Flexible Resources Initiative of the U.S.-India Clean Energy Finance Task Force

Least-Cost Pathway for India's Power System Investments through 2030

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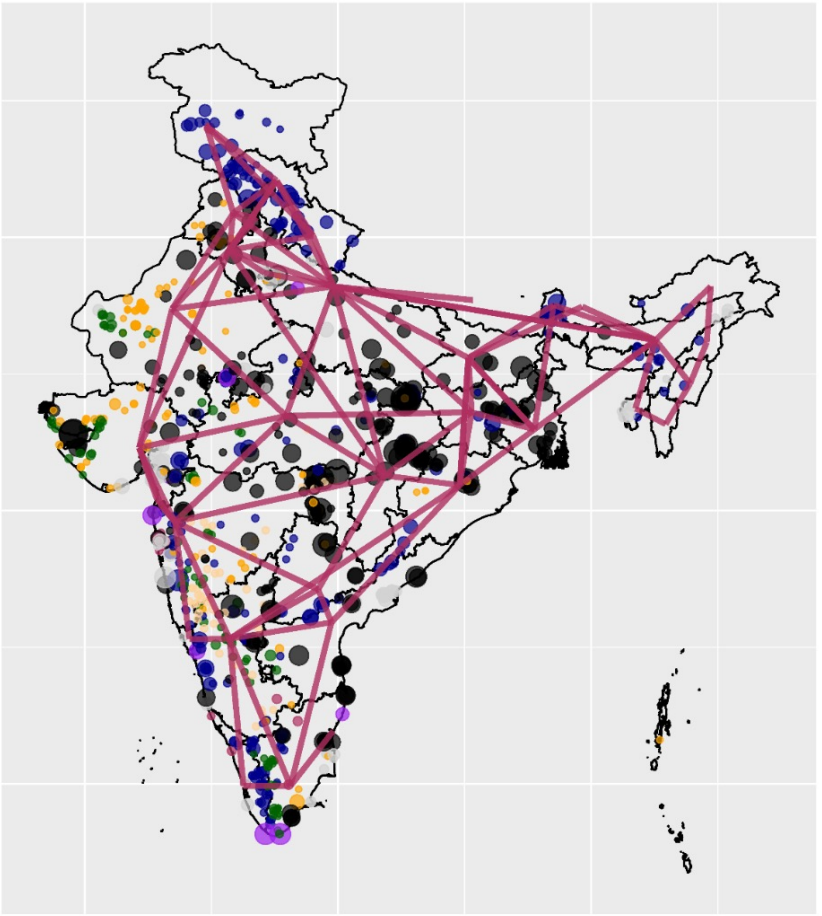
Publication of the Least Cost Power System Studies at the State Level

Flexible Resources Initiative (FRI) National Study Overview

- **What did we do ?**
  - Assess a least-cost resource mix for the Indian power sector up to 2030
  - Comprehensive system expansion and hourly operational modeling at individual power plant level using PLEXOS
  - Identify concrete policy / regulatory solutions

- **What did we find ?**
  - The least cost pathway by 2030 includes 464 GW of RE + flexible resources: 63GW (252 GWh) energy storage, 60GW load shifting, flex operation of 25 GW gas, >140GW new interstate transmission, & national wholesale electricity markets
  - 23 GW of net addition to the coal capacity by 2030 (may be higher in case RE/storage costs do not drop or deployment barriers)
  - Average electricity price reduces by 8-10% between 2020 and 2030
  - CO_2 emissions intensity of power generation reduces by 43-50% from 2020 level
  - Unlikely to lead to job losses in the coal sector in near to medium term
  - Need significant policy / regulatory interventions (resource adequacy framework, storage regulations, capacity markets, wider/deeper energy markets)

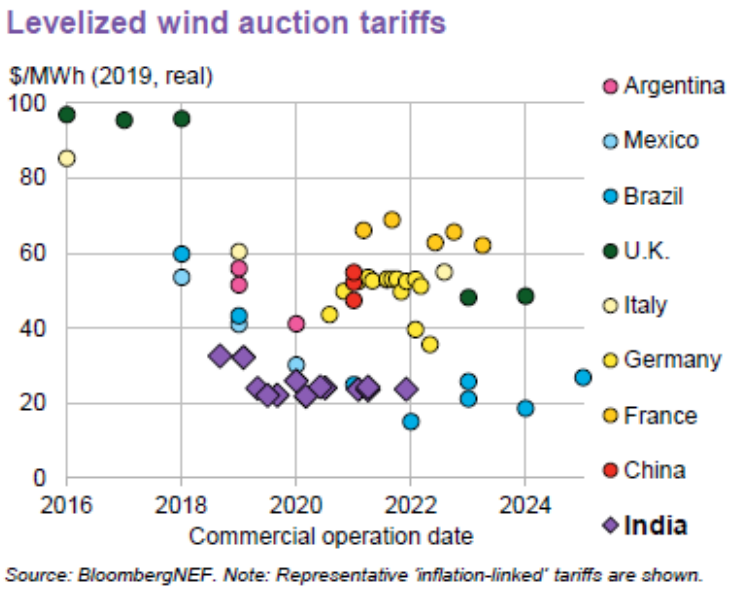


- **What are the implications ?**
  - A least-cost pathway to achieving PM Modi's 500GW clean energy target at COP-26

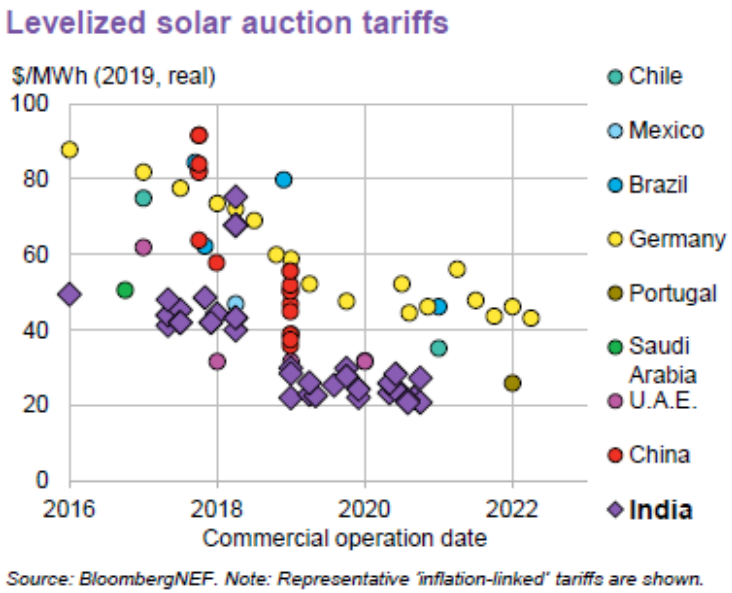
Solar & wind are the cheapest resources in India

- India has achieved some of the lowest solar and wind prices in the world.
- Solar LCOE has reduced by 85% in the last 10 years
- Solar PPA prices in 2020-21: ~Rs 2/kWh, which is lower than the variable cost of ~100 GW of existing coal assets

- Battery prices have dropped by ~90% in the last 10 yrs
- In FY 2022, battery storage capital cost (global avg) is ~Rs 6.5 Cr/MW (4-hour)

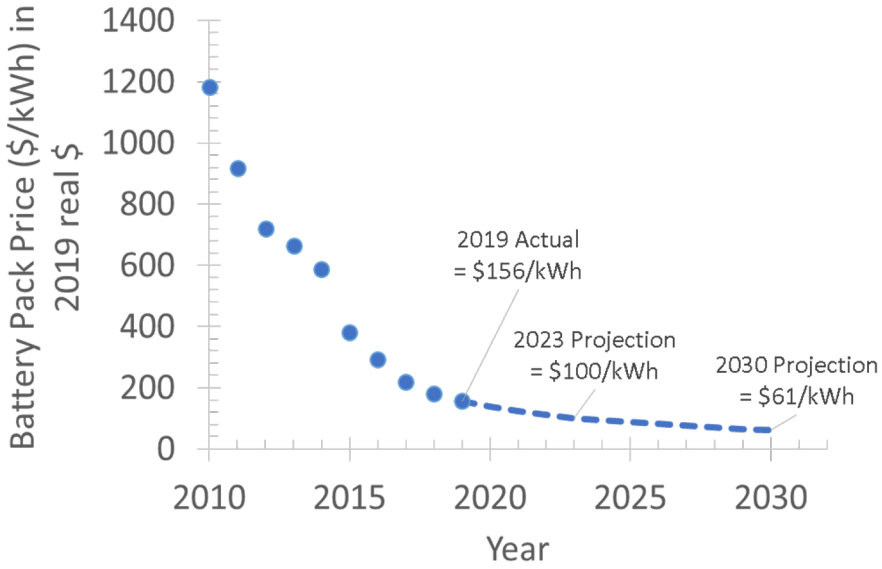


Source: BloombergNEF. Note: Representative 'inflation-linked' tariffs are shown.



Source: BloombergNEF. Note: Representative 'inflation-linked' tariffs are shown.

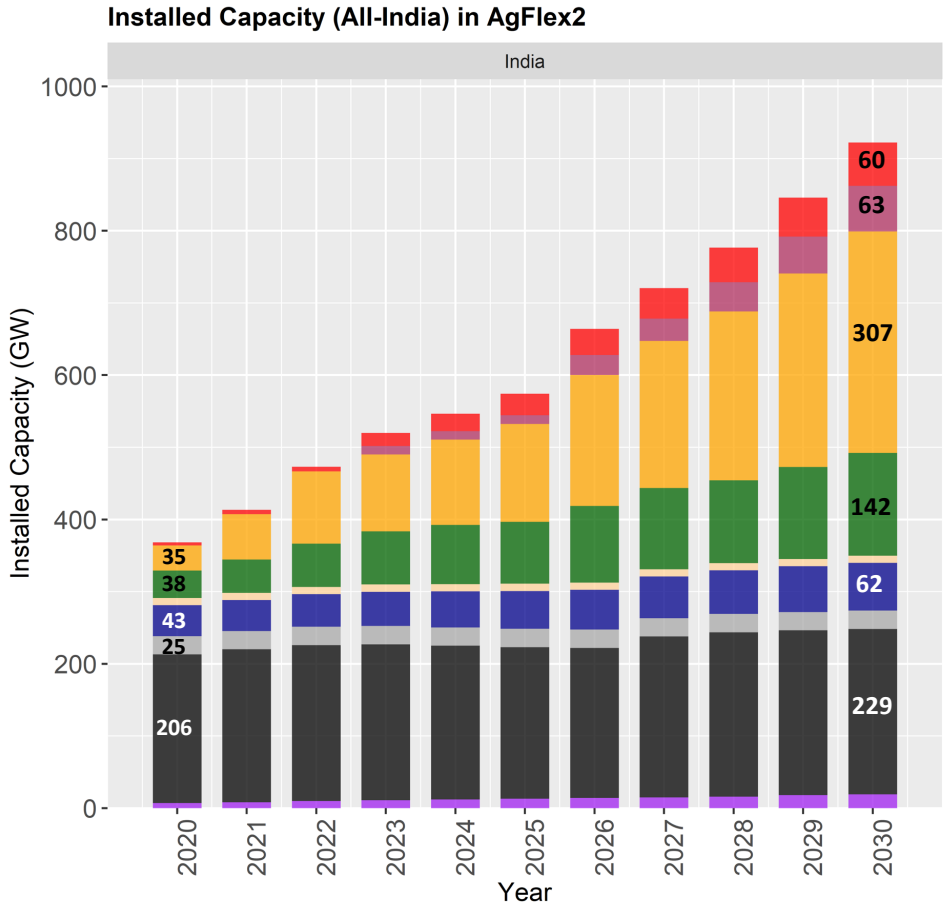
Source: BNEF (2020)

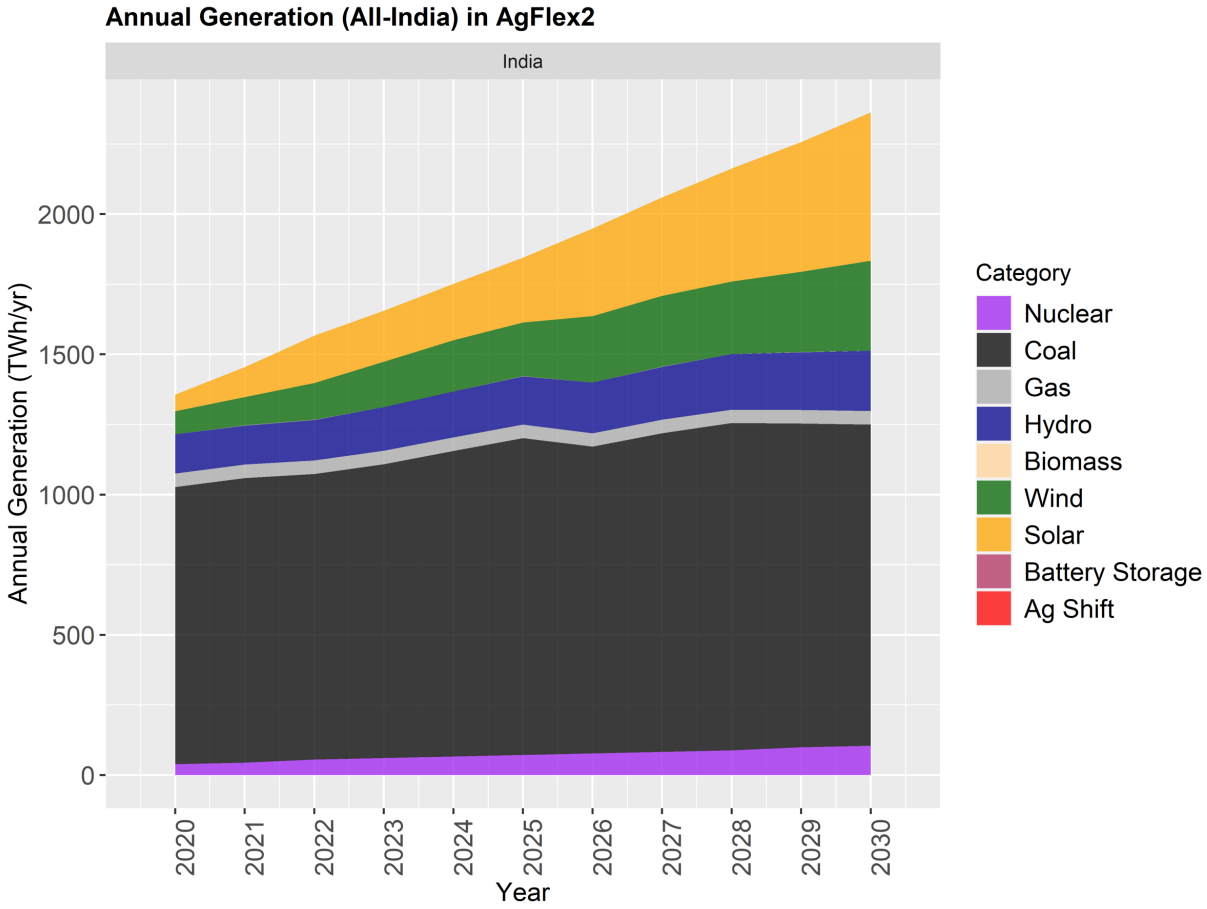


Source: BNEF (2020)

➔ **By 2025-2030 Solar + 30% energy storage would cost ~Rs 3.0-3.5/kWh, nominally flat for 20 yrs.**

The Primary Least Cost Pathway

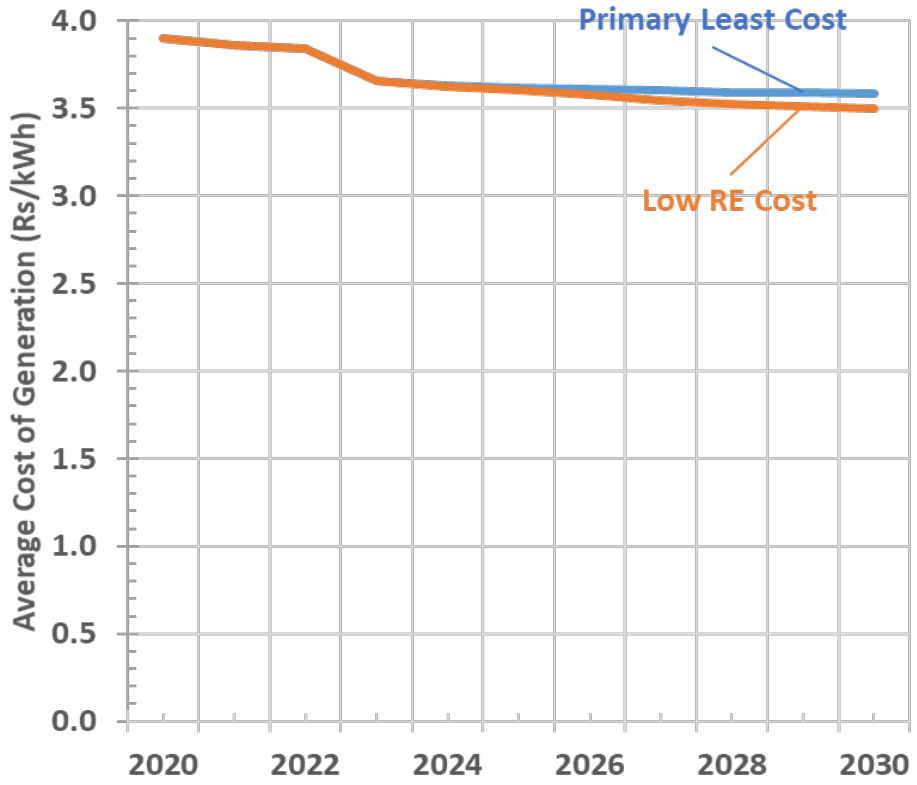




- **Least cost capacity mix for 2030:**
- RE = 465GW (non fossil = 545 GW)
- Net coal capacity addition = 23 GW
- Energy storage = 63 GW/252 GWh

- Between 2020 and 2030, as the load nearly doubles, coal generation increases only by ~10%.
- Non-fossil sources provide ~50% of energy generation by 2030
- Emissions intensity of electricity generation reduces by **43%**

Primary Least Cost pathway would reduce electricity costs by 8% from 2020 levels



- The average cost of electricity generation decreases by 8% from 2020 levels (Primary Least Cost case).
- If RE and storage prices decline faster - in line with the recent global trends - the average cost of generation drops by 10% (Low RE Cost case).

- ***Why?***
  - New solar / wind PPA prices would be lower than even the marginal cost of several coal power plants
  - Solar / wind /storage PPA prices are fixed in nominal terms making a huge portion of power procurement inflation proof.

Is the grid dependable ? (e.g. Primary Least Cost Pathway)

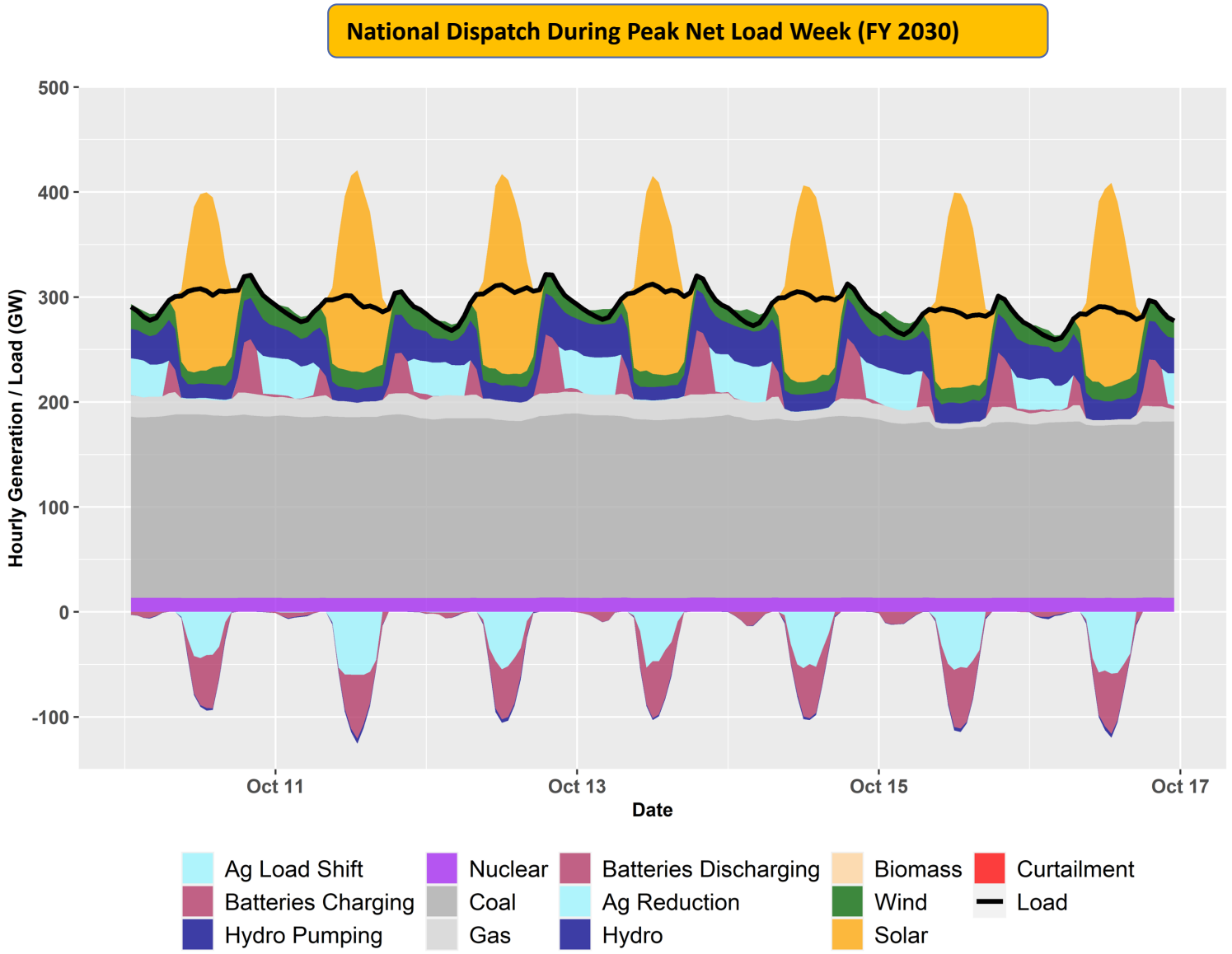


Chart shows results from simulating the hourly power plant level dispatch (8760 hours x ~2,500 generation units x 75 interstate transmission corridors) during the **highest net load week in FY 2030**.

Net Load Peak (National)
= 307 GW on Oct 13 at 7:00 PM

Coal and Nuclear generate at near full load:

Coal	= 175 GW	
Nuclear	= 13 GW	

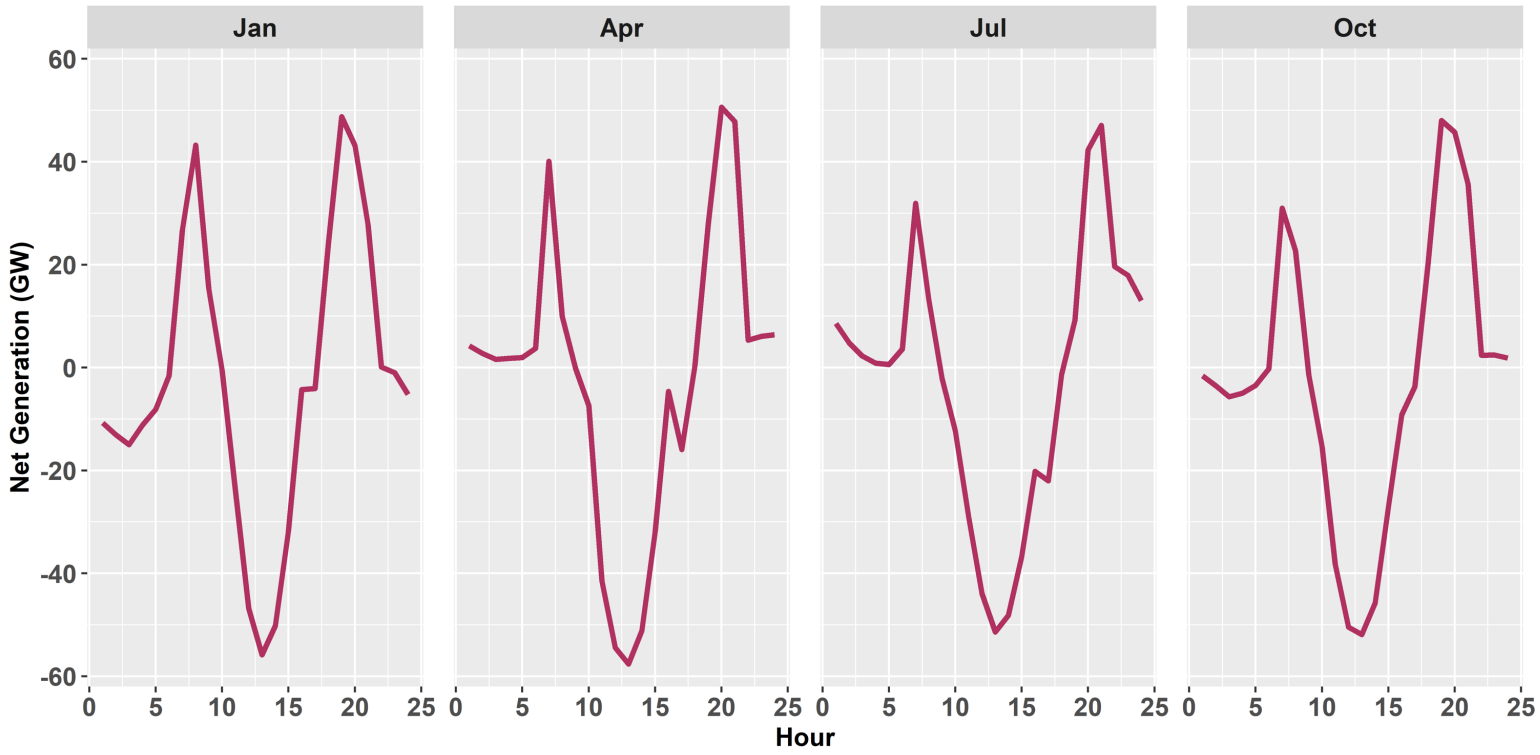
Supply side FRs play a crucial role in meeting the net load peak

Storage	= 60 GW	(diurnal balancing)
Gas	= 22 GW	(seasonal balancing)
Hydro	= 40 GW	(incl small hydro)

Detailed results available at:
https://public.tableau.com/profile/nikit.abhyankar#!/vizhome/FRINationalDispatchVizv2/DispatchSummary

How much storage is required and how is it operated ?

Average charge (negative) and discharge (positive) operation of energy storage in FY 2030 (Primary Least Cost case)



Optimal energy storage requirement (All-India)

2025	2027	2030
12 GW/ 48 GWh	31 GW/ 125 GWh	63 GW/ 252 GWh

Batteries mainly charge during the day and discharge during evening and morning peak hours (4-6 hours/day).

Storage would be a critical source of flexibility starting as early as 2023, especially in states with high solar deployment and low hydro resources such as Rajasthan, Madhya Pradesh, Gujarat etc.

Policy & regulatory measures would be required to achieve least-cost pathway

Power system changes combined with existing regulatory practices could pose challenges for meeting future load reliably and cost effectively:

- Changing load shape and variable supply
- States procuring resources to meet individual state level peak demand
- Low utilization of assets; limited sharing of resources

Capacity assessment	Capacity sharing	Integrate w/ planning & procurement
• How much capacity is needed and when • Determine contribution of all resources to firm capacity	• Streamline capacity sharing amongst states • Leverage load and resource diversity	• Use capacity (RA) requirements as input to planning & procurement • Deploy a portfolio approach to procurement

Resource Adequacy (RA) Framework

Click here for the report on the modeling study.

Click here for the report on regulatory recommendations.

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Flexible Resources Initiative (FRI) National Study Overview

- Context and Objective
  - Current events and recent declines in RE and battery costs and gas prices, and electricity market reforms offer a unique opportunity to India to leapfrog to a more flexible, robust, and sustainable power system, in view of unexpected challenges and disruptions.
  - LBNL assesses a least cost resource mix for India with a focus on key flexible resources ("FRs," e.g. energy storage like batteries / pumped hydro, gas, load shifting, hydro, and electricity markets) to support India's energy transition over the next decade

- PLEXOS, an industry standard tool, is used to:
  - Model optimal capacity expansion at the state level through 2030 and simulate hourly dispatch at the power plant level in 2030, over a range of scenarios on RE costs, gas prices, coal retirements, demand growth, electricity markets, supply chain challenges, etc.

- Key Findings
  - The least cost pathway up to 2030 consists of a combination of RE (~350-450 GW_{DC}) + FRs: 30-60GW energy storage, 60GW load shifting, flexible operation of 25 GW gas, >140GW of additional interstate/inter-regional transmission, and market-based economic dispatch (MBED)
  - 23 GW of net addition to the coal capacity is cost-effective by 2030 (may be higher in case RE/storage costs do not drop or deployment barriers)
  - The complementarity of FRs working in tandem is crucial for maintaining grid dependability in view of high RE penetration
  - Study outcomes point to some key policy and regulatory strategies on resource adequacy

RE + Coal expansion will cause significant stress on thermal assets

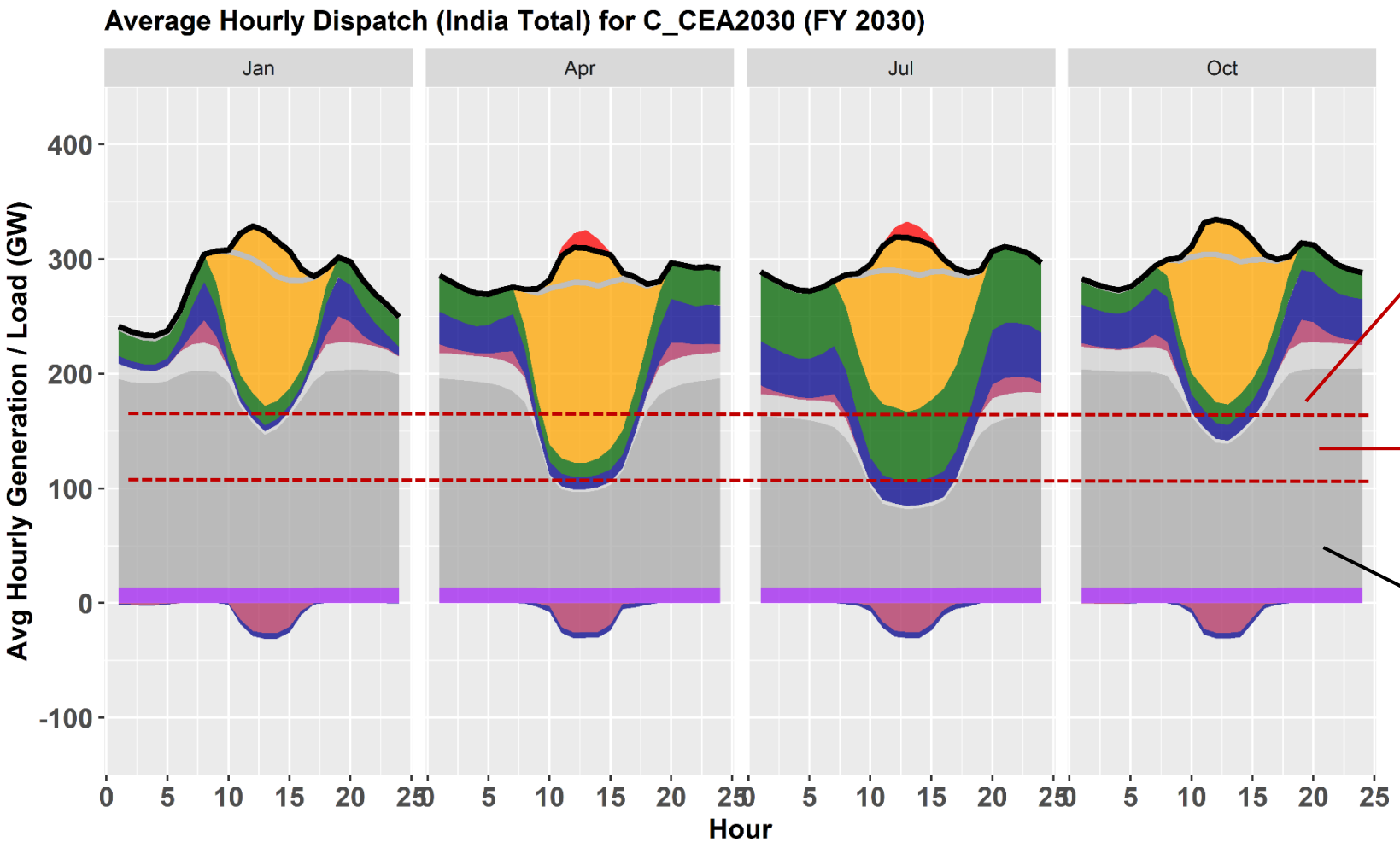

Chart shows average hourly dispatch in FY 2030 with significant RE and coal expansion (435GW RE + 37GW storage + 266GW Coal)

~50GW of coal @ <20-30% capacity factor
➔ **Avg cost of generation = Rs 7-8/kWh**

~50 GW of coal @ ~40-50% capacity factor
➔ **Avg cost of generation = Rs 5-6/kWh**

~160 of coal @ ~70-80% capacity factor
➔ Avg cost of generation = ~Rs 3-3.5/kWh

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RA framework integrated with state level procurement would ensure reliability while lowering costs

- National agency to issue standardized **guidelines for load forecasting** at Discom/state level; thereafter rolled up into a robust national load forecast
- National agency to conduct **Reserve Margin Study** to assess firm capacity requirements at national/state level; allocate RA requirements to states based on share of national coincident peak
- States to assess existing resources using **capacity credits** for all resource types, including renewables and battery storage
- Discoms/states to share capacity resources through **short-term RA contracts** (bilateral in near term, centralized capacity market in longer run)
- Discoms/states to conduct **all-source procurement** for new resources to arrive at least-cost portfolio; evaluate using engineering & economic tools
- Regulatory Commissions to ensure **compliance with RA requirements** using incentives and penalties