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Storing the Sun

How Batteries could Transform Rural India

AN AVALON PERSPECTIVE

“In the heart of India, my summers were spent in my grandfather’s village. The defining ritual wasn’t cricket matches or mango feasts but sleeping on the roof under a blanket of stars. For my cousins, raised there, it was everyday life. For me, a city kid, it was equal parts adventure and revelation.

That revelation came the night I asked: why not sleep inside with a fan or cooler? My parents could have bought the appliances, but not the elixir they ran on. Electricity was scarce. What I thought was rustic charm was, in fact, necessity.

Life without power seemed simple fields to run through, trees to climb, board games by lantern light. But beneath the surface, everything bent to the rhythms of electricity. My grandfather and uncle woke before dawn to run the water pump before the supply cut out. Homework was done under dim bulbs that flickered with each voltage drop. And I remember the sting of missing World Cup matches I had counted down for all year. It was more than inconvenience. It was a reminder that darkness arrived not just with sunset, but with infrastructure gaps.”

Introduction

Today, India has made remarkable progress. Every household is now wired to the grid. Schools, clinics, and small businesses have connections too. Yet reliability remains the missing piece. Frequent outages and unstable voltage still undermine livelihoods, healthcare, and education.

While these power outages and issues with quality of energy delivered across use cases persist in this world. It also presents opportunities across the value chain for various players to design and solve for the problems and derive value from these opportunities.

This paper explores that gap. We examine why reliable electricity matters, and how modern solutions renewables, distributed grids, and batteries can turn fragile access into dependable power.

Reliability: the problem behind the connection - and how it hits the real economy

India has largely finished the *connection* phase of electrification; the *reliability* phase is unfinished. Reported supply has improved dramatically **rural: 21.9 hours/day (FY2024)**, rising to **22.6 hours/day by early-2025** and **urban: 23.4 hours/day**. But feeder-level reality still lags at the times that matter (like evening peaks, irrigation seasons). In several districts, routine micro-outages accumulate into macro-losses: **Koppal (Karnataka)**, for example, saw **8-12 unscheduled cuts per day** for months, each lasting 15 minutes to >2 hours. These are not inconveniences, they are the difference between services delivered and services deferred.

This is caused on the Grid-side through reliability falters under peak congestion, frequency excursions, and weather-related tripping; in high-VRE states it is compounded by local network constraints that trigger curtailment. Customer-side, short sags become long interruptions because of **low voltage**, **weak wiring**, and **underrated inverters**, especially in clinics, cold rooms and small workshops.

The economic cost is large and measurable. New evidence using millions of meter and outage records estimates Indian households' **willingness to pay for avoided outages at ~US$1.50 per kWh of lost consumption >25×** average retail prices capturing the real value of "usable power" rather than nominal connection.

Exhibit 1 : Case studies showing impact of reliability gaps

Case study 1 - Primary health, Chhattisgarh: reliability as a clinical constraint

Across 15 districts, ~90% of PHCs reported power cuts during peak operating hours; >21% reported equipment damage from voltage fluctuations. Staff adapted by delaying or deferring services after sunset and relying on ad-hoc diesel, raising costs and risk. The signal is clear: "access" without reliability translates into unpredictable care, compromised cold chains, and lower utilization. (Study: 147 PHCs, 83 with PV systems; state-wide evaluation.)

Source: CEEW research; Solar power improving primary healthcare in rural Chhattisgarh

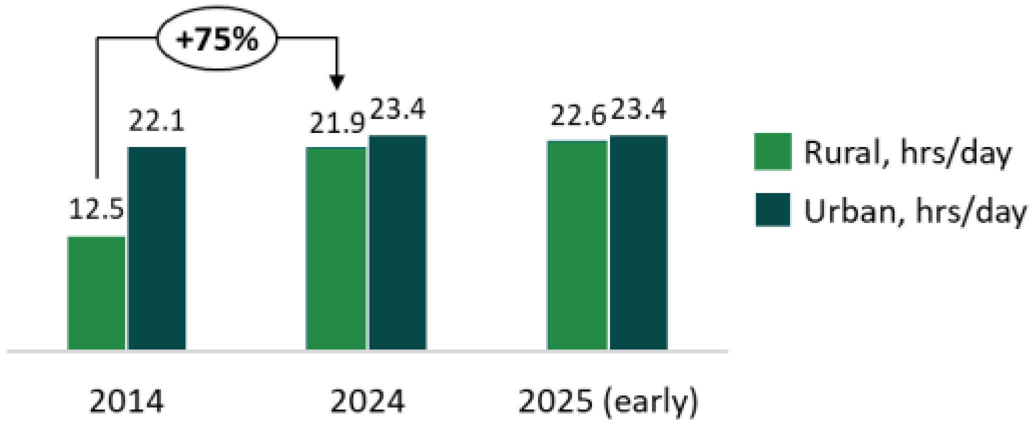
Case study 2 - Horticulture first mile: the cost of warm compressors

National assessments continue to show missing pack-houses (~70,000 required) and thin reefer coverage. When feeders dip at harvest time, compressors cycle off and produce warms, leading to rejects and distress sales. The aggregate loss value ~₹1.53 trillion/year isn't abstract: it is the monetized shadow of unreliable first-mile power interacting with missing logistics.

Source: NCCD, Cold Chain Assessment of India

While economics are suitable, problem persists in areas like **primary healthcare** where reliability gaps jeopardize vaccines, diagnostics, and night-time care. A field study across **147 PHCs in Chhattisgarh** found **~90%** reported cuts during peak hours and **>21%** reported equipment damage from voltage fluctuations—one reason staff ration services after dusk.

Figure 1 : Reported average supply hours (India)



*Urban 2014 shown in MoP/PIB year-end context;
state variance persists (e.g., rural 13.3-16.3 h in some states 2021-22)

Source : PRS Legislative Research

In **food systems**, the first mile is the choke point: India still lacks thousands of pack-houses and reliable pre-cool/reefer links; the latest national estimate puts **post-harvest losses at ~₹1.53 trillion/year (2020–22)**, with outages and low voltage turning compressors off when perishables need them most. In **MSMEs**, even with progress, **~20% of firms** still report outages (2022), averaging **1.3 per month**—small percentages that become large when multiplied across India's enterprise base.

In **daily life**, households compress study, cooling and water pumping into a shrinking, uncertain window—paying in diesel, lost hours, and foregone income.

Figure 2 : Impact of Reliability Failures across selected indicators

Sector / Proxy	Indicator (latest available)	Why it matters
Access ≠ uptime	Rural **21.9 → 22.6 hrs/day** (FY2024 → early-2025); Urban **23.4 hrs/day**	Nominal progress; evening and seasonal gaps persist at the feeder. (Moneycontrol)
Household cost of outage (VoLL)	**US$1.50/kWh** of lost consumption	Captures the economic pain of "usable power" shortfalls. (ScienceDirect)
PHCs (Chhattisgarh)	**~90%** report peak-hour cuts; **>21%** equipment damage	Reliability directly maps to clinical service availability and safety. (CEEW)
Food loss	**~$17 Bn/year** (2020–22)	First-mile power + logistics gaps convert to wastage and lost farm income. (ICRIER)
MSMEs	**19.9%** experience outages; **1.3/month** on average (2022)	Outages disrupt output and raise costs across India's enterprise base.
District reality check	**8–12 unscheduled cuts/day** for months (Koppal, 2025)	Illustrates how routine micro-outages accumulate into macro-losses. (The Times of India)

Why now?

India has crossed the access frontier; the binding constraint is **reliable energy during the 2–6-hour daily window when demand peaks and voltage sags**. Three facts make action urgent and newly economical.

First, peaks have risen fast—from ~190 GW (Jan-2021) to **250 GW (May-2024)** and **231 GW on 15-May-2025** even on a cooler day—steepening the **evening ramp** when feeders trip and rural supply is rationed.

Second, cheap mid-day renewables are being curtailed in high-VRE states (e.g., Rajasthan reporting **~25% mid-day waste** and time-blocks over **50% curtailment** in 2025), exactly when storage could shift energy into the evening gap.

Third, storage economics have inflected: **lithium-ion pack prices fell to $139/kWh in 2023 and $115/kWh in 2024**, the sharpest drop since 2017, driven by LFP adoption and supply-chain easing (figure 3). Together, these forces convert the daily blackout window from a structural hardship into a solvable **temporal mismatch** problem.

As we understand the problem, and its impact, the key question 'What sustains the 2–6-hour blackout band?'

Three overlapping drivers:

Ramp stress as solar output collapses near sunset while cooling, irrigation and household loads peak

Local network constraints - overloaded 11-kV feeders and under-sized distribution transformers - triggering protective trips and planned curtailments

Rationing practices on agricultural and rural feeders that bunch supply into fewer blocks. Storage solves the timing problem: **front-of-the-meter (FTM) BESS** shaves evening peaks and firms RE; **behind-the-meter (BTM)** systems ride through sags at clinics, cold rooms, schools and towers.

The business case of already penetrated areas is anchored by **diesel displacement**. Fuel dominates DG economics—**75–80% of lifetime cost**—so even short evening run-hours are expensive. Typical small-site DGs consume ~**0.25–0.30 L/kWh**; at ₹90–100/L diesel, **fuel alone is ₹22–30/kWh**, before O&M and capital recovery. Field ranges of **₹15–₹40/kWh** are common depending on load factor (Exhibit WN-2). By contrast, **rooftop PV** for C&I loads commonly clears **₹3–₹5/kWh** (capex-driven, minimal variable cost) and pairing with batteries now prices outage insurance rather than baseload energy.

Hence, the economics of **shifting mid-day MWh to evening reliability hours** have never been stronger. Falling battery, prices (figure 3), and **DG fuel cost economics** (figure 4), and visible curtailment are the hard numbers behind a simple idea: **procure uptime** where the blackout window lives—2 to 6 hours a day—and do it with FTM/BTM storage that monetizes diesel avoided and lost-load avoided.

Put simply, India's 2–6-hour evening reliability gap is a **timing** problem we can now afford to solve. Mid-day renewables are increasingly curtailed; **battery packs fell to US$115/kWh (2024)**; **availability bids discovered ₹2.16–2.19 lakh/MW-month**; and **ISTS charges for storage are waived to June-2028**. Diesel back-up still lands at **₹25–₹40/kWh**, while the installed BESS base—**204.5 MW / 505.6 MWh**—signals early traction and vast headroom. The economics are aligned; the next step is execution.

While economics are suitable, problem persists in areas like **primary healthcare** where reliability gaps jeopardize vaccines, diagnostics, and night-time care. A field study across **147 PHCs in Chhattisgarh** found **~90%** reported cuts during peak hours and **>21%** reported equipment damage from voltage fluctuations—one reason staff ration services after dusk.

Figure 3 : LFP Battery Prices

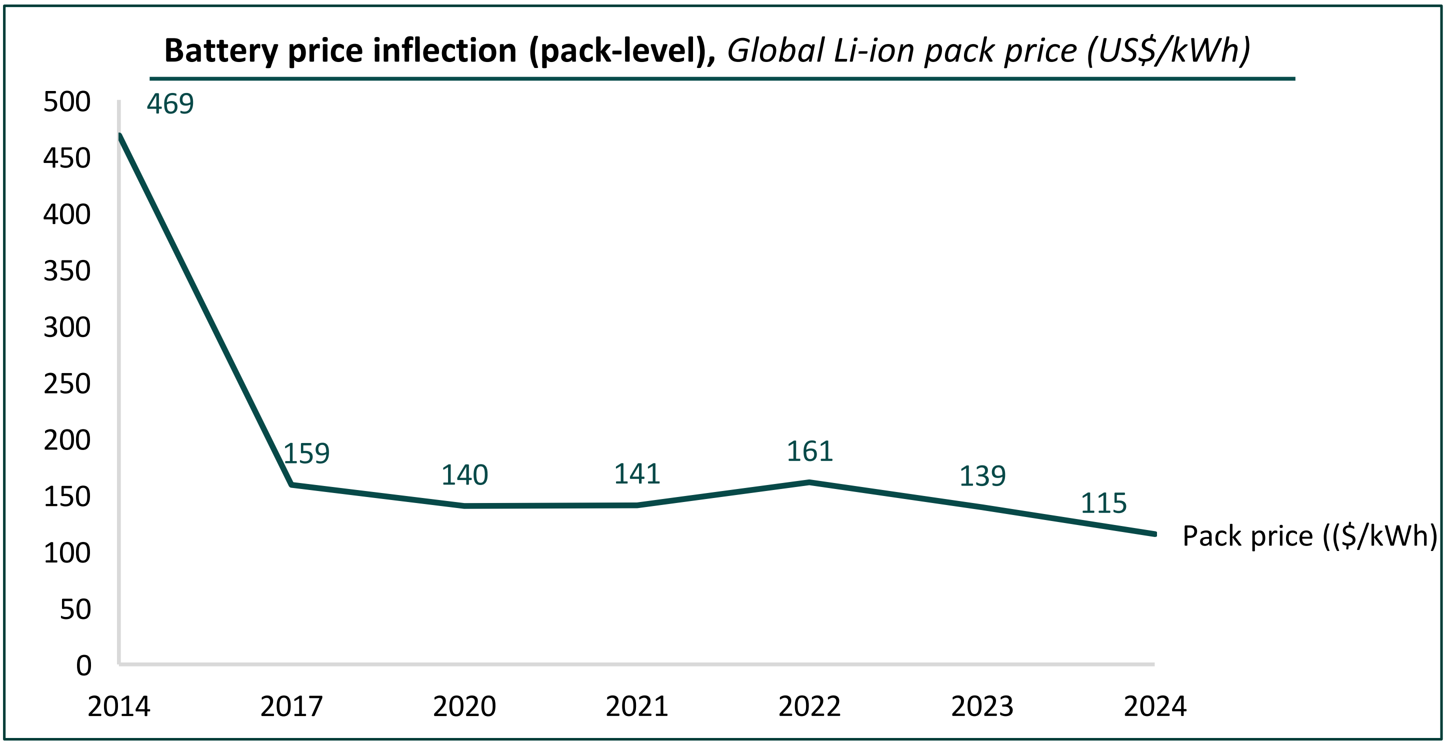


Figure 4 : Backup power economics: DG vs. solar (illustrative, India) Source: Power Line Magazine

Item	Diesel genset (typical small C&I / institutional)	Rooftop solar (C&I-scale)
Capex	15 kVA ≈ **$2000-$2300**; 125 kVA ≈ **$5800** (capex is **6–7%** of lifetime cost)	**$500-$800/kW** installed (site/scale dependent)
Fuel / energy	**$300-$400/kWh** as **$0.2-0.4/kWh** fuel at ₹90–100/L diesel	**No fuel cost**; energy cost driven by capex amortization
O&M	High (filters, lubricants, overhauls) → **₹2–3/kWh** typical	Low (cleaning, inverter service) → **~1–2% of capex/yr**
Delivered cost	**$0.2-0.4/kWh** field range (load-factor dependent)	**$0.04-0.06/kWh** levelized for C&I rooftops
Reliability role	Outage hours; fast start; high local emissions	Daytime energy; with BESS, covers evening outage window

Source : PRS Legislative Research

Key ChallEnges

What still blocks Renewable + Storage from delivering Reliability at Scale

*The case for storage-backed reliability is compelling, but execution in India runs into nine practical blockers: **uncertain revenue design, counterparty risk, grid bottlenecks, land and siting frictions, safety governance, supply-chain localization, financing costs, O&M capacity, and data credibility**. Each is tractable—but only with deliberate policy and program design.*

REVENUE DESIGN AND CONTRACTABILITY

India has begun discovering prices for capacity and flexibility—Rajasthan's availability-based tenders cleared at **₹2.16–₹2.19 lakh/MW-month (2025)**—yet **revenue stacking** (capacity + day-ahead/real-time arbitrage + ancillary services) still lacks standardized playbooks across states. The Centre's **BESS Viability Gap Funding (VGF)** is positive, but **budgeting and disbursement rules are evolving**; in April 2025 the government revised VGF down to **₹46 lakh/MWh or 30% of capex** as costs fell, changing bidder math mid-stream. Meanwhile, the installed base is **small—204.5 MW / 505.6 MWh** operational so lenders still see technology, performance, and counterparty risks as "first-of-kind."

COUNTERPARTY RISK AND PAYMENT CYCLES

Developers and banks price in **DISCOM credit risk**. As of **April 2025**, dues to generators reached **₹717.5 billion**, per the government's PRAAPTI portal, after a brief improvement in March evidence that payment timeliness remains uneven. The **2019 Andhra Pradesh PPA renegotiation attempt** ultimately rebuffed by the High Court still echoes in risk premia: it was a salient reminder that **contract sanctity can be tested** under fiscal stress.

GRID BOTTLENECKS AND CURTAILMENT

Reliability is as much a **network** problem as a generation problem. In **Rajasthan**, time-block curtailment escalated from **8.5% (March 2025)** to **51.5% (August)** on late-morning/early-afternoon blocks due to delayed transmission works **wasting cheap renewables right when storage could shift them to evening**. Nationally, CTUIL recently **revoked grid access for ~17 GW** of delayed projects to de-clog queues, underlining that **transmission readiness** is now the pacing item. Storage mitigates curtailment at the margin, but **evacuation and last-mile constraints** must still be fixed.

LAND, WATER, AND SOCIAL LICENCE (ESPECIALLY FOR LONG-DURATION PSP

Pumped storage is India's most scalable long-duration option, but it needs **land, water rights, and resettlement clearances**. State pipelines are large on paper; execution will hinge on **site selection, cumulative impact assessment, and local benefit-sharing**. These non-financial risks are often under-modelled in bid timetables.

SAFETY, CODES, AND INSURABILITY

High-ambient operations and dense container yards raise **thermal runaway and fire** concerns. In **June 2025**, the Central Electricity Authority issued **draft BESS safety regulations** (set-out for fencing, detection, ventilation, fire separation, and fault tolerance). Until final codes and third-party certification regimes settle, **insurance** can be costly, and **lender technical advisors** will demand conservative designs (de-rating, spacing, suppression), nudging up capex.

SUPPLY CHAIN, LOCALIZATION, AND RECYCLING COMPLIANCE

India's **ACC PLI (₹18,100 crore; 50 GWh)** is the right idea, but **beneficiary delays** and penalty risk suggest a slower localization ramp than hoped, keeping near-term projects dependent on imports and **FX exposure**. At end-of-life, the **Battery Waste Management Rules, 2022** place **EPR obligations** on producers good for circularity, but a **new compliance cost** that integrators must price and operationalize with certified recyclers.

COST OF CAPITAL AND TENOR

Even with falling battery prices, **WACC** and **debt tenor** drive tariffs. Availability contracts help, but **merchant exposure** (arbitrage, ancillaries) adds volatility. Until there is **depth in offtake for flexibility** (standardized ancillary services procurement, creditworthy counterparties), many lenders will insist on higher DSCRs and tighter covenants.

O&M AND FIELD CAPACITY

Reliability products live or die by **ops discipline** spares, MTTR < 4 hours, remote monitoring, and trained district-level technicians. Today, **OEM/O&M networks are thin outside metros**, and **multi-year AMCs** with clear SLAs are not yet the norm in public procurement. For BTM assets at clinics, schools, cold rooms and towers, **workforce depth** is as important as the EPC.

DATA CREDIBILITY AND M&V

To monetize "reliability," you must **measure it**. Yet many procurements **lack clear M&V** for uptime, temperature compliance (cold rooms), or response times (health facilities). Without telemetry, **availability-linked payments** are hard to enforce, and financiers discount projected cash flows.

Bottom line. The obstacles are less about technology and more about **market plumbing**: bankable revenue models, credible buyers, network readiness, safety/insurance comfort, and operational depth. India's **ISTS waiver for storage to June 2028** and the **VGF framework** are important scaffolds; the execution challenge is to turn them into **repeatable, financeable programs** that standardize contracts, measurement, and field operations across thousands of similar sites.

Figure 5 : Where storage projects stall

Challenge	Evidence (latest)	Why it stalls projects
Revenue design	Availability tenders in Rajasthan at **$2500(/MW-mo**, but limited templates for stacking (arbitrage/ancillaries).	Lenders struggle to underwrite non-capacity revenue; higher DSCR required. (Reuters)
VGF mechanics	**VGF revised to $50,000/MWh ($ or 30% capex** as costs fell; budget lines updated.	Moving goalposts complicate bids/financial close timing. (Press Information Bureau)
Small installed base	Only **204.5 MW / 505.6 MWh** operational nationwide.	Limited local operating data → higher perceived tech/performance risk. (Energetica India)
DISCOM payables	**$ 8.1 bn** dues in Apr-2025 (PRAAPTI).	Counterparty risk raises WACC; cashflow delays threaten O&M. (Mercomindia.com)
Contract sanctity	**AP 2019 renegotiation** attempt; High Court later upheld PPAs.	Episodic risk still influences pricing/loan terms. (The Economic Times)
Curtailment & grid	**Rajasthan curtailment 8.5% → 51.5%** (Mar–Aug 2025); **17 GW** grid access revoked for delays.	Transmission pacing item; curtails energy to charge/discharge; schedule risk. (Mercomindia.com)
Safety & insurability	**CEA draft BESS safety** rules (June 2025) out for comment.	Until finalized, insurance premia and conservative designs raise CAPEX. (Mercomindia.com)
Localization & EPR	**ACC PLI** facing timeline/penalty issues; **BWM Rules, 2022** impose **EPR**.	Near-term import reliance; new compliance cost & logistics at end-of-life. (The Economic Times)

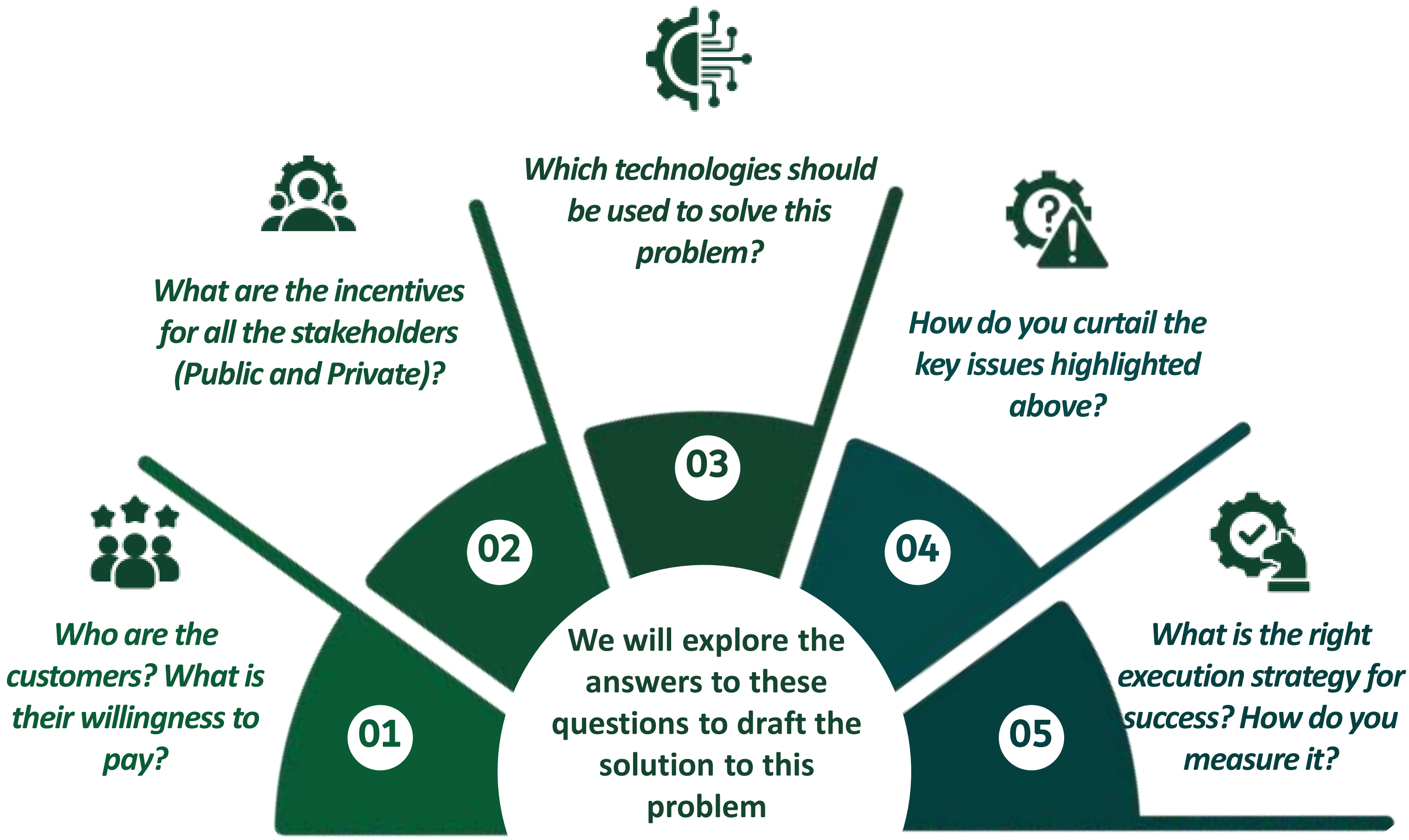
Solution

The solution, as I have tried to establish seems clear right: Find ways to install renewable energy solutions paired with battery energy storage systems and the problem is solved. Well, it's not that simple.

We need to answer some key questions before we can do that, where to start? Does cheaper solutioning means consumers are willing to pay? Why would all the key stakeholders agree to participate? And so on.

See ideally we can hypothesize this success by establishing the right set of incentives for all stakeholders to participate, chose the right areas to invest in. The right areas should be able to solve a real problem and should be able to become a self-sustaining model independent of subsidies and should not be threat to existing energy delivery models. But a supplementary technology supporting disburdening of loads.

Hence, an ideal solution can be developed by answering questions on these 5 dimensions,



Who are the customers? What is their willingness to pay?

The first design choice is **not** technology - it is **customer selection**. Storage-backed renewables clear fastest where (1) **impact** is high (large reach, essential services, high Value of Lost Load) and (2) **payability** is credible (clear willingness/ability to pay, anchor revenue, and enforceable collections). Think of this as a **2×2**: *Impact* on one axis, *Probability of Becoming a Paying Customer* on the other. (*figure 6)*

High-High (Priority Tier 1) — 01

Cold-chain nodes (pack-houses, milk chillers, ripening rooms) and **telecom towers**. These sites already pay a reliability premium via diesel at **$0.25–$0.50/kWh** (fuel dominates total cost). PV+BESS can deliver evening/backup power at **$0.12–$0.22/kWh** (PV LCOE **$0.04–$0.06** + storage adder **$0.08–$0.16**) with service-level agreements (temperature or uptime) and **contracted payors** (co-ops, 3PLs, MNOs). **Primary health centres (PHCs)** also sit here **if** payment certainty exists (department escrow/CSR) because VoLL is extremely high and diesel is unaffordable at scale. **Mandi cold hubs** and **village water schemes** round out Tier 1 where billing can be deducted at source.

02 — High Impact Medium Payability (Tier 2)

Government schools/Anganwadi's, **community water systems**, and **agricultural irrigation at household level**. The social return is clear, but individual payment reliability is mixed. Two tactics lift payability: (i) **anchor-led portfolios** (pair social sites with revenue anchors such as towers or cold rooms) and (ii) **feeder/DT-level solutions** paid by the utility (availability payments) rather than each household.

Medium-Medium (Tier 3) — 03

MSMEs in weak-grid towns (workshops, mills, looms) can pay if the product is *OPEX-replacing*: diesel at **$0.30–$0.45/kWh** swapped for BTM service at **$0.16–$0.22/kWh**. Success depends on prepaid/UPI billing and tight O&M.

04 — High Impact Low Payability (Tier 4)

Remote households for personal backup. These segments require **PAYGo** or lifeline subsidies. They are important for inclusion, but they do not anchor near-term bankability.

TWO ADDITIONAL NUANCES MATTER:

Differentiate agricultural use-cases

Solar pumps (productive, monetizable) are not the same as *household backup*. The former can be bundled under service contracts (per-hour/kWh irrigation) with village deduction at source; the latter is discretionary and price-sensitive.

Prioritize contractability over theoretical WTP

The quickest flywheel is a **five-site cookie-cutter** repeat (same BOM, same contract, same M&V): e.g., 10 pack-houses + 1 mandi hub + 3 towers + 5 PHCs, all prepaid/escrowed. Scale follows standardization.

We should start where **VoLL is high** and **cash is collectable**. Tier-1 customers create early cash yield, lower cost of capital, and fund expansion to Tier-2/4 social loads. Technology is an enabler; **customer selection** is the strategy.

Figure 6 : Use cases across Impact vs Payability Matrix (tier wise classification)

End-use archetype	Impact (0–5)	Payability (0–5)	Tier
Pack-house / pre-cool	5.0	4.3	**Tier 1**
Milk chiller (co-op)	4.8	4.2	**Tier 1**
Telecom tower	4.0	4.8	**Tier 1**
PHC (with escrow/CSR)	4.9	3.8–4.2	**Tier 1**
Mandi cold hub	4.3	3.8–4.1	Tier 1–2
MSME workshop	3.8	3.4–3.7	Tier 3
Community water	4.7	3.5–3.8	Tier 2
Government school	4.5	3.0–3.3	Tier 2–4
Ag pumps (household)	4.2	2.8–3.3	Tier 2–3
Household backup	3.4	2.6–3.0	Tier 4

Incentivizing the stakeholders (Front- and Behind- the meter)

Selecting "paying" customers is necessary but insufficient; **the value chain sustains only when every actor sees a clear, contractable upside**.

- For **government**, the prize is fiscal and strategic: shifting evening reliability from diesel and emergency power purchases to renewables-plus-storage reduces the subsidy burden and peak procurement costs, cuts diesel import exposure, and advances climate and health goals. The policy instruments are simple to operationalize **availability payments for front-of-the-meter (FTM) storage** (think **~$2,600 per MW-month** as an order-of-magnitude signal), targeted **viability-gap support for first cohorts**, and fast clearances tied to standardized safety and measurement protocols. Government's "return" is lower outlays per reliable kWh delivered, deferral of expensive grid upgrades, and visibly improved public services.

- For **private developers and operators** (IPP/RESCO/mini-grid), the incentive is bankable yield on repeatable "cookie-cutter" portfolios. Returns are driven by **contracted availability revenues** (for FTM or utility-paid feeder solutions) and **service SLAs behind the meter** (Ex. as per-crate pre-cooling fees at pack-houses, per-litre chilling at dairies, uptime subscriptions for telecom towers), or **$0.12–$0.22/kWh** reliability tariffs that undercut diesel at **$0.25–$0.50/kWh**. Standardizing the bill of materials, telemetry, and O&M into multi-year AMCs protects margins and compresses soft costs.

- For **technology suppliers** (batteries, inverters, controls), near-term margin sits in **integration and long-term service** performance-linked AMCs, parts pools, and upgrade cycles. Localization and second life/recycling programs can be monetized via **take-back fees** embedded in contracts, turning compliance into stickier customer relationships.

- For **DISCOMs**, storage becomes a controllable reliability product rather than an experimental gadget. The incentives are **peak cost avoidance**, **loss-reduction on weak feeders**, and the ability to **firm midday renewables into evening demand**. That cash flow comes from a **stack**, availability (capacity) payments, day-ahead/real-time arbitrage, and ancillary services(O&M) plus **shared-savings constructs** where substation or feeder-sited storage demonstrably reduces technical losses or diesel support. Crucially, escrowed payment rails and regulatory indexation (e.g., to inflation or a wholesale benchmark) align P&L and risk.

- **Financiers** (banks, NBFCs, DFIs) earn by **scaling receivable-backed portfolios** prepaid Behind The Meter contracts and availability Power Purchase Agreements can be made into assets once telemetry and Measurement & verification are standardized. First-loss guarantees and pooled SPVs lower risk premiums along with green bonds and transition funds which expand the investor base.

- Finally, **customers** (PHCs, cold-chain nodes, MSMEs, towers, water schemes) get **cheaper, dependable energy** and service continuity in the very hours that matter. They pay in ways that protect cash flow as **prepaid, deduction-at-source, or escrowed departmental budgets**.

So the system doesn't depend on perpetual subsidies. **Enablers** like skilling institutes, EPC/O&M providers, and fintech payment rails are compensated through training contracts, O&M retainers, and transaction fees. When these incentives are explicit and measured, reliability becomes a product, not a promise and the value chain should sustain itself at scale.

How to curb the key issues
(and why this approach works)

The problems are known like payment delays, grid bottlenecks, curtailment at mid-day, contract worries, safety, and weak field O&M. The fix is not one big program but a **tight playbook** that turns reliability into a service with **measured uptime** and **clear cashflows**.

01 *Make revenues bankable :*

Use **availability contracts** for front-of-the-meter (FTM) storage at substations/feeders and **SLA-based service fees** for behind-the-meter (BTM) sites (PHCs, cold rooms, towers). Tie payments to verifiable data (hours available, temperature bands, response time). This answers two risks at once **curtailment uncertainty** and **DISCOM cash cycles** by paying for the *service* (firm capacity and uptime), not just energy. Rajasthan's 2025 tenders show that **capacity can be priced and financed**; the missing piece is standardizing these templates across states.

02 *Route money through secure rails :*

Use **escrows** and **deduction-at-source** (e.g., dairy payouts, mandi settlements) so developers and lenders see steady cash. PRAAPTI data on **$8.5 billion** April-2025 dues explains why payment security matters.

03 *Build where the grid needs it most :*

Place FTM storage where curtailment and evening ramps are worst; shift noon solar into the 2–6 pm gap. Rajasthan's curtailment spiking to **~51.5%** in some time blocks is a textbook siting signal.

04 *Lock in contract sanctity and safety :*

Use PPA language aligned with court precedents (AP High Court upheld PPA sanctity in 2022) and comply with **CEA's draft BESS safety code** (spacing, detection, suppression) to keep insurers and banks comfortable

05 *Standardize tech + O&M :*

Deploy **cookie-cutter kits** (LFP for 2–4 h; Na-ion pilots for hot sites; VRFB where >6 h) with **remote telemetry**, district spares, and **<4 h MTTR** contracts. Failed microgrids show that technology alone is not enough; collections and service discipline decide survival.

Figure 7 Previous Issues and lessons to be adopted

	What Failed		The Lesson
01	**Dharnai solar microgrid (Bihar, 2014–2016)** Project stalled as grid arrived, User buy-in was week, and O&M not budgeted correctly	01	Without **contracted anchors**, prepaid collections, and funded O&M, systems fade even if the tech works
02	**Andhra Pradesh PPA scare (2019–2022)** Tried to reopen RE tariffs; **High Court restored PPA sanctity** in 2022	02	Contract clarity and payment security lower WACC; use **central templates/escrows** to protect projects
03	**Rajasthan curtailment (2025)** Time-block curtailment rose from **8.5% (Mar)** to **51.5% (Aug)** as transmission lagged	03	Sites FTM storage where **mid-day spill** is high pay for **availability**, not uncertain energy

Source: IER, Power Line Magazine

Which technologies should be used to solve this problem?

RELIABILITY IMPROVES WHEN WE MATCH CONTEXT TO TECHNOLOGY

Use **front-of-the-meter (FTM)** storage to firm the grid and shift mid-day renewables into the 2–6-hour evening gap; use **behind-the-meter (BTM)** kits to ride through feeder sags at sites where lost load is costly (clinics, cold rooms, towers, MSMEs). Within each context, pair the **right renewable** with the **right storage** so the system delivers *assured service*, not just cheap kilowatt-hours.

FTM (OFF-GRID/HYBRID AND GRID-CONNECTED)

At system level, the problem is timing and ramp. **Solar PV** provides abundant, low-cost energy at noon; **wind** adds diversity but is still variable. **Pumped hydro** and **4–8-hour batteries** convert this variable energy into firm capacity at dusk, provide frequency response, and decongest stressed feeders. In weak corridors, **hybrid micro-grids** (solar-wind-BESS with a minimal engine as last resort) can maintain public services while transmission upgrades catch up. The design rule is simple: **pay for availability (capacity and response), not just energy** and site flexibility assets where curtailment and evening peaks are highest.

BTM (COMMERCIAL, INDUSTRIAL, COMMUNITY, PRIVATE)

Customer-side outages are short but costly. **Distributed PV + 2–4-hour BESS** solves temperature-sensitive loads (vaccine fridges, milk chillers, ripening rooms), protects digital infrastructure (telecom, banking points), and displaces diesel in MSMEs. Where cooling dominates, **thermal storage (ice banks)** is often the cheapest "battery." In river/foothill districts, **micro-hydro + BESS** delivers 24/7 baseload for schools and clinics. For ag pumps, **daytime PV** plus modest storage smooths cloudy hours and reduces evening feeder stress.

STORAGE CHOICES THAT FIT INDIA'SDUTY CYCLES

LFP lithium-ion is the workhorse for 2–4 hours: stable, heat-tolerant, now widely bankable. **Sodium-ion** lowers cost for similar durations and high temperatures, ideal for rural BTM kits where energy density matters less. For 6–12 hours, **vanadium redox flow (VRFB)** trades lower round-trip efficiency for long life and deep cycling, useful on night-peaking feeders and cold-chain hubs. **Pumped hydro** remains the bulk, long-duration backbone where sites exist.

WHAT THIS SOLVES

The FTM stack tackles **evening ramps, mid-day curtailment, frequency dips**, and **feeder congestion**; the BTM stack tackles **voltage sag, short blackouts, and diesel reliance** at critical end-uses. Together, they convert access into **guaranteed service windows** the currency that customers value and pay for. The next section (execution) translates this design into **standard SKUs, contracts, and O&M** so these technologies scale with discipline.

What is the right execution strategy for success? How do you measure it?

*Execution is about **turning intent into bankable, measurable uptime**. The strategy links our four prior pieces **who to serve (Impact × Payability)**, **how to align incentives**, **how to curb the known issues**, and **which technologies fit** into one operating model: **standardized portfolios**, **availability/SLA contracts**, **secure payment rails**, and **O&M-first delivery** backed by transparent measurement.*

Build standardized portfolios, not one-off projects:

Group 20–200 sites into a single SPV per state: e.g., **Tier-1 customers** (pack-houses, milk chillers, telecom towers, PHCs with escrow). Use **cookie-cutter designs** (same PV/BESS SKUs, switchgear, telemetry, enclosure, fire system) and **repeatable contracts** (same availability/SLA schedule, same penalties/bonuses). Standardization compresses soft costs, simplifies training and spares, and makes lenders comfortable.

Contract for services, not just energy:

At **FTM** (feeder/substation or plant-side hybrid), sign **availability PPAs** (e.g., 98–99% slot availability, 2–4 h duration) with clear performance tests and day-ahead dispatch rights. At **BTM** (PHCs, cold rooms, towers, MSMEs), sell **reliability as a service**: monthly **uptime fee** + metered kWh where relevant, with **site-specific SLAs** (e.g., PHC critical loads 24/7, cold-room temperature compliance ≥95% in band). This directly addresses curtailment risk, evening ramps, and feeder trips identified earlier.

Secure the cash flows up front:

Use **escrow accounts** (DISCOM/department), **deduction-at-source** (dairy payouts, mandi settlements), or **prepaid/PAYGo** for MSMEs and households. Align government support to **measured uptime**, not capex: VGF/CSR only unlocks after a quarter of SLA compliance. Clear payment rails neutralize the counterparty risk and dues build-up that have derailed past efforts.

Engineer for the duty cycle - and for maintainability:

Choose **LFP** for 2–4 h, **sodium-ion** for hot sites with similar duration, **VRFB/pumped storage** for >6–10 h. Size PV/BESS to **shift noon to the 2–6-hour blackout window**. Design for **serviceability**: front-access racks, labeled harnessing, uniform firmware, and remote updates. Co-site spares and place **district service hubs** to guarantee **MTTR < 4 hours**.

Make O&M the center of the P&L:

Budget O&M **explicitly and adequately**: plan **3–5% of capex per year** for PV+BESS portfolios (including telemetry subscriptions, site visits, cleaning, HVAC/filtering, fire-suppression upkeep, warranty administration). Establish a **battery augmentation reserve** (~**10–15% of initial storage capex**) ring-fenced for year-7/8 top-ups. Tie vendor AMCs to **availability and safety KPIs**, not just call-outs. Train local technicians and pay them **retainers** plus performance bonuses; this is the cheapest way to buy uptime.

Measure what you get - continuously:

Instrument every site. **Baseline** 4–8 weeks before commissioning (outage logs, diesel run-hours, feeder SAIDI/SAIFI, temperature compliance for cold rooms, PHC clinical hours). After go-live, track:

Availability

(FTM slot availability; BTM load-coverage %).

Quality

(voltage/frequency windows; cold-room 2–8 °C compliance)

Response

(time-to-restore, MTTR)

Economics

(diesel hours avoided; $/kWh delivered; collections efficiency; DSO)

Impact

(PHC night-service hours, wastage reduction at pack houses, tower uptime). Publish a **monthly dashboard** to buyers, financiers, and regulators; make payments **data-triggered**.

Phase the rollout to de-risk:

Run a **12-week proof-of-value** (10–20 sites) to tune SLAs and cash rails; scale to **200–500-site waves** once KPIs stabilize. Sequence by **pecking order** (Tier-1, then Tier-2 social loads bundled with anchors). At grid-scale, start where curtailment and evening peaks are documented, then replicate the template.

Safeguards overview (designed-in, not bolted-on):

Safety and contract sanctity are pre-conditions. Like applying **national BESS safety codes** (cell-level monitoring, gas detection, rated ventilation, fire suppression, spacing, blast panels) and integrate with utility SCADA systems for safe dispatch. Lock **availability/SLA language** to tested templates and escrowed payment flows. Secure **insurance** with documented inspection/maintenance schedules. Treat **data integrity** (tamper-proof logs, third-party audits) as part of the asset, because revenues depend on it. Finally, manage **community consent and siting** through standard checklists (noise, access, benefit-sharing) to protect timelines.

Figure 8 : What "good" looks like (measure to manage)

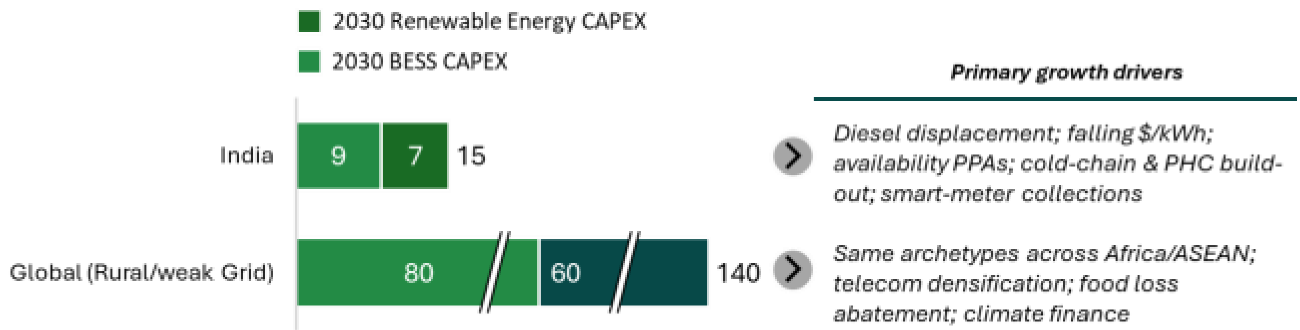
KPI set	Metric (Exemplary)	Target (steady-state)	*Why it matters*
Reliability	Clinical uptime; cold-room temp compliance; feeder evening coverage	≥98% (PHC), ≥95% (cold), +2–4 h evening	*Converts tech into public value*
Cost	Diesel hours displaced; $/kWh ensured	−70% DG run-time; $0.12–$0.22/kWh BTM	*Beats the counterfactual*
Cash	Collection efficiency; DSO; SPV DSCR	≥90%; ≤30 days; ≥1.3×	*Bankability and scale*
Ops	MTTR; first-time-fix; incident rate	<4 h; ≥85%; 0 TRIR	*Resilience and insurance*
System	Curtailed MWh absorbed; evening MWh delivered	Trending upwards monthly	*Grid value, not just site value*

Opportunity : a bankable reliability market hiding in plain sight

Figure 9 : The opportunity

Geography	2025 installed baseline (storage)	2030 addressable (Power / Energy) (*Est.)*
India	~0.2 GW / 0.5 GWh	**~10 GW / ~36 GWh**
Global (rural/weak-grid)	~8–10× India	**~90–110 GW / ~300–400 GWh**

While the India Opportunity grows, it may model similar growth in global adjacent markets



India TAM (2025–2030). Focusing only on the use-cases of reliability, India can support roughly **~10 GW / ~36 GWh** of new storage by 2030:

India's reliability gap is no longer a technology problem; it's a **portfolio build-out**. On the demand side sit **high-VoLL anchors** pack-houses and milk chillers, PHCs, telecom towers, water systems, and MSME clusters already paying a premium for diesel or lost load. On the supply side, **PV + storage** now beats or matches diesel for the **2–6 hour evening window**, while **availability contracts** make front-of-the-meter (FTM) storage financeable. The result is a discrete, high-growth market: **rural and weak-grid reliability**.

- **FTM (substation/feeder and RE-hybrid): ~6 GW / ~24 GWh** (4-hour duty)
- **BTM (PHCs, cold chain, towers, MSMEs): ~2.5 GW / ~7.5 GWh** (3-hour duty)
- **Off-grid/minigrids: ~1.5 GW / ~4.5 GWh** (3-hour duty)

At conservative turnkey costs (2030 view) of **$220/kWh FTM**, **$250/kWh BTM**, and **$300/kWh off-grid**, storage CAPEX totals **~$8.5B**. Co-deployed renewables add **~$6.9B** (e.g., **~3.5 GW** BTM PV @ **$600/kW**; **~2.0 GW** off-grid PV @ **$900/kW**; **~6 GW** FTM RE @ **$500/kW**). Together, this yields an **India TAM ≈ $15–16B** by 2030, plus recurring **O&M revenue ~$0.4B/year**.

Global context (rural/weak-grid segment only). India will likely be **~10%** of the global opportunity by 2030. The same archetypes across Africa and ASEAN imply **~90–110 GW power / ~300–400 GWh energy** and **~$120–160B** cumulative CAPEX (storage + on-site renewables), with **$4–6B/year** in O&M.

Who benefits

DISCOMs reduce peak purchases and losses; earn availability-based flexibility at predictable cost. **01**

Developers/IPPs/RESCOs monetize uptime through **SLA tariffs** and **availability PPAs**. **02**

Cold-chain/dairy/mandi operators, telecom towers, PHCs, MSMEs swap diesel and downtime for contracted reliability. **03**

OEMs/integrators/EPCs capture product + multi-year service margins. **04**

Banks/NBFCs/DFIs deploy de-risked project debt against escrowed receivables. **05**

Local O&M entrepreneurs gain durable service income. **06**

Strategic levers to capture it. Anchor-first **district portfolios**; **standardized kits** (LFP 2–4h; sodium-ion pilots for hot sites; VRFB/PSP for long duration); **availability/SLA contracts** with telemetry-based M&V; **escrow/deduction-at-source** payment rails; blended finance to crowd in private debt; and a **hub-and-spoke O&M** network targeting **<4-hour MTTR**. The prize is not a one-off project; it's an **industrialized reliability product** that scales.

Conclusion :
from star-lit roofs to measured uptime

The story began on a village roof under a sky of stars a ritual born not of romance, but of rationed power. India has wired almost every home; the remaining gap is **usable electricity in the hours that matter**. The 2–6 hour evening window still bends daily life and enterprise: clinics defer services, cold rooms warm, MSMEs idle, and households fall back to diesel. This paper traced why: steepening peaks, feeder constraints, and fragile last-mile assets; and why **now** is different: mid-day renewables are being curtailed, battery prices have fallen sharply, and availability contracts give storage a bankable role.

We mapped the issues that stall scale - uncertain revenue design, counterparty risk, grid bottlenecks, safety, weak O&M, and thin data -and answered them with a practical solution architecture: **pick customers who can pay for reliability**, align **incentives** so money follows measured uptime, **curb execution risks** with escrow and availability PPAs, deploy a **fit-for-purpose tech stack** (LFP and sodium-ion for 2-4h, VRFB/PSP for longer), and run a **portfolio operating model** anchor-led district clusters, standardized kits, hub-and-spoke O&M, and telemetry-based SLAs. The opportunity is material: by 2030, India can support roughly **~10 GW / ~36 GWh** of new storage across FTM, BTM and mini-grids-an investable **$15-16B** reliability market-with a global rural/weak-grid segment an order of magnitude larger.

This opportunity can be captured by actions of key stakeholders,

Policy makers:
Finalize BESS safety code; standardize availability/SLA contracts; target VGF to health, cold-chain and feeder nodes; operationalize payment-security (escrow/deduction-at-source); publish feeder-level telemetry to steer siting.

DISCOMs:
Tender substation/feeder storage where curtailment and evening ramps are worst; enable BTM reliability surcharges tied to SLAs; integrate M&V into billing systems.

Investors & developers:
Build **anchor-first district portfolios**; pre-arrange escrow with departments/co-ops/mandis; lock common BOM/warranties; insure against business interruption; measure and publish performance.

OEMs & service partners:
Productize **2–4h** SKUs for India's heat, stand up district service hubs (<4h MTTR), and certify safety.

CSR & donors:
De-risk social loads (PHCs, schools) and fund independent M&V to lower cost of capital.

If the past phase of electrification was about connections, the next is about **contracting for uptime**. Do that well, and the fan inside the village home stays on - not just tonight, but every night - because reliability has been engineered, procured, and paid for.

Who are the customers? What is their willingness to pay?

The first design choice is **not** technology - it is **customer selection**. Storage-backed renewables clear fastest where (1) **impact** is high (large reach, essential services, high Value of Lost Load) and (2) **payability** is credible (clear willingness/ability to pay, anchor revenue, and enforceable collections). Think of this as a **2×2**: *Impact* on one axis, *Probability of Becoming a Paying Customer* on the other. (*figure 6)*

High-High (Priority Tier 1):

Cold-chain nodes (pack-houses, milk chillers, ripening rooms) and **telecom towers**. These sites already pay a reliability premium via diesel at **\$0.25–\$0.50/kWh** (fuel dominates total cost). PV+BESS can deliver evening/backup power at **\$0.12–\$0.22/kWh** (PV LCOE **\$0.04–\$0.06** + storage adder **\$0.08–\$0.16**) with service-level agreements (temperature or uptime) and **contracted payors** (co-ops, 3PLs, MNOs). **Primary health centres (PHCs)** also sit here **if** payment certainty exists (department escrow/CSR) because VoLL is extremely high and diesel is unaffordable at scale. **Mandi cold hubs** and **village water schemes** round out Tier 1 where billing can be deducted at source.

High Impact - Medium Payability (Tier 2):

Government schools/Anganwadi's, **community water systems**, and **agricultural irrigation at household level**. The social return is clear, but individual payment reliability is mixed. Two tactics lift payability: (i) **anchor-led portfolios** (pair social sites with revenue anchors such as towers or cold rooms) and (ii) **feeder/DT-level solutions** paid by the utility (availability payments) rather than each household.

Medium - Medium (Tier 3):

MSMEs in weak-grid towns (workshops, mills, looms) can pay if the product is *OPEX-replacing*: diesel at **\$0.30–\$0.45/kWh** swapped for BTM service at **\$0.16–\$0.22/kWh**. Success depends on prepaid/UPI billing and tight O&M.

High Impact - Low Payability (Tier 4):

Remote households for personal backup. These segments require **PAYGo** or lifeline subsidies. They are important for inclusion, but they do not anchor near-term bankability.

Two additional nuances matter:

01

Differentiate agricultural use-cases

Solar pumps (productive, monetizable) are not the same as *household backup*. The former can be bundled under service contracts (per-hour/kWh irrigation) with village deduction at source; the latter is discretionary and price-sensitive.

02

Prioritize contractability over theoretical WTP

The quickest flywheel is a **five-site cookie-cutter** repeat (same BOM, same contract, same M&V): e.g., 10 pack-houses + 1 mandi hub + 3 towers + 5 PHCs, all prepaid/escrowed. Scale follows standardization.

We should start where **VoLL is high** and **cash is collectable**. Tier-1 customers create early cash yield, lower cost of capital, and fund expansion to Tier-2/4 social loads. Technology is an enabler; **customer selection** is the strategy.

Our Values

The Avalon EDGE

E — ENTREPRENEURSHIP
Enterprising ownership to transform ideas into pragmatic and profitable solutions

D — DEDICATION TO EXCELLENCE
Commitment to premier quality and highest standards in everything we do

G — GREAT VALUE CREATION
Focus on delivering maximum client impact through innovation and collaboration

E — ETHICAL APPROACH
Respect, fairness, and transparency in all our interactions

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