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Renewable Energy Integration: India's Next Big Challenge

Building Flexibility and Grid-Firming Will Be a Key Focus Going Forward

Executive Summary

India already has 93 gigawatts (GW) of on-grid variable renewable energy (VRE) capacity (as of January 2021). Now, one of the next big challenges for India's electricity sector transition is integration of large-scale VRE into the electricity grid.

Countries such as Germany, which has 46% of its total generation from VRE, and states such as South Australia and California, which had more than 60% and 36%, respectively, of their electricity coming from VRE in 2020, are leaders in integrating large-scale renewables.

The much-bigger Indian market benefits from its strongly connected national electricity grid, but has its own set of challenges and market structure dynamics in dealing with large-scale VRE. However, there are opportunities for cross-learnings as some of the renewable energy rich Indian states such as Rajasthan, Gujarat, Maharashtra, Karnataka and Tamil Nadu could have renewable generation increasing to 50% by 2030 from the current levels of 10-30% of their total power generation.

To begin with, integration of large-scale VRE into India's grid requires policy support for a time-of-day (ToD) pricing mechanism that incentivises investment into a multitude of technology solutions for flexible, peaking power delivery.

Just when the Indian renewable energy industry was coming to terms with the record low solar tariff of Rs2.36/kWh (US$31/MWh) discovered in Solar Energy Corporation of India's (SECI's) auction in June 2020, expectations of tariff deflation were surpassed by ~15% lower tariffs in recent competitive auctions from SECI and Gujarat Urja Vikas Nigam Limited (GUVNL). With tariffs of Rs1.99-2/kWh (US$~27/MWh), solar is not just grid-competitive, it is now even cheaper than the marginal fuel cost of thermal power.

The Central Electricity Authority's (CEA) optimum generation mix report projects India's solar and wind to form 420GW of capacity, 51% of the total installed capacity, by 2030 which will provide 31% of the total generation (biomass and small hydro will add another 30GW to the total installed capacity).

The International Energy Agency (IEA) in its recent India Energy Outlook 2021 predicts that by 2040 India could add 900GW of renewable capacity with renewable energy becoming the dominant source of power supply in India's electricity system.

But this requires a rapid grid system modernisation and the pricing of flexibility in demand and supply.

In this report our focus is to discuss technology and enabling policies that incentivise investments into some of the key grid firming (peak-time power supply) options such as flexible coal-fired power generation, battery storage and green hydrogen, while also noting the key support provided by largely flexible hydro power.

Firming India's Future Power Grid

Stabilizing grid integrity with a three-pronged approach

Flexible Coal Plant Operation	Battery Storage	Green Hydrogen
Run plants at 40-50% capacity, ramp up as needed	Utility scale battery systems to store excess solar	New source of power, increasingly affordable
Incorporate time of day tariff system to offset costs	Standalone cost per MW: **45% of 2020 cost** (by 2030)	Electrolyser cost per MW: **44% of 2020 cost** (by 2030)

Source: TERI, BNEF, Adani Power IEEFA

Flexible coal-plant operation — Coal, which is likely to be the dominant source of Indian electricity generation for some time to come, is playing a vital balancing role in integrating large-scale variable renewables. This highlights the need to differentiate between the cost of and value of power generation in terms of ToD pricing.

To best capture the value of more flexibility, coal-fired plants would require retrofitting, operational and regulatory amendments. This would incur capital costs as well as additional operational expenditure depending upon the size, age and combustion technology of the plant, but could be rewarded with a higher ToD price.

In this report we discuss the findings of a couple of pilot studies on flexible coal-fired plant operation in India, optimising sunk investments to help transition.

Under the current structure in India, the load dispatch merit order incentivises least-cost generation units. Plants with lowest variable charges get dispatched first. In IEEFA's view this metric going forward should evolve to a highly flexible, dynamic ToD pricing to incorporate the flexibility parameters of coal-fired power plants in support of VRE integration.

Battery storage — Like solar and wind generation technology, battery storage technology has also made massive advancements. The cost of standalone lithium-ion battery systems globally has fallen from US$1,100/kWh in 2010 to US$137/kWh in 2020 (2019 prices in real terms). BloombergNEF (BNEF) projects a further decline in the cost to US$58/kWh by 2030.

IEA's India Energy Outlook 2021 predicts that India could have 140-200GW of battery storage capacity by 2040, the largest of any country.

Utility-scale batteries are now thriving in a few leading developed markets such as Australia, the U.S., the U.K. and China – indicative of things to come in India. Deployment of large grid-scale batteries in Australia has brought down power firming costs and grid service-related costs due to the speed of construction and increased competition in the battery storage market, while battery system costs have declined rapidly via learning-by-doing in the domestic context.

IEEFA believes that despite the cost sensitivity of large parts of the Indian market in the face of current high battery costs, grid-scale batteries are not a distant dream for India, particularly for the commercial and industrial (C&I) and high-end consumer segments already paying an excessive cross-subsidy. Domestic and international developers as well as utilities await battery cost deflation and policy support in the form of ToD pricing that incentivises high initial capital investment into such assets.

Smaller batteries from Tata's distribution business in Delhi (10 megawatts [MW]) and Neyveli Lignite Corporation's (NLC) battery in the Andaman and Nicobar Islands are small steps towards what could be India's battery storage dream.

Green hydrogen — Electrolysis of water using electricity, one of the two most common methods of hydrogen production, is now moving towards being competitive by the end of this decade, spurred on by the growing availability of ever-cheaper VRE.

Green hydrogen is an opportunity that India cannot afford to miss.

According to The Energy and Resources Institute's (TERI) recent analysis, the cost of alkaline electrolysers is projected to drop 56% from around Rs6.3crore/MW (US$0.86m/MW) today to around Rs2.8crore/MW (US$0.38m/MW) by 2030.

The decline in electrolyser costs will be partly driven by large-scale deployment in India and globally, by a virtuous circle between falling VRE and electrolyser manufacturing costs, plus a rapidly strengthening global policy to promote hydrogen. Improving efficiencies of electrolysers, as well as increasing load factors of hybrid wind-solar plants, will also play an important role in driving the costs of green hydrogen below Rs150/kg by 2030 (US$2/kg) – versus Rs300-440/kg (US$4-6/kg) as of today.

Though yet to be commercially deployed in India, green hydrogen is a clean fuel with a wide range of potential applications in transport, industrial production of ammonia, methanol, steel and electricity storage, and is an opportunity that India cannot afford to miss.

Billions of dollars of capital commitments across the globe are building a critical mass in the green hydrogen space. India will have the benefit of leveraging these learning-by-doing pilots that are underway in developed economies.

India can look to green hydrogen as a lower cost, zero pollution domestic alternative to using imported LNG as a source of peaking power and the fuel to underpin low cost, zero pollution domestic manufacturing of fertilizers, steel and aluminium et al. However, India's strategy should be to plan in advance and be prepared to ride on this wave when it arrives, to bolster the country's energy security. Hydrogen gas peakers might prove another key tool to managing VRE integration, but again, only when supported by a ToD pricing.

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Introduction

India's energy sector transition gained immense impetus with solar power tariffs reaching new lows of Rs2/kWh in SECI's 1.1GW auction in November 2020, then Rs1.99/kWh (~US$27/MWh) in GUVNL's 500MW auction in December 2020.

Just when the Indian renewable energy industry was coming to terms with the new record low solar tariff of Rs2.36/kWh (US$31/MWh) discovered in SECI's June 2020 auction, expectations of tariff deflation were surpassed by ~15% lower tariffs in these competitive auctions. With tariffs of Rs1.99-2/kWh (US$~27/MWh), solar is not just grid-competitive, it's even cheaper than the marginal fuel cost of thermal power.

A power purchase agreement (PPA) tenure of 25 years with zero indexation for inflation mean the tariffs are deflationary in real terms (taking into account the likely ~3% of average annual Consumer Price Index [CPI] inflation).

Muted power demand growth in FY2019/20, further exacerbated by the COVID-19 pandemic in FY2020/21, has slowed down India's power sector capacity commissioning. However, industry capacity continues to be developed, and 2020 saw progress with the exploratory auctions related to firmed peak-hour renewable power supply. This was a promising development for the power market transition in India.

In January 2020, India held its first renewable energy (RE) plus storage auction of 1.2GW capacity with a differentiated tariff for peak and off-peak supply and contracted for 25 years as a way to underpin bankability.

Greenko and ReNew Power won 900MW and 300MW of capacity at an off-peak tariff of Rs2.88/kWh (US$40/MWh). The peak-time power supply tariff quoted by Greenko was Rs6.12/kWh (US$86MWh) while ReNew Power quoted Rs6.85/kWh (US$96/MWh).[1]

Greenko will reportedly be using pumped hydro storage and ReNew Power will be using battery storage to provide firmed peak-hour supply, while both will over-build gross VRE capacity to firm up required volume delivery.[2]

The resultant firmed peak-time supply tariffs from the auction are still materially higher than average coal-fired power tariffs of Rs4-5/kWh (US$54-68/MWh) in India. These tariffs reflect the first-mover risk the developers are taking on in the absence of prior experience of integrating utility-scale battery storage systems in the Indian market.

In May 2020, in another first-of-its-kind auction, this time for 400MW of round-the-

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[1] Mercom India. Greenko, ReNew Win SECI's 1.2 GW Solar, Wind Auction with Storage for Peak Power Supply. January 31, 2020.
[2] Mercom India. Greenko Seeks EPC Contractors for a 1,260 MW Pumped Hydro Storage Project in Karnataka. February 14, 2020.

clock (RTC) renewable power supply, ReNew Power secured a semi-firmed electricity tariff of Rs2.90/kWh (US$39/kWh).[3]

The auction provided an annual escalation of 3% on the quoted tariff up to the end of the 15th year of the contract. This accounts for the Rs4.39/kWh 15- to 25-year tariff (the last 11 years of the PPA), as there is no indexation after year 15.

India's long-term target of 450GW of renewable energy capacity by 2030 provides an investment opportunity of US$500bn into generation, grid firming capacity, transmission and distribution (T&D) grid expansion and modernisation infrastructure.[4]

Despite a slowdown in capacity building, now with 93GW of on-grid VRE capacity as of January 2021, India must prepare in advance to modernise its electricity network to integrate targeted annual additions of 20-40GW of new VRE capacity. To begin with, integration of large-scale VRE into India's grid requires policy support that incentivises investment into a multitude of technology solutions.

Integrating large-scale VRE requires policy support to incentivise investment.

In our report from October 2019, we recommended the following key steps to integrate large-scale VRE into India's grid:[5]

- Implementation of ToD or contracts-for-difference pricing to incentivise firming power supply on a multi-technology approach to future grid stability;
- Interstate and international grid connectivity enhancements, noting that a broader geographic coverage both somewhat smooths VRE supply, assisting in grid integration and balancing, and opens up international BIMSTEC grid connectivity options as well (as per the One Sun One World One Grid project [OSOWOG] policy suggestion);
- Accelerating deployment and retrofits of pumped hydro storage (PHS) capacity, both on existing hydroelectricity dams and closed loop "off-river" systems;
- Faster ramping of coal-fired power plants;
- Co-located wind-solar-battery hybrid projects;

[3] Mercom India. ReNew Power Wins SECI's 400 MW Round-the-Clock Renewable Tender at ₹2.90/kWh. May 8, 2020.
[4] IEEFA. Capital Flows Underpinning India's Energy Transformation. February 2021.
[5] IEEFA. Flexing India's Energy System Through Market Mechanisms. September 2019.

- Gas peaking plants, given India has 25GW of stranded 'baseload' gas plants already built with insufficient fuel access and an inability to secure a sufficient tariff when competing with least cost renewable energy;

- Stand-alone utility-scale and distributed behind-the-meter batteries;

- Demand response management (DRM) to shift energy consumption from the peak hours in the 24-hour day; and

- Solar thermal with storage in the longer term if this technology cost declines.

Countries such as Germany, and states such as South Australia and California are leaders in integrating large-scale renewables. German energy research institute AG Energiebilanzen's (AGEB) data suggest that VRE comprised 46% of total electricity consumption in 2020 in Germany, up 4% share points from the previous year.[6] India, a much bigger electricity market, has its own set of challenges and market structure dynamics in dealing with large-scale VRE. However, there are opportunities for cross-learnings.

In 2020, the concept of green hydrogen as a fuel for transportation, industries, heating and electricity began to gain momentum, with governments, energy companies, power utilities and infrastructure developers exploring commercial projects with strong investor backing. This underlying economic momentum has led to an increasing number of net zero emissions pledges in recent months.

At the 4th India Energy Forum held in October 2020, Prime Minister Narendra Modi said hydrogen will be one the seven key pillars of the nation's energy strategy.[7] This was followed by the Prime Minister's announcement in November 2020 about the launch of the National Hydrogen Energy Mission.[8]

In this report, we discuss international developments in integration of VRE and translate them for the benefit of the Indian electricity market. Further, our focus is on the technology and enabling policies that incentivise investments into some of the key grid firming (peak-time power supply) options such as flexible coal-fired power generation, battery storage and green hydrogen.

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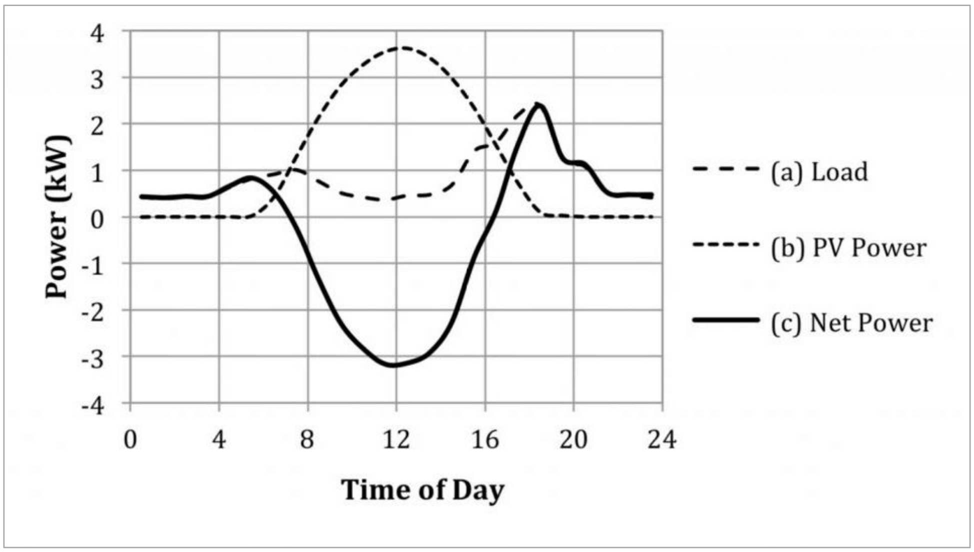
[6] Renew Economy. 2020 was a stunning year for German renewables, and a killer one for coal. 23 December 2020.
[7] ET Energy World. PM Modi underscores 7 key pillars of India's energy strategy. 26 October 2020.
[8] Live Mint. India to launch Nat'l Hydrogen Energy Mission. 26 November 2020.

Flexible Coal-Fired Plant Operation

As solar generation is only available during the day and wind patterns are highly seasonal and intermittent the power system needs to evolve and modernise to respond to grid stability challenges as the share of VRE generation continues to increase in India's energy system. There is also a need for an accelerated deployment of assets that can provide firmed power during the evening peak hours when solar generation is not available.

Figure 1: Duck Curve



Source: US Department of Energy.

Figure 1 depicts what is now popularly known as the "duck curve", first experienced in the U.S. state of California's electricity grid due to high penetration of solar power. Curve (c) in Figure 1 represents the net power — total demand load minus the solar power supplied on the grid.

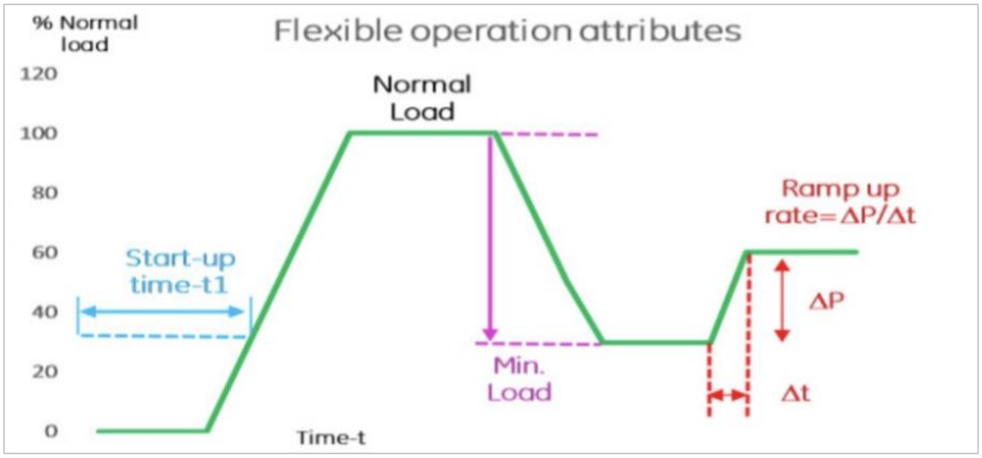
The net power requirement dips when there is plenty of solar power available during the afternoon. In the evening, the net power requirement rises rapidly as solar generation dips, giving the net power curve its duck shape. This curve indicates the ramping up requirements of power supply to serve the peak demand concurrent with the cessation of solar power into the grid.

Flexibility Parameters

Thermal power forms the major generation resource in the Indian electricity system, so flexing its generation to cater to the majority of grid variability requirements should be an important focus area.

Following are some of the key flexibility parameters for thermal power plants:

Figure 2: Flexibility Parameters



Source: CEA.

Ramp rates — The ramp rate describes how fast a power plant can change its net power during operation.[9] It is the change in net power over time expressed in MW/min. In the Terms and Conditions of Tariff Regulations 2019-24, Hon'ble Central Electricity Regulatory Commission (CERC) has mandated a minimum 1% ramp rate per minute. Ramping in excess of 1% per minute has been commercially incentivised as per the tariff regulation.[10]

Minimum Thermal Load (MTL) — MTL is the ratio of the actual minimum possible load a plant can operate at to its rated capacity. For example, if a 200MW plant runs at a minimum load of 120MW during the day, then the MTL for that plant is 60%. The parameter represents a thermal plant's ability to back down its generation rate during periods of low demand.

Start up and shut down time — The start-up time is defined as the period from starting plant operation till minimum load is attained. Start-up time varies depending on the size of the unit and technology of the boiler used in thermal plants. Depending on the time from unit shutdown, start-ups are categorised into hot start-up, warm start-up and cold start-up. Quick start-up is a key attribute of a flexible resource. Shut down time is linked to ramping down capability of the thermal unit.

As the share of VRE increases on India's power grid, the electricity system will require much steeper ramp rates and lower minimum generation levels from the thermal generation fleet, which will need increased capacity overall to be flexible enough to meet the ramping demands imposed by higher VRE generation.

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[9] CEA. Flexible Operation of Thermal Power Plants for Integration of Renewable Generation. January 2019.
[10] POSOCO. Flexibility Analysis of Thermal Generation for Renewable Integration in India. May 2020.

As the country progresses to a surplus scenario with high RE integration, the generation resources should be benchmarked with modern indices like flexibility reflecting present day requirements. Flexibility is defined as *"The ability of a power system to respond to changes in electricity demand and generation."* Flexible generation is characterised by the ability to rapidly ramp up and ramp down the generation, quickly start up and shut down and operate efficiently at lower generation levels.

The average daily thermal generation in India varies in the range of 20-30GW. And the intraday flexibility requirement is increasing at the rate of 5-7GW per annum. According to Power System Operation Corporation (POSOCO), the intraday flexibility requirement reached a maximum of 56GW during the winter of FY2019/20. Increased grid reliability is a service to Indian consumers, but the higher the reliability, the higher the potential total cost of the system – a cost that consumers must ultimately wear. But against that, increased grid reliability will allow a progressive phase-out of the very expensive backup capacity widely relied upon in India (there is reportedly over 90GW of expensive, polluting, imported diesel-fired generation capacity behind the meter).

Coal Versus Gas

Gas-fired power plants in general rate better on flexibility parameters with better ramp up and ramp down rates and minimum generation levels. However, economic constraints primarily due to the lack of a domestic gas supply in India mean that the 25GW of gas-fired capacity has been operating at an extremely low utilisation of below 20% in recent years (noting utilisation rates improved temporarily in FY2020/21 as LNG import prices reached unprecedented record lows, but traded LNG has rallied more than 600% into the start of 2021).

Table 1: Comparison of Flexibility Parameters

Plant Type	Hard Coal	Lignite	CCGT	Pumped Storage	Batteries
Load range (%)	40% to 90%	40% to 90%	40% to 90%	NA	0% to 100%
Minimum Load (%)	40% / 25% / 10%	60% / 40% / 20%	50% / 40% / 30%	10	-100%
Ramp rate (%/min)	2% /4% / 9%	2% /4% / 8%	4% / 8% / 12%	>40%	100%
Start-up time - hot start (within less than 8 hours)	3h / 2h / 1h	6h / 4h / 2h	1.5h / 1h / 0.5h	<0.2h	<1 second
Start-up time - cold start (after more than 48 hours)	7h / 4h / 2h	8h / 6h / 3h	3h / 2h / 1h	<0.2h	<1 second

Source: GIZ,[11] IEEFA estimates.

Note: CCGT is combined cycled gas turbine (gas-fired generation).

As shown in Table 1, the CCGT plants have greater ramp rates and shorter start up times but for higher minimum loads. CCGT plants could ramp up their net generation at the rate of 12% per minute compared to 9% and 8% for coal and

[11] USAID – Greening the Grid. Keeping Flexibility at the centre stage of India's energy transition. October 2020.

lignite respectively. However, CCGT plants would only be able to achieve a minimum load of 30% compared to 10% and 20% for coal and lignite respectively.

In August 2018, the Central Electricity Authority (CEA) suggested a plan to test NTPC's gas-fired fleet as 'peakers' by operating only in the evening for supply smoothing and to deal with grid fluctuations. The plan envisaged testing of NTPC's 2.3GW of gas-fired capacity to begin with, then gradually operating 20GW of national gas-fired capacity as evening 'peakers' by FY2022.[34] In the absence of documented evidence, we assume that this planned pilot did not progress. And a ToD pricing system is required to acknowledge the value of peaking power, rather than requiring an ongoing subsidy, which could then lock in coal and reduce the capacity for market competition as batteries become cost competitive.

Coal, which is the Indian electricity system's dominant source of generation, plays – and should continue to play – a vital role in integrating large-scale VRE.

As of December 2020, India has 205.8GW of in-front-of-the-meter coal-fired capacity. Over the years, coal-fired generation has served as baseload for the Indian electricity system. We note the emergence of zero marginal cost renewable energy in a merit-order grid system has, in effect, made the 'baseload' power concept redundant. In IEEFA's view, efficient and flexible utilisation of India's giant coal-fired power fleet will provide resource as well as protect the coal-fired power assets from stranding and becoming non-performing assets.

There have been multiple studies and pilots performed by NTPC, POSOCO and GIZ (a German development bank) and the U.S. Agency for International Development, or USAID, (under the Greening the Grid initiative). We detail below some of the findings and recommendation of these case studies and pilots.

Pilot for Flexible Coal-fired Power Plant Operation in Gujarat

In March 2020, Gujarat State Electricity Cooperation Limited (GSECL) successfully conducted a pilot run to operate its 500MW Ukai Thermal Power Plant at minimum load of 40% (200MW) while maintaining all its other operational parameters under stable condition.[12] However, the study does not clarify for how long the plant could run on minimum load of 40%.

The pilot run was conducted under USAID's Greening the Grid initiative. The plant's equipment manufacturer Bharat Heavy Electricals Limited (BHEL) was involved in conducting this test run. GSECL sought the pilot to evaluate the possibility of operating its 5GW coal-fired fleet more flexibly so as to allow integration of 30GW of VRE on Gujarat's state grid in the medium term.[13]

The coal-fired plants would require retrofitting and operational amendments to

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[12] Greening the Grid. Gujarat successfully operates its coal plant at 40% load in a first to support integration of renewable energy. March 2020.
[13] Mercom India. Gujarat Successfully Runs Coal Project at 40% Capacity to Support Renewable Integrationcs. 12 March 2020.

become more flexible. This will incur capital costs as well additional operational expenditure.[14]

Cost of Flexibility

Capital Expenditure

The capital intervention and retrofitting required will vary with the capacity, age and technology of combustion of the plant.

The CEA and NTPC study on flexible operation of coal suggests that no major retrofits are required to operate a coal-fired plant at 55% load, and with reduced demand in the last two years, the average coal plant in India has operated at a decade low of just 53% in FY2020/21. However, operating a thermal unit below 40% load requires implementation of measures that depend on various factors such as the plant's design type, capacity, coal quality, historical operation, maintenance, and age of the units.

Siemens estimated a capital cost of Rs20 crore (US$273m) to operate NTPC's 470MW unit 6 of Dadri thermal power station below 40% load (Rs4.0 lakh/MW).

Similarly, GE estimated Rs50 crore (US$680m) of capital intervention for unit 2 of NTPC's Talcher TPS to enable stable operation at 40% minimum load (Rs7.3 lakh/MW).

We note with the reduced profitability of coal-fired power plants in recent years, these relatively high retrofit costs need to be weighed against the not dissimilar cost of building an entire greenfield coal-fired power plant, with all the added emissions controls incorporated. Further, any such investment must be evaluated for commercial viability in light of lower wholesale electricity prices and record low coal plant utilisation rates.

Operational Expenditure

Flexible operation of coal-fired power plants incurs additional operational expenditure mainly due to costs associated with following changes in the operation:

1. Increase in the heat rate and auxiliary power consumption;
2. Increase in operation and maintenance requirements due to reduced life of components; and
3. Increase in oil consumption due to frequent starts and stops.

The operational expenditure varies with the capacity and the average operating minimum load of the plant. Table 2 illustrates the cost impact per unit of power due to the additional operational expenditure incurred because of a change in heat rate.

[14] CEA. Flexible Operation of Thermal Power Plants for Integration of Renewable Generation. January 2019.

The tariff (Rs/kWh) impact is lowest for smaller (210MW) units due to lower load fluctuation. Also, the operational cost varies higher for running the unit at lower minimum load. Per unit cost impact is highest at Rs0.40/kWh for a 600MW unit running at 30% minimum load compared to Rs0.15/kWh for a 210MW plant running at 50% minimum load.

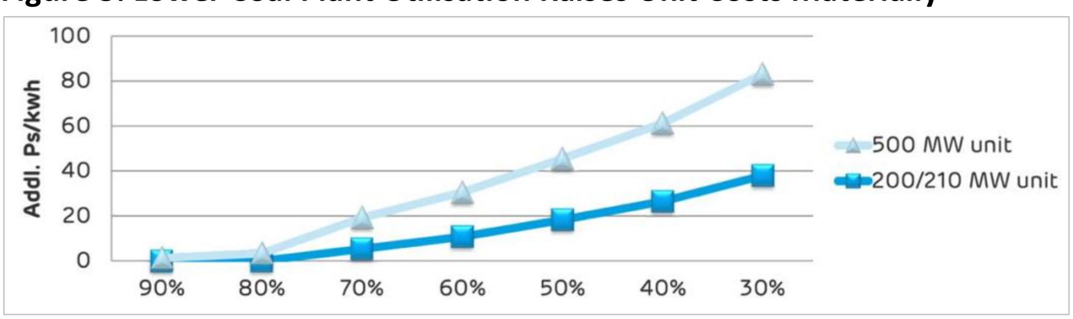
Table 2: Estimated Increase in Tariff Due to Change in Heat Rate

Capacity (MW)	Unit Loading (%)	Increase in Net Heat Rate (%)	Energy Charge (Variable Tariff) (Rs/kWh)	Additional Charge Due to Change in Heat Rate (Rs/kWh)
210	50%	7.5%	2.15	0.15
	40%	11.6%	2.23	0.23
	30%	17.3%	2.34	0.34
500	50%	10.0%	2.20	0.20
	40%	13.8%	2.27	0.28
	30%	19.0%	2.38	0.38
660	50%	9.2%	2.18	0.18
	40%	14.4%	2.28	0.28
	30%	20.4%	2.40	0.40

Source: GE, NTPC, CEA.

Adani Power references an additional tariff of Rs0.50/kWh (+20% vs current average solar tariffs of Rs2.40-2.60/kWh) would compensate for the higher capital cost per kWh and lower thermal efficiency that results from a 40-50% utilisation rate vs the expected 70-80% (Figure 3). This reflects the increased operating cost as well as the increased depreciation cost per kWh of generation.

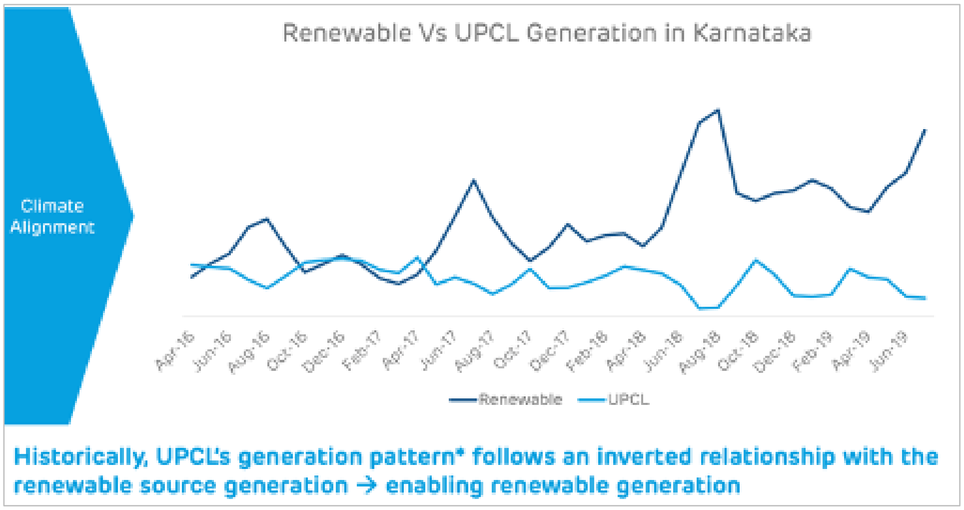
Figure 3: Lower Coal Plant Utilisation Raises Unit Costs Materially



Source: Adani Green investor presentation day, CEA, September 2020.

Adani's Udupi import coal plant is doing precisely this in Karnataka, providing a generation pattern inverted to that of renewables, albeit supported by an expensive Rs5.50/kWh (US$75/MWh) tariff to help cover the high cost of imported coal and the high capital cost per kWh that results from the lower utilisation rate (Figure 4).

Figure 4: Adani Power's Udupi Generation Profile



Source: Adani Power investor presentation, December 2019.

Policy Interventions Required

Time of Day Pricing

There needs to be a well-designed tariff mechanism to incentivise power plants to provide flexibility services which would incur considerable capital and operational expenditure. Time-of-day pricing that differentiates between periods of peak and off-peak power supply will reward plants that provide flexible ramp-up and ramp-down of their generation as per the need of the grid.

This also provides a complementary source of income for the assets that are necessary to the system but are unable to maintain business-as-usual generation due to less utilisation.[15]

In the current structure, India's load dispatch merit order incentivises least cost generation units. Plants with lowest variable charges gets dispatched first. In our view this metric should evolve going forward to also incorporate flexibility parameters of coal-fired power plants to support VRE integration.

Blending of Thermal and RE Power

The Ministry of New and Renewable Energy (MNRE) has plans to bundle thermal power with renewable power to provide lower-cost, round-the-clock power. This would also allow better utilisation of some plants which are able to operate flexibly to complement influx of VRE whilst maintaining a balance on the grid.

Recently, MNRE released guidelines to bid for a planned 5GW of bundled thermal

[15] IEEFA. Flexing India's Energy System. January 2019

plus renewable round-the-clock power tender.[16]

Due to the COVID-19 pandemic and the resulting collapse in power demand, the auction was delayed but may be conducted when demand picks up.

The tender's guidelines specify that no new greenfield thermal power development will be allowed for this tender. It mandates new renewable energy capacity to be combined with existing thermal power capacity. A minimum 250MW of renewable energy capacity could be tied up with multiple thermal plants.

Key highlights from the guidelines include:

- A single composite tariff to be bid for the power to be supplied (no peak supply tariff differentiation indicated).
- >85% availability should be maintained annually as well as during peak hours by the developers.
- >51% supply must come from renewables and the balance could be provided from a thermal power source.
- Any form of storage can be used, however, no tariff differentiation for peak supply is indicated.
- 25% of the composite tariff shall be indexed and adjusted with the index of domestic coal or imported coal as per CERC.
- The indexed tariff is to be split 50-50 between fixed and variable thermal power charges.

[16] MNRE. Guidelines for Tariff-Based Competitive Bidding Process for Procurement of Round-the Clock Power From Grid Connected Renewable Energy Power Projects, Complemented With Power From Coal-Based Thermal Power Projects. July 2020.

Battery Storage

As India plans to integrate 300GW of solar capacity on its grid by 2030, battery storage will be an extremely important technology solution as it allows time to shift the dispatch of solar and wind power. Solar generation peaks during the afternoon hours when the demand is lower on the grid. Batteries would help store cheap solar when it is available in excess and supply power on the grid during peak demand hours, creating a valuable arbitrage opportunity if a ToD pricing structure is evolved.

A hybrid system of solar plus wind plus batteries has also been extensively pursued as a solution to provide round-the-clock supply.

Like solar and wind generation technology, battery storage technology has also made massive advancements. The cost of standalone Lithium-ion battery systems globally has fallen from US$1,100/kWh in 2010 to US$137/kWh in 2020. BNEF projects a further decline in the cost to US$58/kWh by 2030.[17]

Batteries allow time to shift the dispatch of solar and wind power.

However in the absence of a fully developed value chain for batteries in India, the cost deflation curve could be slightly flatter compared to already developed markets such as the U.S., Europe, Australia and China.

In April 2020, a report from the Lawrence Berkeley National Laboratory (LBNL) in the U.S. estimated the cost of utility-scale lithium-ion battery systems and solar plus battery costs and resultant tariffs for the Indian market. These estimations are benchmarked from a couple of similar solar plus battery auctions in the U.S. that illustrate the rapid pace of deflation, technology innovation and scaling up of batteries as a strong complement to low cost but intermittent renewable energy.[18]

The bottom-up estimates of total capital cost for a 1MW/4MWh standalone battery system in India were $203/kWh in 2020 and are projected to be $134/kWh in 2025, and $103/kWh in 2030. However, when co-located with solar PV systems, the storage capital cost would be lower – $187/kWh in 2020, $122/kWh in 2025, and $92/kWh in 2030.

The report also concludes that the delivered cost (wholesale electricity tariffs) of solar plus storage bids in India for a battery charged using 25% of the rated solar capacity could be Rs3.94/kWh (US$54/MWh) by 2020, Rs3.32/kWh (US$45/MWh)

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[17] BNEF. Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh. 16 December 2020
[18] Lawrence Berkeley Lab. Estimating the Cost of Grid-Scale Lithium-Ion Battery Storage in India. April 2020.

by 2025, and Rs2.83/kWh (US$39/MWh) by 2030.

IEA's India Energy Outlook 2021 predicts that India could have 140-200GW of battery storage capacity, largest for any country by 2040.[19]

We look at Lithium-ion battery storage developments across the globe as a cross-learning exercise for the Indian market.

Battery Storage Developments Across the Globe

Australia

On the back of the state of South Australia's 100MW/129MWh Hornsdale battery project, the Australian electricity market is thriving with utility-scale battery storage developments. With a total of 7GW of utility-scale battery projects proposed,[20] the penetration of battery storage is set to significantly increase on Australia's National Electricity Market (NEM), from 215MW of battery storage capacity as of January 2021 that dispatched 0.04% of total power consumed during 12 months to February 2021.

The states of New South Wales, Queensland, Victoria, Western Australia and South Australia all have battery projects proposed. Table 3 provides a list of some of the recently announced projects.

Table 3: Recently Announced Utility-scale Battery Projects in Australia

Project & Proponents	Capacity	Year of Commissioning
AGL South Australia Battery Project	250MW/1,000MWh	2023/24
Neon/Tesla Victoria Battery Project	300MW/450MWh	2021/22
Australian Capital Territory's Neon Battery Project	150MW/300MWh	Yet to be declared
Origin Energy's New South Wales Battery Project	700MW/2,800MWh	First of the three stages to be commisioned by 2022
Neon's New South Wales Battery Project	500MW/1000MWh	2023

Source: Renew Economy, Energy Storage News, IEEFA.

South Australia

AGL Energy, one of Australia's biggest utilities, has announced it will build a 250MW/1000MWh battery in South Australia. This would be Australia's first battery project with four hours of power dispatch capability, which makes it a perfect substitute for gas peakers to supply bulk energy and provide important grid services.

[19] IEA. India Energy Outlook 2021.
[20] Energy Storage News. Australia has a 7GW pipeline of large-scale battery storage projects. 10 December 2020.

South Australia is a leading state for renewable energy with 60% of its power on the grid coming from renewables in the 12 months to February 2021.[21] The average power tariff for the power dispatched from the batteries in South Australia was AU$59.8/MWh (US$45.8/MWh) compared to an average tariff of AU$63.5 (US$48.6/MWh) for gas-fired generation during the same period, suggesting batteries are already cheaper than gas-fired plants.

AGL plans to roll out 850MW of utility-scale batteries across the NEM by FY2023/24. This includes a couple of earlier announcements of battery projects in the state of Queensland – a 200MW/400MWh sized battery in Maoneng and a 100MW/150MWh battery in Wandoan.[22]

Victoria

In November 2020, the state government of Victoria contracted the French battery developer Neoen to build a mega battery project with 300MW/450MWh capacity (1.5 hours of storage capacity).[23]

Like South Australia's Hornsdale battery, the new Victoria battery will also be built by Tesla. The battery will be to meet ramp up requirements of a major peaking plant four times quicker than traditional fossil fuel projects.

Neoen will own the asset and will receive AU$12.5m per year of service fees for the 250MW and 125MWh component under a 10-year contract with the Australian Energy Market Operator.

The battery will also allow more operational capacity on the main transmission link between Victoria and New South Wales, improving the interstate power trade.

New South Wales

The state of New South Wales is leading the race for batteries with announcements of three of the largest battery projects globally.

Origin Energy, another big Australian utility, in January 2021 unveiled a plan for a massive 700MW/2400MWh battery co-located with its Eraring power station.[24]

As NSW's coal-fired power plants gradually reach their end-of-life period, the state has an ambition to add 2GW of utility-scale batteries on its grid.[25]

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[21] OpeNEM.org
[22] Renew Economy. AGL sets new storage benchmark with 1,000MWh big battery in South Australia. 14 November 2020.
[23] Renew Economy. Neoen, Tesla win contract to build Australia's biggest battery in Victoria. 5 November 2020.
[24] Renew Economy. Origin Energy plans mammoth 700MW big battery in NSW's Hunter Region. 12 January 2021.
[25] Renew Economy. NSW targets 12GW of renewables and storage under roadmap that includes auction. 9 November 2020.

The battery could allow early retirement of the Eraring power station which is otherwise due in 2032. The strategic location of the battery near the existing coal-fired plant will allow it to utilise the same network connection after the plant's retirement.

Another big battery of 500MW/1,000MWh has been proposed by Neoen in Western Sydney, dubbed as the 'Great Western Battery'. This would be one of the largest batteries in the world.

The big batteries in NSW are deemed to support integration of 12GW of new variable solar and wind capacity.

In February 2020, an Australian renewable energy fund, CEP.Energy, announced its plan to build a much bigger battery of 1,200MW at the industrial centre of Kurri Kurri in the Hunter Valley in NSW. This development could quash viability of the proposed development of a 1,000MW of gas-fired power plant in the Hunter region, to replace the aging Liddell coal-fired power station.[26]

The electricity data analytics platform OpenNEM provides insights on the share of variable, fast flexible and slow flexible sources of power dispatch. In 2020, the share of variable, fast flexible and slow flexible sources of power dispatch was 19.3%, 13.5% and 67.2% respectively (refer Table 4).

Table 4: Australian National Electricity Market Share of Flexibility Generation 2020

Source	Energy (GWh)	Contribution to Demand	Average Value (AU$/MWh) in 2020	Average Value (AU$/MWh) in 2019	Change in YOY Average Value (AU$/MWh)
Variable	39,118	19.3%	$41.3	$78.6	-47%
Fast flexible	27,415	13.5%	$72.1	$123.8	-42%
Slow flexible	136,217	67.2%	$54.9	$89.6	-39%
Gross dispatch	**202,750**		$54.8	$93.2	-41%
Pumps	-547	-0.3%	$25.7	$58.3	-56%
Battery (charging)	-58	-0.03%	$18.2	$62.4	-71%
Charging load	**-605**				
Total dispatch	**202,145**				

Source: OpenNEM.

Note: The average value represents weighted average of all the prices transacted during the year.

[26] Renew Economy. "World's biggest battery" at Kurri Kurri will deflate Morrison's gas dreams. 5 February 2021.

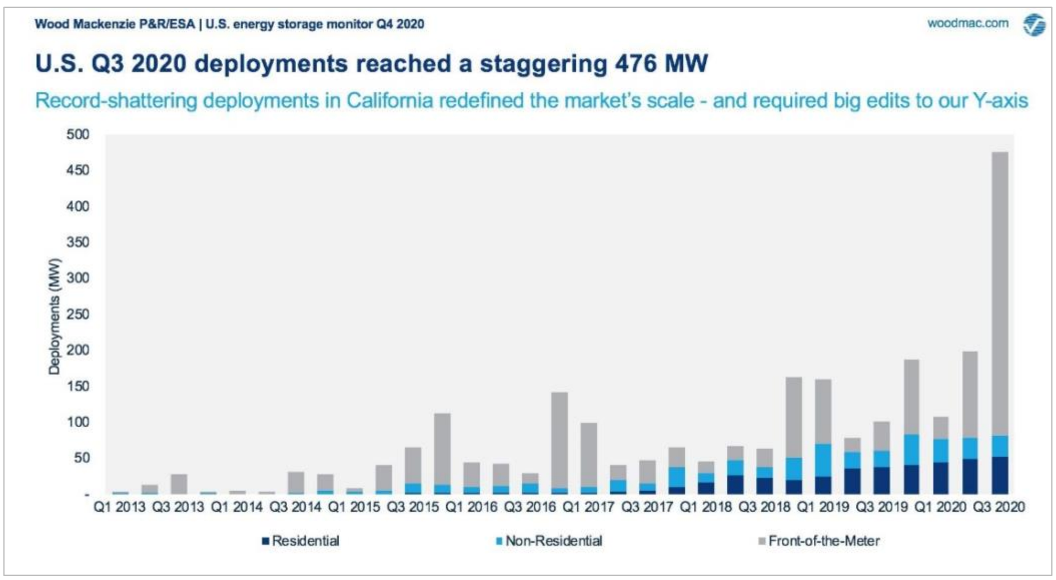
The average value of power from fast flexible sources in 2020 dropped by 42% to AU$54.9/MWh from AU$89.6/MWh in 2019. As these big batteries come online, the share of fast flexible dispatch on the grid will increase. Subsequently, a competitive market for grid services and higher flexibility dispatch will also bring costs down significantly in the Australian electricity market.

U.S.

In 2020, the U.S. battery market surpassed 1GW of battery storage installation and US$1bn of market value, a doubling of capacity addition compared to 2019. In the third quarter of 2020 alone, the battery installation number was 476MW (including behind-the-meter residential and non-residential battery storage capacity).

According to Wood Mackenzie, the U.S. market is expected to reach 7.5GW in 2025, which amounts to a sixfold growth from 2020.[27]

Figure 5: U.S. Battery Storage Capacity Addition



Source: Wood Mackenzie.

The accelerated uptake of batteries in the U.S. market is driven by state-level enforcement of battery storage requirement as well as subsidy support through tax credit incentives. The states of California, Oregon, Massachusetts, New York, New Jersey and Virginia have defined capacity targets for the state utilities for battery storage.[28]

Many states require utilities to produce integrated resource plans (IRPs) that demonstrate each utility's ability to meet long-term demand projections using a

[27] Greentech Media. WoodMac: Biggest US Battery Build-Out Ever in Q3. 02 December 2020
[28] US Energy Information Administration. Battery Storage in the United States: An Update on Market Trends. July 2020

combination of generation, transmission, and energy efficiency investments, while minimising costs.

Incorporating storage into IRPs can be a challenge because storage is different from conventional electricity generators and demand-side resources. For example, storage has unique operational constraints, can be interconnected at various points throughout the system, can serve a variety of applications, and is faced with policy and regulatory uncertainty that may affect system profitability.

As of July 2020, total of 16 states have begun to incorporate battery storage in their IRPs.

World's Largest Operational Batteries

In December 2020, Texas based developer Vistra announced commissioning of its 300MW/1,200MWh grid-scale battery located on-site at its Moss Landing Power Plant in Monterey County, California.[29] This is the largest operational battery storage project in the world – double the size of South Australia's Hornsdale Power Reserve.

Furthermore, construction is already underway on Phase II of the project, which will add an additional 100MW/400MWh to the facility by August 2021, bringing its total capacity to 400MW/1,600MWh.

The developer has further scoped potential for a massive expansion on the storage asset up to 1,500MW/6,000MWh of capacity given the available physical space, existing grid connectivity, and the industrial location of the system if market conditions permit.

It was only in August 2020 that New York-based developer LS Power's Gateway Energy Storage Project in California had worn the crown of world's largest battery with 230MW/230MWh of discharge capability.[30]

There is a massive wave of large grid-scale battery projects under construction in the state of California, many of which are designed to step in for retiring gas and nuclear plants by shifting solar supply into the evening to ramp up supply for after sunset hours.

The momentum in grid-scale battery systems also resonates in the falling tariffs of solar plus battery storage in the U.S.

According to LBNL, levelised energy prices have dipped into the range of US$30/MWh to US$40/MWh, in nominal dollars, for many projects scheduled to come online in the next few years. Adjusted for inflation over the estimated 30-year lives of the projects, those contracts are in the US$20/MWh to US$30/MWh range.

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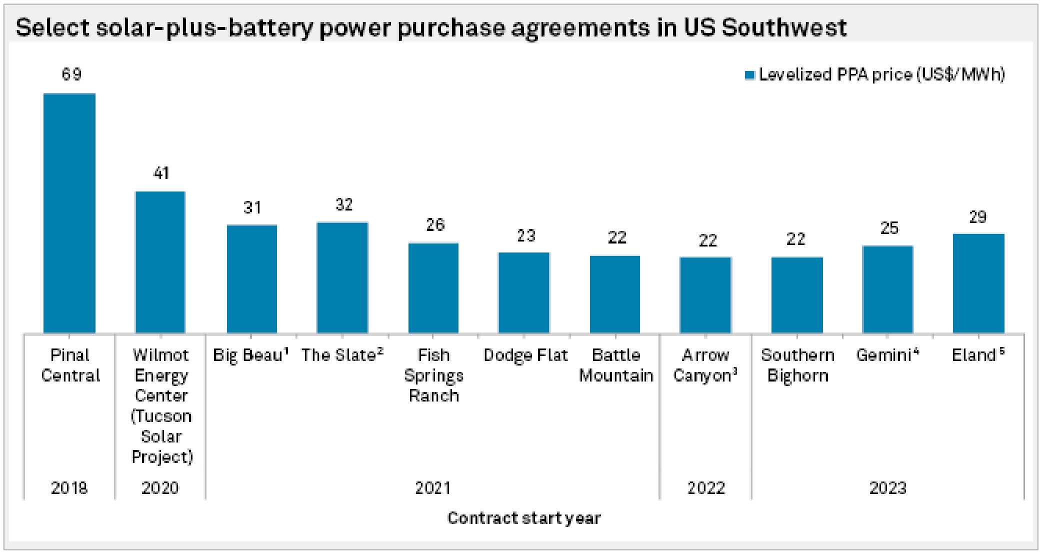
[29] Vistra. Vistra Brings World's Largest Utility-Scale Battery Energy Storage System Online. 6 January 2021.
[30] Greentech Media. LS Power Energizes World's Biggest Battery, Just in Time for California's Heat Wave. 19 August 2020.

Figure 6: US Solar Plus Storage PPAs



Source: S&P Global Market Intelligence.[31]

Grid-scale Batteries Not a Distant Dream for India

Despite the cost sensitivity of the Indian market, in the face of current high battery costs grid-scale batteries are not a distant dream for India. Domestic and international developers as well as utilities await policy support in the form of time-of-day price signalling that incentivises high capital investment into such assets.

There have been some small developments in the grid-scale battery space in India already.

Tata Power

Tata Power's Delhi Distribution Limited (TPDDL) operates India's only grid-scale battery. The 10MW/10MWh battery serves TPDDL's distribution network in the Delhi area to serve customers providing essential services such as hopitals, Delhi Jal (water) Board, Delhi Metro, government offices, and schools. The battery also provides essential grid services such as grid stabilistaion and peak-load management.[32]

AES and Mitsubishi own the battery asset, which was developed and commissioned by Fluence, a battery development giant who is also the solution provider for the 30MW/30MWh Ballart project in Australia and has developed 2.4GW of battery storage capacity globally.

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[31] S&P Global Market Intelligence. Falling US solar-plus-storage prices start to level as batteries supersize. 20 February 2020.
[32] Tata Power-DDL. Tata Power-DDL wins CII Industrial Innovation Award for Development of Mega Inverter - A Grid Scale Battery Energy Storage System. 12 December 2020.

Neyveli Lignite Corporation of India

In June 2020, Neyveli Lignite Corporation (NLC), India's largest lignite producer, commissioned a 20MW solar plus 8MWh battery system on the Andaman and Nicobar Islands' grid.[33] This was India's first solar plus utility-scale battery project. For islands with no grid connectivity with the national grid, battery storage is an important ingredient for reliable power supply and grid management.

First RE Tender With Differentiated Peak-time Supply Tariff

In January 2020 India held its first renewable energy (RE) plus storage auction of 1.2GW capacity with a differentiated tariff for peak and off-peak supply and contracted for 25 years as a way to underpin bankability.

Greenko and ReNew Power won 900MW and 300MW of capacity at an off-peak tariff of Rs2.88/kWh (US$40/MWh). The peak-time power supply tariff quoted by Greenko was Rs6.12/kWh (US$86MWh) while ReNew Power quoted Rs6.85/kWh (US$96/MWh).[34]

Greenko will reportedly be using pumped hydro storage and ReNew Power will be using battery storage to provide firmed peak-hour supply.[35]

A Targeted Policy Framework and Planning for Batteries

For battery storage to flourish in the Indian power sector, there needs to be a focused policy framework and support in the three key battery segments – generation-coupled, transmission-coupled and behind-the-meter battery storage systems.

Akhilesh Magal, Head of Gujarat government-backed consulting group, Gujarat Energy Research and Management Institute (GERMI), in his recent note prescribes following policy-related nuances for each of the battery segments.[36]

Generation-coupled battery systems — SECI could roll out tenders that mandate battery storage systems couple with RE capacity, just like the tender with differentiate peak-time power supply tariff. The battery addition should be planned with consultation of national and local dispatch centres to avoid building overcapacity and stranded assets.

Transmission-linked storage assets — These assets would be to provide

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[33] Mercom India. NLC India Commissions 20 MW Solar Project with Battery Energy Storage in Andaman. 13 July 2020.
[34] Mercom India. Greenko, ReNew Win SECI's 1.2 GW Solar, Wind Auction with Storage for Peak Power Supply. January 31, 2020.
[35] Mercom India. Greenko Seeks EPC Contractors for a 1,260 MW Pumped Hydro Storage Project in Karnataka. February 14, 2020.
[36] ET Energy World. A framework for a comprehensive energy storage policy in India. 17 January 2021

important grid operations services such as grid-balancing and addressing grid congestion issues.

Policy makers can organise separate tenders for such assets. It would also require planning exercises from POSOCO and other state transmission agencies to identify transmission bottlenecks and carefully add storage capacity where necessary.

Behind-the-meter storage assets —These are smaller battery systems coupled with rooftop solar that are installed for consumer-level applications, such as at residences and commercial & industrial entities.

India's massive ambition to have 40GW of rooftop solar capacity scales up the opportunity of behind-the-meter batteries.

However these smaller systems will directly eat into the revenues of the distribution companies by reducing power requirement from the grid and taking its most valuable customers. As the cost of battery systems continues to decline, these smaller batteries will become even more economically viable. Discoms are better off preparing for the inevitable change by adapting a suitable business model.

The Indian government must proactively look to incentivise segments in the whole value chain of batteries from lithium exploration, battery manufacturing, battery replacements to battery recycling. Batteries will be key not just for the power sector but also in electrifying the transportation sector.

Green Hydrogen

As many governments and industries across the globe try to decarbonise their economies and businesses, green hydrogen has found a new life as a clean energy alternative. Hydrogen has a wide range of applications in transport, industrial production of ammonia, methanol, steel and electricity storage and with massive deflation in hydrogen production technology, there is an accelerated flow of capital into green hydrogen production projects.

There is an accelerating flow of capital into green hydrogen production projects.

Electrolysis of water using electricity, one of the two most common methods of hydrogen production, is now ultra-competitive with availability of cheap renewable energy.

India's renewable energy price deflation is playing a key role in the transformation of its energy sector. In IEEFA's view, building a parallel economy with green hydrogen alongside the mega renewable energy target of 450GW will be transformative for India's energy security efforts. Green hydrogen production would be key for managing the 'spill' from the 450GW variable renewable energy fleet that will come online in the next 10-15 years.

NTPC's Executive Director Mohit Bhargava recently mentioned the state-owned thermal giant is focusing on green hydrogen as a key growth strategy to complement company's 32GW of renewable energy target by 2032.[37] This resonates with the Government of India's ambition for green hydrogen to be one of the key pillars of the country's energy future.

A recent report from TERI, *The Potential Role of Hydrogen in India — Harnessing the Hype,* projects a cost decline of 50% in production of green hydrogen in India.[38]

According to TERI's analysis, the cost of alkaline electrolysers is projected to drop roughly 56% from around Rs6.3crore/MW (US$0.86m/MW) today to around Rs2.8crore/MW (US$0.38m/MW).

The decline in electrolyser costs will be partly driven by large-scale deployment in India and globally, by a virtuous circle between falling costs and strengthening policy to promote hydrogen. Improving efficiencies of electrolysers, as well as increasing load factors of solar plants, will also play an important role in driving the costs of green hydrogen below Rs150/kg by 2030 (US$2/kg) – versus Rs300–440/kg (US$4–6/kg) as of today.

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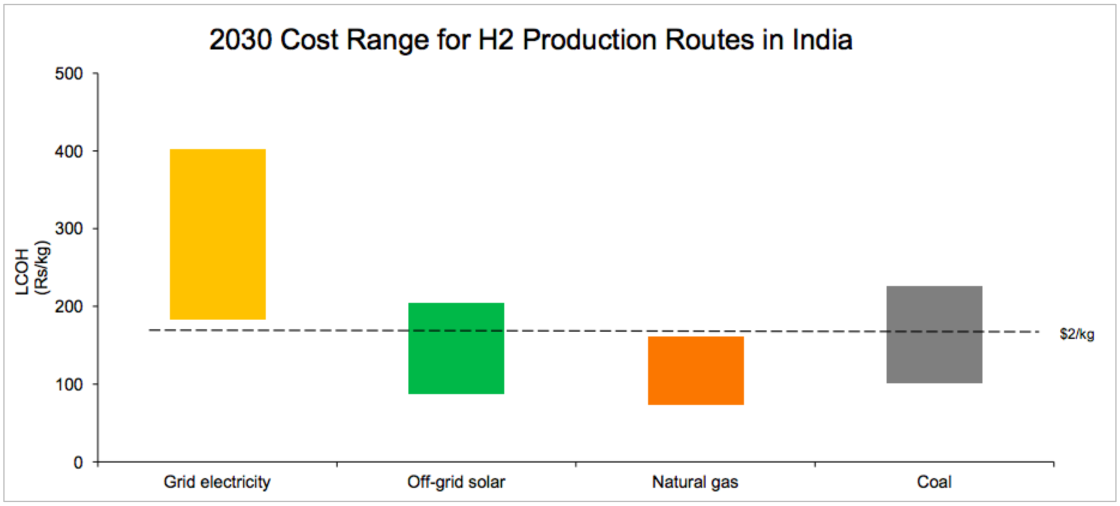
[37] ET Energy World. We are looking at both green hydrogen and battery storage: Mohit Bhargava, executive director, NTPC. 26 October 2020.
[38] TERI. The Potential Role of Hydrogen in India — Harnessing the Hype. December 2020.

Figure 7: Range of Levelised Cost of Hydrogen from Different Sources by 2030



Source: TERI analysis based on (IEA, BEIS, BNEF).

We discuss some of the top green hydrogen projects that are being planned across world that featured in IEEFA's August 2020 report, *Great Expectations — Asia, Australia and Europe Leading Emerging Green Hydrogen Economy, but Project Delays Likely*.[39]

Australia

Asian Renewable Energy Hub, Western Australia

The Asian Renewable Energy Hub, the world's most ambitious green hydrogen project, is backed by a consortium of the world's biggest wind developer Vestas, top renewable energy developer Intercontinental Energy and CWP Renewables and Australia's top investment bank Macquarie group.[40]

The hub will be the world's largest renewable energy generation facility, generating 26GW of renewable energy in Western Australia. Up to 3GW of capacity will be directed to large energy users in the Pilbara region, which could include new and expanded mines and downstream mineral processing. The bulk of remaining capacity will be used for large scale production of green hydrogen products for domestic and export markets.[41]

The mega project will draw AU$36bn of investment, boasting a hybrid generation system with 1,600 wind turbines and solar panels spread across an area of 78 square kilometres (sq. km).

[39] IEEFA. Great Expectations Asia, Australia and Europe Leading Emerging Green Hydrogen Economy, but Project Delays Likely. August 2020.
[40] Financial Times. Australia backs desert project to export green hydrogen to Asia. 22 October 2021.
[41] Asian Renewable Energy Hub.

The state government of Western Australia has given environmental approval for the first 15GW phase. An investment decision will be taken on the project in 2025 and construction is planned to begin in 2026 with first exports in FY2027/28.

Arrowsmith – Pilot Green Hydrogen, Western Australia

Australia's biggest green hydrogen plant looks set to proceed in Western Australia after an initial A$300m investment was secured for its first phase of construction. Infinite Blue Energy (IBE), a Perth-based company, aims to have the plant operational by 2022.

The Arrowsmith Project,[42] located in Dongara, 320km north of Perth, is expected to produce about 25 tonnes of green hydrogen a day using around 85MW of solar power, supplemented by 75MW of wind generation capacity.

IBE intends to build a series of similar projects across regional Western Australia, and already has plans for a second-stage project that should increase daily hydrogen production by 75 tonnes a day.

IBE has also planned a world-scale integrated hydrogen plant in New South Wales, dubbed Project Neo,[43] which could see up to 1GW of combined wind, solar and hydrogen fuel cell power plants. This project could cost up to AU$2.7bn and deliver baseload electricity to the New South Wales grid.

Europe

In July 2020, the European Commission unveiled a long-term strategy to scale up hydrogen production in Europe in an effort to push for clean energy fuels and efficiency to achieve EU's net-zero emissions target by 2050.

The EU perceives investment into hydrogen production infrastructure to be a vital stimulus for economic recovery from the slowdown caused by the COVID-19 pandemic. Hydrogen Europe sets out a €430bn (US$520bn) investment plan by 2030 for hydrogen production, storage and other related application infrastructure.[44]

This EU Hydrogen Strategy charts out specific targets, notably:

- In the first phase from 2020-24, hydrogen electrolyser installations of at least 6GW are to be set up in the EU, with production of up to 1Mt of green hydrogen.
- In the second phase from 2025-30, hydrogen electrolyser installations of at least 40GW with production of up to 10Mt of green hydrogen.

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[42] Renew Economy. Massive hydrogen project gets green light after securing $300m investment. April 2020.
[43] IBE. Project NEO to kickstart Green Hydrogen baseload power in NSW. May 2020.
[44] EU. Green Hydrogen Investment and Support Report.

- From 2030 onwards, green hydrogen is to be deployed at large scale across all hard-to-decarbonise sectors.

NortH2 in Eemshaven, Netherlands

In February 2020, Shell, Gasunie and Groningen Seaports of the Netherlands announced plans for NortH2,[45] Europe's biggest green hydrogen project, powered by up to 10GW of offshore wind in the North Sea, and a large hydrogen electrolyser slated to be sited in the Dutch port of Eemshaven.

The feasibility study was due to be finalised by the end of 2020 and first hydrogen production from the Eemshaven electrolyser could begin by 2027. This would be powered by an initial 4GW of offshore turbines developed by Equinor (Norway) and RWE (Germany). By 2040, the offshore wind fleet could grow as large as 10GW with electrolyser production of 800,000 tonnes of green hydrogen annually.

This project solves the issue of the impending legislated closure of the Groningen gas field by 2022. This field has a unique pipeline network dedicated to carrying the specific lower-calorific value quality gas of the giant Groningen field and will no longer be needed. The NortH2 project would integrate these pipelines, thereby creating value for all investors.

At 10GW, the project's offshore wind ambition exceeds even mega-developments such as the UK's Dogger Bank, where Equinor and Innogy are currently building a 5.2GW offshore wind farm.

The project is also considering placing the electrolyser offshore to avoid the transmission of electricity back to the mainland, a process which requires costly underwater cables and will incur transmission losses. The possibility of installing and operating an electrolyser offshore is currently being tested at a separate oil and gas platform in the North Sea, run by Neptune Energy.

In another big development, Siemens Energy recently announced that it will upgrade its offshore wind turbines to incorporate electrolysis technology to produce hydrogen[46] – eliminating a step of electricity transmission from the green hydrogen production process. The initial capital deployment would be to the tune of €120m (US$146m) and project size of 100-200MW to serve industries located in coastal areas. With their 14MW turbine technology that eliminates transmission-related costs with above 50% utilisation rates, the cost of hydrogen production could be dramatically low.

HyGreen in Provence, France

The HyGreen Provence project aims to develop a large-scale solar power and green hydrogen project in France's Durance Luberon Verdon Agglomération (DLVA).[47]

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[45] Gasunie.nl. Europe's largest green hydrogen project starts in Groningen. 27 February 2020.
[46] Reuters. Exclusive: Siemens spin-offs tap hydrogen boom in wind alliance. 13 January 2021.
[47] Engie. How to produce, store and distribute green hydrogen on an industrial scale. December 2019.

French developers Engie SA and Air Liquide SA will be developing a solar farm to provide power to the Provence region and with enough electricity left to produce hydrogen.[48]

The project is based on two competitive advantages, notably:

1. One of the most competitive solar resources in France enabling the construction of a local renewable electricity generation system.

2. The existence of salt caverns currently used to store natural gas on the geomethane site in Manosque, some of which could be used to store renewable hydrogen and be integrated into a green hydrogen production chain.

The project is currently in the pre-development phase and involves three development stages:

By 2022, electricity production from 730 hectares of photovoltaic panels, 10% of which is dedicated to hydrogen production, with centralised hydrogen storage.

By 2025, the first extension phase with 840 hectares of photovoltaic panels and 3,000 tonnes of hydrogen produced per year. Centralised storage in salt caverns ensuring integration between production and local uses.

Engie plans to further scale the electrolysis capacity involve ramping up to as much as 250MW by 2026. This would produce about 20,000 tonnes of clean hydrogen each year.

Hyport in Ostend, Belgium

In January 2020, Port of Oostende, DEME Concessions and PMV announced a partnership to build a green hydrogen plant in the port area of Ostend, Belgium, by 2025.[49]

This project aims to tap curtailed power from Belgium’s existing wind capacity of 2.26GW, which could be expanded to 4GW under a new marine spatial plan that leaves space for several hundred more wind turbines.

The project is currently in the general feasibility phase and involves three subsequent development steps:

- First, an innovative demonstration project with mobile shore-based power will be built. A demonstration project with an innovative electrolyser of around 50MW is also scheduled.

- By 2022, the roll-out of a large-scale shore-based power project running on green hydrogen will start.

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[48] Bloomberg. A Greener Way to Make Hydrogen Emerges in France. 9 July 2020.
[49] Deme. Hyport green hydrogen plant in Ostend. January 2020.

- The project is expected to cross the finish line in 2025 with the completion of a commercial green hydrogen plant in the context of plans for new offshore wind concessions.

Each partner brings technical and financial resources. The Port of Oostende is expanding its sustainable "Blue Economy" activities with this area-specific development. PMV has experience in financing the development, the construction and operation of the infrastructure necessary for energy projects and DEME is one of the pioneers in the development of offshore energy projects.

Iberdrola's Solar Plus Battery Plus Electrolyser, Central Spain

In July 2020, Iberdrola and Fertiberia signed an agreement to construct a €150m (US$181m) plant to produce green hydrogen for industrial use in Europe. Iberdrola and Fertiberia are to build the plant in Puertollano, central Spain, and plan for it to be operational in 2021.[50]

Iberdrola will be responsible for producing green hydrogen from 100% renewable sources, leveraging Spain's excellent renewable energy resources with world competitive costs. The solution will consist of a 100MW photovoltaic solar plant, a lithium-ion battery system with a storage capacity of 20MWh, and a 20MW hydrogen electrolyser.

The green hydrogen produced will be used at Fertiberia's ammonia plant in Puertollano. This large-scale plant has production capacity of more than 200,000 tonnes a year. Fertiberia will update and modify the plant to be able to use the green hydrogen produced to manufacture green fertilisers.

By adopting hydrogen as a fuel, Fertiberia will be able to reduce natural gas requirements at the plant by more than 10% and will be the first European company in the sector to develop expertise in large-scale green ammonia generation.

Coal Plant Making Way for Green Hydrogen in Moorburg, Germany

Germany's 1.6GW Moorburg coal-fired power plant which was only planned in 2015 will now make way for a green hydrogen production facility.[51] The Swedish state-owned developer and plant owner Vattenfall acknowledged last year that the plant is economically unviable and will be closed down in 2021.

Vattenfall is aiming to close all its remaining fossil-fuel generation by 2030. The approval of Germany's €45bn coal phaseout plan cleared the path for a December tender that will compensate firms for the closure of 4.8GW of capacity at a cost to the government of €317m (US$385m).[52]

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[50] Iberdrola. Iberdrola and Fertiberia launch the largest plant producing green hydrogen for industrial use in Europe. July 2020.
[51] Greentech Media. Coal to Green Hydrogen: Germany's Energy Transition Summed Up in One Project. 29 January 2021.
[52] Greentech Media. Germany Seals $45B Coal Phaseout Deal. 16 January 2020.

Shell, Mitsubishi Heavy Industries and municipal heat provider Wärme Hamburg will be partnering with Vattenfall to develop a 100MW electrolyser powered by wind and solar, with green hydrogen production expected to be commencing around 2025. We note this is a fivefold expansion on the largest operating electrolyser, that being Air Liquide's Canadian facility (20MW, opened in January 2021).[53] And this plant represented a doubling on the previous largest facility, that being a 10MW green hydrogen plant in Japan (commissioned 2020).[54]

A transformative move to develop a green hydrogen facility is aided by some fundamental advantages, notably:

- The location of the plant on the banks of the Elbe River provides easy access to the port of Hamburg. Also, the plant is connected to the national transmission network, the distribution system, the gas grid and the district heating network.
- The range of off-takers for the hydrogen, including the German steel giant ArcelorMittal.
- The local gas network is already working toward developing a hydrogen pipeline connecting the port and the city this decade.

Asia

Jingneng Power's Hydrogen Storage Facility, Inner Mongolia

In March 2020, Chinese state-owned utility Jingneng Power (JP) said it will spend RMB23bn (US$3bn) on a 5GW hybrid solar, wind, hydrogen and storage facility in Eqianqi, Inner Mongolia. The energy complex is expected to be commissioned in 2021, with project bidding and equipment procurement and construction already underway.

Jingneng Power said Eqianqi was chosen for its good business environment and abundant resources. Upon completion, full production capacity will be 400,000–500,000 tonnes a year of hydrogen.[55]

This project is part of a broader RMB24bn (US$3.4bn) plan from BJP which includes a natural gas pipeline, an agricultural logistics centre, an industrial steam facility and a quartz sand processing plant.

JP is the coal-fired power subsidiary of Beijing Energy Group and was listed in May 2002 on the Shanghai Stock Exchange. Since the initial public offering, JP has expanded its size and invested in projects throughout North China, including

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[53] Recharge News. World's largest green-hydrogen plant inaugurated in Canada by Air Liquide. 27 January 2021.
[54] Energy Storage News. Hydrogen electrolysis using renewable energy begins at 10MW Fukushima plant. 20 April 2020.
[55] PV tech. Jingneng plots 5GW wind-solar-hydrogen-storage hub in Inner Mongolia. March 2020.

Beijing, Hebei, Inner Mongolia, Shanxi, Ningxia, and Hubei.

At present, JP holds controlling stakes in over 22 companies and non-controlling stakes in over 15 companies, resulting in controlling stakes of 10.8GW of installed capacity and non-controlling stake interests of 13.3GW.

Apart from green hydrogen production projects for electricity storage and industrial usage, projects related to hydrogen fuel cells production are making sizable strides.

Plug Power's Asian Entry

Plug Power, an American Hydrogen fuel cell and electrolyser manufacturer, in January 2021 made a big entry in South Korea with an investment of US$1.5bn from South Korea's SK group.[56]

The partnership intends to produce and sell products across the entire hydrogen economy value chain, including Plug Power's GenSure stationary power fuel cell, ProGen fuel cell engine, GenFuel liquid hydrogen and dispensing equipment and Plug Power electrolyser products. The partnership will focus on near-term opportunities in South Korea, taking advantage of captive applications with SK Group.

South Korea has a massive ambition to create a hydrogen economy in Asia with a target of 15GW of fuel cell production capacity by 2030 and for the country to become the world's top maker of hydrogen-powered cars by decade's end, with the commensurate refuelling infrastructure to support their domestic use.[57]

Middle East

Ammonia From Green Hydrogen Project in NEOM, Saudi Arabia

In July 2020, a consortium of Air Products, ACWA Power and NEOM (a new city planned near Saudi Arabia's border with Egypt) announced plans to build a US$5bn green ammonia plant powered by 4GW of wind and solar power.[58] The facility will produce 237,000 tonnes a year of green hydrogen to be shipped as ammonia to markets globally then converted back to hydrogen to take advantage of ammonia's lower transportation costs. Ammonia production is expected to start in 2025.

The project would be a big step forward for Saudi Arabia's ambition for NEOM to become an important global centre for renewable energy and green hydrogen.

The key components of the project are:

- Air Products (APD) will supply the air separation unit (ASU) to produce nitrogen and will be the exclusive off-taker of green hydrogen for global sales. APD will invest a further US$2bn to construct downstream

[56] Plug Power. Plug Power and SK Group Partnership. 8 January 2021.
[57] Greentech Media. Plug Power Raises $1.5B to Tap Into Green Hydrogen Economy in Asia. 07 January 2021.
[58] Greentech Media. World's Largest Green Hydrogen Project Unveiled in Saudi Arabia. July 2020.

distribution including ammonia dehydrogenation facilities and hydrogen refuelling stations.

- ACWA Power, Saudi Arabia's leading power and water desalination operator, will supply the solar plant. It has a track record of delivering major solar projects in recent years and achieving record-low solar power prices.

- Germany's Thyssenkrupp will supply the electrolysers. It has increased its electrolyser manufacturing capacity to 1GW per annum this year.

- Denmark's Haldor Topsoe will supply the ammonia production technology.

A Not-to-be-Missed Opportunity for India

India's top renewable energy states such as Rajasthan, Gujarat, Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu cumulatively have a target to build more than 150GW of renewable energy capacity by 2030. Whilst rampant cost deflation in solar and wind technology will allow accelerated deployment of generation infrastructure, integrating this capacity onto the grid such that the curtailment risk is minimum is important. Planning and investing early into green hydrogen provides that added security against commercial risk of curtailment.

As mentioned earlier, green hydrogen production is perfect to absorb the 'spill' (excess generation that cannot be supplied on the grid) from variable renewables.

In one such early development in India, Adani Group announced a strategic collaboration with Italy's Snam on development of hydrogen and its value chain, biogas, biomethane and other low-carbon mobility in the Indian market.[59]

Snam has also signed an agreement with renewable energy developer Greenko to collaborate on development of the hydrogen value chain in India.[60]

Adani and Greenko cumulatively already have more than 10GW of operational renewable energy capacity and more than 8GW under construction. The strategic collaboration with an international technology expert is promising for India's green hydrogen prospects.

Hydrogen is an important alternative clean fuel that offers decarbonisation in power, transportation and other industrial sectors. The project and capital commitments across the globe are building a critical mass in the hydrogen space. India will have the benefit of developed economies incurring the cost of learning by doing. However, its strategy should be to plan in advance and be prepared to ride on the green hydrogen wave when it arrives.

[59] ET Energy World. Adani announces strategic collaboration with Italy's Snam on energy transition. 6 November 2020.
[60] ET Energy World. Snam and Greenko sign pact to develop Hydrogen value chain in India. 6 November 2020.

About IEEFA

The Institute for Energy Economics and Financial Analysis (IEEFA) examines issues related to energy markets, trends and policies. The Institute's mission is to accelerate the transition to a diverse, sustainable and profitable energy economy. www.ieefa.org

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