



Planning for Firm Power:

What India's Resource Adequacy Plans Should Count from the New Storage Bids

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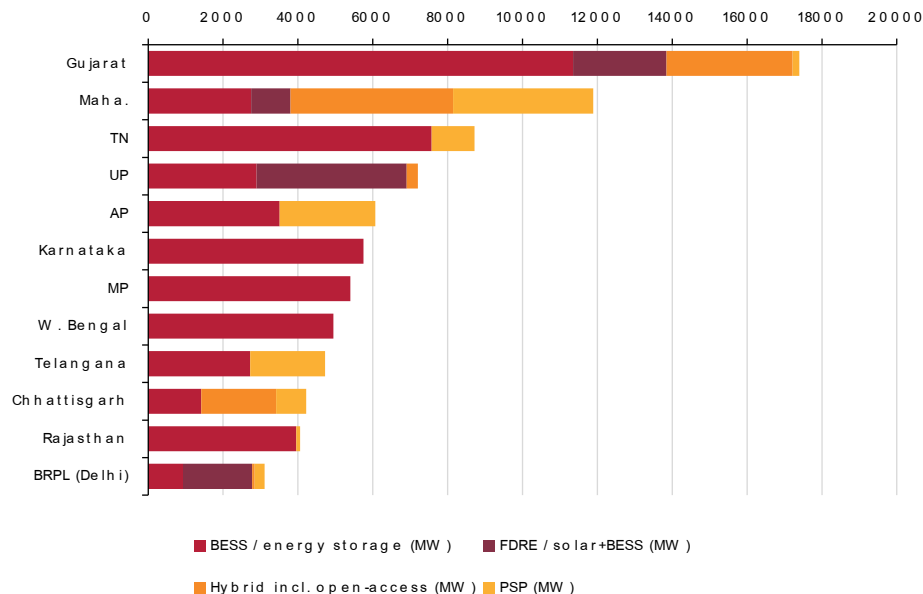
Why this matters now: states are writing these tenders into their plans as firm capacity

- Several state RA plans enter the new products (RTC, FDRE, solar+BESS, standalone BESS) as the firm capacity closing the 2027–30 evening gap, usually at contracted MW
- CEA's own credits say otherwise: 4-hour BESS 0.67, 2-hour 0.33 against the ~6-hour non-solar block; solar ~0 after sunset; coal 0.8
- The tenders relax the obligation: annual or monthly CUF instead of hourly delivery, 4-hour assured blocks, merchant freedom for storage
- What do these tenders actually deliver, hour by hour and season by season – and who serves the hours they skip?

States already count the new products as 2029-30 capacity

Hybrid, FDRE, RTC, BESS and PSP entered in state resource adequacy plans for 2029-30

Capacity in state RA plans for 2029-30: contracted, planned and to be tied up (MW)



- About 95 GW of the new products sits in state plans for 2029-30: storage ~60 GW, hybrid ~12 GW, FDRE ~8.6 GW, PSP ~12 GW – part contracted, part planned, a large part still to be tied up
- Where stated, firmness assumptions vary widely: FDRE at 94% CUF (GUVNL), 75–76% (MSEDCL), ~61% (UPPCL), 60% (Punjab)
- Most plans do not say what they assume – so the tender itself is the only evidence of what these are worth at the peak

Study: What do current cheap storage bids mean?

- India's newest storage+solar bids are remarkably cheap, some even cheaper than new coal
- But what the bids actually promise matters: most cover limited (the easy) hours, with generous relaxations for the hard ones
- The hard hours do not disappear – they become “leftover” (residual) demand that the grid / discom / consumers still pay to serve
 - Firmness is not free: a Rs 3 bid and a Rs 6 bid are usually different products, not a cheap and an expensive version of the same one
- We study what the headlines skip: (1) the cost of genuinely firm (hourly) 24x7 clean power, and (2) the cost of the leftover when bids avoid it
- **Bottom line: India needs much more storage... but the true cost of reliability must be visible, or it quietly lands on DISCOMs and consumers**

Four terms that carry this analysis

- 1) **CUF: Capacity Utilization Factor (akin to PLF)** – total energy delivered over the year as a share of the maximum. It counts energy, not which hours
- 1) **Firmness:** the share of demand the project must meet in every hour (time block), not just on average
(95% firm = at least 95% of demand in every single hour)
- 2) **Relax worst hours (cost-optimized):** allow a small % of hours (e.g., 5%) for relaxation in firmness – the model skips the hardest hours
- 3) **Residual (“leftover”) demand:** the hours a project does not serve; the discom must procure elsewhere

Other key terms: RTC = “round-the-clock” (tenders); FDRE = “firm and dispatchable RE”; VGF = viability gap funding (an upfront subsidy)

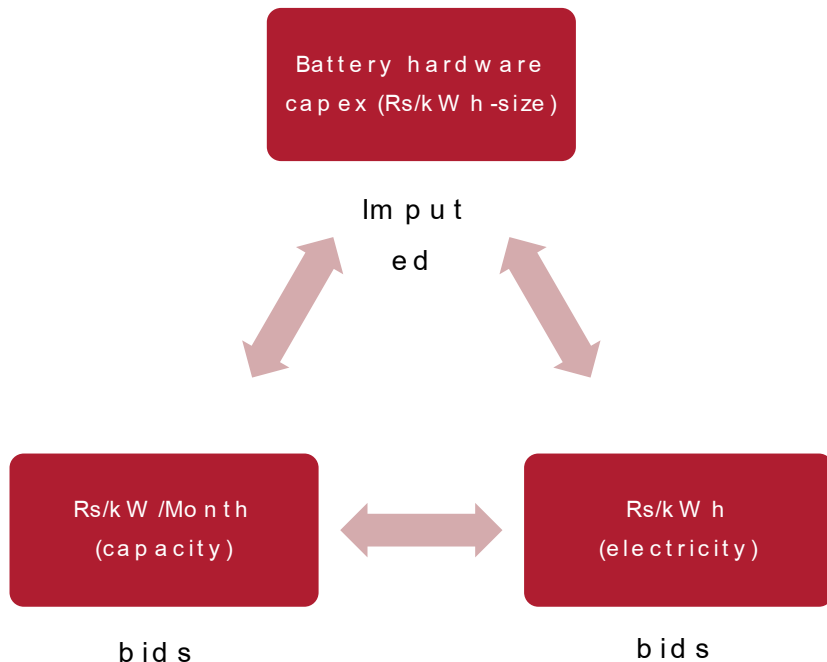


Part 1 – What do the cheap bids actually promise?

Reading the fine print behind the headline ₹/kWh

Storage bids are not directly comparable

The same hardware can yield very different ₹/kWh, depending on assumptions

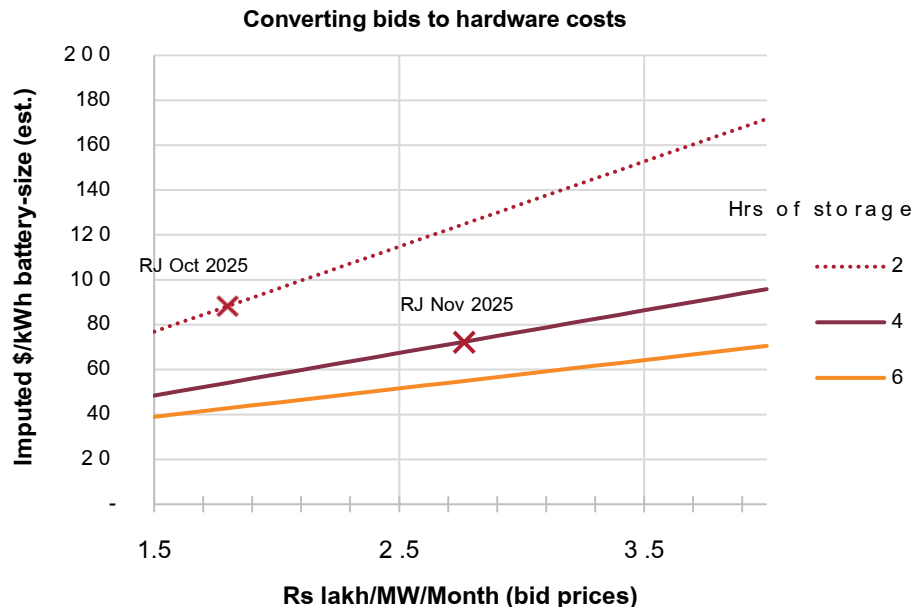


- Bids can come in different units: ₹/kW h of battery hardware, ₹lakh/MW /month rentals, ₹/kW h of electricity delivered, etc.
Converting between them requires assumptions
- The biggest assumption is the duty cycle: Assume two full daily charge-discharge cycles and the per-unit electricity cost looks far cheaper
But how, and at what price, will it charge twice a day?
- Many bids also include VGF (an upfront subsidy) that the headline tariff does not show
- Hardware is more than cells/packs: inverter, electronics, cooling, installation
Press focuses on packs, which are largely imported

Arithmetically convertible into each other, but only if you make assumptions like duty cycle

Many bids have entered the realm of “challenging”

Risks: (a) quality (esp. for Indian heat); (b) will it get built?



- \$~74/kW h-battery system costs is quite aggressive considering :

- Installation
- Duties
- Balance of systems, including inverter!

- The cells (if imported) thus are in the order of ~\$42/kW h!

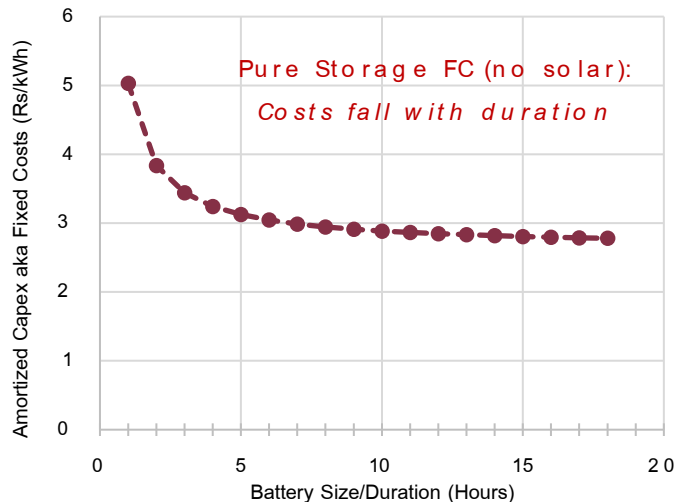
By Dec 2025, China tightened export rules: no selling batteries below cost (EBITDA-negative)



Blended (w/ solar) bids complicate comparisons

Simplistic modelling (linear arithmetic)

- FDRE (firm & dispatchable) bids asked for (say) 4 hours of overnight supply

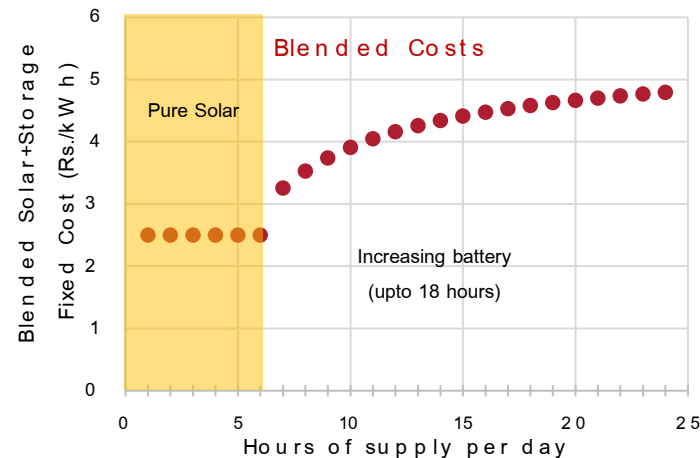


Pure battery: Larger size is cheaper as BoS costs are based on kW, not kWh

Solar farms can give 25% PLF =
6 hours per day



Thus, 18 hours of battery + 6
solar
= 24 hours supply (*on paper*)



Solar + Storage: Costs rise with more hours/d ay of supply (solar is cheap)

Notes: Storage assumes a pack cost of \$50/kWh, BOS (balance of system) cost of \$50/kW, EPC/installation of \$10/kWh, 10.15% WACC, 12 year lifespan, 3% O&M costs, Round trip efficiency of 85%, 90% depth-of-discharge (DoD) limit, Rs 90/US\$ forex rate, and one cycle per day in full

A recent bid: UPPCL storage (May 2026)

Storage with RE for charging included, but not blended with direct solar

- The bid pays for just 4 hours of discharge, during evening/night periods
- Headline tariff: ₹6.45/kW h, plus viability gap funding worth roughly another 70 paise/kW h
- Blend in cheap solar for 6 hours equivalent (₹2.50/kW h, an aggressive assumption) and a simple weighted average for “24×7” converts to about ₹6.0/kW h
- But see the fine print:
 - (1) The bid requires only 95% availability, measured monthly, not hour by hour;
 - (2) that is only for a flat output
- **Takeaway:** even at ₹6/kW h for 24×7, this is not yet truly firm power

Part 2 – What does genuine 24×7 clean power cost?

We build a model that starts simple and adds reality one constraint at a time (The goal is not a single price, it is to see which assumptions move the price)

Pro Tip: Don't focus on a specific cost result, but the *changes in cost* or trends when we add constraints or factors that matter

Wonky details:

Built in GAMS · Thousands of MIP (Mixed Integer Programming) problems to solves a single MINLP Problem · Thousands of runs for Demand Flexibility in loop · Planning with Operational Granularity

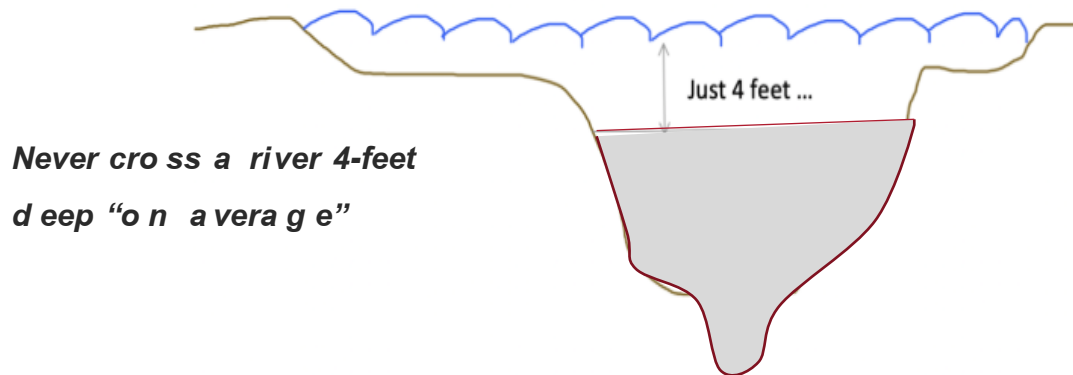
Needs powerful computing (days per run): Intel Core i9-14900K 3.20 GHz, 192 GB RAM System

The biggest problem with headline 24x7 claims is extrapolating from current bids (often linearly)

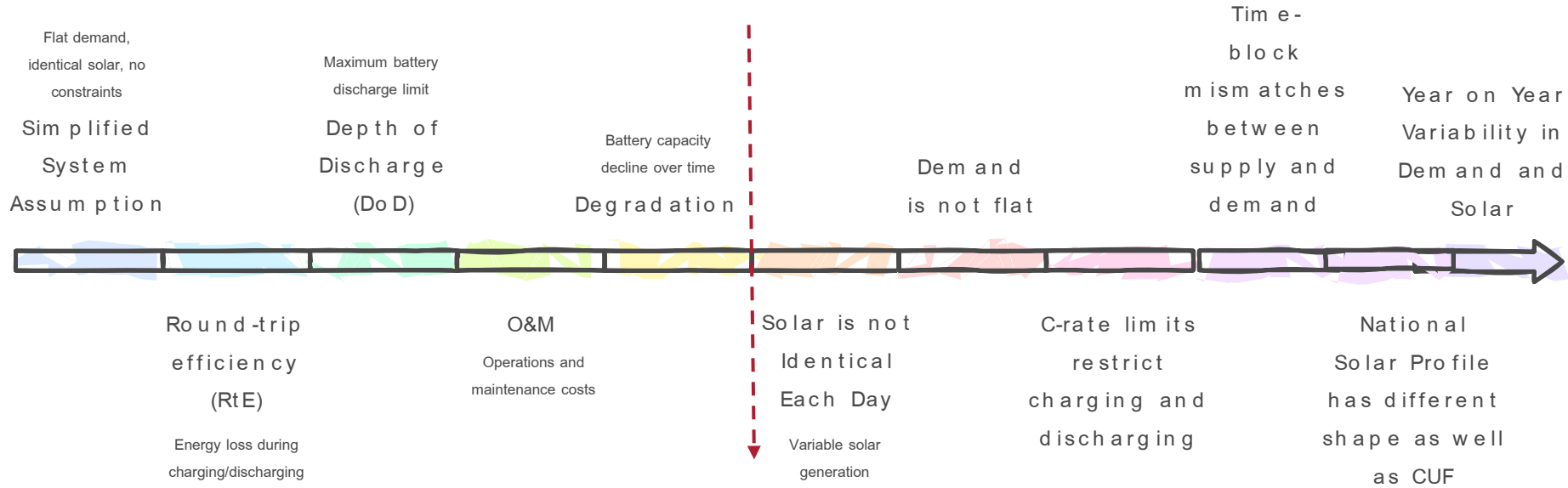
- The goal isn't to produce a flat demand like current bids (even ignoring lack of firmness)

Demand varies by season, as does RE supply

- Lack of firmness isn't a cost reduction, it's a risk transference



Every real-world constraint you add moves the cost



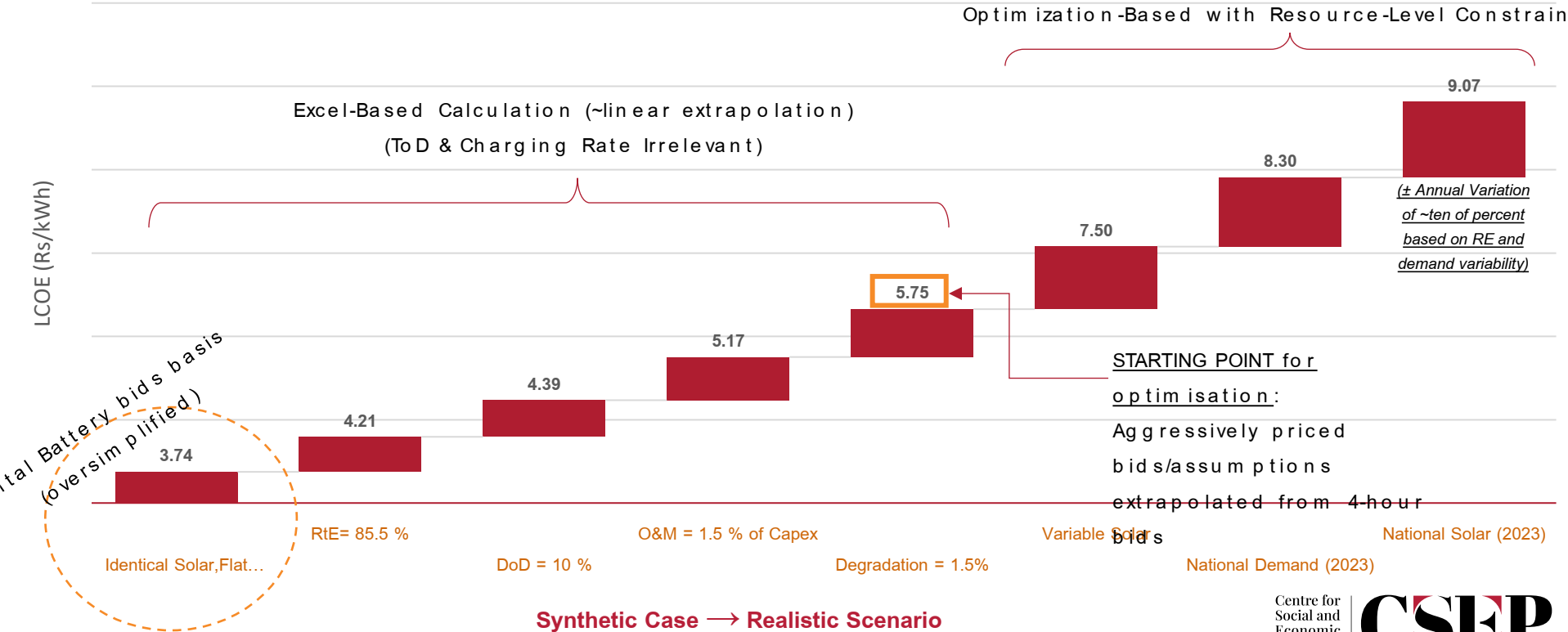
Spreadsheet calculations can estimate this with reasonable accuracy

These require optimization with ToD matching

The cost of “24×7” power: same technology, very different price

Small changes in modelling constraints and assumptions can significantly change costs

(Adding constraints layer by layer: Cheapest is flat demand, identical daily good solar output)





Part 3 – The workaround: promise less than everything

Relaxing the obligation makes bids cheaper...but the hours you skip are precisely the expensive ones

“Firmness” isn’t the same as energy served

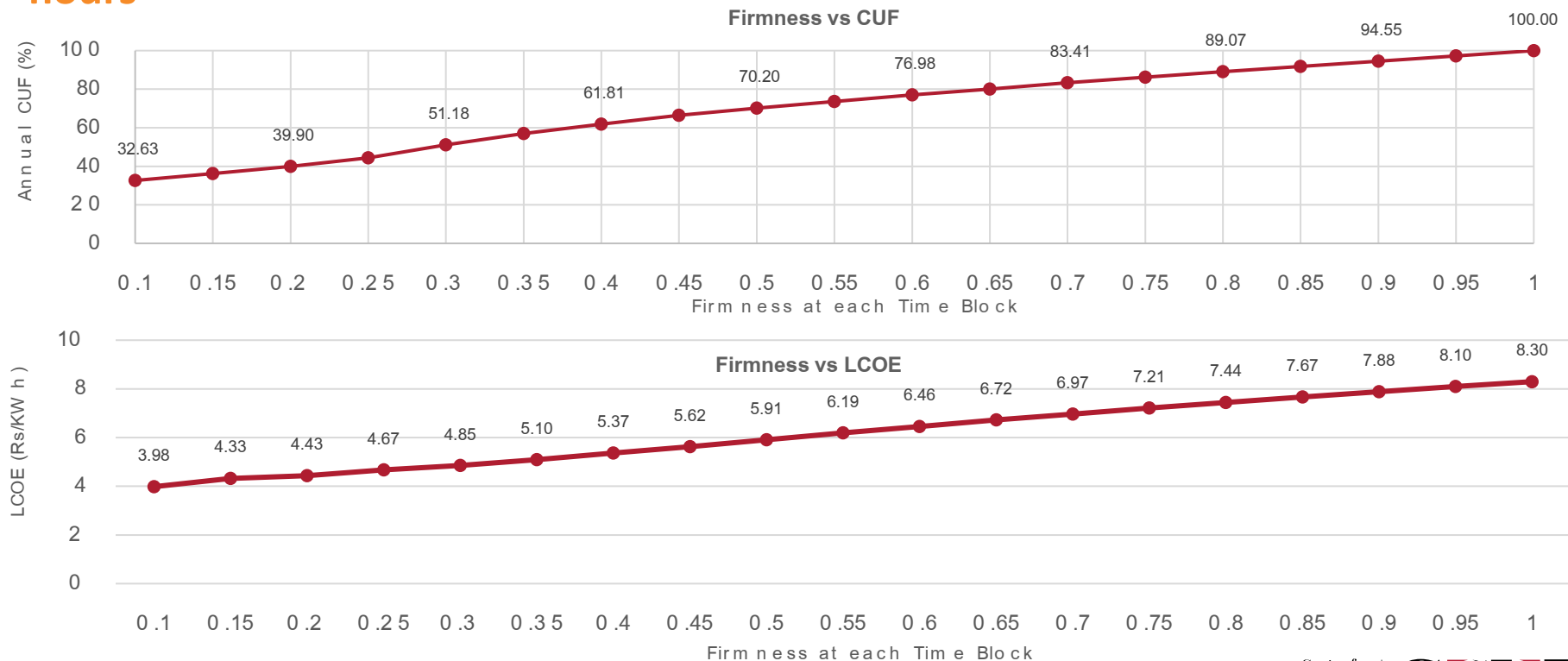
- **CUF is a promise about the year as a whole:** Total energy delivered over the year, regardless of which hours it came in
- **Firmness is a promise about every hour:** At 50 % firmness, the project must supply at least 50 % of demand in every time block of the year; at 100 % firmness, it must match demand in every single hour
- **Firmness dominates CUF:** Even a low firmness promise still delivers a lot of annual energy, because system output often exceeds the minimum

Thus, a bid can showcase a high annual CUF while quietly skipping the hardest-to-serve hours

High CUF $\neq$ reliable supply

Hourly Firmness Vs Annual CUF vs LCOE

Increasing firmness raises LCOE because the system must solve the most difficult hours



Case with good solar, instead of national (2023) solar profile

(a reasonable assumption for new projects, in the short run till land limitations arise)

Two Ways to Achieve the Same Energy (CUF) — Very Different Costs

Meeting every hour is expensive; relaxing a few worst hours sharply reduces cost without necessarily changing annual energy

1) Firmness at every time block (Optimization with Strict reliability)

- Supply minimum % in every hour (e.g., 80% each block)
- Must handle hard(er) hours → more RE + storage
- Leads to higher annual CUF and higher cost (LCOE)

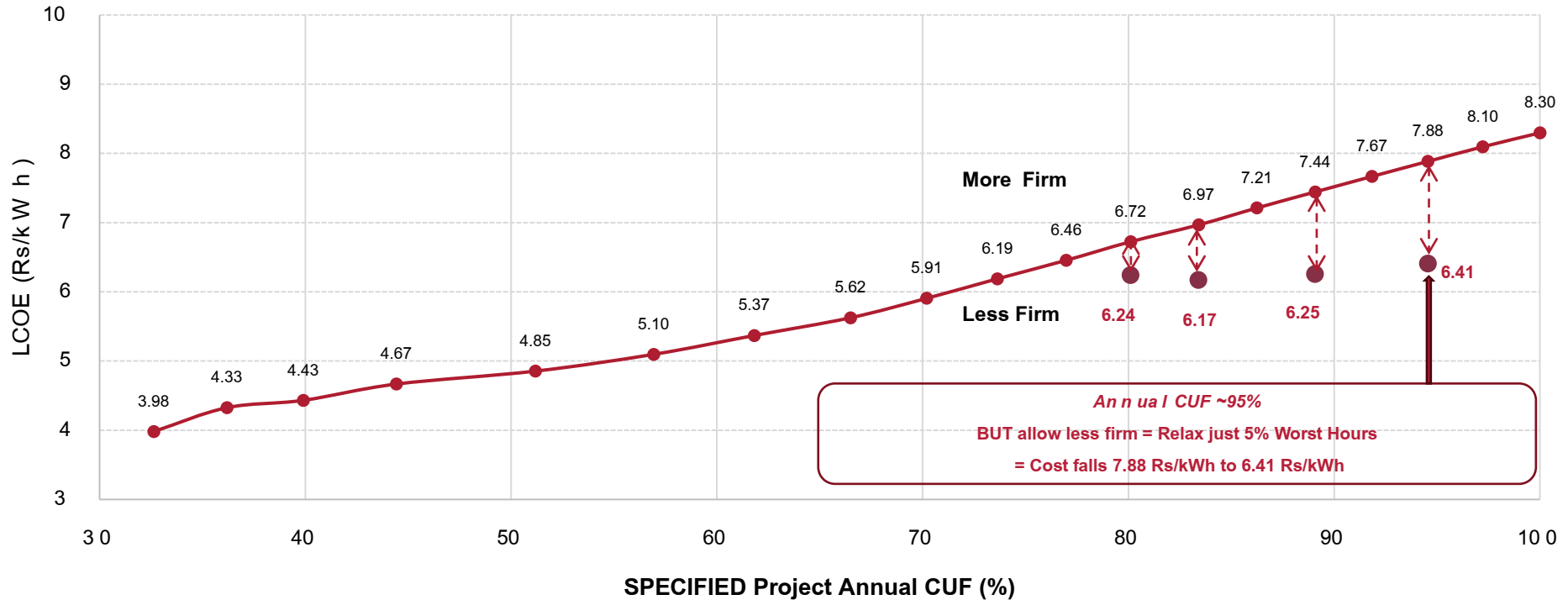
2) Case 2: Relax worst hours (Cost-optimized)

- Allow small % of hours (e.g., 5%) to relax firmness
- Model avoids most difficult hours
- Achieves similar annual CUF (~95%) at much lower cost

Same annual energy (CUF) $\neq$ same reliability $\neq$ same cost

Relax the worst 5% of hours: ₹7.88 falls to ₹6.41/kWh

Nearly the same annual energy (CUF), significantly lower cost



Small flexibility in the worst 10% of hours enables almost the same CUF outcome, with a lower overall LCOE

“Coal only runs at ~85% too, so 85% green is equivalent (and good enough)”? *Not quite*

- A popular argument: coal plants are only expected to run at ~85% PLF availability, so 85% coverage from solar + storage is just as good
- That is not an apples-to-apples comparison:
 - Coal downtime is often chosen, with maintenance scheduled in easy seasons; RE shortfalls are imposed by weather, often on everyone at the same time (high correlations)
 - New coal can run ~90% of the year, so covering 100% needs only ~10% oversizing. For solar + storage, covering the last difficult hours needs multiple times higher oversizing
 - Oversized but underused coal saves fuel, but oversized but underused RE/storage systems offer near-zero savings
- Bottom line: “85% from coal” and “85% from solar + storage” are not fungible

Part 4 – The leftover:

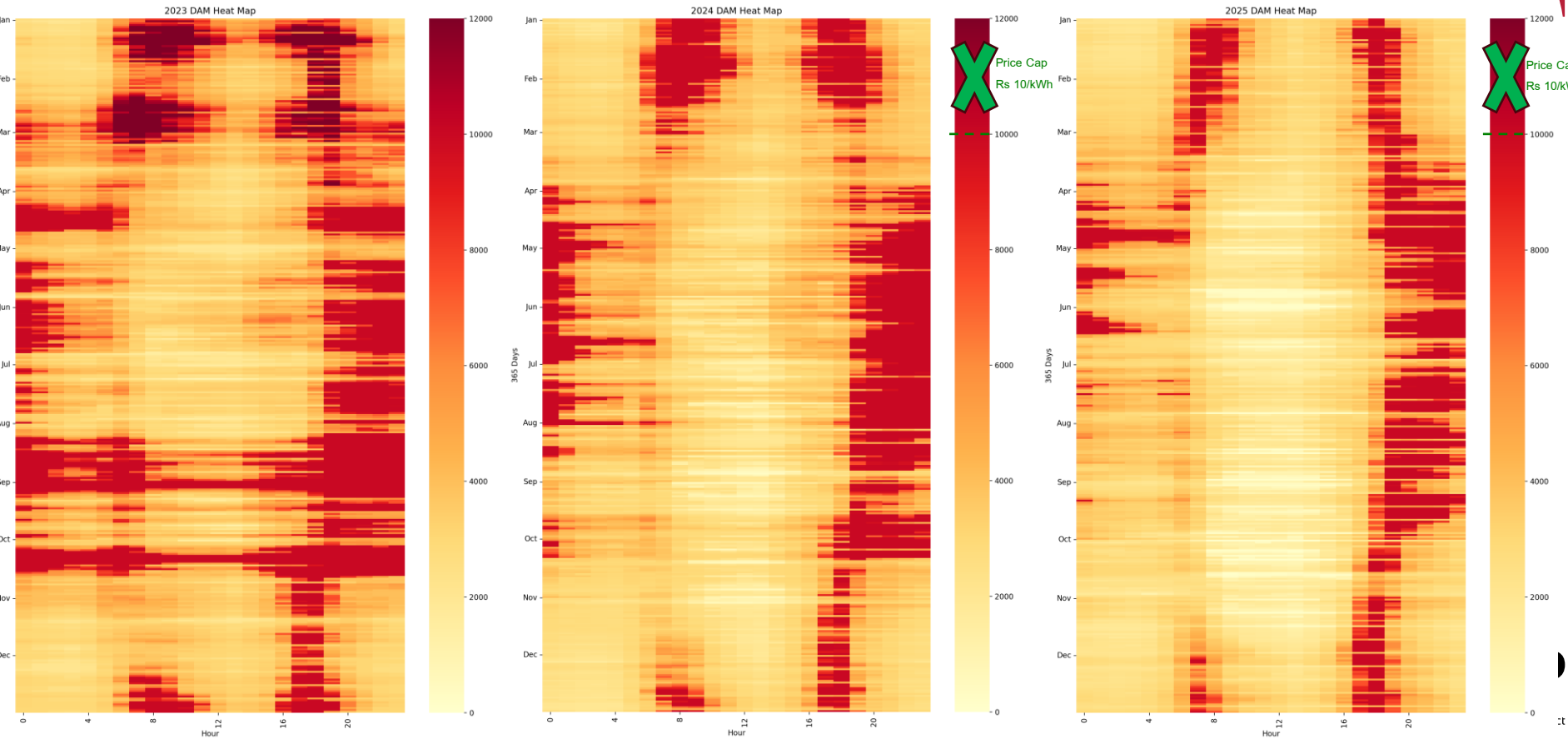
Who serves the hours that the bids skip?

- Serving “90 % of demand” leaves 10 % unmet – but WHEN matters
- Consider 730 hours’ worth of residual (unserved) energy a year (on a normalised 1 kW average demand)
 - Best case: spread evenly, about 2 hours a day. A small battery fixes it.
 - Worst case: concentrated in a few cloudy/high-demand weeks. Needs far more storage, plus extra RE to charge it
- Two ways to fill the gap, each with a cost:
 1. Buy from the power exchange (spot/day-ahead)
Worries: (1) Is the market liquid enough?; (2) Today’s price spreads are likely to worsen
 2. Run coal or gas as backup
But coal plants are not designed for stop-start duty, and imported gas supply is insecure (and expensive)
(Demand flexibility would be the ideal filler)
- We test both using 2023 data, which likely understates the future problem

Option 1 – buy the leftover from the market: prices spike in exactly those hours

Hard to find generators willing to contract at ~10% utilisation today; time-of-day price spreads will widen further

3 years of Day Ahead Market prices from IEX

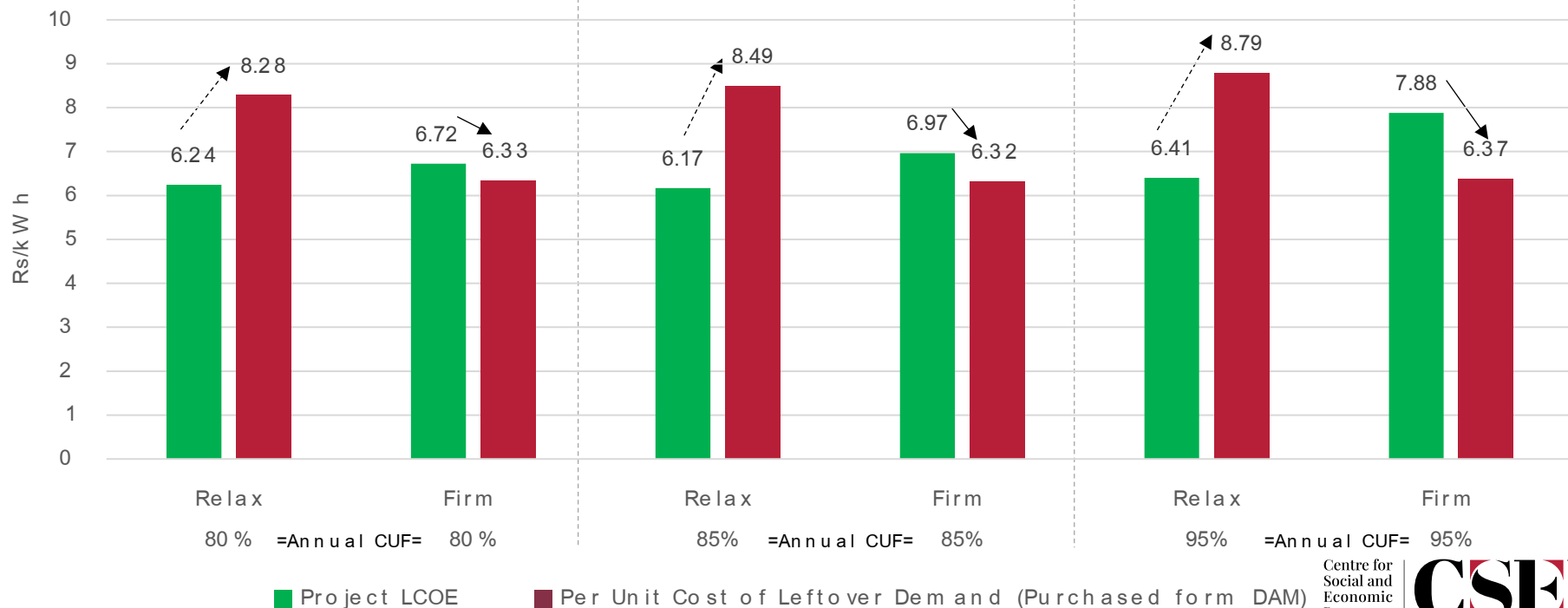


Option 1 (cont.): The tradeoff in filling the gap: Firm vs Relaxed

In relaxed (worst-hour) cases, the per-unit cost of leftover demand exceeds project LCOE, while in strict time-block firmness the leftover cost

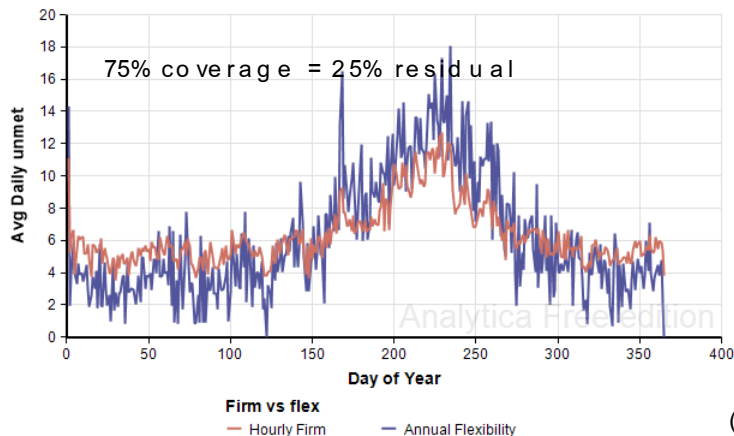
However, the overall DISCOM burden depends on RE penetration and system flexibility, implying that a balanced firmness with peaking support is more cost-effective than either overly strict or highly relaxed approaches

More flexibility can lower portfolio costs (more so if DAM prices are modest)

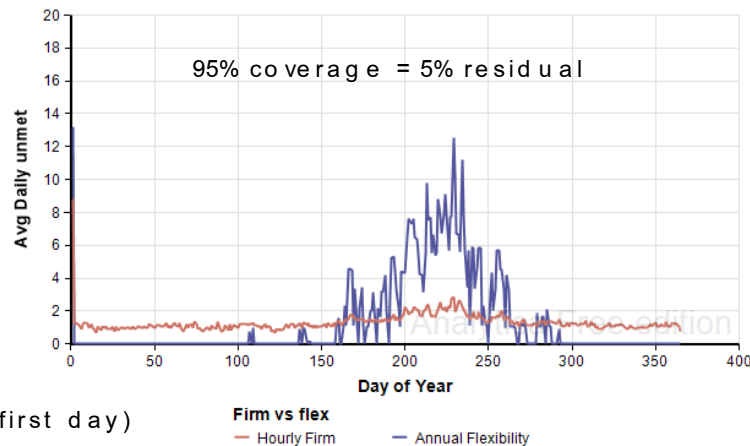


Option 2 – Run new coal or gas as backup (at painfully low utilisation)

- There is great uncertainty in capex and (more so) fuel – and we haven't explored demand flexibility
- Fixed costs depend on usage (duty cycle, or PLF)
- Case: 1 kW normalized demand, for different annual CUF coverages via solar+storage (e.g., 75%/95%) DAILY



(Ignore first day)

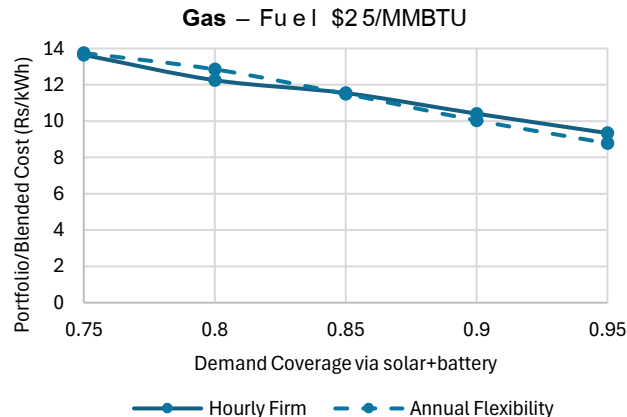
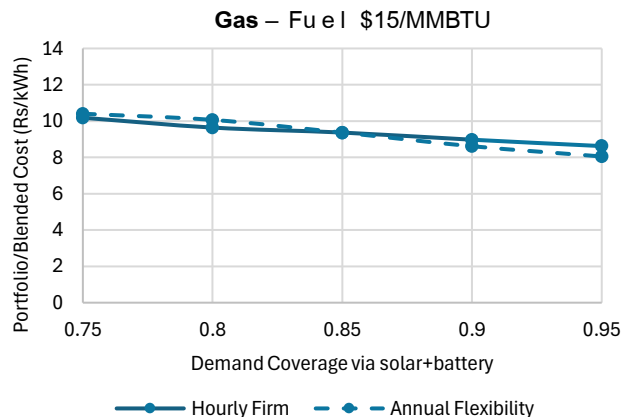
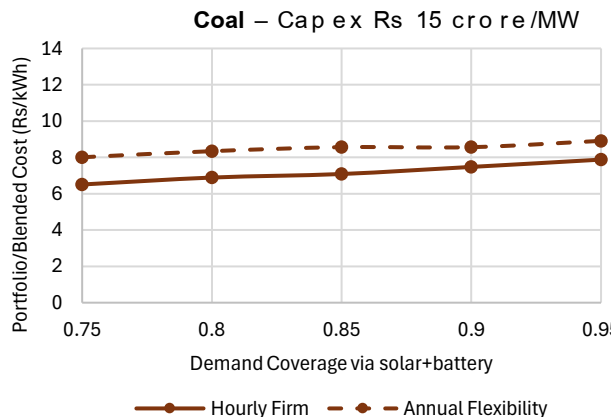


- As RE+storage coverage increases, the leftover shape changes for a firmer bid spec;
More seasonal/bursty residual load is more expensive to meet because it will be underused many days

Demand Coverage via solar+storage:	75%	95%
PLF of residual for Firm (hourly firmness design)	45.89%	42.65%
PLF of residual for Flexible (annual CUF design)	19.42%	4.66%

Portfolio level (blended) costs depend on your worldview

Will gas be available, and if so, how expensive?



- If the expectation is to have coal and not gas, then RE+storage bids should be more firm
 - Very cheap gas is cheaper AND MORE FLEXIBLE than coal
- India will also need more portfolio analysis (incorporating “rest of grid” (not just new builds like here), demand and flexibility, etc.)
- **Bottom line: Cheap solar + battery needs expensive balancing**

Highlights of Key findings

- Storage is still important and critical for India – we are way behind other countries
 - It's just that storage isn't yet ready to “do it all”
- Cheap storage of today is based on incomplete accounting
- A more nuanced full-grid analysis which factors in both other supply options and demand flexibility will show the full system costs
 - Any such analysis will be assumption-laden – technology learning curves, costs of capital, fuel costs, etc.
 - But the balancing numbers shown (for residual demand) are indicative of the trends and issues: *lack of firmness compared to hourly demand is a real cost for discoms*

Conclusions and Policy Implications

India is not choosing between cheap and expensive power, it is choosing where and how the cost of reliability is paid

- It is a false analysis to claim RE+Storage can obviate all new coal
 - Current bids are cherry-picking demand and coverage and **artificially cheap**
 - ◆ Even partial firming (for 75% - 95% annual coverage) raises costs measurably (exceeding Rs 7.5/kWh – with best solar profiles/sites)
 - ◆ Even worse, the **balancing of the residual demand is non-linearly expensive**
- One cannot apply the same modelling for coal costs vs. RE costs
 - E.g., 85% demand fulfilment isn't the same in both cases – when you can deliver is different
- Current storage bids leave enormous flexibility for RE developers – whose cost is borne by the DISCOM
- There are multiple ways to achieve a chosen annual output
 - With hourly firmness – raises project costs but lowers system costs elsewhere
 - With flexibility to the developer – looks cheaper on paper but raises costs elsewhere

Conclusions and Policy Implications (2)

Storage in current bids helps compared to “vanilla” solar, but its interpretation needs system-reality alignment

- The exact combination of how flexible vs. firm depends on a range of assumptions
 - Modest clean energy flexibility lowers costs measurably – but needs complementary alternative supply
 - ◆ Small flexibility in the worst hours gives disproportionate cost savings
 - ◆ Relaxing even ~5% of hardest hours reduces LCOE significantly with zero impact on annual energy (e.g.,: 7.88 Rs/kW h to 6.41 Rs/kW h for 95% annual CUF)
 - ◆ This leftover can be met through demand response/flexibility (cheaper than “peakers” like open cycle gas)
 - ▶ Note: Some FDRE and peak-period bids today have a whole month allowed for relaxation, plus monthly averaging
- Ignoring the residual demand is risky
 - The less you have leftover to supply, the inherently more expensive it will be
 - ◆ The shape of the leftover really matters
 - Market (DAM) prices hint at the problem – which will get worse over time (greater ToD spread – e.g., “Necklace Curve” seen in 2026)

Ultimately, there is enormous value to adding more storage and RE

...but not (yet) getting rid of coal entirely



Thank You

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