nm^3 of biogas per day[54] (c. 3m3 biogas per m3 wastewater), depending on the operating status. There is also a biogas storage tank with a volume of 250 m^3 at 35 mbar. The produced biogas is cleaned in a biogas scrubber and combusted in boilers for thermal energy and in a combined heat and power (CHP) process for electrical and thermal energy production. The wastewater is finally treated in an aerobic stage in house before final cleaning offsite in the municipal wastewater treatment facility.

Potential of biogas to achieve cross sectoral benefits in urban settings

Urban biogas not only provides a clean energy source but also offers a multitude of benefits across various sectors, contributing to a more sustainable and liveable urban environment.

- **Waste Management:** Biogas plants process organic waste, diverting it from landfills and reducing the burden on waste management systems. This not only lowers waste disposal costs but also minimises environmental pollution caused by landfills. Additionally, it creates valuable compost as a by-product, enriching soil and promoting sustainable agriculture.
- **Public health:** By diverting organic waste from landfills, biogas production reduces air and water pollution caused by methane emissions and leachate contamination. This improves public health by minimising exposure to harmful pollutants and mitigating respiratory illnesses.
- **Energy independence:** Reliance on biogas reduces dependence on imported fossil fuels, contributing to energy security. Communities or countries with successful biogas programmes can diversify their energy sources and enhance their resilience against global energy market fluctuations.
- **Livelihood creation:** The biogas sector creates diverse employment opportunities throughout the value chain, including waste collection, plant operation, and compost marketing. This empowers local communities and contributes to economic development.
- **Climate change mitigation:** Biogas replaces fossil fuels, leading to significant reductions in greenhouse gas emissions such as methane and CO2. This contributes to India's climate change mitigation goals and promotes a low-carbon future.

53. http://naturvardsverket.diva-portal.org/smash/get/diva2:1780007/FULLTEXT01.pdf
54. task37.ieabioenergy.com/wpcontent/uploads/sites/32/2022/03/Case_Story_Austria_July_2021.pdf

Few cross-sectoral benefits realised from a 1 TPD compressed biogas plant is as follows:

Import dependency reduction

Entire imported coal needed for power production can be replaced with biomass without creating a dent on the Indian exchequer (In FY21, 215.25 MT of coal was imported)

Saving in cross sectoral subsidies

- 1 TPD of CBG plant can produce ~3 TPD of bio-manure which can replace the fertilizer used in crops
- 1 TPD CBG plant can help in saving ~INR 1.5 Crores of fertilizer subsidy

Environmental benefits

1 TPD of MSW processing at the CBG plant can help in saving INR 225-400/ton/day as solid waste management cost through landfill development

Social benefits

- 1 TPD CBG plant typically creates 5-6 direct jobs and 30-35 indirect jobs
- Boost to rural economy by job generation, poverty reduction, access to decent living, better health care, etc.

These cross-sectoral benefits highlight the multifaceted impact of biogas in urban settings. By harnessing its potential effectively, Indian cities can move towards a more sustainable future, tackling waste management, improving public health, creating new jobs, and combating climate change, all while generating clean energy.

Bioenergy policy landscape in India

Achieving the ambitious renewable energy targets and fostering self-reliance in the energy sector necessitate the optimal utilisation of domestically available renewable alternatives. Modern bioenergy stands out as a viable option, given the substantial surplus of biomass and other waste in the country. To address this opportunity, the Ministry of New and Renewable Energy (MNRE) has officially introduced the National Bioenergy Programme, spanning from 1 April 2021 to 3 March 2026, with an allocated budget of INR 858 crore for Phase-I[55]. This initiative aims to harness the potential of bioenergy for sustainable energy recovery, aligning with the broader goal of achieving a resilient and self-sufficient energy landscape.

Component-wise details of the capacity to be added along with the expected investment and budget outlay is given in the table below:

Budget outlay of National Bioenergy Programme Phase-I (Rs in crore)

Sub-schemes	Budget outlay of Phase-I (INR in crore)
Waste to energy programme	600
Biomass programme	158
Biogas programme	100
Total	858

The details on the sub-schemes are as follows:

- **Waste to energy programme (Programme on energy from urban, industrial and agricultural wastes/residues):** The programme supports the recovery of energy in the form of biogas, bio-CNG, and power from urban, industrial, and agricultural wastes and residues. The programme also aligns with the SATAT scheme of the Ministry of Petroleum and Natural Gas on CBG production, which targets the production of 15 MMT of CBG from 5,000 plants by 2023.
- **Biomass programme (Scheme to support manufacturing of briquettes & pellets and promotion of biomass (non-bagasse) based cogeneration in industries):** This programme supports the manufacturing of pellets and briquettes for use in power generation, and the promotion of biomass-based cogeneration in industries. The programme also supports the implementation of the National Mission on Co-firing of Biomass in Thermal Power Plants, which can help reduce stubble burning and air pollution.
- **Biogas programme:** The programme provides financial assistance for the setting up of biogas plants from 1 to 2,500 cubic meter biogas per day, for providing clean gaseous fuel for cooking, lighting, and power generation in rural areas.

Key market developments

The Indian biogas sector is witnessing a surge in private sector participation, driven by growing awareness of the environmental and economic benefits of biogas. Here are some notable initiatives:

- Finance Minister in Budget 2024: The government to mandate phased blending of biogas in CNG, PNG[56].
- Reliance to set up 100 compressed biogas plants in 5 years[57]. This is expected to create a significant impact on the sector's growth.
- The Adani Group has also announced plans to set up multiple CBG plants[58]. These initiatives by major industrial players are expected to boost investor confidence and attract further investment into the sector.
- Adani Total Gas was awarded to design, build, finance, and operate a 500-tonnes-per-day capacity Bio-CNG (CBG) plant[59] by the Ahmedabad Municipal Corporation (AMC).
- EverEnviro is currently undertaking 20 CBG projects across India, with five projects slated for commissioning by March 2024[60].
- Thermax has secured an order worth over 5 bn rupees (USD 60mn)[61] from an energy conglomerate to set up five bio-CNG plants across India. The company will set up one plant in the state of Rajasthan, one in the state of Madhya Pradesh, two in the state of Maharashtra and one in Uttar Pradesh. With the capacity to produce 110 tonnes/day of bio-CNG, these plants will utilise local feedstock exceeding 1,000 tonnes/day, which includes rice straw, Napier grass, cane trash and soya trash.
- India also announced the Global Biofuel Alliance as one of the top priorities of its G20 Presidency[62]. The alliance, proposed by India, was launched on 9 September 2023, along with leaders from Singapore, Bangladesh, Italy, the United States of America, Brazil, Argentina, Mauritius and the United Arab Emirates (UAE).

55. mnre.gov.in/bio-energy/
56. static.pib.gov.in/WriteReadData/specificdocs/documents/2024/feb/doc202421304701.pdf
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Challenges and solutions in urban biogas adoption

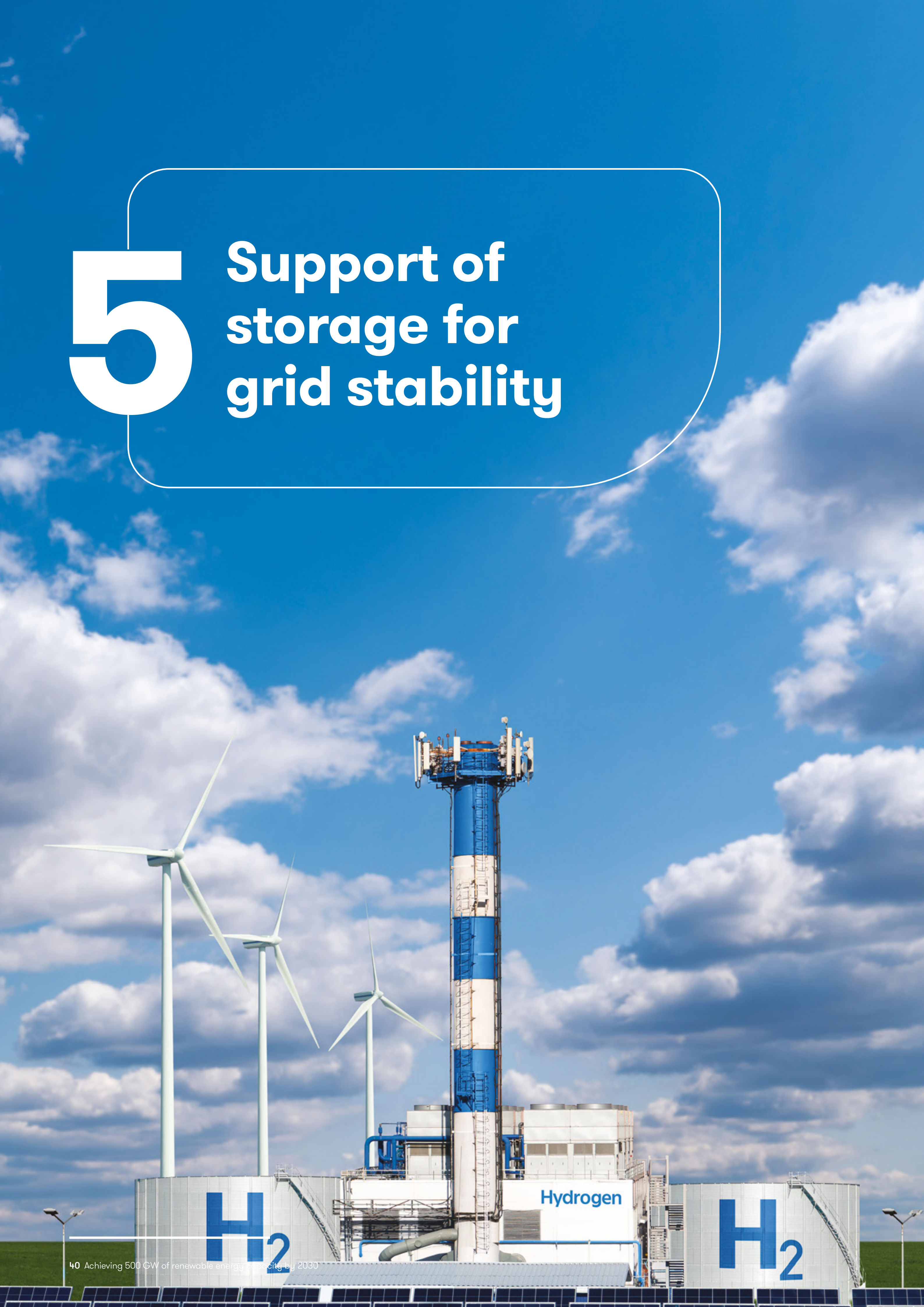
Key challenges

- **Disaggregated and uncoordinated policy support:** Multiple departments and ministries have different schemes and packages for biogas or CBG plants, which results in implementation gaps and slow uptake of the sector.
- Another limitation of biomethane injection to natural gas systems is that the production of biogas can significantly fluctuate due to changes in environmental and digestion parameters, such as feedstock quality, humidity, temperature, and seasonal variations, and this can cause supply challenges to small gas distribution systems, thus limiting economic viability of the gas supply systems.
- **Lack of private sector participation and investment:** The biogas sector lacks a comprehensive market ecosystem in terms of pricing and offtake, which discourages private players from entering the sector. There is also high capital cost and risk involved in setting up biogas plants.
- **Technical and operational issues:** Biogas plants require proper design, construction, and maintenance. Lack of technical expertise and operational knowledge can lead to inefficient plant performance, gas leaks, and other issues.
- **Variability in feedstock availability:** Availability of organic waste (feedstock) for biogas production can be inconsistent due to seasonal variations, crop cycles, and waste management practices.
- **Financing and funding constraints:** Setting up biogas plants involves capital investment, which can be a barrier for small-scale consumers and entrepreneurs. Access to affordable financing options is crucial.

Key solutions

- **Policy consolidation and coordinated working:** The government should consolidate the various schemes under a unified portal and ensure a 'whole of government' approach to promote biogas.
- In Germany, biogas power generation is profitable just because of grid connection and attractive feed-in tariffs. It is noted that output-oriented support schemes as opposed to investment-oriented financial support are more effective and successful in promoting biogas power generation.
- **Enhance private sector participation:** The government should provide incentives and guarantees for CBG offtake, co-mingling of CBG in the CGD network, and market development assistance for biogas slurry. The public-private partnerships, blended finance and microfinancing can help in easing the financial burden and de-risk the sector.
- **Skill development and technical support:** The report suggests establishing training centers or institutes to train technicians, operators, and maintenance personnel. Providing technical assistance and troubleshooting support to existing biogas plant owners can improve plant efficiency and reliability.
- **Diversification and waste management:** Encouraging diversification of feedstock sources (such as agricultural residues, kitchen waste, and animal dung) can mitigate the impact of variability. Integrated waste management practices, including waste segregation and collection, can ensure a steady supply of feedstock.
- New municipalities, which have infrastructures yet to be developed, can take steps in sewage water treatment system into their agenda of development. This will certainly help in waste management as well as utilisation in the production of biogas.
- **Financial incentives and credit facilities:** The government can provide subsidies, grants, and low-interest loans for biogas plant installation. Collaborating with financial institutions to create specialised credit products for biogas projects can facilitate investment.

5 Support of storage for grid stability



Need for grid resilience and emergency preparedness

The support of energy storage for grid stability is not merely an option but a necessity in transition to a sustainable and reliable energy future. As technology continues to advance and investments in storage solutions increase, one can expect even greater strides in fortifying our grids against the challenges posed by renewable energy integration. In this regard, battery storage is a promising technology that can enhance grid resilience and emergency preparedness. By providing backup power, micro-grid capabilities, frequency control, voltage support, and black start services, battery storage can help the power system withstand and recover from disruptions caused by natural disasters, cyberattacks, or other events. Battery storage can also reduce the impacts of emergencies by reducing peak demand, congestion, and losses on the transmission and distribution network, and by increasing the utilisation of renewable energy sources.

Green hydrogen

Green hydrogen and green ammonia – produced using renewable electricity and air or biomass-based thermochemical pathway having emissions of no more than 2 kg CO2 per kg of hydrogen produced – are poised to be game-changers in India's quest for 500 GW of renewable energy by 2030[63]. Electrolysis separates water into hydrogen, offering a clean fuel for power generation, transportation, and industrial applications. However, ammonia presents additional advantages. As a liquid at room temperature, it is easier to transport and store compared to gaseous hydrogen, unlocking its potential for long-distance energy transport and seasonal energy storage.

Current status and projected growth

India plans to develop green hydrogen production capacity of at least 5 MMT by 2030, but the potential holds much more promise. Green hydrogen can replace grey hydrogen (derived from fossil fuels) in sectors such as petroleum refining, fertilizer production and steelmaking, significantly reducing CO2 emissions. Furthermore, its role in blending with existing fuels such as CNG and diesel can decarbonise transportation, while its use in fuel cells for heavy-duty vehicles and shipping offers a clean alternative to traditional combustion engines.

Current green hydrogen demand to meet the needs is as follows:

5 MMT GH2 production annually

50 GW Electrolyser capacity

50 MMT of carbon emission reduction annually

125 GW Renewable energy capacity

50bn litres of water requirement

While challenges remain – including high production costs and limited infrastructure – the Indian government's support through the National Hydrogen Mission and increasing private investments indicate a rapidly evolving landscape. With technological advancements and cost reductions expected, green hydrogen and green ammonia are poised to not only contribute significantly to India's 500 GW target but also play a key role in achieving long-term energy security and climate goals.

63. static.pib.gov.in/WriteReadData/specificdocs/documents/2023/aug/doc2023819241201.pdf

Potential of hydrogen-based energy storage

Hydrogen energy storage technologies would play a key role when India transitions to a full-scale decarbonisation pathway beyond 2030. The potential of hydrogen-based energy storage, especially for medium- and long-duration storage, is being pursued because of the technical advantages it brings in comparison to battery storage. Green hydrogen, rather than fossil fuel-based hydrogen production, is the way forward for complete decarbonisation. The cost of green hydrogen is declining due to the falling price of RE. The focus is now on reducing the cost of electrolysers, which is the major component in the green hydrogen value chain. Policy and regulatory support to foster production of green hydrogen is being put in place under the National Hydrogen Mission. Further, the use of hydrogen in pilot hydrogen energy projects for (a) remote locations as a substitute for diesel generation and (b) for seasonal peak needs may be taken up. Large-scale hydrogen-based storage presents a strong case to balance long-term intermittency in electricity generation from wind and solar power, especially in relation to inter-seasonal shifts (Stafell I., et al., 2019).

Policy and regulatory framework for storage integration

With a steady eye on a clean future, India's targeted policy initiatives pave the way for large-scale green hydrogen production and national-level adoption, positioning it as a future green hydrogen export hub. The timeline below maps out these key policy initiatives, fuelling the nation's ambitious green hydrogen journey.

Feb, 22'	Jan, 23'	Jun, 23'	Aug, 23'	Jan, 24'
Green Hydrogen Policy	**National Green Hydrogen Missions**	**Guidelines for SIGHT Programmme Component-I**	**Green Hydrogen Standards**	**Guidelines for Implementation of SIGHT Programme Component-II**

Green Hydrogen Policy

In line with the goals of the Hydrogen Mission, a significant portion of the Green Hydrogen Policy deals with initiatives that encourage the production of green hydrogen. The Green Hydrogen/Green Ammonia Policy was notified by the central government in February 2022[64]. It is a major step to help India achieve its climate targets and aid in the smooth implementation of the National Hydrogen Mission. The policy also aims to make India an export hub for green hydrogen and green ammonia.

The salient features of the policy are:

- Grant of connectivity to the inter-state transmission system and waiver of inter-state transmission (ISTS) charges for 25 years for projects commissioned before 30 June 2025.
- Allotment of land within renewal energy parks and creation of manufacturing zones for green hydrogen projects.
- Renewable energy used for the manufacture of green hydrogen would be counted towards the renewable purchase obligation (RPO) compliance of the manufacturer.
- Permission to power bank for the renewal energy used in green hydrogen for 30 days and regulation of power banking charges.
- Establishment of a single portal by the MNRE for all clearances and permissions required for manufacture, transportation, storage, and distribution of green hydrogen.

Memorandum on waiver of ISTS charges for GH and its derivates

The Green Hydrogen Policy allowed the waiver of ISTS charges for setting up of green hydrogen/ammonia projects commissioned before 30 June 2025[65][66] . However, after receiving feedback from the industry on commissioning of such large-scale green hydrogen/ammonia projects, the government notified the memorandum that allowed the complete waiver on ISTS charges for projects commissioned up to 31 December 2030. The waiver shall be applicable to renewable energy generated from solar, wind, hydro (commissioned after March 2019), hydro-PSP, BESS or any hybrid combination of these technologies. This initiative is expected to reduce the cost of green hydrogen production by almost INR 60 or USD 0.75.

64. powermin.gov.in/sites/default/files/Green_Hydrogen_Policy.pdf
65. india-re-navigator.com/public/tender_uploads/wind_utility_policy-642ebb388719c.pdf
66. static.pib.gov.in/WriteReadData/specificdocs/documents/2023/aug/doc2023819241201.pdf

Green energy open access rules

On 6 June 2022, the Ministry of Power (MoP) notified the Electricity (Promoting Renewable Energy Through Green Energy Open Access) Rules[67]. Green hydrogen and green ammonia are now incorporated within these rules, enabling entities such as licensees, captive users, and open access consumers to meet their RPO obligations.

National Green Hydrogen Mission

On 4 January 2022, the Union Cabinet of India announced the National Green Hydrogen Mission with a financial budget of USD 2.4 billion (INR 197 billion), to become a global leader in green hydrogen production, reduce carbon emissions and fossil fuel dependency, and generate economic growth.

The mission will result in the following likely outcomes by 2030:

Integrated strategy

- Focused and co-ordinated steps to be taken by about 13 central ministries (including the Ministry of Steel, Power, Road Transport and Highways, etc.)
- State governments to frame fair and rational policies for provision of land, water, suitable tax structures, etc.

Demand creation

- Domestic demand creation by substituting grey with green – GoI to specify guidelines on minimum consumption by designated consumers.
- Capturing global markets by building mechanism for dollar denominated bids for Green hydrogen / NH3
- Subsituting imports of fossil fuels, fertilizers

Incentivising supply

- Under Strategic Interventions For Green Hydrogen Transition (SIGHT), distinct fiscal incentives to be given to boost domestic manufacturing of electrolysers and green hydrogen

Key enablers

- Emphasis on R&D, pilot projects
- Availability of resources (renewable energy, banking & storage, transmission, land, water, etc.)
- Infra and supply chain - re-fueling, hydrogen hubs, pipelines
- Formation of regulations and standards

Expected outcomes by 2030

- Renewal energy capacity addition ~ 125 GW
- Attract over INR 8 lakh crore investment
- Create over 6 lakh full time jobs
- 50 MMT p.a. of CO2 emissions are expected to be averted.

The mission will facilitate demand creation, production, utilisation and export of green hydrogen. Under the Strategic Interventions for Green Hydrogen Transition Programme (SIGHT), two distinct financial incentive mechanisms – targeting domestic manufacturing of electrolysers and production of green hydrogen – will be provided under the mission. The mission will also support pilot projects in emerging end-use sectors and production pathways. The regions capable of supporting large scale production and/or utilisation of hydrogen will be identified and developed as green hydrogen hubs.

67. pib.gov.in/PressReleaseIframePage.aspx?PRID=1842737

Guidelines for SIGHT Programme Component-I

The SIGHT programme was one of the main components of the National Green Hydrogen Mission with an outlay of INR 17,490 crore[68]. The SIGHT programme comprised of two incentive schemes - one for electrolyser manufacturing (component-I) and the second for green hydrogen production (component-II). On 28 June 2023, the government of India (GoI) released guidelines for Component-I of the SIGHT programme, aiming to maximise domestic electrolyser manufacturing capacity and achieve globally competitive lower levelised costs for green hydrogen production. The guidelines offer incentives for 5 years for Component-I, starting at INR 4440/kW in the first year and decreasing annually to INR 1,480/kW in the fifth year. The Solar Energy Corporation of India Limited (SECI) was selected as the designated implementing agency and recently announced the results of the SIGHT Scheme (Tranche-I), in which a total of 8 companies were announced as winners.

Green hydrogen standard

On 18 August 2023, the MNRE issued the green hydrogen standard for India[69]. The document defined green hydrogen as "Hydrogen produced using renewable energy, including, but not limited to, production through electrolysis or conversion of biomass. Renewable energy also includes electricity generated from renewable sources, which is stored in an energy storage system or banked with the grid in accordance with applicable regulations." The definition defines the green hydrogen production through electrolysis-based and biomass-based.

Scheme guidelines for implementation of 'Strategic Interventions for Green Hydrogen Transition (SIGHT) Programme — Component II: Incentive Scheme for Green Ammonia Production and Supply (under Mode 2A)' of the National Green Hydrogen Mission

On 16 January 2024, the MNRE released the guidelines for implementation of Mode-2A of SIGHT Programme Component-II with an aim to supercharge green ammonia production, making it cost-effective and a top choice for large-scale use, ultimately pushing aside fossil fuel alternatives with an outlay of INR 13,050 crore[70]. There are several modes of implementation of the SIGHT programme; under Mode-2A, the implementing agency SECI shall aggregate the demand and invite bids for the production and supply of green ammonia at the least possible cost. The guidelines offer incentives for 3 years, starting at INR 8.82 / kg in the first year, INR 7.06 / kg in the second year and INR 5.30 /kg in the third year. The capacity available for bidding under Tranche I of Mode 2A is 5,50,000 MT per annum of green ammonia.

Scheme guidelines for implementation of pilot projects for use of green hydrogen in the shipping sector under the National Green Hydrogen Mission (NGHM)[71]

Budgetary outlay: INR 115 crore till FY 2025-26

Component-A: Retrofitting of existing ships

Under this component, the following activities are included:

- Retrofitting of an existing ocean-going vessel (ship), having an engine with electronic fuel injection system, with green methanol/green ammonia-based propulsion system.
- Retrofitting of an existing ocean-going vessel (ship), not having electronic fuel injection system, with an appropriate green fuel-based propulsion system.
- Retrofitting/development of an inland waterways vessel/ coastal waters ship with indigenously developed green methanol/green ammonia/hydrogen fuel cells-based propulsion system.

  Note: Only the cost of retrofitting/development of the propulsion system would be covered under this component.

Component-B: Creation of bunkers and refuelling facilities

Under this component, the scheme implementing agencies (SIAs) nominated by the Ministry of Ports, Shipping and Waterways (MoPSW) will develop bunkering and refuelling facilities on a pilot basis at least one port on the international shipping route. The financial support for the pilot project will exclude the component related to the production of green hydrogen.

Scheme guidelines for implementation of pilot projects for use of green hydrogen in steel sector under the National Green Hydrogen Mission (NGHM)

Scheme guidelines for pilot projects for use of hydrogen in shipping sector

68. cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2023/10/202310051289006251.pdf
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Challenges and recommendations

The Indian green hydrogen sector grapples with technical, regulatory, and financial obstacles. Key challenges and recommendations include:

Technical challenges

- High production cost: Current green hydrogen production is costly due to electricity-intensive electrolysis.
- Scaling up production: Meeting rising demand is hindered by the limited availability of renewable resources and standards gaps in the hydrogen value chain.

Regulatory challenges

Infrastructure integration: Essential regulations are needed to seamlessly integrate green hydrogen into the existing energy structure.

Financial challenges

- High capital investments: Establishing green hydrogen production facilities demands significant capital.
- Limited market demand: Insufficient market demand hampers investor interest in green hydrogen initiatives.

Recommendations

- **Invest in R&D:** Foster research in green hydrogen production technologies to cut costs. Prioritise upscaling renewable resources to meet production demands.
- **Standardisation leadership:** Lead efforts to standardise hydrogen value chain practices both nationally and globally in alignment with the National Green Hydrogen Mission.
- **Policy clarity:** Develop clear policies encouraging green hydrogen production and utilisation. Establish regulations facilitating its integration into the existing energy infrastructure.
- **Public-private partnerships:** Encourage partnerships for investments. Provide financial incentives, grants, or subsidies for companies entering into green hydrogen production. Promote or mandate green hydrogen use in specific sectors to boost investment.

India's pursuit of a sustainable hydrogen economy stands ready for revolutionary expansion. Despite challenges such as water dependence and economic barriers, the nation's commitment is demonstrated by strategic initiatives such as the Green Hydrogen Mission and other supportive policies. It will be crucial to address technical obstacles, reduce costs, and clarify regulatory frameworks. India seeks to secure a leadership position in the global hydrogen landscape by focusing on technological innovation and holistic approaches, thereby fostering economic growth, sustainability, and energy independence.

Battery energy storage system

While not a direct source of renewable energy, battery storage is the crucial underpinning that enables a robust and flexible grid powered by intermittent sources like solar and wind. Storing excess renewable energy during peak generation and releasing it during peak demand periods helps stabilise the grid, reduce reliance on fossil fuels, and ultimately pave the way for higher penetration of renewables.

Current status and projected growth

India's ambitious 500 GW renewable energy goal necessitates significant scaling up of battery storage capacity. The National Electricity Plan (NEP) estimates India's battery storage requirement to the tune of 41.65 GW/208 GWh by 2030, with potential for additional expansion. This can be achieved through diverse technologies, including lithium-ion batteries, pumped hydro storage, and flow batteries, each offering unique advantages depending on the application and location.

Battery storage facilitates peak saving, reducing dependency on expensive peaking power plants fuelled by fossil fuels. Additionally, it enables time-shifting of renewable energy, allowing utilisation of excess power generated during the day to meet evening peak demand. Furthermore, batteries empower grid resilience, providing backup power during outages and improving reliability, particularly in remote areas. Broad ESS services are highlighted below:

Ancillary Services
- Fast Frequency Response
- Primary/Secondary/Tertiary Reserve
- Voltage Support
- Black Start

Bulk Energy Services
- Electric energy time-shift (arbitrage)
- Electric Supply Capacity

Transmission Infrastructure Services
- Upgrade Deferral
- Congestion Relief

Distribution Infrastructure Services
- Upgrade Deferral
- Congestion Relief
- Voltage Support
- Ramp Support

Energy Management Services
- Power Realiability
- Retail Electricity Time Shift
- Power Quality
- Demand Side Management

Policy and regulatory framework

The government agrees that in the initial phase of the adoption of energy storage technologies, market mechanisms and innovative economic models will be required for the development and deployment of energy storage technologies, which would be most beneficial to the country in the long-term.

The following initiatives have been taken to promote growth of energy storage technologies:

Legal status for ESS

Legal status for energy storage systems (ESS) has been issued by the MoP on 29 January 2022[72], wherein ESS has been designated as a power system element, which can be utilised as a generator, transmission or distribution element.

Bidding guidelines

On 11 March 2022, The MoP notified bidding guidelines for the procurement and utilisation of BESS[73], establishing provisions to enable their implementation with the objective to facilitate procurement of BESS, to provide standardisation and uniformity in the process, to identify business cases of BESS and to achieve renewable energy and decarbonisation goals.

Ancillary services regulations

In January 2022, new regulations for ancillary services, crucial to maintain grid voltage and frequency, were notified[74]. BESS plays a key role in balancing intermittencies of wind and solar power. The waiver will be applicable for a period of 25 years for Hydro PSP and for a period of 12 years for BESS, or for a period subsequently notified for future projects by the central government from the date of commissioning of the power plant.

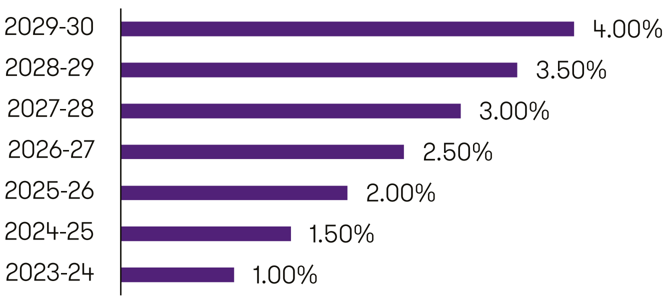
Interstate transmission charges waiver

In June 2021, the MoP ordered the waiver of interstate transmission system charges for battery storage and pumped hydro systems commissioned until June 2025.

Renewable purchase obligations (RPO) trajectories

In July 2022, the MoP issued RPO trajectories until 2029–2030, which, for the first time, included energy storage obligations trajectories until 2029–2030.

Energy storage obligation(Storage on energy basis)****



****percentage of total energy consumed shall be solar/ wind along with/ through storage

National Electricity Plan

In May 2023, the Central Electricity Authority (CEA) notified the National Electricity Plan (NEP) (Vol-I Generation) for the period of 2022-32[75]. According to the National Energy Policy, there is a need for an energy storage capacity of 73.93 GW, with 47.24 GW designated for battery energy storage systems (BESS) by 2031-32 to meet the growing demand for integrating renewable energy into the grid.

Production linked incentive (PLI) scheme

The PLI scheme incentivises the development of a localised value chain for the battery industry. Under the national programme on Advanced Chemistry Cell (ACC) battery storage, the government has allocated INR 181 billion (USD 2.49 billion) in financial allocations[76]. The programme is designed in such a manner that it is technology agnostic. The beneficiary firm shall be free to choose suitable advanced technology and the corresponding plant and machinery, raw material, and other intermediate goods for setting up cell manufacturing facility to cater to any application.

72. sansad.in/getFile/loksabhaquestions/annex/1711/AU2721.pdf?source=pqals#:~:text=(MoP)%20on%2029th%20January%2C,Generator%2C%20Transmission%20or%20Distribution%20element.&text=dated%2022nd%20July%2C%202022.&text=30.06.,Order%20dated%2023rd%20November%2C%202021.
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76. heavyindustries.gov.in/pli-scheme-for-national-programme-on-advanced-chemistry-cell-acc-battery-storage

Challenges and recommendations

India's battery storage sector faces several technical, regulatory, and financial challenges. Few are listed as follows:

Technical challenges

One of the most significant technical challenges is in the R&D and implementation of sustainable, efficient, and cost-effective battery storage technologies. This ranges from developing batteries with high energy density and longevity to establishing infrastructure for recycling and disposal of used batteries. Furthermore, the integration with the existing grid and the variability of renewable energy generation are other substantial technical challenges.

Regulatory challenges

Lack of a robust policy framework is a major regulatory hurdle. India needs to establish comprehensive guidelines on the use, safety aspects, and environmental impact of battery storage technology. This includes regulations concerning battery manufacturing, deployment, transportation, and end-of-life battery management. Currently, the absence of specific norms and frequent policy changes creates unpredictability, hindering the sector's expansion.

Financial challenges

One considerable financial challenge is sourcing investment for the battery storage sector. With high initial setup costs, the financial viability of storage solutions is a concern for many investors. Moreover, the high cost of the batteries themselves—largely due to the cost of raw materials like lithium—makes it more challenging.

Addressing these challenges will require a concerted effort from stakeholders, ranging from the government to research institutions and the private sector. A combination of policy support, research and development, and innovation in business models will be needed to unlock the sector's full potential and ensure its contribution to India's renewable energy goals.

Recommendations

Policy level

- Prioritise grid-level storage: Implement supportive policies and daytime tariffs to incentivise battery use during peak demand and reduce reliance on expensive fossil fuels.
- Pull in utilisation: Develop a robust policy framework encouraging battery storage deployment and ensuring usage through renewable energy charging.
- Create market demand: Define clear policy directions to stimulate adoption and establish a thriving market for energy storage.

Innovation and sustainability

- Boost R&D: Promote research and development alongside a strategic focus on mineral mining and extraction efforts for battery production.
- Embrace circularity: Enact policies and frameworks that incentivise and regulate battery recycling and reuse, fostering a circular economy for batteries.

Customer-centric solutions

- Tailored offerings: Focus on customer needs by providing affordable solutions such as pay-per-use models for battery storage and EVs, fostering wider adoption.
- Standardisation: Implement standardised technical, safety, and performance norms for battery swapping stations, encouraging mass EV adoption.

Collaboration and support:

- Attract international partners: Support the government's efforts to attract technological collaborations and financial investments from overseas for mid-size players.
- Secure market demand: Encourage commitments from customers for specific battery volumes to provide manufacturers with confidence and market visibility.
- Responsible recycling: Develop regulations and frameworks for organised and responsible battery recycling, recovering critical minerals and minimising environmental impact.

Pumped storage plants

Pumped storage hydropower (PSH) plants have been established worldwide, primarily in the past century, to fulfill peaking power demands. This technology is well-established and has a wealth of operational experience globally, including in our country. Representing 94% of the world's energy storage capacity[77]., PSH technology is relatively straightforward. There is a considerable potential for pumped storage plants (PSPs) to play a significant role in meeting storage requirements by 2030. According to estimates by the Central Electricity Authority (CEA), India possesses a potential on-river pumped storage hydro capacity of approximately 103 GW[78]. Presently, out of the 4.75 GW of installed pumped storage plants in the country, 3.3 GW are operational in pumping mode, while approximately 44.5 GW of projects are in various stages of development. In April 2023, the Ministry of Power issued guidelines to encourage the development of pumped storage projects[79].

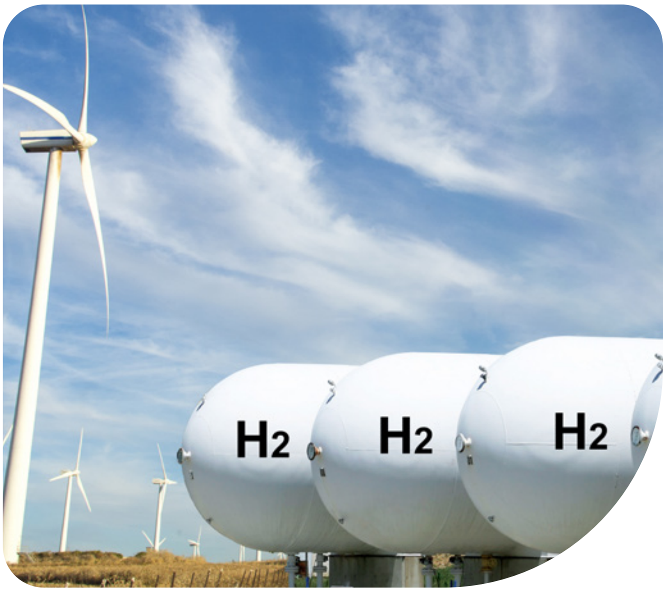
The lifespan of these plants exceeds 40 years, boasting an impressive 80% energy efficiency throughout their operational cycle, with the capability to furnish electricity[80] for up to 10 hours. Such attributes empower pumped storage hydroelectric (PSH) systems to offer a myriad of services to the power grid. Their high ramping capability equips them to manage abrupt increases in power system load seamlessly. Additionally, they excel in mitigating sudden fluctuations in renewable energy (RE) generation, while also furnishing essential ancillary services such as frequency and voltage support. Beyond their immediate grid services, PSH systems can address seasonal imbalances between RE generation and load demands, owing to their substantial bulk storage capacity.

PSH in abandoned mine shafts in the world

- The world's first PSH plant that utilises an abandoned mine shaft was built in the Prosper-Haniel hard coal mine in Germany. This coal mine has a horizontal underground roadway that extends for approximately 25 km. The roadway depth is 1.2 km, and the water storage capacity reaches 1 million m3. Germany also plans to build a fully underground PSH plant in Upper Harz, where an abandoned metal mine with a roadway with a diameter of 3.5m and depth of 760m is used as an underground reservoir. The reservoir capacity is estimated to be 250,000 m3, and the installed capacity is 100 MW.
- In the state of New Jersey, United States, a semi-underground pumped storage hydroelectric (PSH) plant with a capacity of 1,000 MW has been constructed within an abandoned iron ore mine located 760 meters below the surface. Similarly, the Eagle Mountain PSH project in California utilised two abandoned mine pits — one upper and one lower — to establish a facility with an installed capacity of 1300 MW. In Spain, the occurrence of a mine water influx in the Asturian coal mine is harnessed as a water source for constructing a semi-underground PSH plant. Additionally, South Africa has repurposed an abandoned gold mine to create a cascade PSH plant.

Current status and projected growth

According to the National Electricity Plan 2023 (NEP 2023), the projected storage capacity by the year 2031-32 is estimated to be 73,930 MW[81]. Taking into account the 2,780 MW of pumped storage plants (PSPs) currently under construction, achieving the aforementioned target by 2032 will necessitate an annual capacity addition of approximately 7,900 MW. To accomplish this, it is imperative to expedite the tendering process to select bidders for the development of PSPs. Notably, Tata Power and NHPC have entered into a Memorandum of Understanding (MoU) with Maharashtra for the development of 2.8 GW and 7.4 GW of pumped storage plants, respectively. Additionally, Karnataka has been awarded the development of 1 GW of PSPs within the state, and the implementation of a standalone energy storage facility with a capacity of 500 MW/3,000 MWh is underway. These initiatives are expected to yield valuable insights and lessons. Currently, approximately 10.5 GW of on-river and 34 GW of off-river pumped storage schemes are in various stages of development. Consequently, developers are faced with the task of developing about 45 GW of PSPs across the country.



77. www.hydropower.org
78. powermin.gov.in/sites/default/files/webform/notices/Draft_Guidelines_to_promote_development_of_PSPs_in_the_Country_Seeking_Comments.pdf
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80. www.eesi.org/papers/view/energy-storage 2019#:~:text=Pumped%2Dstorage%20hydropower%20is%20more,hours%20for%20lithium%2Dion%20batteries.
81. pib.gov.in/PressReleseDetailm.aspx?PRID=1928750

Global perspectives on storage for grid integration

The global race to decarbonise energy systems hinges on one critical challenge: harnessing the fluctuating power of renewables. Enter the game-changer - energy storage. From balancing grids to unlocking value stacking, storage is poised to reshape the future of electricity. Let's explore the diverse perspectives on this pivotal technology across the globe, armed with data and forecasts from trusted sources.

The US

Leading the charge, the US has cumulatively deployed over 11 GW of grid-scale storage having reached 11,071 MW/31,066MWh as at the end of Q2 2023[82]. With nearly twice the current numbers already in the pipeline, it is anticipated that the capacity will double by the next year, with some of the forecasts predicting a tenfold increase to 80 GW by 2030[83]. Lithium-ion batteries dominate, but pumped hydro remains a key player, accounting for nearly 80% of existing capacity. Value stacking is gaining traction, with projects such as Tesla's Hornsdale Power Reserve offering frequency regulation and peak shaving services alongside energy arbitrage.

Germany

Europe's renewables powerhouse, Germany, is rapidly scaling up storage. By 2030, the nation aims for 15 GW of installed capacity[84], driven by a combination of grid-scale batteries and pumped hydro.

Japan

Facing limited space for storage facilities, Japan is looking beyond lithium-ion. Redox flow batteries, well-suited for long-duration storage, are gaining traction, with 1.5 GW of capacity planned by 2030[85]. Additionally, innovative solutions, such as underground pumped hydro in abandoned mines, are being explored.

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6 Conclusion

India's ambition to achieve 500 GW of renewable energy capacity by 2030 reflects a bold commitment to sustainable development and climate action. The nation has made significant strides in the renewable energy sector, leveraging its vast natural resources and implementing supportive policies and initiatives. India's preparedness to attain this ambitious target is evident through various measures. The government's focus on renewable energy auctions, incentives for developers, and the establishment of dedicated institutions, such as the International Solar Alliance, demonstrates a proactive approach to fostering renewable energy deployment.

In addition, India's renewable energy sector has witnessed substantial investments, both domestic and foreign, indicating confidence in the country's renewable energy market. Collaborations with international partners for technology transfer and capacity building further enhance India's readiness to accelerate renewable energy deployment.

Key notable insights are as follows

- **While India is making important progress in implementing its climate agenda at the sectoral level, emissions remain on a strong upward trend.** The primary contributors to emissions are the power and industrial sectors, necessitating significant efforts beyond current policies to effectively reduce emissions. There is a pressing need for increased backing for renewable energy options, investment in innovative and eco-friendly technologies, and the implementation of market-driven mechanisms to encourage reductions in emissions.
- **Challenges remain across sectors on the path towards decarbonisation.** In the realm of the power sector, the prevailing market framework and the unstable financial state of DISCOMS pose significant obstacles to augmenting the proportion of renewables in the electricity mix. Additionally, the dependence of numerous communities on coal and its associated industries compounds these challenges. This situation is exacerbated in residential and transport sectors due to the projected increase in household incomes, which will continue to drive up the demand for electricity, vehicles, and air travel. To address this, heavy industry may have to pivot towards recycling practices and banking on the future viability of green hydrogen to power energy-intensive processes. Simultaneously, other industrial players will need to transition towards existing renewable energy sources.
- **The cumulative impact of the actioned solutions, while ambitious, will nonetheless fall short of meeting the net zero 2070 goal.** The level of investment in the renewable energy sector falls significantly short of the amount needed[86] for effective decarbonisation, as stated by the Ministry of New and Renewable Energy. To bridge this gap, it will be essential to harness technology transfer and international finance, while also tapping into domestic debt markets as significant sources of funding. With numerous schemes already announced or in operation, there is a collective demand for substantial fiscal resources. This demand becomes even more critical in light of projected extreme climate events. Therefore, it is prudent to assess the effectiveness of various fiscal instruments, such as taxation versus subsidies, in achieving the country's emissions reduction goals.
- **Shifting away from coal is a formidable challenge, and the Indian government is taking a multipronged approach.** The Indian economy heavily depends on coal, which fuels over 70% of electricity generation and contributes to nearly 40% of the country's CO2 emissions. Additionally, a significant portion of the industrial sector relies on coal, and approximately 20 million individuals are employed directly or indirectly in its extraction and utilisation. In an endeavour to transition towards renewable energy sources and mitigate emissions, the Indian government has implemented various policy measures. These include widespread subsidies for the adoption and generation of renewable energy, such as production-linked incentive (PLI) schemes for solar module and battery manufacturing, the National Motor Replacement Programme, incentives under the Faster Adoption and Manufacture of Hybrid and Electric Vehicles (FAME) programme for electric vehicles (EVs), and initiatives promoting the adoption of LED streetlights and bulbs. Furthermore, regulatory measures, such as Renewable Purchase Obligations (RPOs) for electricity, building efficiency standards, vehicle emissions standards, standards and labeling programmes, and the promotion of bioethanol, have been instituted. Tradable energy certificates, including Renewable Energy Certificates (RECs) and Perform, Achieve, and Trade (PAT) certificates, are also part of the policy landscape. These policy interventions are instrumental in initiating India's transition towards emission reduction. However, without further concerted efforts, India's emissions are projected to continue increasing at a rapid rate. To address this challenge, substantial scaling up of investment in renewable energy is imperative. This necessitates leveraging technology transfer, international financing mechanisms, and domestic debt markets, particularly to accelerate the adoption and deployment of renewable energy technologies.

While challenges remain, India's journey towards 500 GW presents an unparalleled opportunity. By addressing the identified gaps, leveraging its strengths, and adopting a collaborative approach, India can not only achieve its ambitious target but also position itself as a global leader in the clean energy transition. The path ahead demands agility, innovation, and unwavering commitment to build a sustainable future powered by renewable energy.

86. Parliamentary Standing Committee on Energy (2021-22), 2022, Financial Constraints in Renewable Energy Sector: Twenty First Report

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