CLEANTECH

2026

An integrated investment thesis across Renewable Energy, Mobility, Charging Infrastructure, CCUS, Circular Economy & Enabling Technologies.

01 **Renewable Energy**

02 **Future of Mobility**

03 **Charging Infra**

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Varanium CleanTech Sector Outlook 2026 — an integrated thesis across the cleantech value chain.

SECTION 01

CleanTech Sector Overview

The macro thesis — why cleantech has become an unavoidable investment imperative for the next decade.

Clean tech sector Mindmap

Storage Tech — **$55B** (Total Funding)
- Home & Distributed energy storage
- EV Battery storage & Recycling
- Thermal energy storage
- pneumatic & Compressed air storage
- mechanical & Flywheel storage
- Hydrogen based energy Storage
- Grid scale chemical battery storage

Climate Finance — **$14B** (Total Funding)
- Climate insurance & Risk transfer
- Carbon market & Offset Platforms
- Climate risk, ESG & Carbon intelligence

Renewable Energy — **$60B** (Total Funding)
- Biomass and Others
- Hydrogen Fuel Solution
- Solar
- Wind
- nuclear

Charging Infrastructure — **$11B** (Total Funding)
- Battery Swapping Solution
- Enablers
- Equipment
- Hydrogen
- Network Stations (Operators)

CCUS (Carbon Capture, Utilization, and Storage) — **$12B** (Total Funding)
- Direct Air Capture
- Point of Extraction
- Storage
- Utilization

Energy Efficiency — **$32B** (Total Funding)
- Building Management
- Grid Management
- Industrial Energy effciency & Electrification

Mobility — **$130B** (Total Funding)
- EV Charging Networks & Fleet Infrastructure
- EV Hardware, Components & Mobility Software Suppliers
- Electric Commercial Vehicle Manufacturers
- Electric Two-Wheeler & Multi-Vehicle Platforms
- Vehicle-as-a-Service (VaaS) & Battery-as-a-Service (BaaS)
- Smart Mobility, Ride-Hailing & Shared Transport
- Electric Aviation & Advanced Air Mobility
- Autonomous & AI-Driven Transportation
- Green Logistics & Autonomous Delivery
- Electric Passenger Vehicle Manufacturers

Circular Economy — **$28B** (Total Funding)
- Circular Economy platform & Infrastructure
- EV Battery Recycling
- Advanced Materials
- Waste Management
- Water Treatment
- Recycling of General Materials
- Sustainable Packaging

Source: Industry aggregated funding database (2017 – Present); Sector taxonomy based on global climate tech investment tracking.

Why CleanTech Now?

Six structural forces are converging to create one of the largest investment supercycles in history.

Climate Imperative

The 1.5°C pathway requires roughly **$4.5–5T/yr** of clean investment by the early 2030s (IEA, IRENA) — up from ~$2T today. Renewables remain the lowest-cost path to new power in most markets.

Technology Cost Curves

Solar LCOE is down **90%** since 2010; battery pack costs are down **93%** since 2010 (IRENA). Every year of delayed adoption of new technology costs more — not less.

Policy & Regulatory Shift

- EU: €1T Green Deal investment plan by 2030.
- India: ₹1.5+ lakh crore committed through PLI and PM E-DRIVE for EVs and batteries.
- U.S.: Rollback of several IRA clean-energy incentives makes policy support more uneven across markets.

Capital Flows Re-routing

Global sustainable investment assets exceed $30T. Capital is increasingly flowing toward renewables, energy storage, grid infrastructure, and electrification—driven by attractive economics, long-term demand, and energy security rather than ESG mandates alone.

Energy Security Imperative

Energy security is now a key driver of clean-tech investment. Countries are expanding domestic renewables, storage, and grid infrastructure to improve resilience, reduce import dependence, and protect against energy price shocks.

Cost Competitiveness

Renewables now compete on economics alone. As of 2026, 91% of newly commissioned utility-scale renewable projects globally produce electricity at a lower cost than the cheapest new fossil-fuel alternative, making clean energy the lowest-cost choice for new power generation. (IRENA)

Source: IEA, IRENA, BloombergNEF (BNEF), GSIA, Bloomberg Intelligence, European Commission, Government of India (MNRE, DPIIT, Ministry of Heavy Industries), U.S. Congress, White House.

India: Electrification as a GDP Growth Engine

Electrification is no longer a byproduct of India's growth — it is becoming one of its primary engines.

Growth Tracks Electrification

India's electricity demand is set to grow **6.4%/yr** through 2030, a pace the IEA ties directly to the IMF's GDP growth outlook. Electrification is now a leading indicator of expansion, not just a byproduct of it.

The $30T Pathway

NITI Aayog's Viksit Bharat 2047 roadmap models an **8-fold GDP expansion** to $30T by 2047, with electricity's share of final energy rising from ~21% today to ~60% under its Net Zero Scenario, growth deliberately decoupled from emissions.

A Jobs Dividend

India's clean energy build-out could generate over **44 lakh (4.4M)** full-time jobs by 2030 (CEEW-NRDC), with rooftop solar alone accounting for ~43% of that employment.

Capital Is Reallocating

The investment ratio between fossil and non-fossil power capacity has shifted from **1:1 to 1:4** over the past decade and clean energy is absorbing a rising share of India's capital formation.

Auto Sector Re-Tooling

India's ~$240B automotive sector (**7.1% of GDP**, 30M+ jobs, IISD) is being reshaped by electrification; NITI Aayog/RMI project the EV finance market alone reaching ~$50B by 2030.

The Import-Substitution Dividend

India's fossil-fuel subsidies and import exposure cost roughly **2.3% of GDP (~$51B)** in FY25 — every point of electrification-led displacement is a direct fiscal and GDP tailwind.

Data Centres Get a Fast Lane

India has granted data centres **infrastructure status** and **direct power access**, letting AI hyperscalers skip DISCOM queues and capacity is set to grow **~8x, to ~10GW by 2030**, backed by **$200B** in AI-infrastructure investment.

Sources: *IEA, Electricity 2026 (Feb 2026) · NITI Aayog, Scenarios Towards Viksit Bharat and Net Zero (2026) · CEEW–NRDC, Driving Energy Transition (Jun 2026) · Amundi Research Center, India's Clean Energy Moment (2026) · IISD, Global Subsidies Initiative — India fossil-fuel subsidies (FY25); IISD/RMI, EV finance market analysis · Government of India / IEEFA, India's Power-Hungry Data Centre Sector at a Crossroads (2026).*

VARANIUM

Where India's Emissions Come From

India's greenhouse gas footprint remains concentrated in two hard-to-abate sectors — energy and industry now account for two out of every three tonnes emitted.

TOTAL GHG EMISSIONS, 2024

4,371

MT CO_2e

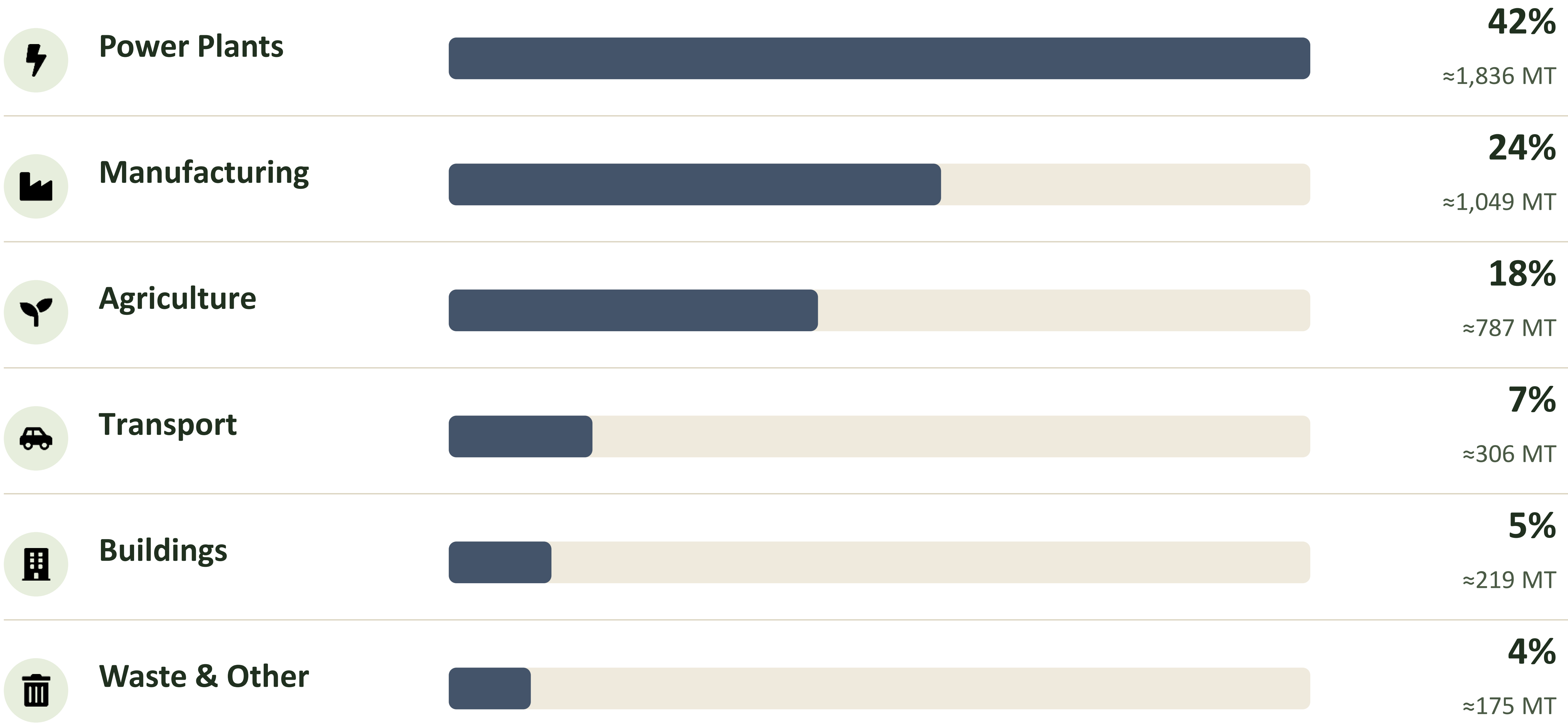
▲ 3.9% vs. 2023

3.0 t CO_2e per capita (world avg. 6.6 t)

India added the **largest absolute increase** of any country in 2024 — but remains well below the global per-capita average.

EMISSIONS BY SECTOR

Share of 4,371 MT CO_2e



Two sectors, two-thirds of the total

Energy and industry together account for 66% of national emissions — the same hard-to-abate concentration seen in 2022.

Coal still anchors power

Coal supplied roughly 72% of generation in late 2024, even as non-fossil installed capacity crossed 50%.

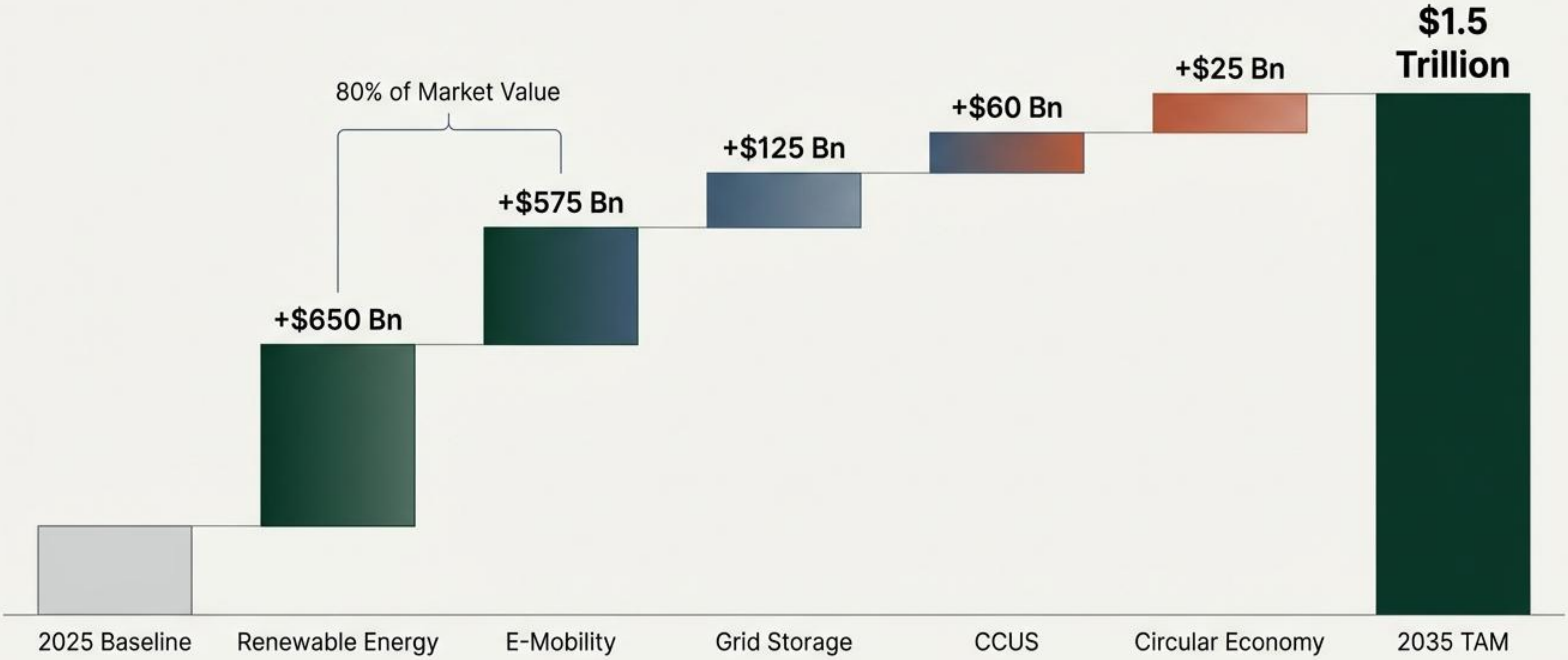
World's largest agricultural emitter

Emissions from farming are dominated by two sources: methane from rice paddies and livestock digestion (cattle/buffalo "enteric fermentation"), plus nitrous oxide from fertilized soils

Source: Total emissions and per-capita/global-share figures: EDGAR (JRC/European Commission), “GHG emissions of all world countries — 2025 Report” (4,371 MT CO_2e, 2024, excl. LULUCF). Sector shares are 2024 estimates compiled from Climate TRACE country-level sector trends and EDGAR sector data, applied to the updated 2024 total; figures are directional, not an official government inventory.

A Decade of Disruption: The Consolidated Opportunity

India's transition is driven by economics: Lower TCO and Energy Security.



The CleanTech Opportunity

India's clean energy build-out, benchmarked against the global market.

GLOBAL

$2.2T

Global clean energy investment in 2026

Nearly 2x the $1.2T going to fossil fuels

$665B

Global renewable power investment in 2026

Includes $365B for solar alone — $1B a day

$750B

Annual grid investment needed by 2030

More than double today's ~$330B

INDIA

$170B

India's record energy investment in 2026

Growing 11% a year over the past five years

283GW

Non-fossil capacity installed, March 2026

Includes a record 55 GW added in FY26 alone — India's best year yet for clean energy addition

50%

Share of power capacity from non-fossil sources

Reached in 2025 — five years ahead of India's NDC target

India's energy investment is compounding faster than the global average

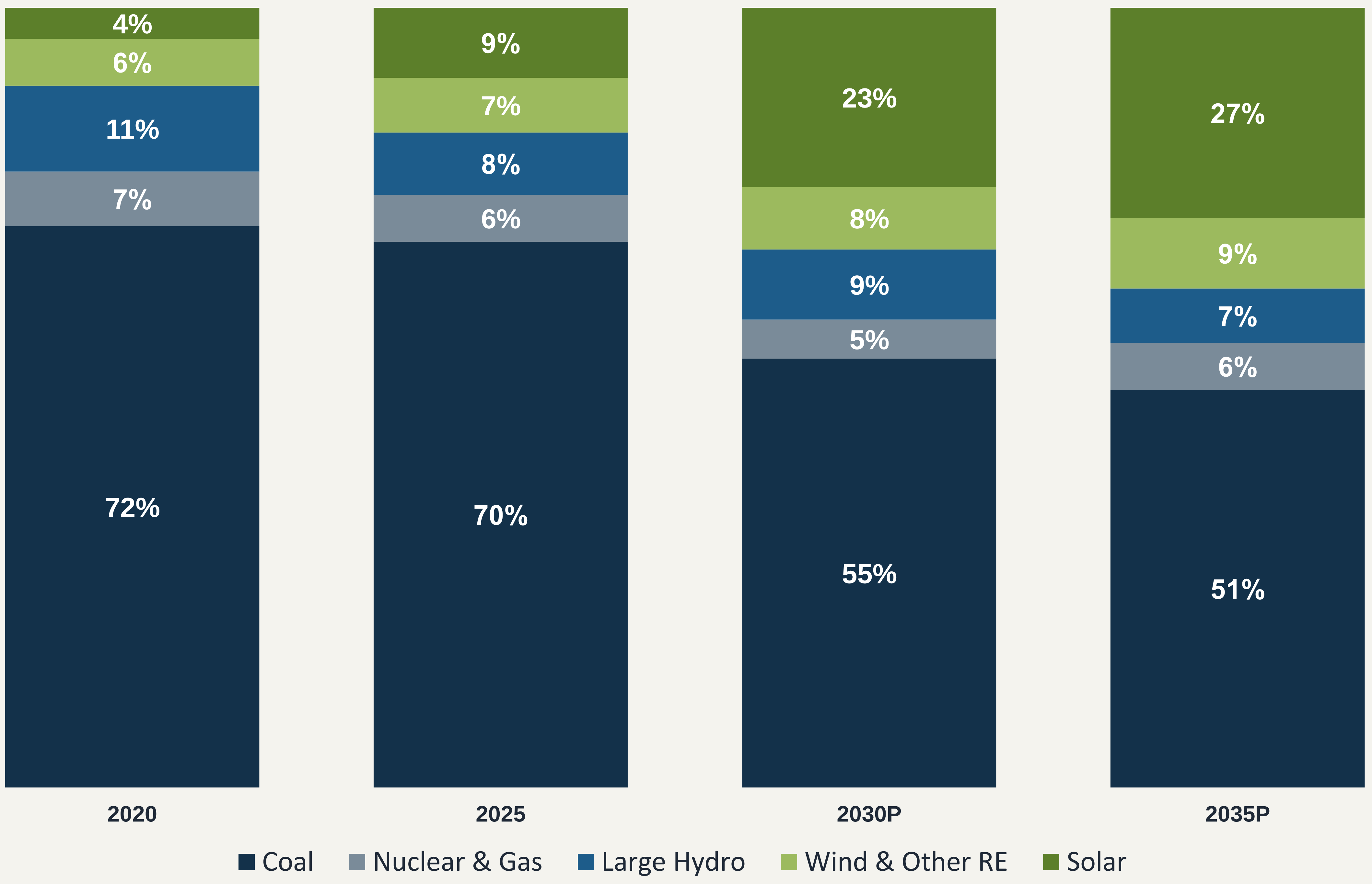
11% annual growth over 5 years in India vs. a 5% rise in global investment for 2026 alone — IEA, World Energy Investment 2026.

Note: Figures reflect total global infrastructure CapEx, project finance, and asset deployment for 2026, distinct from private venture/startup equity funding.

Sources: IEA, World Energy Investment 2026; Ministry of New & Renewable Energy (MNRE) / PIB, April 2026.

India's Electricity Generation Mix

Coal still leads, but solar is reshaping the mix — 2020 to 2035 (projected).



The Headline Shift

Solar's share of generation grows 7x
from 4% in 2020 to a projected 27% by 2035.

Coal remains the single largest source
but its share falls from 72% to 51% as demand growth is increasingly met by clean power.

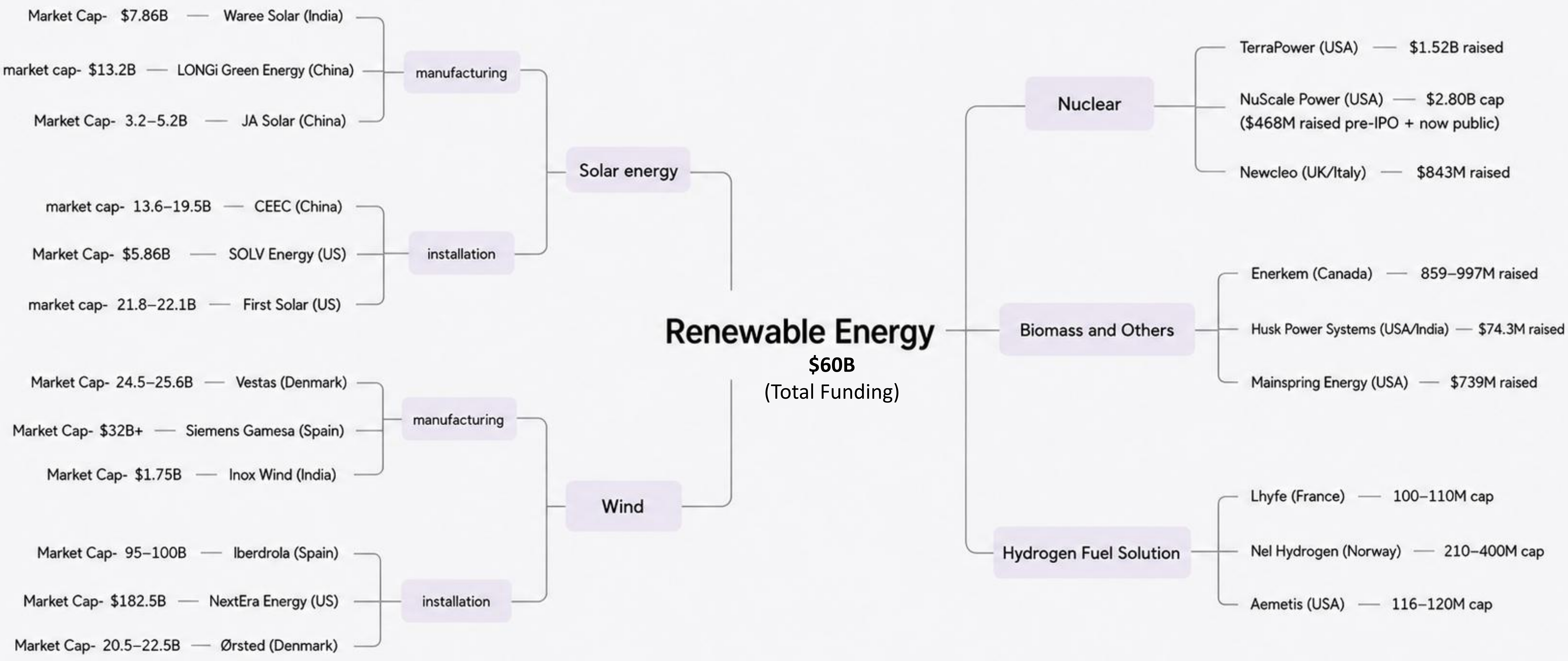
Non-fossil generation climbs from a quarter to half the mix
from ~28% of the mix in 2020 to ~49% by 2035.

Sources: CEA, Optimal Generation Mix 2030 (v2.0); CEA, National Generation Adequacy Plan 2026-27 to 2035-36 (Mar 2026); Ember, Global Electricity Review 2026; IEEFA analysis of CEA data, FY2019-20. 2030P and 2035P are CEA projections, not actuals.

SECTION 02

Renewable Energy

Solar, wind, storage, grid & software — building the new energy economy from the generation layer up.



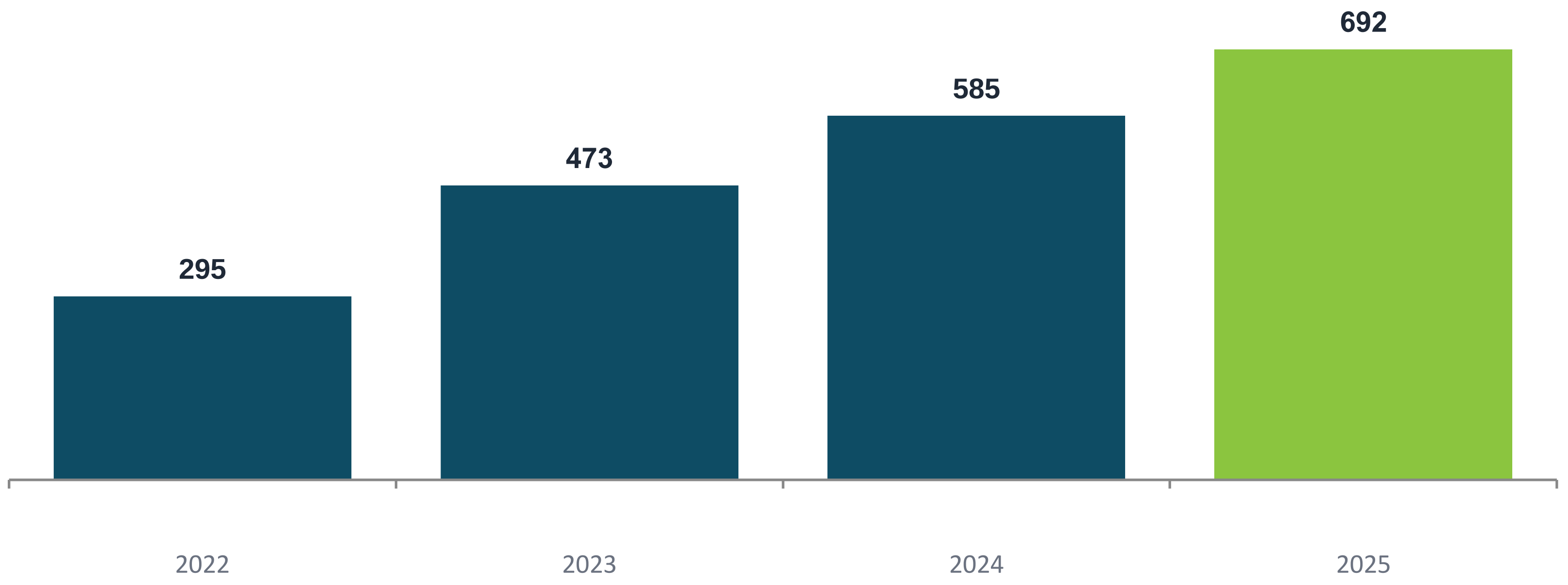
Note: Public companies are represented by their current market capitalization, as comparable total funding data is unavailable. Private companies are represented by their total funding raised.

Renewable Energy — The Big Picture

Deployment keeps scaling exponentially — and India is now leading its own charge.

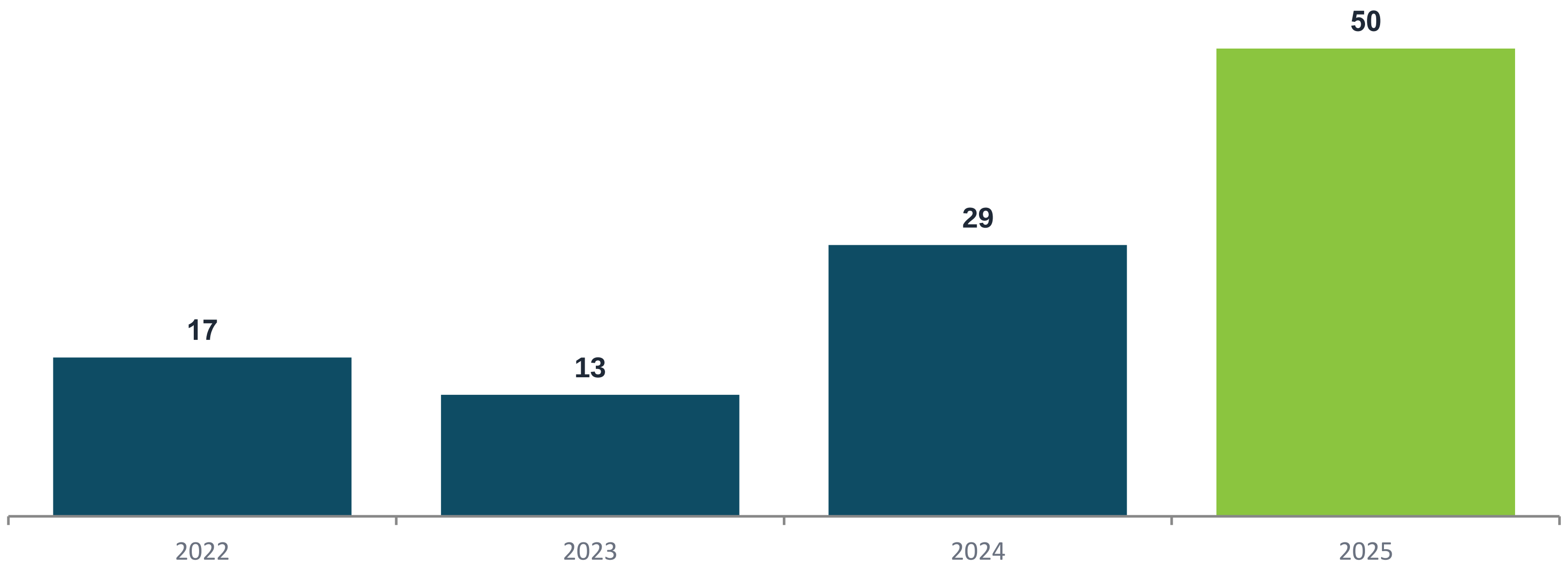
GLOBAL RENEWABLE CAPACITY ADDED PER YEAR (GW)

Source: IRENA, Renewable Capacity Statistics 2026 (data to end-2025)



INDIA RENEWABLE CAPACITY ADDED PER YEAR (GW)

Source: MNRE, Govt. of India (PIB); IEA, Global Energy Review 2026



692 GW

Record global capacity added in 2025 — the highest ever, an 18% jump over 2024

51%

India's installed power capacity is now non-fossil, five years ahead of its 2030 goal

$467B

Fossil-fuel spend avoided worldwide by renewables in 2024

<$40/MWh

2025 global cost of new solar & wind — under half the price of new gas power (>$100/MWh)

Sources: IRENA, Renewable Capacity Statistics 2026 & Renewable Power Generation Costs in 2024; IRENA, 24/7 Renewables (2026); Ministry of New & Renewable Energy, Govt. of India; IEA, Global Energy Review 2026.

VARANIUM

The Global Energy Transition

Transitions take decades — but each new era is additive, not a clean replacement.

1800s – 1940s

Coal

Industrial revolution. Steam power, railways and manufacturing.

1940s – 1980s

Oil

Motorization, plastics, global trade and geopolitics.

1980s – 2010s

Gas

Power generation. Cleaner than coal, but still fossil.

2010s – Now

Renewable

Cheapest new power. Exponential deployment. Policy tailwinds.

2030s+

Hybrid

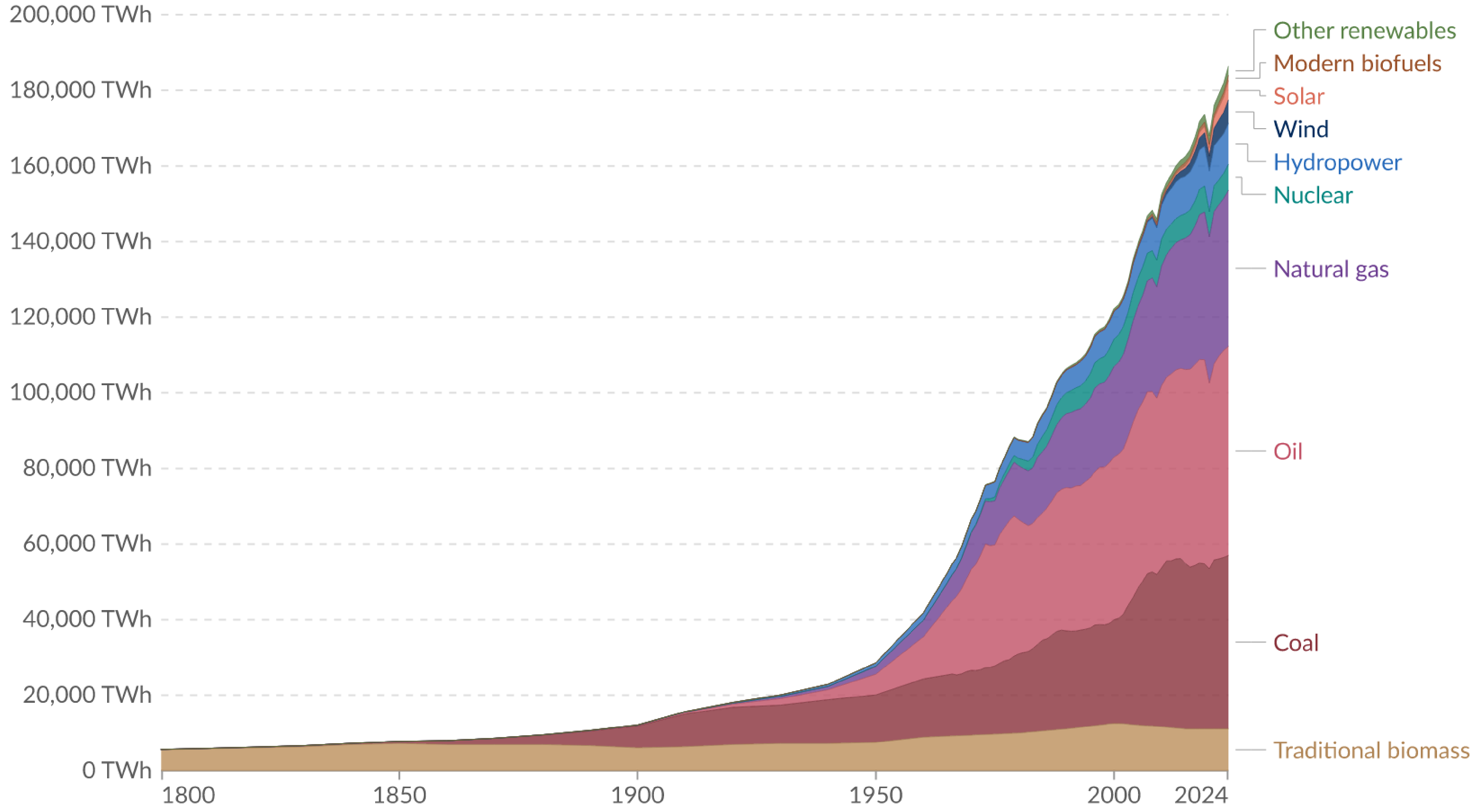
Integrated solar, wind, storage, H2O and software optimization.

Investor insight: renewables solve geopolitical problems — not only environmental ones.

Source: Vaclav Smil, Energy Transitions: Global and National Perspectives

Global Primary Energy Consumption by Source

Primary energy is based on the substitution method and measured in terawatt-hours

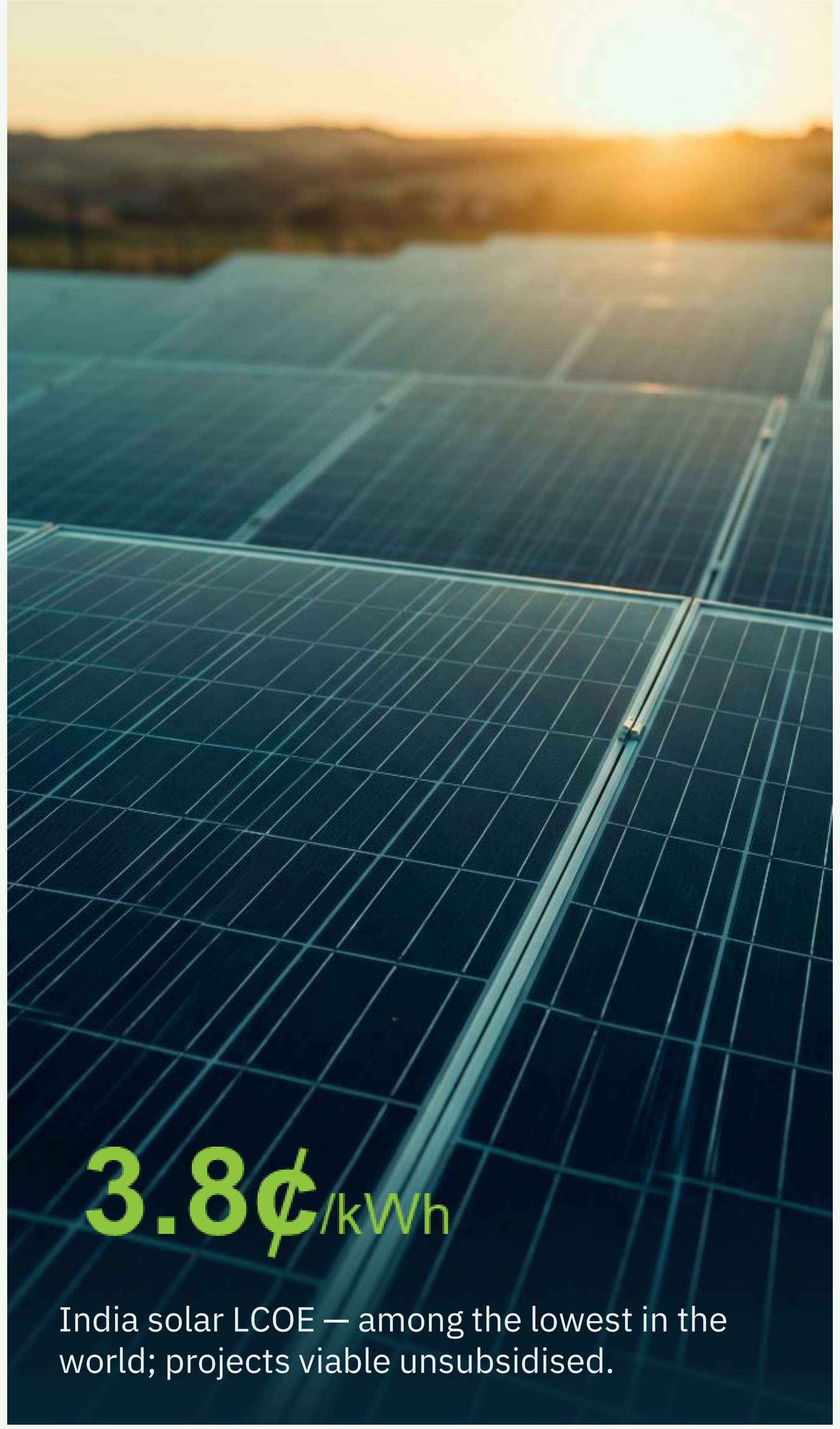


Data source: Energy Institute - Statistical Review of World Energy (2025); Smil (2017)

Note: In the absence of more recent data, traditional biomass is assumed constant since 2015.

Solar — Cheapest Electrons, Migrating Margin

India's solar LCOE is ~3.8¢/kWh — and value flows downstream, from silicon to projects.



CELL TECHNOLOGY EVOLUTION

Technology	Efficiency	Status
Mono PERC	21–23%	Mainstream
TOPCon	24–25.5%	Growing fast
HJT	24–26%	Premium
Perovskite	24–26%	**Future ★**
Perovskite (Tandem)	29–32%	**Future ★**

Sources: IRENA, *Renewable Power Generation Costs in 2024* (July 2025); cell efficiency ranges per NREL Best Research-Cell Efficiency Chart and industry data (ITRPV 2025, ISE Fraunhofer 2025)

Silicon to module — four stages, rising complexity

Each stage moves the material closer to a sellable product — and each one is a distinct capital-intensive business.

FEEDSTOCK
Polysilicon
Metallurgical-grade silicon is purified to 6N+ purity via Siemens CVD or FBR process.

→

CRYSTALLISATION
Ingot & wafer
Silicon is melted, grown into monocrystalline ingots, then diamond-wire sliced into wafers.

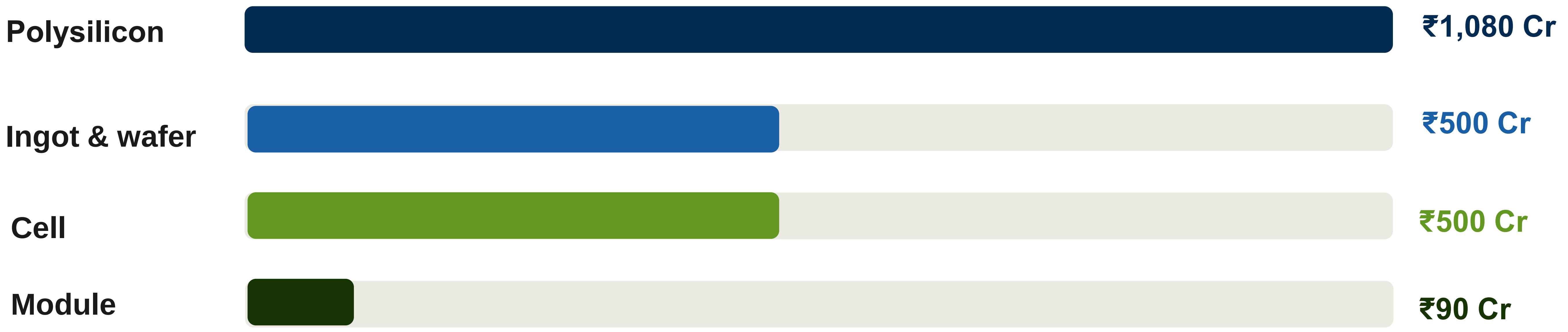
→

CONVERSION
Cell
Wafers are doped, passivated & printed to create the p-n junction (PERC / TOPCon / HJT).

→

ASSEMBLY
Module
Cells are strung, laminated with glass & backsheet, framed, and fitted with a junction box.

CAPEX REQUIRED TO SET UP 1 GW OF CAPACITY (₹ CRORE)



~10.8x

more capex for 1 GW of polysilicon than 1 GW of module capacity

Source: JMK Research & IEEFA, “India’s Photovoltaic Manufacturing Capacity Set to Surge” (April 2023)

Who Makes It — India & the World

India dominates cell and module assembly; China still controls the upstream chain.

STAGE	INDIA	OUTSIDE INDIA
Polysilicon	No commercial production yet. Reliance (Jamnagar, under development), Tata Power (announced)	GCL Technology, Tongwei, Daqo New Energy, Wacker (Germany), OCI Holdings (S. Korea)
Ingot & Wafer	Adani Solar (Mundra), Premier Energies-Sino-American Silicon JV, Tata Power (Nellore, from 2028)	LONGi, TCL Zhonghuan, Tongwei
Cell	Waaree, Adani Solar, Premier Energies, Tata Power Solar (TP Solar), Vikram Solar	Tongwei, JA Solar, Aiko Solar, Trina Solar
Module	Waaree Energies, Adani Solar, Tata Power Solar, Vikram Solar, RenewSys, Goldi Solar, Avaada	JinkoSolar, LONGi, JA Solar, Trina Solar, Canadian Solar, First Solar (US, thin-film)

~80%
of global polysilicon, wafer, cell & module capacity is Chinese-controlled

21
Indian companies now rank in the Terawatt PV Global Top 100 (Q1 2026)

2 GW
India's installed ingot & wafer capacity — the tightest bottleneck

SOURCES: IEA · Wood Mackenzie · PV Tech · pv magazine · Mercom India · ORF America

Solar panels: how they work, and why the economics keep improving

Falling costs and rising efficiency are the two forces compounding to make solar the cheapest new power source.

HOW IT WORKS

Photovoltaic effect

Silicon cells absorb sunlight and release electrons, generating DC current. An inverter converts this to usable AC power for the home or grid.

COST IN INDIA, 2026 (USD)

Panels from 1.1–2.3¢/kWh

- Non-DCR mono PERC / TOPCon modules: 1.1¢/kWh
- DCR TOPCon modules (ALMM-listed): 1.9-2.3¢/kWh
- Utility-scale solar power: 2.9–3.2¢/kWh
- Typical 3kW rooftop: ~4.4 – 5.3 ¢ / kWh installed, ~2.6 – 3.1¢/kWh after subsidy

EFFICIENCY GAINS

13% → 22–24%

Early-2000s panels converted about 13% of sunlight. 2026's mainstream TOPCon panels reach 22–24%, with record lab cells now past 27–28%. Module efficiency has nearly doubled in two decades.

MODULE SOURCING

DCR vs non-DCR modules

- DCR: cells and modules both made in India (ALMM List I+II) — required for PM Surya Ghar, PM-KUSUM and CPSU subsidies
- Non-DCR: uses imported (mostly Chinese) cells — cheaper and often 1–2% more efficient, but not subsidy-eligible
- Price gap: DCR TOPCon ~$0.28/W vs non-DCR TOPCon ~$0.17/W — roughly a 65% premium (Jan 2026)
- Driven by India's cell-vs-module capacity gap: ~30GW of domestic cells against ~120GW of module capacity

PANELS PER SYSTEM SIZE

2 panels per kW

Based on standard 580W panels:

1 kW	**2 panels**
3 kW	**6 panels**
5 kW	**9 panels**
10 kW	**18 panels**

Investor insight: a panel that was 13% efficient in 2010 is about 23% efficient today — the same rooftop now produces nearly double the power, while module cost per watt has fallen over 70%. That combination, not subsidies alone, is what makes 3–5 year payback periods possible in India today — though DCR-mandated (subsidy-eligible) systems still pay back a little slower than cheaper non-DCR alternatives.

Sources: JMK Research module price tracker (Jan 2026); Mercom India, DCR vs non-DCR cost analysis (Dec 2025); MNRE PM Surya Ghar subsidy circular (2026); SECI ISTS Solar+BESS auction results (Jun–Jul 2026); pv magazine / Solar Stack, cell efficiency records (Feb–Jun 2026). USD/INR ≈ 96.5 (Jul 2026).

Beyond silicon: perovskite, tandem cells, and the next efficiency leap

Perovskite-graphene composites and tandem architectures are pushing lab efficiency past 34% — and India is entering the race.

THE TECHNOLOGY

Tandem stacking

A perovskite top layer captures blue/green light while silicon below absorbs red/infrared, together breaking the 33.7% ceiling that caps single-layer silicon cells.

MATERIALS SCIENCE

Graphene reinforcement

Perovskite's weak point is moisture damage. Blending in graphene oxide fixes crystal defects. Indian researchers hit 16.6% efficiency with 1,300+ stable hours this way.

EFFICIENCY RECORDS

22% → 34.85%

Standard silicon tops out near 22-24%. LONGi's lab tandem cell hit an NREL-certified 34.85% in 2025; Oxford PV's commercial module reached 26.9%. Theoretical ceiling: ~43%.

WHO'S BUILDING THIS

A global race, with India in it

INDIA

P3C Technology — IIT-BHU spinoff, India's first perovskite cell maker

ABX3PV — IISc-incubated flexible perovskite modules

GLOBAL

Oxford PV (UK) — first commercial tandem panels

LONGi & Trina (China) — hold the lab efficiency records

Sources: PM Surya Ghar (pmsuryaghar.gov.in), NREL, Mercom India, pv magazine India — 2026.

Silicon vs. Perovskite: the head-to-head

Two materials, one race to break past the 33.7% single-junction ceiling.

Si Silicon (crystalline)

Established · dominant technology

Efficiency ceiling — 22–24% typical modules; ~26.8% theoretical max

Manufacturing — Decades-mature; over 90% of global solar market

Cost — Lowest $/watt; established supply chains

Durability — Proven 25+ year field lifespan

Form factor — Rigid; heavier, glass-backed panels only

Pk Perovskite (tandem)

Emerging · fastest-rising technology

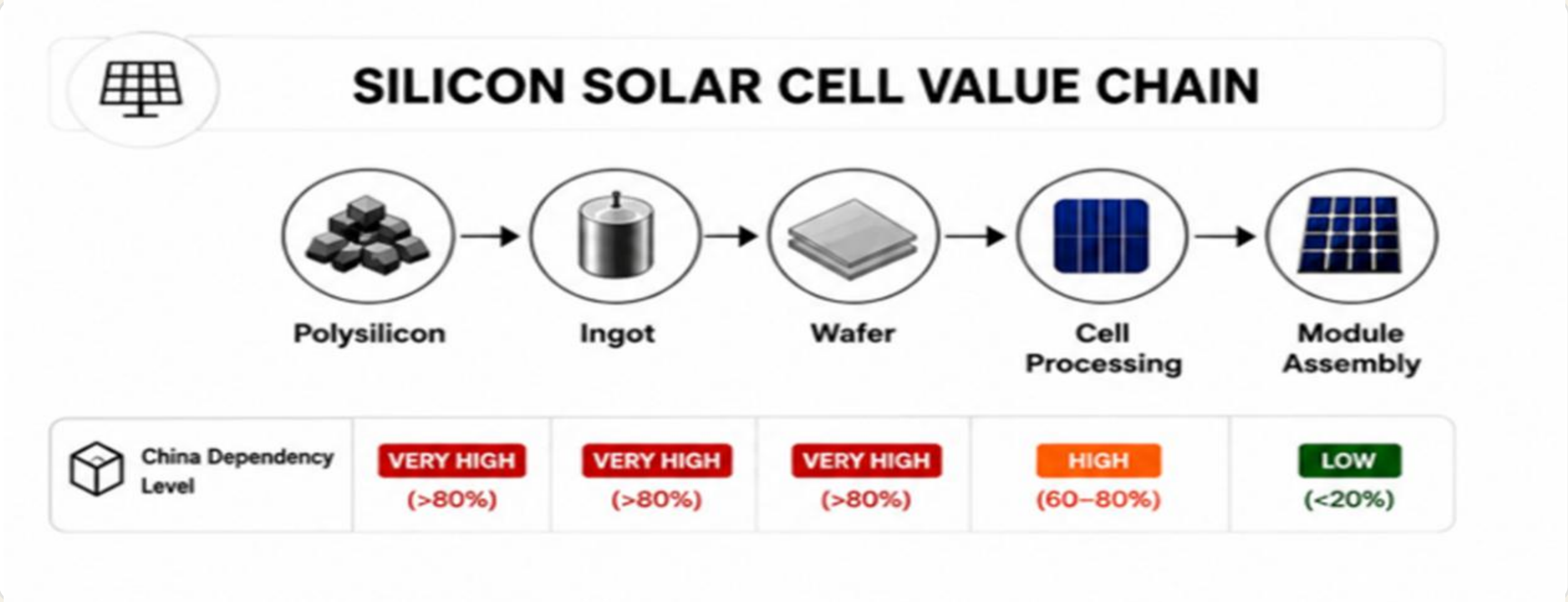
Efficiency ceiling — 34.85% NREL-certified tandem; ~43% theoretical max

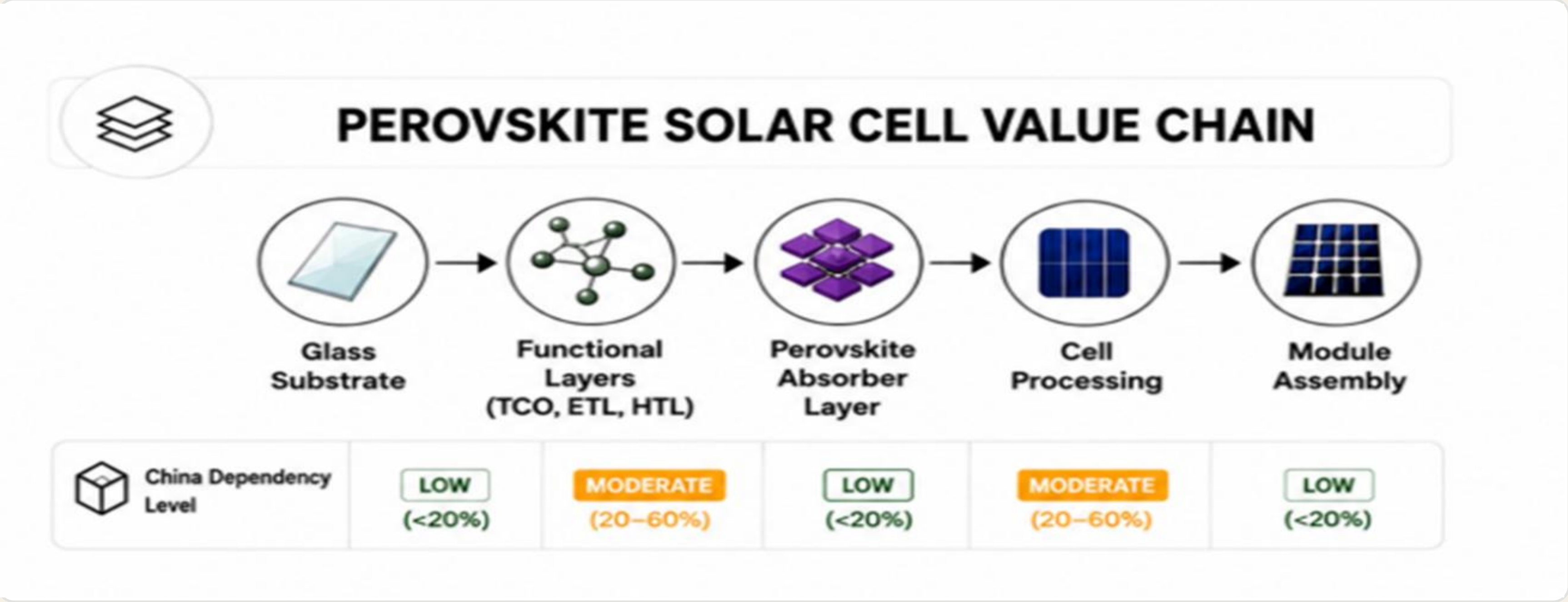
Manufacturing — Early stage; first commercial modules shipped 2025

Cost — Cheaper raw materials; scale-up still developing

Durability — Moisture-sensitive; graphene blending improves stability

Form factor — Can be made thin, flexible, and lightweight



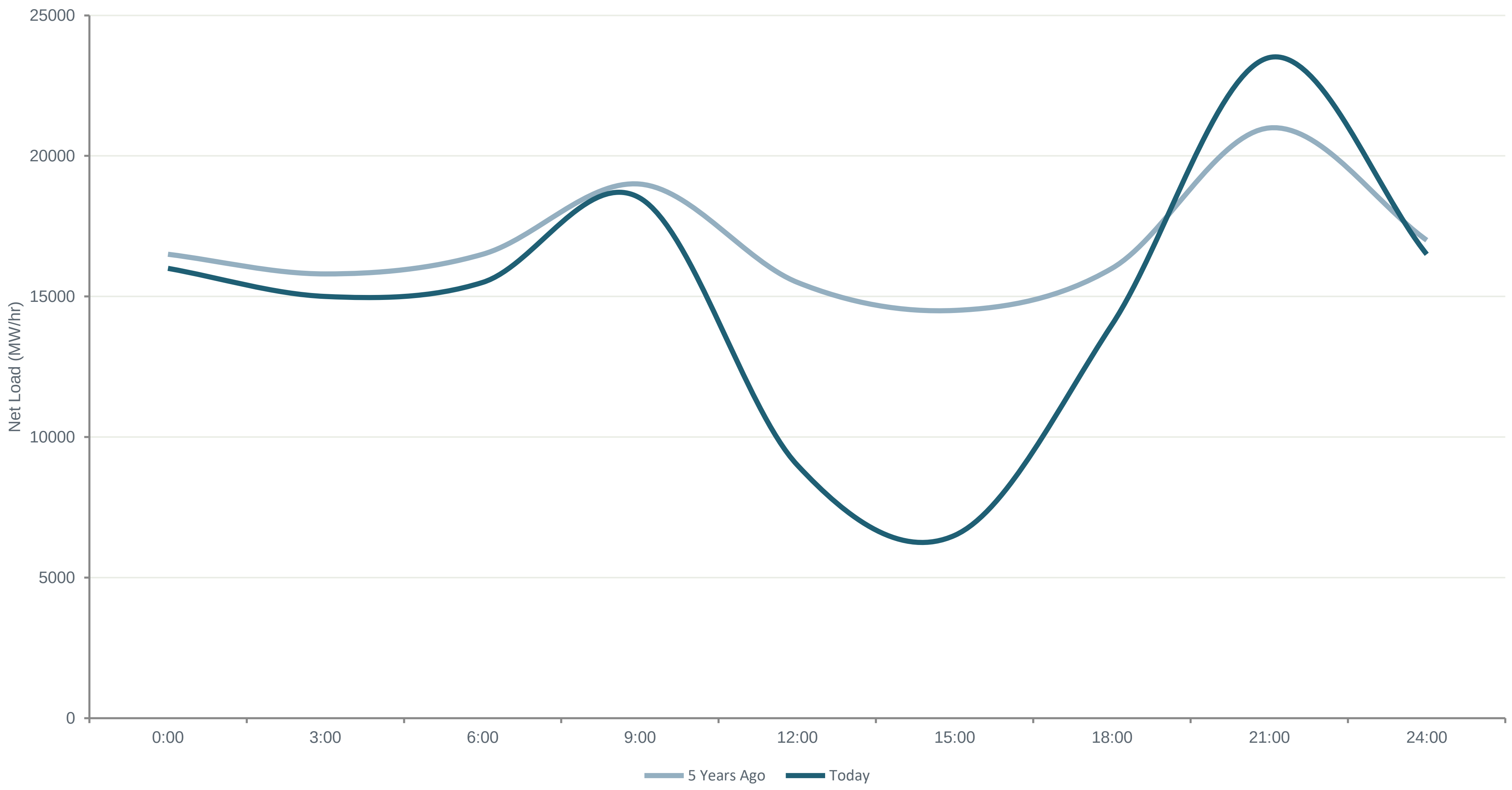


Sources: NREL, Mercom India, pv magazine India — 2026.

The Duck Curve

As rooftop and utility-scale solar grow, net grid demand develops a deep midday belly and a steep evening neck.

Illustrative Net Load Curve, by Hour



WHY IT MATTERS

RAMP-UP RATE

~13 GW/hr

Needed as the sun sets and evening demand peaks at the same time.

FILL WINDOW

3–4 hrs

The evening span each day when flexible or stored power must cover the gap.

TOOLS THAT FILL THE NECK

- Batteries
- Gas peakers
- Demand response

Morning Ramp

Demand climbs before sunrise generation kicks in.

Midday Belly

Solar's marginal cost ≈ $0/MWh
so it's dispatched first, pushing net load down.

Evening Neck

Sun sets while demand peaks — fast ramp required.

Sources: CAISO, U.S. EIA, NREL

Cost of Power — Thermal vs Solar

Solar has crossed grid parity in auctions; new coal keeps getting costlier to build and run.

COMPONENT	THERMAL (COAL)	SOLAR
Capital cost (Capex)	$1,040–$1,250/kW for new supercritical plants — in line with recent projects (Udangudi, Khurja)	$350–$425/kW — among the lowest capex of any major economy
Fuel cost	Dominant cost driver, commonly ~60–70% of generation cost; volatile, passed through to tariffs	Zero — no fuel input once the plant is commissioned
O&M	Higher — boiler, ash handling, and emission-control (FGD) upkeep	Low — mainly panel cleaning, inverter servicing, minimal moving parts
Levelised cost — new build	~6.9¢/kWh, estimated for new supercritical plants at current capex levels	2.5–3.6¢/kWh in FY26 utility-scale auctions; record low of 3.06¢/kWh
Levelised cost — existing fleet	~5.4¢/kWh weighted-average pithead cost for already-operating capacity, rising to 6.2–7.0¢/kWh as utilisation falls	Mostly new-build capacity; auction tariffs above are the relevant benchmark
Cost trend	Rising — capex has climbed sharply, fuel cost pass-through continues	Falling — down ~21% year-on-year on cheaper modules and financing

3.06¢/kWh

Record-low tariff in a 2025 standalone solar auction — 21% below 2024's lowest bid

~2x

Directional rise in new coal-plant capex over the past decade, per industry estimates

7.4¢ vs 5.4¢

Coal's health-related social cost vs its pithead cost, per kWh — carbon costs would widen this further

Sources: Power Line Magazine, Mercom India, Ember Energy, ISID Working Paper, CEA National Electricity Plan

VARANIUM

Wind — Generation When Solar Rests

Capacity factor is the share of a plant's maximum possible output it actually generates over time

Onshore Wind

Low cost, mature technology, but increasingly land-constrained.

Capacity Factor: 25–35% **Capex:** $1–1.5M/MW Plains, hills, rural

Offshore Wind

Higher capex but significantly higher output — closer to coastal demand.

Capacity Factor: 45–55% **Capex:** $3–5M/MW Coastal cities

Floating Offshore

Deep-water frontier — unlocks vast wind resources beyond shallow zones.

Capacity Factor: 50%+ **Commercial:** 2030s

> Solar peaks midday; wind peaks at night and offshore — together they deliver grid stability.

Wind Energy: Clean Power, Real Trade-offs

A mature, fast-scaling renewable source — but cost, intermittency, and grid integration remain key hurdles

178 GW

Global wind capacity added in 2025 — a record year (GWEC)

56 GW

India's cumulative wind capacity, 4th largest globally (MNRE, Mar 2026)

Benefits

- Zero fuel cost, near-zero operating emissions
- Record 178 GW added worldwide in 2025 (GWEC)
- Turbine costs falling as manufacturing scales
- Strong local manufacturing & jobs (India, EU, US)

Challenges

- High upfront capex: $1–5M per MW installed
- Intermittent output — CUF just ~18–25% onshore
- Grid bottlenecks, transmission delays, curtailment
- Land use, noise, and wildlife impact concerns

Key Players

INDIA

- Suzlon Energy — largest Indian OEM (~20 GW global base)
- Adani Wind — fast-scaling in-house turbine maker
- ReNew, Inox Wind, NTPC — leading project developers

GLOBAL

- Goldwind (China) — world's top supplier, 29+ GW in 2025
- Vestas (Denmark) — 200+ GW cumulative, most global reach
- Siemens Gamesa & GE Vernova — offshore & US leaders

India added a record 6.05 GW of wind capacity in FY26 — but reliability and grid-scale storage remain the sector's biggest test.

Sources: GWEC Global Wind Report 2026 · BloombergNEF Global Wind Turbine Market Shares 2025 · MNRE, Govt. of India · IRENA Renewable Statistics 2026

Grid Storage Capabilities

No single technology covers every timescale — the storage fleet is really a spectrum.

WHY IT MATTERS

2025 BUILD-OUT

108 GW

of new battery storage added worldwide in 2025 — up 40% from 2024.

LONG-DURATION RESERVE

200+ GW

of pumped-hydro capacity worldwide — still the largest multi-hour reserve.

Matching each technology to its timescale is what keeps a solar-heavy grid reliable.

Instant response for frequency regulation.
Seconds–Minutes
Flywheels & Supercapacitors

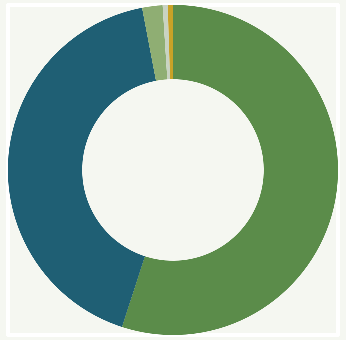
Lithium-ion and Sodium-ion Batteries
2–4 Hours
Today's workhorse for daily solar shifting.

Longer cycles with minimal capacity fade.
6–10 Hours
Flow Batteries

Pumped Hydro
8–12+ Hours
The largest source of multi-hour reserve.

Emerging option for multi-day, seasonal gaps.
Days–Weeks
Hydrogen & Thermal

MARKET SHARE
by installed capacity



- **Pumped Hydro — 55%**
- **Li/Na-ion Batteries — 42%**
- Flow, flywheel, H_2/thermal — ~3%

Sources: IEA, Global Energy Review 2026; International Hydropower Association, 2026 World Hydropower Outlook.

Storage Is Becoming the Grid's Center of Gravity

From a niche balancing tool to the hub connecting generation, transmission, and demand

112 GW added globally in 2025 — a record year (BNEF)

411 GWh India's storage need by 2032, vs <0.5 GWh live (CEA)

STORAGE

Renewables Integration

- FDRE tenders pair wind/solar with storage for firm, round-the-clock power
- India tendered 92 GWh of BESS in 2025 alone

Grid & Transmission

- Grid-forming inverters ease curtailment & frequency swings
- Storage-as-transmission defers costly new line builds

New Demand: EVs & Data Centers

- Global BESS installed capacity set to grow from 200 GWh (2025) to 1,200 GWh (2030) as data-center demand quadruples
- Virtual power plants now aggregate rooftop & EV batteries

Frontier Technology

- Long-duration (6+ hr) flow, thermal & CO_2 batteries scaling up
- Sodium-ion entering at scale (CATL-HyperStrong's 60 GWh deal)

Storage no longer just balances the grid — it's becoming the hub every other piece of the system plugs into.

Sources: IEA Global Energy Review 2026 · BloombergNEF Energy Storage Market Outlook 1H 2026 · CEA / MNRE, Govt. of India · Energy-Storage.News

BESS: Turning Intermittent Power into Firm Power

Battery Energy Storage Systems are batteries that store electricity smoothing out intermittency and providing grid stability.

HOW BESS SOLVE THE BALANCING PROBLEM

1. Charge
Soaks up surplus solar & wind that would otherwise be curtailed

→

2. Store
Holds energy for minutes to hours — 6+ hrs for long-duration systems

→

3. Discharge
Releases power during evening peaks and overnight demand

→

4. Stabilize
Delivers frequency regulation & grid-forming support

Without storage, solar's marginal grid value ≈ $0. Once demand is met, extra midday solar has nowhere to go and gets curtailed — BESS is what lets that power be used later instead of wasted.

WHO'S BUILDING IT

INDIA

Tata Power — utility-scale BESS pioneer (Rajasthan, 200 MWh)

Adani Energy Solutions — 1,126 MW / 3,530 MWh mega-BESS in Gujarat

JSW Energy × Fluence — 500 MWh JV across Karnataka & Maharashtra

GLOBAL

CATL (China) — world's largest battery & BESS cell maker

Tesla Energy (US) — Megapack utility storage, deployed worldwide

BYD (China) — vertically integrated LFP cells & BESS systems

Sources: BloombergNEF Energy Storage Market Outlook 1H 2026 · IEA Global Energy Review 2026 · CEA / MNRE, Govt. of India · Company disclosures (Tata Power, Adani, JSW Energy, CATL, Tesla)

VARANIUM

The Rest of the Renewable Toolkit

Each technology fills a gap solar and wind cannot — especially baseload and storage.

Hydro

~16% of global electricity

The original renewable. Pumped hydro = 90% of global energy storage — baseload + storage in one asset.

ĠÑŎPOÑǾÖMÕ

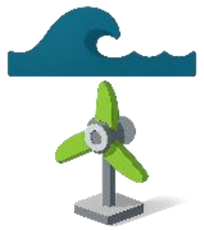
90%+ capacity factor

24/7 clean baseload, near-zero emissions, small footprint. Location-constrained — EGS may unlock new regions.

Bioenergy

Waste → power, heat, fuel

Versatile — biogas, ethanol, biodiesel from crop & municipal waste. Feedstock sustainability is the key risk.



Î ŃÑMŌ C İÒŇMÕ

~2 TW wave potential

Predictable tidal flows, untapped frontier. Oceans cover 71% of Earth. Commercial scale post-2035.

Nuclear / Small Module Reactor Reactor

<300 MW per SMR unit

Renewables' silent partner — zero-emission, always-on baseload. Traditional plants exceed 1,000 MW; SMRs are factory-built, under 300 MW, and deployable at smaller sites. Still pre-commercial in most markets, with the first units targeted for the early 2030s.

VARANIUM

Hydro

~16% of global electricity · India's oldest and largest renewable source

The original renewable. Hydropower uses flowing or falling water to spin turbines and pumped-storage variants double as grid-scale energy storage. Globally it still supplies more electricity than all other renewables combined, and in India it is the fifth-largest hydro market in the world with roughly 52 GW installed and 145,000 MW of theoretical potential and most of it undeveloped.

Benefits

- Mature, dispatchable baseload with decades of proven reliability
- Pumped-storage hydro doubles as large-scale energy storage
- Long asset life (60–100 years) and low operating cost once built
- Reservoirs support irrigation, flood control and drinking water

Challenges

- High upfront capital cost and long, complex construction timelines
- Output tied to monsoon rainfall — a forecast weak 2026 monsoon (~90% of normal) and already-low reservoirs could cut generation by up to 10% this fiscal year
- India's largest untapped potential (~60 GW) sits in ecologically fragile, seismically active Himalayan terrain
- Land acquisition, resettlement and environmental clearances slow projects

Companies in India

- **NHPC Ltd.** — India's largest pure-play hydro company; ~7 GW installed
- **SJVN Ltd.** — State-run developer with ~2 GW of hydro capacity
- **Tata Power** — Private player combining hydro with solar and wind
- **JSW Energy** — Expanding hydro and pumped-storage for grid balancing

Companies Outside India

- **China Three Gorges** — Builder/operator of the world's largest hydro plant
- **Andritz Hydro** — Austria-based turbine and equipment manufacturer
- **Voith Group** — German mechanical engineering leader in hyro gear
- **Hydro-Québec** — Canadian utility, one of the world's largest hydro operators

Sources: Wikipedia, "Hydroelectric power in India" | Ken Research, India Hydropower Market | Blackridge Research, Top Hydroelectric Plants in India (2026) | Verified Market Research, Top Hydropower Companies

Geothermal

90%+ capacity factor · India's most under-tapped baseload resource

Geothermal draws heat from the Earth's crust to generate steam that drives turbines or supplies heat directly for industry and agriculture. It runs 24/7 regardless of weather, with capacity factors above 80–90%. India has no major operational geothermal power plant yet, but a 2026 CEEW/Project InnerSpace study estimates ~450 GW of electricity-generation potential, and a first National Geothermal Policy (2025) now aims to unlock it.

Benefits

- True baseload — continuous power unaffected by weather or time of day
- Small land footprint compared with hydro or utility-scale solar
- Can reuse depleted oil & gas wells, easing capital cost and permitting
- Suited to remote/rural power and industrial heating and cooling

Challenges

- Exploration and drilling are capital-intensive and geologically risky
- Best Indian sites (Puga, Ladakh; Himalayan belt) are remote, high-altitude
- No dedicated commercial-scale plant yet — sector is still pilot-stage
- Limited domestic drilling expertise; potential land subsidence and gas leakage risk

Companies in India

- **Thermax —** Pilot project at Puga, Ladakh with Iceland's Reykjavík Geothermal
- **ONGC —** Exploring geothermal alongside its oil & gas well infrastructure
- **NTPC Renewable Energy —** Public-sector entrant evaluating geothermal sites
- **SEROS Energy / Nishra Energy —** Emerging exploration-stage private players

Companies Outside India

- **Ormat Technologies —** US-based global leader in geothermal plant technology
- **Fervo Energy —** US pioneer of enhanced geothermal systems (EGS)
- **Pertamina Geothermal —** Indonesian operator of 200+ MW geothermal projects
- **Chevron —** Oil major with large-scale geothermal operations in Asia

Sources: Discovery Alert, India's Geothermal Potential: A 450 GW Opportunity (May 2026) | Sanskriti IAS, Geothermal Energy in India | Cyril Amarchand Mangaldas, National Geothermal Energy Policy brief | Market Research Future, India Geothermal Energy Market

Bioenergy

Waste → power, heat, fuel · versatile and feedstock-driven

Bioenergy converts organic waste like crop residue, municipal solid waste, cattle dung, sugarcane press-mud into biogas, compressed bio-gas (CBG), ethanol and biodiesel via anaerobic digestion or fermentation. India's biogas market alone is valued near $1.8 billion in 2025 and is growing at over 10% a year, backed by government schemes like SATAT and the National Bioenergy Programme.

Benefits

- Turns agricultural and municipal waste into a revenue-generating fuel
- Versatile: powers vehicles (Bio-CNG), industrial boilers, and the grid
- Digestate by-product doubles as organic fertiliser, aiding farm incomes
- Strong policy support in India (SATAT, National Bioenergy Programme)

Challenges

- Feedstock supply is fragmented and seasonal — sustainability is the key risk
- High capital cost for collection logistics and plant infrastructure
- Feed variability (moisture, composition) can cause downtime and foaming
- Competes with fossil CNG/diesel on price without continued subsidy support

Companies in India

- **Praj Industries —** ~10% of global ethanol capacity; RenGas CBG technology
- **GAIL —** Building CBG plants via JVs with TruAlt Bioenergy, VERBIO India
- **EverEnviro —** Municipal solid-waste-to-Bio-CNG plant developer
- **Thermax —** Waste-to-energy and biomass solutions for industry

Companies Outside India

- **Engie —** French utility with a large biogas and biomethane portfolio
- **EnviTec Biogas —** German anaerobic digestion plant manufacturer
- **Wärtsilä —** Finnish supplier of biogas power generation systems
- **Ørsted —** Danish energy major converting plants to sustainable biomass

Sources: Fortune Business Insights, India Biogas Market | RK Windmast, Top 10 Biogas Companies in India | Moglix Business, Top Biofuel Manufacturing Companies in India (2026) | Mordor Intelligence, Biogas Market — Key Players

Ocean / Tidal

~2 TW wave potential · the untapped frontier

Ocean energy captures the predictable rise and fall of tides or the motion of surface waves using submerged turbines, barrages or wave converters. Oceans cover 71% of Earth's surface, and India's own 7,500 km coastline is estimated to hold roughly 12.5 GW of tidal and 40 GW of wave potential — but the technology remains pre-commercial, with most projects worldwide still in pilot or demonstration stage ahead of an expected commercial scale-up post-2035.

Benefits

- Highly predictable output — tidal cycles follow fixed lunar patterns
- Zero-emission generation with a long theoretical resource base
- India's long coastline offers largely untapped, geographically diverse sites
- Complements solar/wind intermittency; some designs enable desalination too

Challenges

- Still pre-commercial — very few grid-connected, revenue-generating plants
- High capital cost for underwater turbines, cabling and marine construction
- Harsh marine conditions raise maintenance cost and equipment wear
- Environmental concerns: barrages can disrupt tidal flow and marine ecosystems

Companies in India

- **BPCL —** MoU with Eco Wave Power for a Mumbai wave-energy pilot
- **RMC Green Energy —** New subsidiary targeting tidal & wave pilot projects
- **WaveGen Energy —** NITK-tested wave-to-electricity proof-of-concept
- **INCOIS —** Government body mapping India's ocean-energy atlas

Companies Outside India

- **Orbital Marine Power —** UK market leader; floating O2 tidal turbine
- **SIMEC Atlantis Energy —** Operator of large-scale tidal stream arrays
- **Eco Wave Power —** Israeli wave-energy technology developer
- **Minesto —** Swedish developer of underwater tidal energy "kites"

Sources: Grand View Research, Wave and Tidal Energy Market | IMARC Group, India Tidal Energy Solutions Market | GMI, Wave & Tidal Energy Market Size Report | EAI.in, Ocean Energy in India

Nuclear / Small Modular Reactor

<300 MW per SMR unit · renewables' silent, always-on partner

SMRs are compact, factory-built reactors under ~300 MW — a fraction of a traditional 1,000+ MW plant — that can be deployed at smaller, decentralised sites with shorter build times. India is developing three indigenous designs (BSMR-200, SMR-55, and a hydrogen-focused HTGR) under a ₹20,000-crore Nuclear Energy Mission, targeting 100 GW of nuclear capacity by 2047, with private industry now permitted to participate after 2025 legal reforms.

Benefits

- Zero-emission, always-on baseload — the ideal complement to solar and wind
- Factory-built, modular design cuts construction time versus large reactors
- Can be sited near industry (steel, refineries, railways) for captive power
- Reuses "brownfield" retiring coal-plant sites, grid links and cooling water

Challenges

- Still pre-commercial in most markets; first Indian units targeted early 2030s
- High regulatory, safety and liability hurdles — India only opened private entry in 2025
- Requires enriched uranium supply chain and specialised manufacturing
- Public perception and long-term waste management remain unresolved concerns

Companies in India

- **NPCIL / BARC —** Designing India's BSMR-200, SMR-55 and HTGR reactors
- **Tata Power, Adani Power —** Among 6 private bidders for Bharat Small Reactors
- **L&T, BHEL —** Manufacturing partners for reactor components
- **NTPC —** Planning SMRs to replace retiring coal capacity

Companies Outside India

- **NuScale Power —** US-based, first SMR design with NRC certification
- **Rolls-Royce SMR —** UK reactor developer backed by government funding
- **GE Hitachi —** BWRX-300 SMR design being built in Canada and the US
- **Rosatom —** Russian state firm with operating floating SMRs

Sources: World Nuclear News, Maharashtra and AP proposed for first Indian SMRs | ORF, Big Aspirations for Small Modular Reactors (2026) | MP-IDSA, Small Modular Reactors and India | Indian Chemical News, India pushes ahead with SMRs (March 2026)

Generation IV Nuclear: The Next Reactor Wave

Six reactor families move beyond today's light-water plants toward higher efficiency, passive safety, and uses far beyond the grid.

SIX GEN IV REACTOR FAMILIES

SFR
Sodium-Cooled Fast

Breeds fuel from spent uranium — India's 500 MWe PFBR

VHTR
Very-High-Temp Gas

Runs to 950°C — best suited to hydrogen production

MSR
Molten Salt

Liquid fuel, walk-away-safe; can run on thorium

GFR
Gas-Cooled Fast

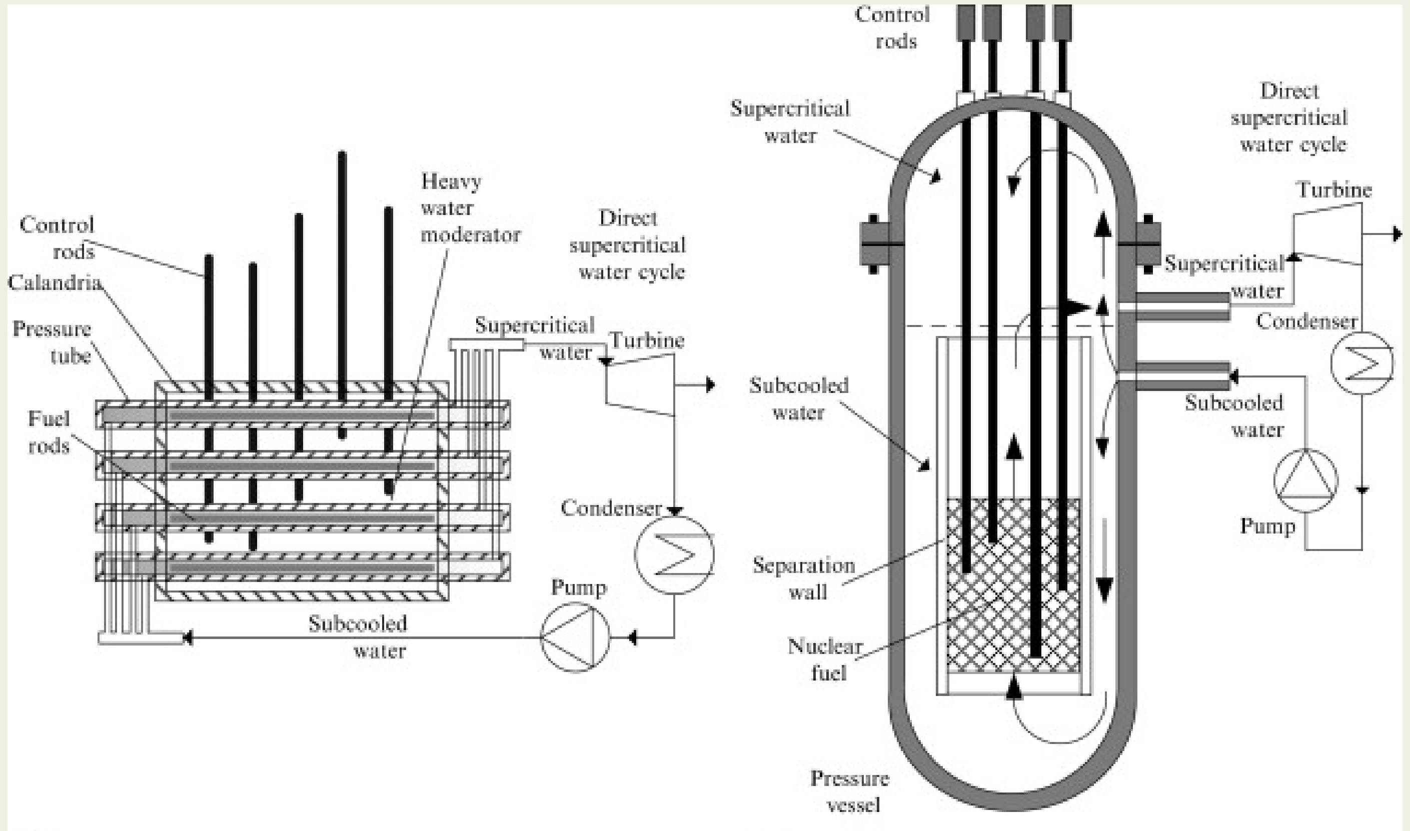
Helium-cooled, higher thermal efficiency

LFR
Lead-Cooled Fast

Compact core, 10-15 year refuelling intervals

SCWR
Supercritical Water

Simplified design, higher efficiency than PWRs



BEYOND ELECTRICITY: WHERE GEN IV HEAT GOES

Grid Electricity
Baseload power

Green Hydrogen
High-temp electrolysis

Industrial Heat
Steel & refining

Desalination
Coastal freshwater

INDIA'S FIRST BREEDER REACTOR

PFBR at Kalpakkam reached first criticality on April 6, 2026 — India's first operational fast breeder reactor, designed by IGCAR and built by BHAVINI. Sodium-cooled and MOX-fueled, it breeds Plutonium-239 from Uranium-238, marking India's entry into stage two of its three-stage nuclear program. Commercial power is targeted for around September 2026.

INDIA'S GEN IV PATH

Apr 2026
500 MWe PFBR (SFR) reaches first criticality at Kalpakkam

5 SMRs
Targeted operational by 2033 across 3 indigenous BARC designs

100 GW
National nuclear capacity target by 2047

Sources: World Nuclear Association; World Nuclear News; Dept. of Atomic Energy / BARC (2026 data).

VARANIUM

Gen IV Reactor Families, Explained

What sets each of the six families apart — coolant, fuel, operating temperature, and how close it is to running today.

SFR
Sodium-Cooled Fast
Coolant: liquid sodium · ~550°C · MOX/metal fuel, breeds Pu-239 from U-238
Most mature Gen IV line. India's 500 MWe PFBR reached first criticality Apr 2026; China's CFR-600 and Russia's BN-800/1200 already run.

VHTR
Very-High-Temp Gas
Coolant: helium · 750–950°C · TRISO particle fuel
China's HTR-PM (210 MWe pebble-bed) has run commercially at Shidao Bay since late 2023 — the only Gen IV design at grid scale today.

MSR
Molten Salt
Coolant: molten fluoride/chloride salt · 600–700°C · liquid fuel, can run on thorium
Walk-away safe — fuel drains to a passively cooled tank if power is lost. Kairos Power and TerraPower lead in the West.

GFR
Gas-Cooled Fast
Coolant: helium · 850°C · fast-spectrum ceramic/composite fuel
Higher thermal efficiency than thermal-spectrum designs. Europe's Allegro demonstrator remains in design, targeting the 2030s.

LFR
Lead-Cooled Fast
Coolant: molten lead/lead-bismuth · ~550°C · nitride uranium-plutonium fuel
Compact core, 10–15 yr refuelling intervals. Russia's BREST-300 is under construction at Seversk, targeting 2026 startup.

SCWR
Supercritical Water
Coolant: supercritical water (>374°C, >22 MPa) · ~625°C · standard UO2 fuel
Closest lineage to today's light-water reactors, no steam generator needed. Still at R&D/concept stage worldwide.

VALAR ATOMICS: FIRST US ELECTRICITY FROM A NEXT-GEN REACTOR

Valar Atomics' Ward 250 reactor (a helium-cooled VHTR variant) reached first criticality in June 2026 at its Utah test site. In a July 2026 demonstration it generated real electricity to power an Nvidia Blackwell AI chip — the first time a US next-gen reactor has produced power outside a national lab. Output was small and the design targets off-grid buyers (data centers, industrial heat) rather than the utility grid; commercial scale-up to a 5 MWe unit is still years out.

Sources: World Nuclear Association; World Nuclear News; TechCrunch; Bloomberg; Utah San Rafael Energy Lab

RENEWABLE ENERGY · RISKS

Risks Nobody Talks About

Risk management is alpha — investors who model these outperform those who don't.

CRITICAL

Grid Congestion

Renewables get built faster than grid capacity. Generators sit waiting years to connect.

CRITICAL

Curtailment

Operators switch off solar output when supply exceeds demand — revenue is simply lost. Growing in Tamil Nadu, Rajasthan.

HIGH

Policy Risk

Subsidy roll-backs, permitting delays and election-cycle reversals destroy IRRs. DISCOM financial health is a critical India-specific risk.

EMERGING

Recycling Gap

25M tonnes of solar panels retire by 2050 — with no at-scale recycling ecosystem yet. A pending regulatory burden.

SECTION 03

Future of Mobility

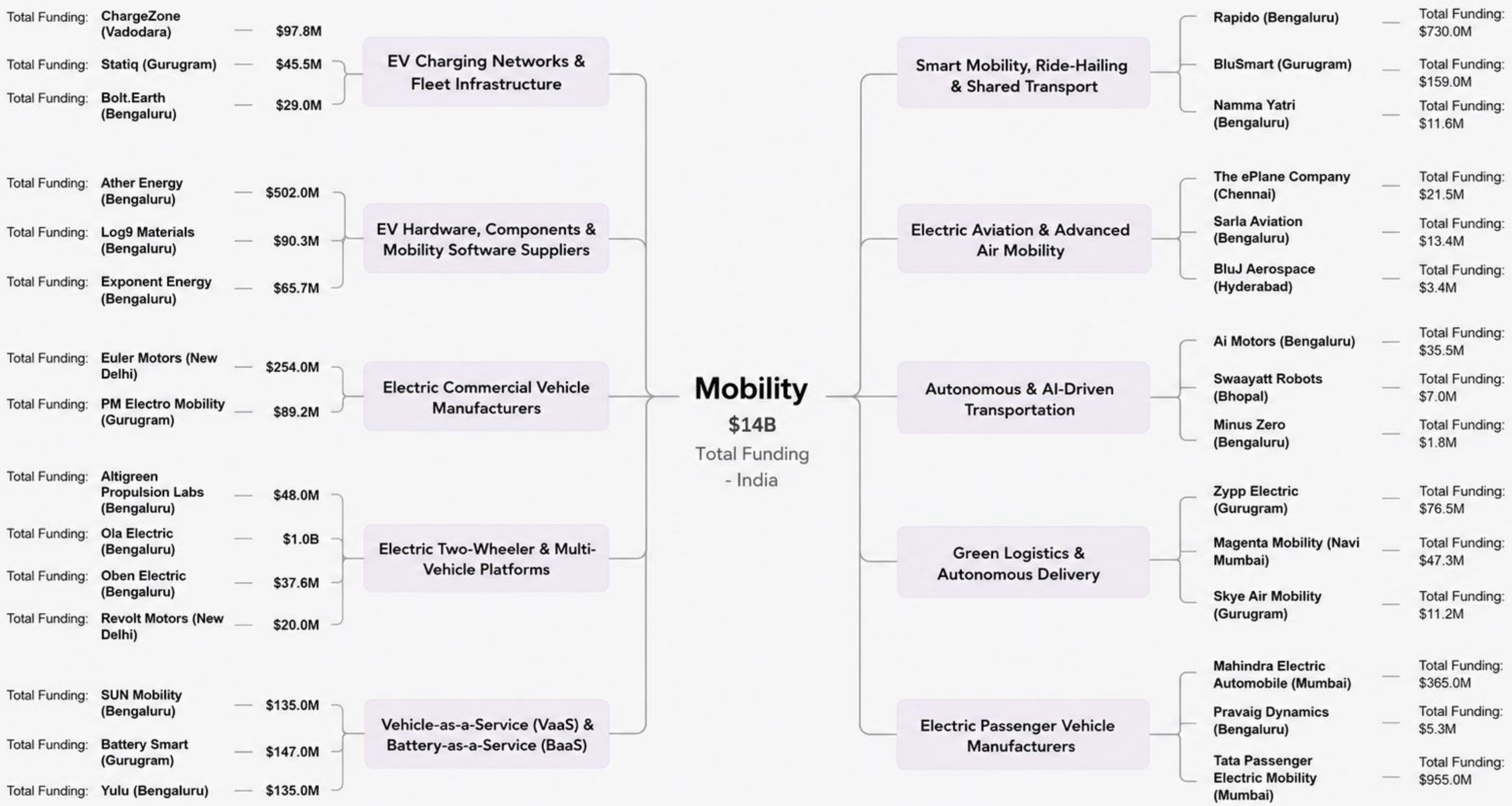
Battery technology, EV economics, and India's electrification inflection point.

VARANIUM

Mobility

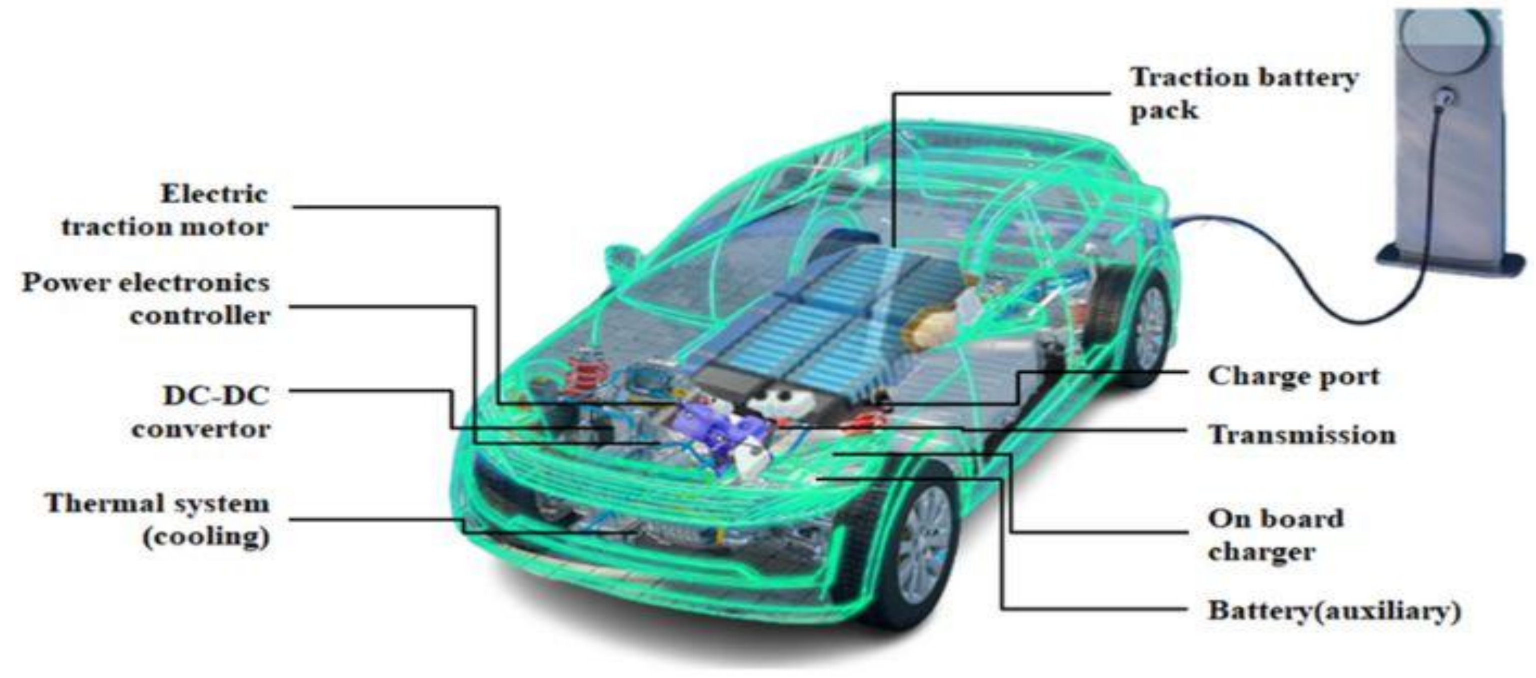
$130B
(Total funding)

- **EV charging networks & fleet infrastructure**
  - IONITY (Germany): $1.20B
  - Statiq (India): $45.5M
  - SparkCharge (USA): $50.7M
- **EV hardware, components & mobility software suppliers**
  - Aurora Innovation (USA): $2.20B
  - A123 Systems (USA): $1.68B
  - Luminar (USA): $932.0M
- **Electric commercial vehicle manufacturers**
  - Hyzon Motors (USA): $400.0M
  - Einride (Sweden): $654.0M
  - DeepWay (China): $400.0M+
- **Electric two-wheeler & multi-vehicle platforms**
  - Ola Electric (India): $1.00B
  - Segway-Ninebot (China): $1.02B
  - Oben Electric (India): $37.6M
- **Vehicle-as-a-Service (VaaS) & Battery-as-a-Service (BaaS)**
  - Gogoro (Taiwan): $765.0M
  - SUN Mobility (India): $220.0M
  - Yulu / Battery Smart (India): ~$147.0M
- **Smart mobility, ride-hailing & shared transport**
  - Revel (USA): $126.0M
  - Cabify (Spain): $477.0M
  - Tier Mobility (Germany): $660.0M
- **Electric aviation & advanced air mobility**
  - Joby Aviation (USA): $690.0M
  - Beta Technologies (USA): $1.30B
  - EHang (China): $100.0M+
- **Autonomous & AI-driven transportation**
  - Waymo (USA): $11.0B+
  - Cruise (USA): $15.0B+
  - Nuro (USA): $2.20B
- **Green logistics & autonomous delivery**
  - Zipline (USA): $821.0M
  - Starship Technologies (Estonia): $230.0M
  - Gatik (USA): $370.0M
- **Electric passenger vehicle manufacturers**
  - Polestar (Sweden): $1.60B
  - Rivian (USA): $10.70B
  - Aptera Motors (USA): $100.0M+


Mobility
$14B
Total Funding - India
EV Charging Networks & Fleet Infrastructure
Total Funding: ChargeZone (Vadodara) — $97.8M
Total Funding: Statiq (Gurugram) — $45.5M
Total Funding: Bolt.Earth (Bengaluru) — $29.0M
EV Hardware, Components & Mobility Software Suppliers
Total Funding: Ather Energy (Bengaluru) — $502.0M
Total Funding: Log9 Materials (Bengaluru) — $90.3M
Total Funding: Exponent Energy (Bengaluru) — $65.7M
Electric Commercial Vehicle Manufacturers
Total Funding: Euler Motors (New Delhi) — $254.0M
Total Funding: PM Electro Mobility (Gurugram) — $89.2M
Electric Two-Wheeler & Multi-Vehicle Platforms
Total Funding: Altigreen Propulsion Labs (Bengaluru) — $48.0M
Total Funding: Ola Electric (Bengaluru) — $1.0B
Total Funding: Oben Electric (Bengaluru) — $37.6M
Total Funding: Revolt Motors (New Delhi) — $20.0M
Vehicle-as-a-Service (VaaS) & Battery-as-a-Service (BaaS)
Total Funding: SUN Mobility (Bengaluru) — $135.0M
Total Funding: Battery Smart (Gurugram) — $147.0M
Total Funding: Yulu (Bengaluru) — $135.0M
Smart Mobility, Ride-Hailing & Shared Transport
Rapido (Bengaluru) — Total Funding: $730.0M
BluSmart (Gurugram) — Total Funding: $159.0M
Namma Yatri (Bengaluru) — Total Funding: $11.6M
Electric Aviation & Advanced Air Mobility
The ePlane Company (Chennai) — Total Funding: $21.5M
Sarla Aviation (Bengaluru) — Total Funding: $13.4M
BluJ Aerospace (Hyderabad) — Total Funding: $3.4M
Autonomous & AI-Driven Transportation
Ai Motors (Bengaluru) — Total Funding: $35.5M
Swaayatt Robots (Bhopal) — Total Funding: $7.0M
Minus Zero (Bengaluru) — Total Funding: $1.8M
Green Logistics & Autonomous Delivery
Zypp Electric (Gurugram) — Total Funding: $76.5M
Magenta Mobility (Navi Mumbai) — Total Funding: $47.3M
Skye Air Mobility (Gurugram) — Total Funding: $11.2M
Electric Passenger Vehicle Manufacturers
Mahindra Electric Automobile (Mumbai) — Total Funding: $365.0M
Pravaig Dynamics (Bengaluru) — Total Funding: $5.3M
Tata Passenger Electric Mobility (Mumbai) — Total Funding: $955.0M

Anatomy of an EV — Components & Cost Breakdown

Nine core systems replace the internal combustion drivetrain — the battery pack alone is over a third of total vehicle cost.



SHARE OF TOTAL EV COST BY COMPONENT

Component	What it does	Cost share
Traction battery pack	Stores electricity that powers the traction motor	~35%
Electric traction motor	Drives the wheels using power from the battery	~6%
Power electronics controller	Manages energy flow; sets motor speed & torque	~5%
Thermal system (cooling)	Keeps battery, motor & electronics in temperature range	~3%
Transmission	Transfers motor output to the wheels	~2%
Onboard charger	Converts incoming AC to DC to charge the battery	~2%
DC/DC converter	Steps battery voltage down to run accessories	~1%
Charge port	Connection point for external power supply	~1%
Auxiliary battery	Powers vehicle accessories & electronics	~0.5%
Body, chassis, interior & assembly	Non-drivetrain structure and finishing	~44%

Sources: U.S. DOE Alternative Fuels Data Center, "How Do All-Electric Cars Work?" (component definitions); McKinsey & Company, "The future of affordable EVs" (2026); Thunder Said Energy, EV cost breakdown by component; ICCT, "Update on Electric Vehicle Costs in the United States Through 2030". Cost shares are illustrative industry estimates for a typical mid-size BEV, not a specific model.

ICE vs EV: India's Vehicle Mix

EV penetration is climbing fastest in three-wheelers, while cars and commercial fleets are just getting started.

NATIONAL EV PENETRATION

8.07%

of all vehicles sold in CY2025

3-YEAR TREND

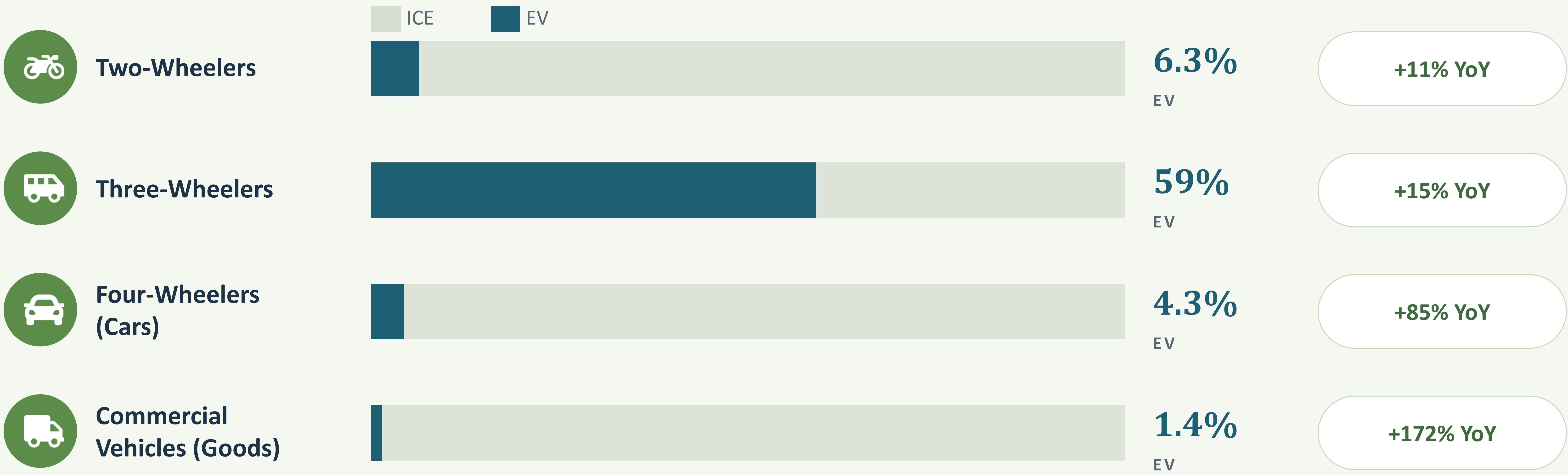
6.38% → 7.47% → 8.07%

CY2023 CY2024 CY2025

TOTAL EV SALES

2.27M units

sold in CY2025 — up 16% YoY



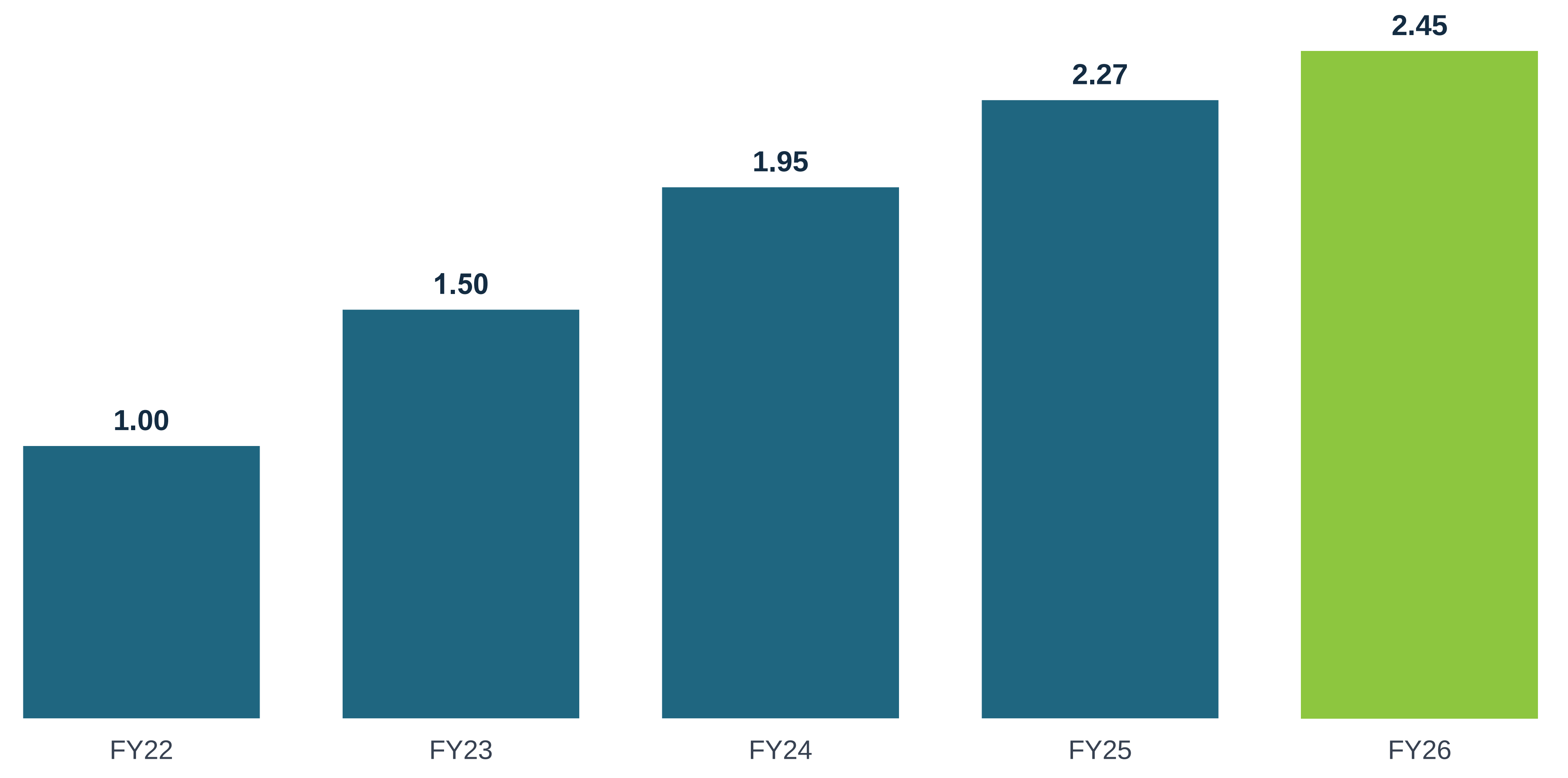
Sources: JMK Research & Analytics; Autocar Professional; EVreporter (CY2025 data).

India — A Market at Its Inflection Point

Annual EV sales reaching 2.45M units in FY26, up from 2.27M in FY25 — racing toward the 30%-by-2030 target.

INDIA ANNUAL EV SALES (MILLION UNITS)

Source: Vahan / IESA / EVreporter, FY basis (Apr–Mar)



↓93%

Battery cost decline since 2010 — packs now ~$105–108/kWh

₹100+/L

Petrol near ₹100/L in most metros — fast EV payback, especially commercial

PM E-DRIVE

FAME, PLI for cells & state EV policies all aligned

30%

Target EV share of new sales by 2030 (EV30@2030)

Sources: Vahan Dashboard via EVreporter (FY26 data, June 2026); Autocar Professional, “EV sales in India surpass 2.45 million units in FY2026” (April 2026).

VARANIUM

The Economics Pulling Delivery Fleets Electric

Lower tax, lower running cost, and a rental model built for gig riders are driving e-2W adoption in last-mile delivery.

EV vs. PETROL 2W — TAX, TOLL, RUNNING COST & DEPRECIATION

Parameter	Electric 2W	Petrol 2W
GST rate	5%	18% (≤350cc) / 40% (>350cc)
Road tax / registration	Exempt in most states	₹3,500–₹9,000 payable
Running cost / km	₹0.15–₹0.20	₹2.0–₹2.5 (~10x higher)
Annual maintenance	₹1,000–₹2,000	₹5,000–₹8,000
Depreciation (business use)	40% accelerated, Yr 1 (Sec 32, IT Act)	15% standard (Sec 32, WDV)
Toll (highways)	2Ws exempt nationally; BEV 4W/fleet toll waivers in select states (e.g. Maharashtra)	2Ws exempt nationally; standard toll for 4W

~10x

Lower running cost per km for e-2W vs petrol

5% vs 40%

GST on EVs vs. large-capacity petrol bikes post GST 2.0 reform

₹0 + 40%

Registration fee waived, plus 40% accelerated depreciation for corporate & fleet buyers in Yr 1 (Sec 32, IT Act) — vs 15% for petrol fleets

LAST-MILE DELIVERY — E-2W SUBSCRIPTION PLAYERS REPLACING PETROL BIKES

Hala Mobility

Hyderabad-led

E-2W rental & E-MaaS platform for gig riders; battery swap, service and charging network bundled in.

VoltUp

15 cities

Flexible weekly/monthly e-2W rental with 30-sec battery swaps; 280+ swap stations, zero maintenance for riders.

Ryde (Electric Ryde)

App-based

QR-unlock shared e-scooter rentals; per-trip/hourly access model for short-hop urban delivery and mobility.

Sources: Razorpay & Angel One (GST on two-wheelers, 2026); Ride N Repair, Electric vs Petrol Bike Cost Comparison (2026); NHAI/MoRTH FASTag rules; Maharashtra EV Policy 2025 (MSRDC toll exemption); Section 32, Income Tax Act, 1961 (accelerated depreciation for EVs); Hala Mobility, VoltUp, Ryde — company websites.

What Drives the EV Purchase Decision?

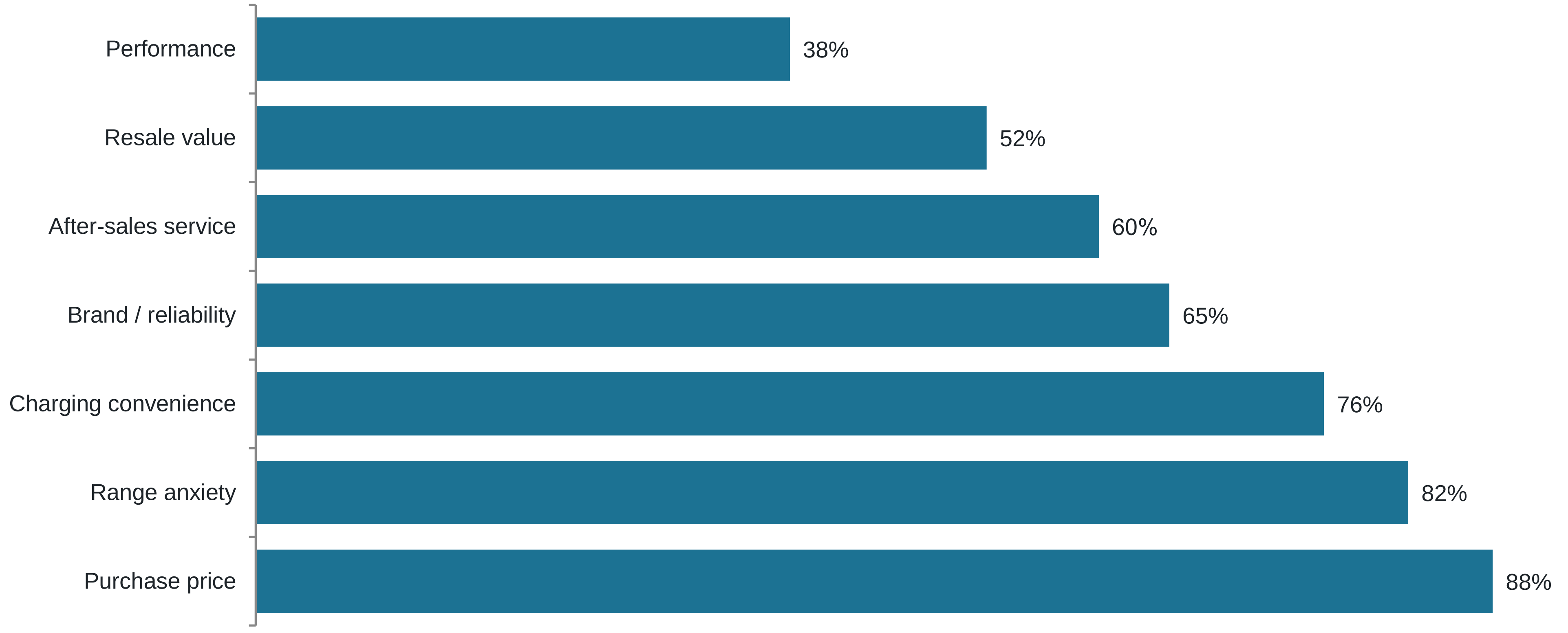
Price leads every survey — and India's scaling EV market means the winners will be those who solve the battery-cost equation.

88%
of buyers cite upfront purchase price as the #1 barrier to EV adoption

2.27M
EVs sold in India in 2025 — ~8% of new registrations

$200B
India EV opportunity by 2030 (NITI Aayog)

% CITING AS A KEY FACTOR IN THE EV PURCHASE DECISION



BATTERY PACK PRICES, GLOBAL AVG.

$108/kWh ▼ 22% since 2023

$139 → $115 → $108 /kWh (2023–2025, BNEF)

Falling packs are compressing sticker price faster than any subsidy.

MITIGANTS EASING RANGE ANXIETY

- Fast charging: 10–80% in ~15–20 minutes now
- Charging network: India crosses 29,000+ points
- Longer range: EVs now average 300–400 km/charge
- Battery swapping: sub-5-min swaps scaling fast

Sources: BloombergNEF, 2025 Lithium-Ion Battery Price Survey (Dec 2025); Ministry of Power / government EV charging data (Dec 2025); NITI Aayog.

VARANIUM

The Battery Evolution — Lead-Acid to Graphene

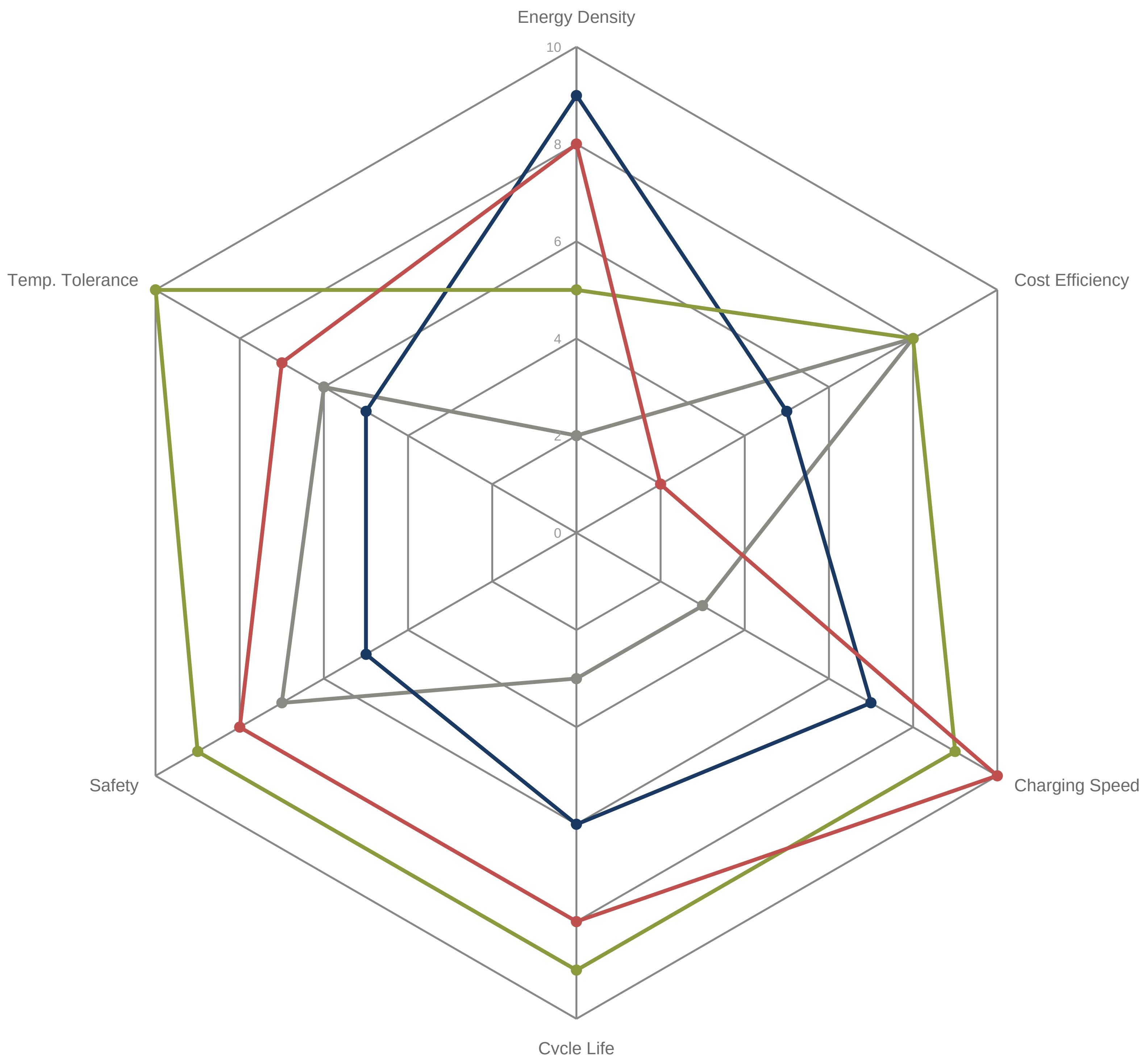
Five generations of chemistry, each optimized for a different segment of the mobility stack

	Lead-Acid	Li-ion NMC/NCA	Sodium-ion	Multi-ion Batteries	Graphene
Timeline	1859	1991	2023–25	2025–27	Emerging
Stage	*Commercialized 1859*	*Commercialized 1991*	*Commercial launch 2023–25*	*Pilot production 2025–27*	*R&D / early-stage commercial*
OUTPUT (ENERGY DENSITY)	30–50 Wh/kg	150–300 Wh/kg	100–175 Wh/kg	150–350 Wh/kg (chemistry-dependent)	250–400+ Wh/kg (claimed)
COST	$70–100 / kWh	$115–140 / kWh	$46–77 / kWh (cell)	$60–120 / kWh (projected, pre-scale)	$180–280 / kWh (2026 est.)
PREFERRED FOR	Auto SLI, UPS & telecom backup, low-cost stationary	Long-range EVs, premium 4W, e-buses, electronics	Grid & stationary storage, cold climates, low-cost 2W/3W	Multivalent (Mg, Zn, Al-ion) chemistries for safer grid & low-cost storage	Ultra-fast charging, drones, next-gen premium EVs
KEY PLAYERS — GLOBAL	Clarios (US), EnerSys (US), GS Yuasa (Japan)	CATL (China), LG Energy Solution (South Korea), Panasonic (Japan), Samsung SDI (South Korea)	CATL (Naxtra) (China), BYD (China), HiNa Battery (China), Natron Energy (US)	TeraWatt Technology (US), Zinc8 Energy Solutions (Canada), Enerpoly (Sweden)	Nanotech Energy (US), Real Graphene (US), NAWA Technologies (France)
KEY PLAYERS — INDIA	Exide Industries, Amara Raja, Luminous	Amara Raja (Giga Corp), Exide Energy Solutions, Tata Agratas, Ola Electric	Reliance–Faradion, Log9 Materials	Log9 Materials (multi-ion R&D)	Log9 Materials (graphene-enhanced R&D)

Sources: BloombergNEF 2025 Lithium-Ion Battery Price Survey; CellEst 3.0 process-cost model (ScienceDirect, 2025) & IRENA sodium-ion cost outlook; DOE Energy Storage Technology & Cost Characterization report (lead-acid); company disclosures (Exide Industries, Amara Raja, Log9 Materials, Reliance–Faradion); multivalent-ion materials-cost review (MDPI, 2025) & TeraWatt Technology disclosures; IndexBox Graphene Battery Market report (2026).

The Spiderweb View — Comparing Battery Chemistries

Relative performance across six dimensions (1=weakest, 10=strongest); illustrative scoring based on published specs



Lead-Acid

Mature, safe, cheap — low energy density

Li-ion (NMC/NCA)

Best energy density — the current EV standard

Sodium-ion

Strong all-rounder — cost, safety & temperature range

Graphene

Emerging — fastest charging, unproven at scale

GRAPHENE — EMERGING TECHNOLOGY

Claimed specs (250–400+ Wh/kg, sub-5-min charging) come from lab and pilot-scale data. Graphene packs are not yet mass-produced or cost-competitive — $250–400+/kWh today versus $108/kWh for standard Li-ion. Best viewed as a 3–5 year watch item, not a near-term allocation.

Sources: BloombergNEF 2025 Battery Price Survey; CATL Naxtra & IRENA sodium-ion technical briefings; Log9 Materials & IMARC Group graphene battery disclosures (2025). Scores are illustrative, directional comparisons — not a formal benchmark study.

Beyond Lithium-Ion: What's Next for EVs

Solid-state cells, proton batteries, and hydrogen power are moving from lab prototypes toward commercial fleets.

SOLID-STATE ENERGY DENSITY TARGET	PROTON BATTERY DENSITY (RMIT)	INDIA GREEN HYDROGEN TARGET
400–500 Wh/kg	**245 Wh/kg**	**5M tonnes/yr**
vs 150–240 Wh/kg for today's Li-ion cells	rivals a Tesla Model 3 pack, built from carbon not lithium	National Green Hydrogen Mission goal for 2030

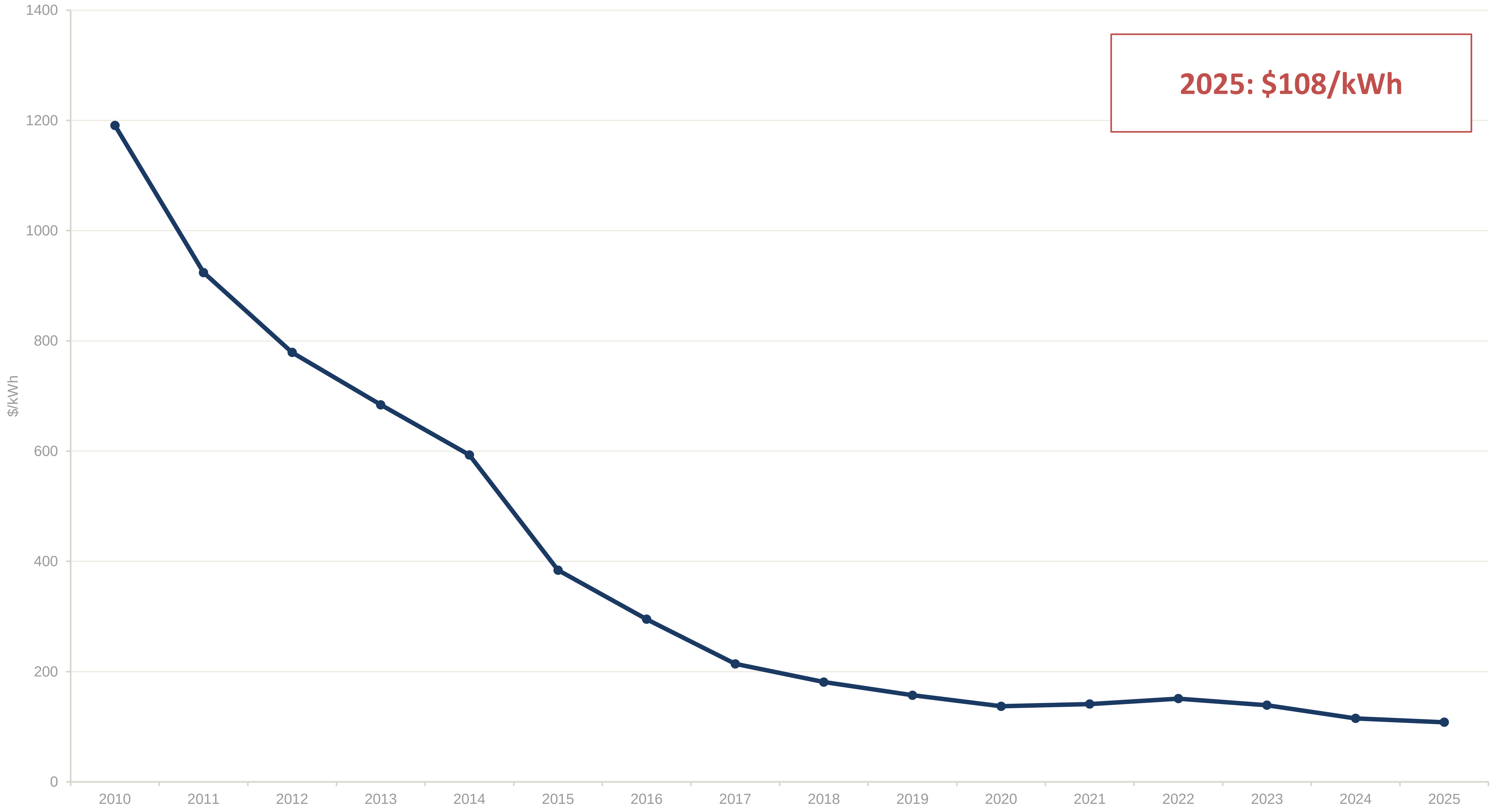
Solid-State Batteries	Toyota, BYD, and CATL are targeting small-scale production by 2027–2028, with true solid electrolytes promising higher range and faster charging.	Mass production ~2030
Proton Batteries	RMIT's carbon-electrode design splits water to store hydrogen directly, using cheap, abundant carbon instead of lithium or cobalt.	~5–10 yrs to market
Hydrogen Cars (FCEVs)	Toyota Mirai units are on pilot trials with ICAT on Indian roads; no fuel-cell car is commercially on sale in India yet.	Pilot phase
Hydrogen Trucks & Buses	Tata Motors is trialing 16 H2-ICE and fuel-cell trucks on Mumbai, Pune, and Delhi-NCR and other freight corridors under the National Green Hydrogen Mission.	24-month trial underway

Note: Experimental technologies often take longer to become real world relevant from predicted timelines

Sources: RMIT University; Tata Motors; Toyota Motor Corp. FY2026 20-F; Interact Analysis; BatteryTechOnline (2026 data).

Battery Prices Have Fallen 91% Since 2010

Lithium-ion pack prices, global volume-weighted average ($/kWh, nominal)



Lower battery prices are the single biggest driver making electric vehicles economically superior to internal combustion vehicles.

91%

cumulative decline in pack prices since 2010 (BNEF)

$70

per kWh for stationary storage — now the cheapest segment

Sources: BloombergNEF 2025 Lithium-Ion Battery Price Survey (Dec 2025); BloombergNEF 2024 Battery Price Survey (Dec 2024); BloombergNEF historical battery price series, 2010–2023.

VARANIUM

The Battery Value Chain

Where the cost of a lithium-ion EV pack actually goes — and who leads at each stage

SHARE OF FINAL PACK COST BY STAGE

STEP 1

Lithium & Material Refining

Lithium, nickel, cobalt & graphite refined into battery-grade cathode/anode material

GLOBAL

Albemarle (US), SQM (Chile), Ganfeng Lithium (China), Tianqi Lithium (China)

INDIA

KABIL, Vedanta, IREL — domestic refining still nascent

STEP 2

Cell Manufacturing

Formats: cylindrical (18650/21700/4680), prismatic & pouch

GLOBAL

CATL (China), LG Energy Solution (South Korea), Panasonic (Japan), Samsung SDI (South Korea), BYD (China)

INDIA

Tata Agratas, Exide Energy Solutions, Amara Raja ACT, Ola Electric

STEP 3

Pack Assembly

Cells into modules, housing, thermal & wiring integration

GLOBAL

Tesla (US), LG Energy Solution (South Korea), Samsung SDI (South Korea), Bosch (Germany)

INDIA

Mahindra Electric, Tata AutoComp, Exponent Energy, Log9

STEP 4

BMS & Integration

Monitors cell voltage, temp & health; manages charge/discharge safety

GLOBAL

Bosch (Germany), Sensata Technologies (US), Texas Instruments (US), Analog Devices (US)

INDIA

Vecmocon Technologies, Exicom, Log9 Materials

Sources: Argonne National Laboratory, BatPaC EV Battery Cost Model, GPRA 2025 report (pack cost breakdown); BloombergNEF 2025 Lithium-Ion Battery Price Survey; company disclosures (Tata Agratas, Exide Energy Solutions, Amara Raja, Log9 Materials, Vecmocon).

VARANIUM

Four Motor Types, Four Trade-offs

The motor + controller is the second most expensive system after the battery. Choice of architecture drives cost, efficiency, durability — and who supplies and buys it in India.

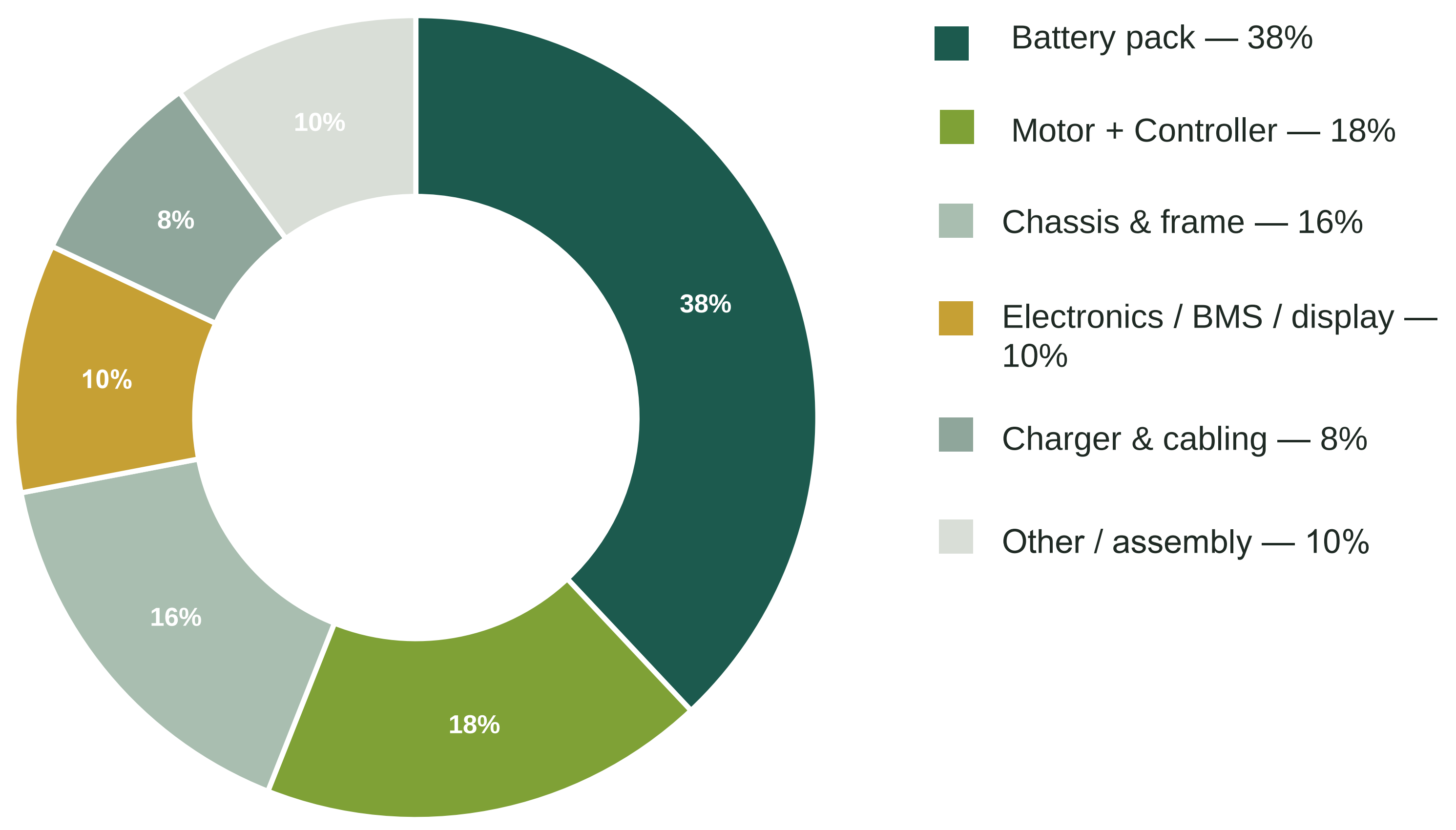
MOTOR	HOW IT WORKS	PROS	CONS	MAKERS IN INDIA	USERS IN INDIA
BLDC Brushless DC	Permanent-magnet rotor, electronically commutated; hub or mid-drive mount	Simple & rugged; low maintenance; hub form doubles as the wheel; cheapest at scale	Lower efficiency at high speed; hub-mount adds unsprung weight; coarser torque control	Sona Comstar · Bosch/SEG · Varroc (legacy) · Sterling Gtake · EMF Innovations · Napino · Tork Motors · DOL Mobility · Elecnovo	Hero Electric · Okinawa · Ampere (Greaves) · Kinetic Green · Bounce · Pure EV · most e-rickshaws & entry 2W/3W fleets
PMSM Permanent Magnet Sync.	Sinusoidal AC drive, field-oriented control, rare-earth magnets	Best power/torque density; 93–95%+ efficiency; strong low-speed torque, smooth pickup	Rare-earth magnet cost & supply risk; needs a more complex FOC controller; priciest option	Bosch · Flash Electronics · Sona Comstar · Varroc (current focus) · Sterling Gtake	Ather (450X/Rizta) · Ola Electric (S1 Pro, mid-drive IPM) · TVS iQube (top variants) · Hero Vida V1 Pro · Tata Nexon/Tiago EV · Honda Activa e
IM Induction (ACIM)	Rotor current induced by rotating stator field; no permanent magnets	No rare-earth exposure — stable cost; rugged, handles overload well; proven at scale (early Tesla)	Lower efficiency at low speed/partial load; heavier for same output; more complex control	Jayem Automotives · Sterling Gtake (induction line) · custom-motor houses (VINURUK, Aatrael)	Legacy Mahindra e2o · some early Tata EV prototypes · niche industrial/fleet conversions
SRM Switched Reluctance	Reluctance torque from switched stator poles; no magnets, no rotor windings	Lowest material cost — no magnets/rotor windings; simple, robust, high fault tolerance	Torque ripple & noise need sophisticated control; lower power factor; still maturing for EVs	Quanteon Powertrain (IIT-Delhi incubated, prototyping) · scattered R&D-stage players	No mass-market Indian EV yet — confined to pilot/prototype fleets and academic test rigs

Source: EVreporter, "Top EV Powertrain Component Manufacturers in India"; company websites; Autonexa, PsPowers, Electrical India coverage of Indian EV motor market. Company/model lists are illustrative, not exhaustive.

Where the Money Goes

Indicative bill-of-materials share for an e-2W and an e-4W, and how each splits across its cost lines.

E-2W BILL OF MATERIALS (INDICATIVE SHARE OF COST)



The battery pack alone is more than double the next-biggest line item. At 38% of BOM, cell and pack costs are the single biggest lever for bringing e-2W prices down further — motor/controller (18%) and chassis (16%) are already fairly commoditized, and electronics, charging hardware and assembly together add up to the remaining ~28%.

.

Source: Thunder Said Energy, EV cost-breakdown analysis; ICCT, E2W cost study (India); McKinsey, e-2W and e-4W BOM commentary; general EV powertrain-cost literature. Figures are illustrative and vary by OEM, vehicle architecture and scale.

VARANIUM

Magnets and the Rare Earth Chokepoint

NdFeB magnets power almost every EV traction motor — and one country controls nearly all of the value chain behind them.

NdFeB Neodymium-Iron-Boron

~96% of global magnet demand — the default EV traction-motor magnet

Strength: highest energy density · Rare earth elements need: high (Nd, Pr + Dy/Tb for heat)

Makers: JL Mag, Zhong Ke San Huan, Ningbo Yunsheng (China) · Vacuumschmelze (Germany) · Hitachi Metals/Proterial, Shin-Etsu (Japan) · IREL, Lohum (India, emerging)

SmCo Samarium-Cobalt

Stable to 350°C — used where NdFeB would demagnetize

Strength: strong, slightly below NdFeB · Rare earth elements need: samarium only, no Dy/Tb

Makers: Electron Energy Corp (US) · Vacuumschmelze (Germany) · Hitachi Metals (Japan)

Ferrite Ceramic / Strontium Ferrite

The rare-earth-free fallback for cost-sensitive motors

Strength: much lower energy density · Rare earth elements need: none

Makers: TDK, Hitachi Metals, Ningbo Yunsheng · Bunting Magnetics (US)

THE GLOBAL CHOKEPOINT — CHINA'S SHARE OF THE VALUE CHAIN

~65% of global rare-earth mining

~90% of global refining / separation capacity

90%+ of global rare-earth magnet manufacturing

INDIA'S EXPOSURE

93% of India's rare-earth magnets imported from China, FY24–25

2–3 wks stockpile buffer industry held when China tightened export licensing, Apr 2025

INDIA'S RESPONSE

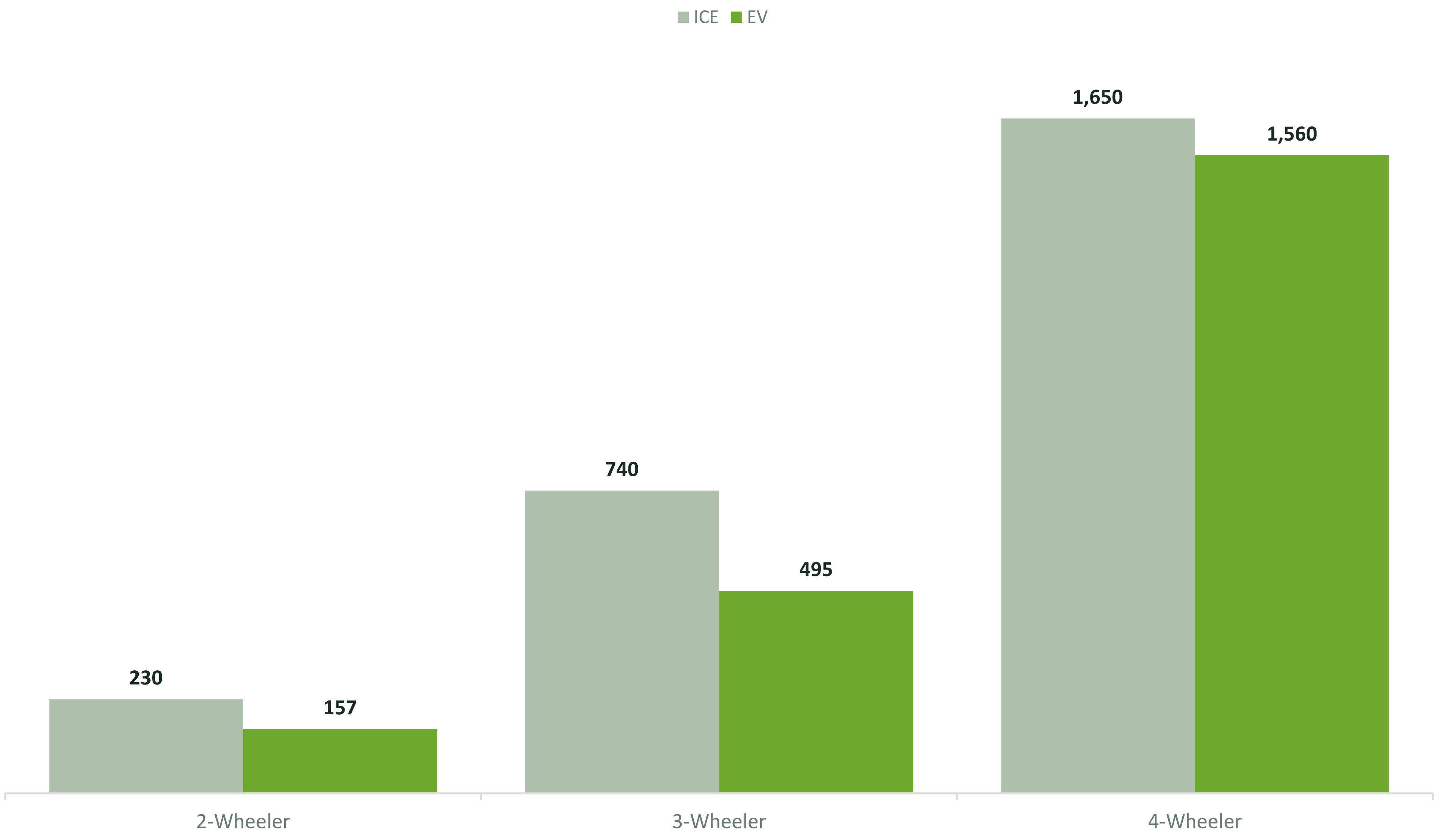
Apr 2025	China tightens export licensing on rare earths; Bajaj, TVS, Maruti warn of output halts
Nov 2025	Union Cabinet approves ₹7,280 cr Rare Earth Permanent Magnet (REPM) scheme
2026	4 rare-earth corridor states named (incl. Andhra Pradesh); global tenders invited
By 2030	Target: 6,000 MTPA integrated domestic magnet capacity

Source: Rest of World, "China's rare-earth dominance keeps EV makers dependent" (2026); Rare Earth Exchanges, chokepoint analysis (2026); The Federal & OpIndia coverage of India's REPM scheme (2025–26); IEA critical minerals data. Figures are directional and vary by estimate/year.

EV Beats ICE in Every Class

Lower lifetime cost in every segment today. 3-year TCO, indicative ₹ '000s, ex-subsidy retail use case.

3-YEAR TCO BY SEGMENT (₹ '000s)



2W EV already wins

Retail TCO crossover in 18–22 months; 3-year cost runs roughly 30% below a comparable petrol scooter.

3W Strongest ROI

High daily mileage gives commercial e-3Ws the fastest payback — typically 18–24 months versus 3–5 years for ICE 3W loans, per ICCT and industry TCO studies.

4W Approaching parity

4W battery costs have already crossed the ~$100/kWh parity benchmark globally — but 2W/3W battery prices rose in 2025 on strong India demand, keeping that gap open a bit longer.

Source: Avendus Capital, "The Economics of Electric Vehicles in India"; ICCT, E2W cost-parity analysis; IMARC Group, India Electric Two-Wheeler Market (2026); Business Standard reporting on 4W TCO. Figures are indicative, ex-subsidy estimates for representative retail/commercial use cases and vary by city, usage, and model.

VARANIUM

EV Value Chain — Where the Money Is

Bar length = CAGR. Batteries, recycling and charging compound fastest — not vehicle assembly.

OEM / Vehicles $320B	+28% CAGR	Assembly + brand. Commoditising as platforms converge.
Battery Mfg $180B	+35% CAGR	Cell & pack — winner-take-most. India PLI driving domestic scale.
Charging Networks $85B	+40% CAGR	Infrastructure + recurring software revenue — long runways.
EV Financing $45B	+30% CAGR	BaaS, leasing, insurance. BaaS unlocks mass 2W/3W adoption.
Battery Recycling $15B	+55% CAGR — fastest compounding	Circular cathode recovery. Scarcity premium.

Sources: Market sizes and CAGRs are order-of-magnitude estimates synthesized from multiple industry reports (Grand View Research, MarketsandMarkets, Precedence Research, Fortune Business Insights, Straits Research); public research vendors define scope very differently, so figures should be read as directional value-pool ranges, not a single traceable primary source.

The Road to 2030 — Mobility Milestones

Battery costs, penetration rates, and the domestic industry coming into full view.

2025

- LFP dominates 2W & 3W
- 2.3M+ EV sales
- Battery-swap standards crafted
- $108/kWh average pack

2026

- NMC Gen-4 (300+ Wh/kg)
- 4W TCO parity
- Domestic cell manufacturing scales
- Solid-state pilots begin

2027

- Solid-state commercial pilots
- AI-BMS standard
- Battery passport mandated
- Na-ion mass production starts

2028

- Na-ion mass production
- 6M EV sales
- 75% 2W penetration of new sales
- V2G grid integration

2030

- 30% 4W penetration
- Battery < $60/kWh
- ₹500B+ domestic industry
- AI fleet-management standard

30% 4W penetration by 2030 · 75% 2W penetration · **Battery < $60/kWh by 2030**

Source: BloombergNEF, 2025 Lithium-Ion Battery Price Survey (avg. pack price) and long-term battery-price outlook (<$60/kWh by 2030); EU Battery Regulation (EU) 2023/1542, Art. 77 (battery-passport mandate, effective 18 Feb 2027); NITI Aayog & RMI, "India's Electric Mobility Transformation" (2030 EV-penetration targets). Technology-adoption milestones (solid-state/Na-ion scale-up, AI-BMS, V2G rollout, fleet-management standards) are Varanium analyst projections based on industry roadmaps, not verified third-party data.

EV Cybersecurity: The Hidden Risk Layer

As vehicles become software platforms, the ***attack surface becomes the risk surface*** — a battery bet is only as safe as the code, chargers, and grid links around it.

$8.3B
Global automotive cybersecurity market, 2026

9.6%
Projected CAGR through 2034

3 years running
Pwn2Own Automotive has found dozens of zero-days every year since 2024, with 2026 the worst yet

Where the Vulnerabilities Live

Charging Infrastructure (EVSE)
Chargers link vehicle, app, cloud & grid into one surface; multiple charger models were exploited at Pwn2Own 2026.

Telematics & OTA Updates
Remote software delivery is efficient — and one unsecured update channel from a fleet-wide compromise.

Vehicle-to-Grid (V2G)
Two-way power flow creates IoT-style entry points into demand-side grid infrastructure.

Software Supply Chain
ECUs, APIs & third-party code multiply as vehicles are defined by software, not hardware.

Why It Matters for Investors

- **Grid-scale exposure:** EV chargers sit outside utility monitoring — a soft entry point into power infrastructure.
- **Regulatory tailwind:** UNECE WP.29 & ISO/SAE 21434 make compliance mandatory, creating a real moat for certified suppliers.
- **Data & liability risk:** Breaches (e.g., ELECQ, March 2026) expose customer data and brand trust, not just hardware.
- **An investable layer:** Automotive cybersecurity is growing faster than EV unit sales — a standalone value pool across chargers, telematics & OTA.

Source: VicOne, Pwn2Own Automotive 2026; U.S. Department of Energy (CESER); NIST IR 8473, EV Extreme Fast Charging Cybersecurity Profile; Fortune Business Insights, Automotive Cybersecurity Market (2026); IEEE/arXiv EVSE security research; EV Infrastructure News (ELECQ breach, Mar 2026). Figures vary by source and year.

VARANIUM

Mobility — Investment Conclusion

01

Cell Chemistry R&D

Develop or partner on next-gen chemistries — especially Na-ion for India's 2W/3W market.

02

BMS & Software

The software moat. AI-powered battery management is defensible, recurring, platform-extensible.

03

Battery Manufacturing

India PLI creates a rare domestic manufacturing opportunity — follow capex with strategic equity.

04

Battery Recycling

The fastest-growing sub-segment ($15B, 55%+ CAGR). Circular cathode recovery is the next frontier.

05

Ethanol & Other Fuels

E20 hit 5 years early; flex-fuel 2W/3W and mandatory CBG blending scale in parallel — batteries won't win every segment or timeline.

06

Fleet Financing / BaaS

Battery-as-a-Service unlocks the mass market. High-margin, recurring, credit-risk-manageable.

Source: BloombergNEF, battery price & recycling market outlooks; NITI Aayog & Ministry of Heavy Industries, India PLI-ACC scheme; PIB / Ministry of Petroleum & Natural Gas, Ethanol Blended Petrol Programme (E20 achieved Mar 2025) and CBG Blending Obligation (SATAT); CEEW, "After E20" (2026). Figures are directional and vary by source/year.

SECTION 04

Charging Infrastructure

The electricity business behind the vehicle — grid, software, and the V2G opportunity.

Charging Infrastructure

$11B
(Total Funding)

Enablers

- Monta (Denmark) — Funding: $141M
- Virta (Finland) — Funding: $108M
- Softberry (South Korea) — Funding: ~$10.5M
- WeaveGrid (USA) — Funding: $78M

Hydrogen Infrastructure

- HysetCo (France) — Funding: ~$215M
- H2 MOBILITY (Germany) — Funding: ~$120M
- Hydrogenious LOHC (Germany) — Funding: $102M

Battery swapping solution

- Vammo (Brazil) — Funding: $83.5M
- Battery Smart (India) — Funding: $157M
- SUN Mobility (India) — Funding: $135M

Network stations (operators)

- IONITY (Germany) — Funding: ~$1.2B
- Statiq (India) — Funding: $45.5M
- EV Connect (USA) — Funding: $49.9M

Equipment

- ChargePoint (USA) — Funding: ~$660M
- FreeWire (USA) — Funding: $260M
- myenergi (UK) — Funding: $36.8M

CHARGING INFRASTRUCTURE · THESIS

58M to 250M EVs by 2030

As EVs scale toward 250M, the real bottleneck moves from car batteries to power grids.

Every kilowatt-hour a car draws is a kilowatt-hour the grid must generate, move, and price — in real time, at a scale utilities were never built for.

FLEET SIZE

58M

Global EV fleet, end-2024 — more than triple the 2021 total

1.8M

Public charging points added worldwide in 2025 alone, +33% YoY

2030 TRAJECTORY

250M

Projected global EV fleet by 2030 — roughly 4x the 2024 level (IEA STEPS scenario)

~11:1

EVs per public charger globally in 2025 — the ratio the build-out must keep pace with

GRID & MARKET IMPACT

$16–24T

Global grid investment needed by 2050 to support electrification (BloombergNEF base-case to net-zero range)

$19.5B

Projected size of the vehicle-to-grid (V2G) market by 2030, up from ~$5.75B in 2025

Sources: IEA, Global EV Outlook 2025 & 2026 — global EV fleet, 2030 projection, and public charging additions; BloombergNEF, New Energy Outlook: Grids 2024/2025 — global grid investment needed by 2050; Mordor Intelligence, Vehicle-to-Grid (V2G) Market Size & Forecast 2025–2030 — V2G market sizing.

Charger Types Across the EV Fleet

The right charger depends on the vehicle, not just the plug — from an overnight **Bharat AC-001** top-up to an 800V-ready **CCS2 hypercharger**.

CHARGER TIER	POWER	CONNECTOR	VEHICLE FIT	TYPICAL CHARGE TIME	COMPANIES THAT MAKE THIS
Home / Slow AC	2.3–3.3 kW	Bharat AC-001 / 15A socket	2W · 3W · small 4W	**4–8 hrs (full charge)**	Exicom · Delta Electronics India · Servotech Power Systems · KlickWatt · Uznaka Solutions · BEL
Light-EV Fast (LECCS)	up to 12 kW DC	Type 6/7 (India std.)	2W · 3W · micro-4W	**30–45 min (partial)**	Bolt.Earth · EVQPoint · Exicom
Legacy DC Fast	up to 15 kW	Bharat DC-001 (GB/T-based)	3W · older e-bus fleets	**20–30 min (partial)**	Exicom · Griden Power · EVerFuels (ChargET) · Volttic
Public AC Fast	7–22 kW	Type 2 (Mennekes)	Passenger 4W	**4–6 hrs (0–100%)**	Delta Electronics India · ABB India (E-mobility) · Statiq · VerdeMobility
DC Fast	25–60 kW	CCS2	Passenger 4W	**45–60 min (10–80%)**	Exicom · Statiq · Delta Electronics India · Servotech
DC Ultra-Fast	100–350 kW	CCS2 (800V-ready)	Premium 4W	**15–20 min (10–80%)**	Exicom · ABB E-mobility (Terra HP) · Kempower (via Fortum Glida) · Tata Power

Source: e-AMRIT / BIS standards & specifications (Ministry of Heavy Industries); EVreporter, Guide to EV Charging and Standards in India; Bolt.Earth, EV Charging Connectors in India (2026); Zevpoint, Type 2 vs CCS2 vs GB/T Connector Guide (2026); IndiaESA, Charging of Electric Vehicles. Times are approximate and vary by battery size, temperature, and state of charge. Company lists are illustrative, not exhaustive.

VARANIUM

What It Costs — and Why It Must Talk to Everyone

A station is cheap to bolt on and expensive to connect and worthless to drivers unless it ***speaks the same protocol*** as every app and network around it.

What It Costs to Set Up

₹2–4L

AC-only setup (2 chargers)

₹15–25L+

DC fast hub (1 DC + 1 AC)

Transformer & Grid Connection

₹2–5L extra if a dedicated transformer or DISCOM upgrade is needed

Civil Work

Shed, flooring, bollards, branding — typically ₹1–3L

CMS Software

Charging management platform: ₹500–1,000 per charger, per month

DISCOM Load Sanction

1–3 months for approval — usually the real critical path

Why Interoperability Matters

VEHICLE ↔ CHARGER **ISO 15118**

Enables Plug & Charge — automatic authentication via digital certificate, no RFID card or app needed.

CHARGER ↔ BACKEND (CMS) **OCPP 1.6J / 2.0.1**

Lets operators mix hardware vendors and monitor remotely; mandated by MoP/CEA for all new public chargers.

NETWORK ↔ NETWORK **OCPI (Roaming)**

One app, many networks — a driver on one CPO app can charge and pay on another operator's station.

Without open protocols, India's 30+ charging apps stay siloed — **interoperability turns a station into a network.**

Source: Ministry of Power / CEA EV charging guidelines (2024–26); Bolt.Earth, EV Charging Compliance Checklist for CPOs (2026); IMARC Engineering & Pulse Energy, EV Charging Station Setup Cost in India (2026); Shriram Finance, Complete Guide to Setting Up EV Charging Stations (2026); Open Charge Alliance (OCPP); AMPECO / S44, ISO 15118 & OCPI guides. Costs vary by state, site, and charger scale.

VARANIUM

The Charging Conundrum

Stations need EV density to pencil out; buyers need stations to feel confident.

01
Too Few EVs
Low regional density weakens the case for charger investment

02
Weak Utilization
Most public chargers run below 25% capacity, stretching payback

03
Underbuilt Network
~1 charger per 235 EVs vs. the global 1:6–20 benchmark

04
Range Anxiety Persists
Sparse, unreliable charging slows the next wave of EV adoption

↻ *cycle repeats until density, uptime, and grid capacity break the loop*

Grid & DISCOM Delays
Dense charging loads strain local transformers; feasibility studies and approvals can add 15+ days per connection.

High Capex, Tight Land
A single 60kW DC unit costs ₹3–7 lakh before land and civil work — hard economics in dense metros.

Fragmented Interoperability
Separate apps, tariffs, and payment rails across operators complicate the plug-and-charge experience.

Source: Ministry of Power data via Parliament (Mar 2026); ITDP EV charger-to-vehicle ratio analysis; ORF charging-infrastructure projections; PM E-DRIVE scheme documents; Marqstats & IMARC, India EV Charging Station Market (2026). Figures vary by tracker and vehicle-category scope.

Fast Charging Is an Infrastructure Play

High capex, long horizon — utilization is the only lever that matters.

$50K–$300K

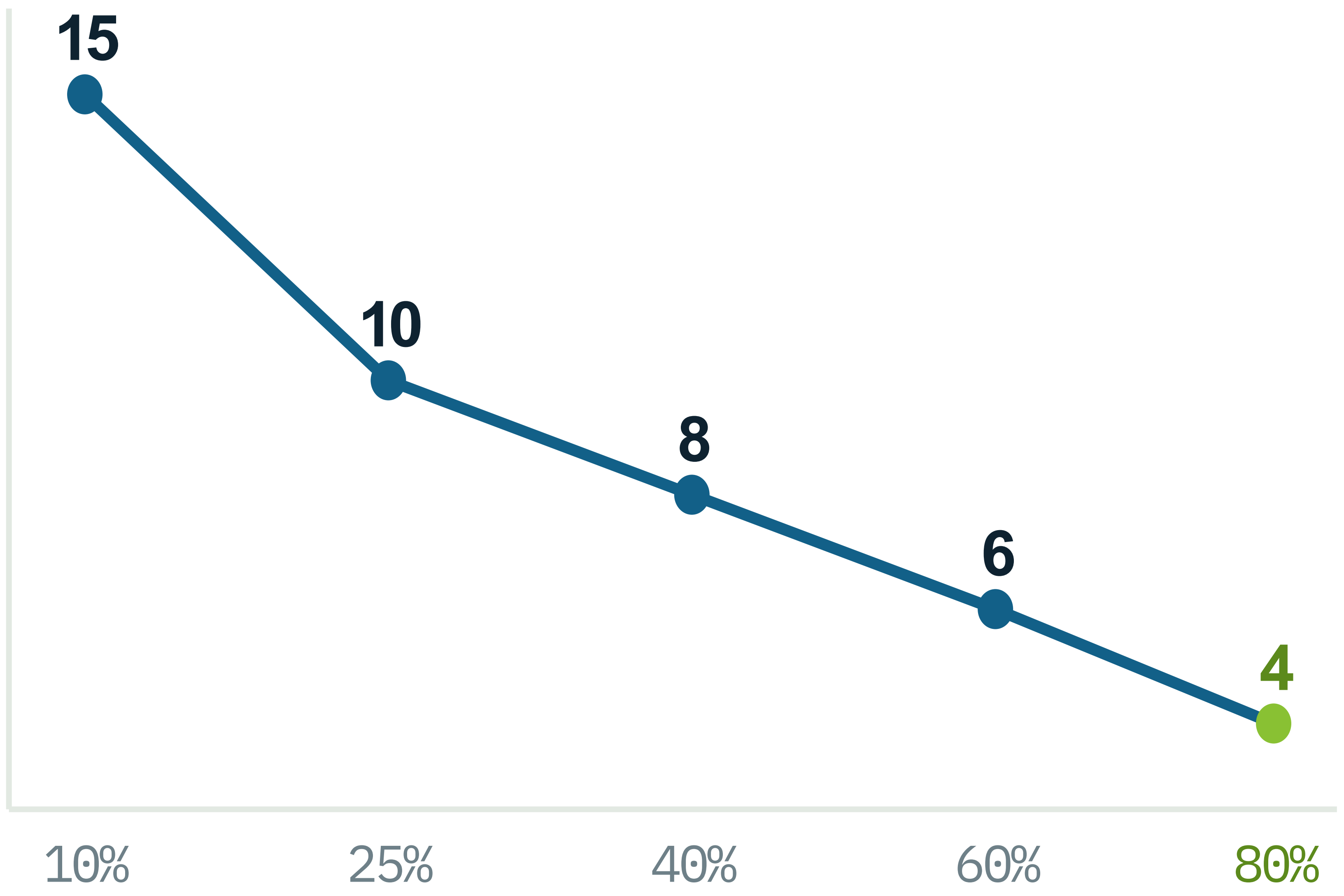
Capex per DC fast-charge unit, before grid-upgrade costs.

25%+

Utilization required to break even — yet most public chargers run below 15%.

UTILIZATION RATE vs. YEARS TO PAYBACK

Location intelligence is everything



Payback period (years) falls sharply as utilization rises.

Sources: McKinsey & Company (2023); Paren, *State of the US EV Fast-Charging Industry Report* (2025–2026); NREL/DOE Alternative Fuels Data Center.

The Charging Value Chain — Where Is the Profit?

Electricity and hardware commoditize. Margin migrates downstream to whoever controls software and utilization.

Utility / Grid
Electricity · Low capture

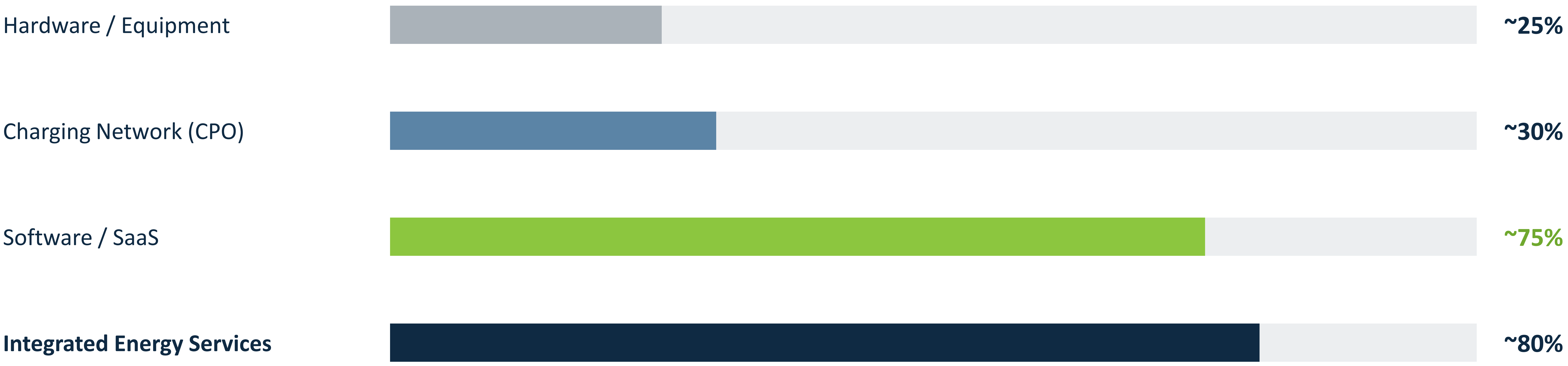
→

OEM / Hardware
Equipment · Low-mid capture

→

CPO / MSP
Network Ops · Low-mid capture

THE MARGIN LADDER — GROSS MARGIN BY LAYER



Source: IEA Global EV Outlook 2025; Arthur D. Little (2023); ChargePoint, EVgo, and Wallbox FY2025 .

ChargeZone vs. Statiq — Two Paths to Scaling India's Charging Network

Both operators are racing to own the charge point — but they're converging on the same asset-light playbook: put capital on partners' balance sheets, keep the software and operations.

ChargeZone

Vertically integrated network operator

Founded	2018 · Vadodara, Gujarat
Scale	15,000+ charge points, 1,200+ locations (India + UAE)
Funding	~$98M raised across 11 rounds
Model	Owns hardware + software; DOCO franchise for capex-light growth
Bet	1,000+ highway superchargers (500kW–1.5MW) by FY27

Statiq

Full-stack hardware + software platform

Founded	2020 · Gurgaon, Haryana
Scale	10,000+ chargers across ~100 cities; targeting 20,000 by end-2026
Funding	$45.5M raised over 4 rounds (incl. $18M, Feb 2026)
Model	Builds hardware + software; FOCO — partners own stations, Statiq operates
Bet	Double network by 2026; app aggregates rival networks (E-Fill, GLIDA)

Takeaway: Both are shifting capex risk to landowners/dealers (DOCO/FOCO) and retaining the higher-margin layer — software, operations, and OEM/fleet relationships — the CPO-to-SaaS pattern from the value chain.

Sources: Tracxn company profiles — ChargeZone, Statiq (2026); Autocar Professional, "ChargeZone Plans 1,000 Franchise Supercharging Stations" (Mar 2026); Entrackr / YourStory / Entrepreneur India, "Statiq Raises $18M led by Tenacity Ventures" (Feb 2026); CB Insights company profile — ChargeZone

Battery Swapping for Electric Two-Wheelers

Battery-as-a-Service is India's answer to slow charging and high upfront EV costs — but standardisation, not station count, is the real bottleneck.

$1.4B
India 2W/3W battery-swapping infrastructure market size

2,600 → 111,000
Active swap stations today vs govt.'s FY2030 target

~300K
Battery swaps performed daily across India (est.)

$1B+
Capital raised collectively by Battery Smart & Sun Mobility

SETUP COST BY STATION TYPE

Manual mini-kiosk (~20 packs)
~₹1 lakh
Bare-bones swap point, no automation

Mid-capacity 2W/3W station
₹10–15 lakh
Grid upgrade + battery inventory — the typical build

Automated multi-bay hub
up to ₹3.7 crore
Robotic swap; higher-end, 4W-capable format

Automating a station can cost ~10x a comparable plug-in charging setup.

KEY PLAYERS

Sun Mobility — 800+ stations; JV with Indian Oil

Battery Smart — 1,400+ stations across 40+ cities

Ola Electric — Swap-ready scooters, urban hubs

Bounce Infinity — Subscription-based 2W swapping

Yulu (Bajaj-backed) — Micromobility fleets + Yuma Energy

Honda Power Pack Energy — Honda's dedicated swap JV for 2W

VoltUp— 1,000+ stations across 14 cities; HPCL-partnered, expanding to 20 cities

POLICY & ECONOMICS

Battery Swapping Policy (2023)
Ministry of Power guidelines set interoperability and safety standards, building on NITI Aayog's 2022 draft blueprint.

BaaS pricing
Pay-per-week runs ~₹300–550 (2W) to ₹1,800–3,150 (e-rickshaw); Battery-as-a-Service cuts the upfront EV price by roughly 25–40%.

The real bottleneck
Lack of battery-format standardisation across OEMs, not station count, is what's slowing nationwide scale-up.

Sources: Ken Research, India EV Two-Wheeler Battery Swapping Infrastructure Market (2025); Mordor Intelligence, India Battery Swapping for Electric 2W Market; AllIndiaEV / BloombergNEF (2025); DIYguru, Battery Swapping in India 2025–2030; E-Vehicle Info; Ministry of Power Battery Swapping Policy Guidelines (2023); NITI Aayog Draft Battery Swapping Policy (2022).

Swapping vs. Charging

For gig-economy riders, downtime is lost income — the refueling method shapes fleet economics as much as the vehicle.

Plug-in Charging

- 4–8 hrs for a full charge at home
- ~30 min on DC fast chargers to reach 80%
- Vehicle is off the road for the duration

Battery Swapping

- 90 sec – 5 min to exchange a depleted pack
- Rider never idles waiting for a charge
- Best fit for high-utilization commercial fleets

TIME TO BACK ON THE ROAD

Across India, China, and Taiwan, delivery and courier fleets are gravitating toward swap networks over depot charging. The logic is simple: riders paid per trip can't afford to sit idle while a battery charges

Sources: Goeen, "Battery Swapping vs Fast Charging" (goeen.in); EV Magazine, "Top 10 Advantages of Battery Swapping" (evmagazine.com); EVjoints, "Electric Scooters: Battery Swapping vs. Charging" (evjoints.com)

VARANIUM

Vehicle-to-Grid (V2G) — The Next Layer

Bidirectional charging turns parked EVs into distributed, revenue-generating grid assets.

SOFTWARE STACK — WHERE VALUE IS CAPTURED

Payments · roaming, invoicing	VERY HIGH
Fleet SaaS · dispatch & analytics	HIGH
Energy management · demand response, V2G	HIGH
Network management · OCPP middleware	MEDIUM

$1,500

Annual revenue potential per EV from V2G services

100GWh

UK EV-fleet V2G storage potential by 2030

40%

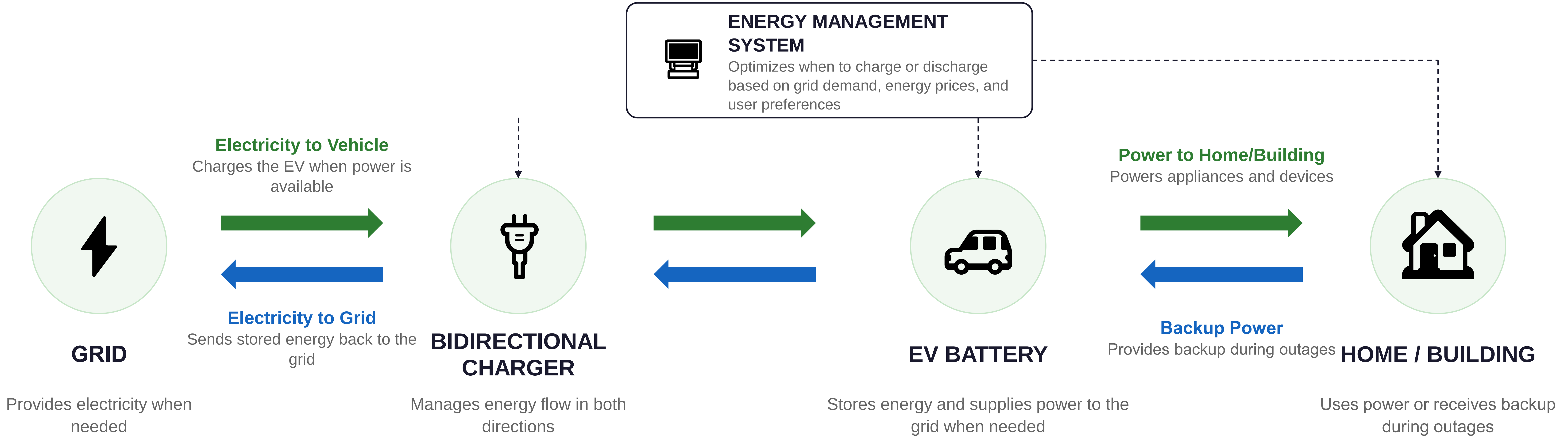
Potential reduction in grid-balancing cost from V2G

Software captures the margin — and V2G is where defensible, recurring value sits.

Source: Adapted from Ofgem/Kaluza V2G case study, IEA "Vehicle-to-Grid Technology" analysis, and industry V2G revenue estimates.

How Vehicle-to-Grid (V2G) Works

V2G technology enables energy to flow in two directions: charging the vehicle and sending power back to where it's needed.



How It Works (In Simple Steps)

1. EV is plugged in to a bidirectional charger.
2. When electricity is cheap or abundant, the EV charges.
3. The system monitors grid demand, energy prices, and needs.
4. When needed, the EV sends stored energy back to the grid or home.
5. This supports the grid, lowers energy bills, and provides backup power.

Key Benefits

Lower Energy Costs
Charge when prices are low, use or sell when prices are high.

Grid Stability
Helps balance supply and demand, especially during peak times.

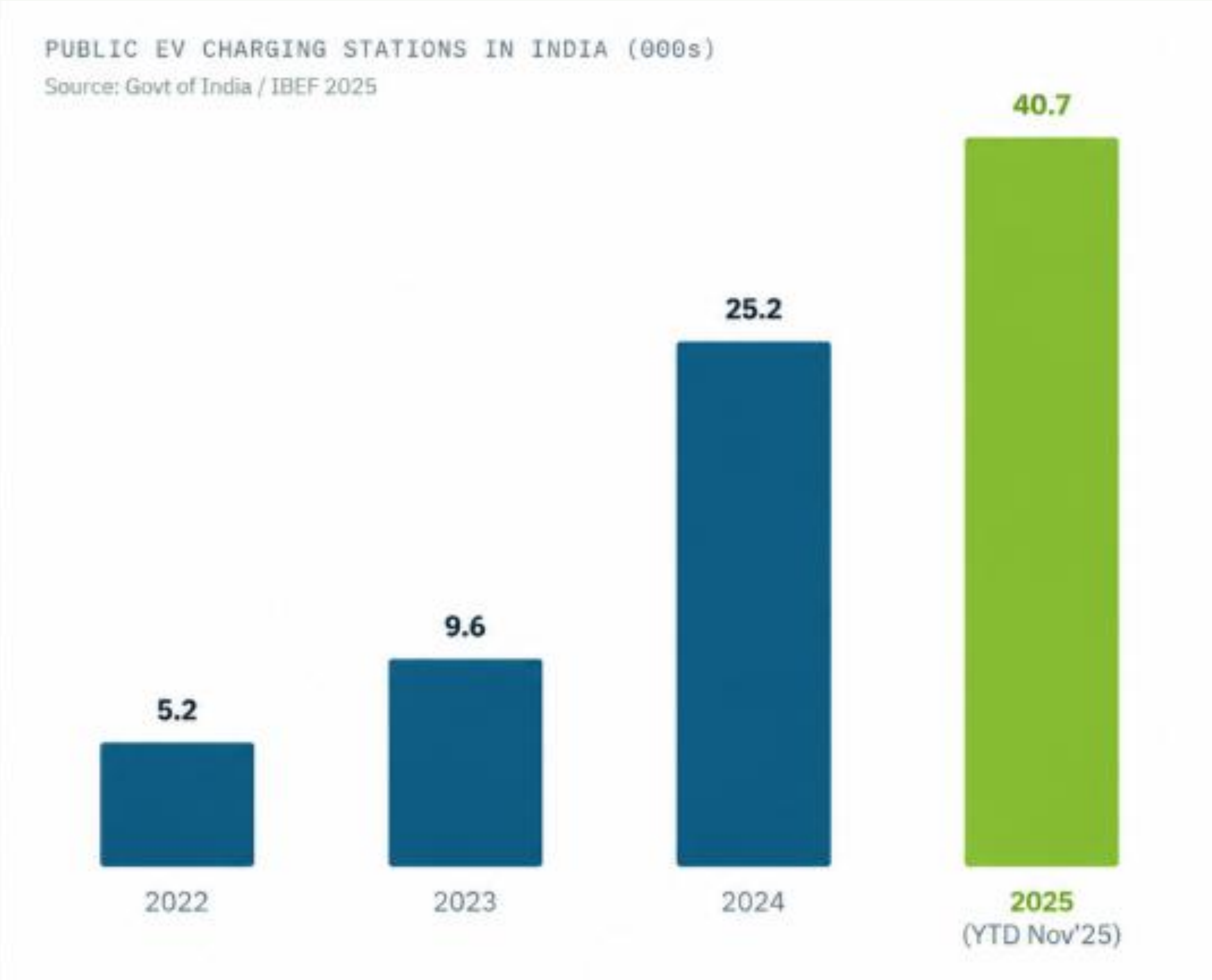
Clean Energy Integration
Supports renewable energy by storing excess power.

Backup Power
Provides energy to your home during outages.

Sustainable Mobility
Maximizes EV value and reduces overall emissions.

India — The Supply Gap Is the Opportunity

Hyper-growth in chargers, yet still vastly under-supplied versus the fleet it serves.



1 : 235

Charger-to-EV ratio in India vs. global benchmark of 1:6–20

72,300

Chargers funded under PM E-DRIVE (₹2,000 cr) across 50 corridors

30%

EV market-share target by 2030 driving mandated rollout

Source: Ministry of Power (Govt. of India), PM E-DRIVE Scheme Guidelines (Ministry of Heavy Industries), NITI Aayog — as reported in Parliament (Rajya Sabha/Lok Sabha replies, 2024–2025) and PIB press releases; IBEF 2025.

VARANIUM

Where Businesses Quietly Fail

Underwriting must screen for these — most failures are structural, not technological.

CRITICAL

Low-utilization Trap

Most public chargers run below 15%. At that rate no model works — location intelligence is everything.

CRITICAL

Grid-constraint Reality

Shovel-ready sites are rare. Grid upgrades can cost $500K+ and take 2–4 years — the silent killer.

HIGH

Standards-war Fragmentation

CCS vs NACS vs CHAdeMO. Winner takes all; losers hold stranded hardware. NACS momentum decisive.

HIGH

Battery-evolution Risk

Solid-state and ultra-fast charging can reshape hardware needs within the asset's useful life.

MEDIUM

Subsidy-cliff Risk

Many models only work with subsidies. As NEVI and IRA evolve, margins can collapse overnight.

MEDIUM

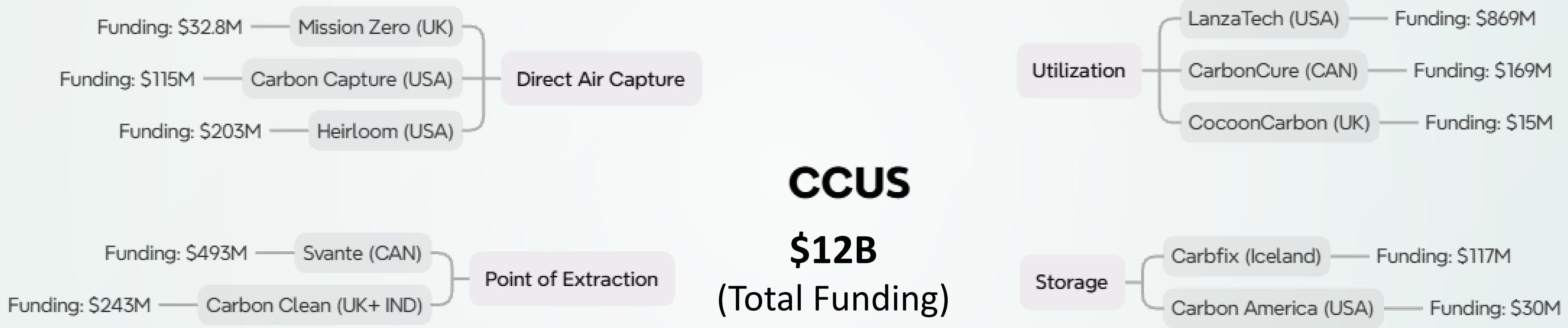
Moat Erosion

Hardware commoditizes fast. Software moats need network effects that take years and are copyable.

SECTION 05

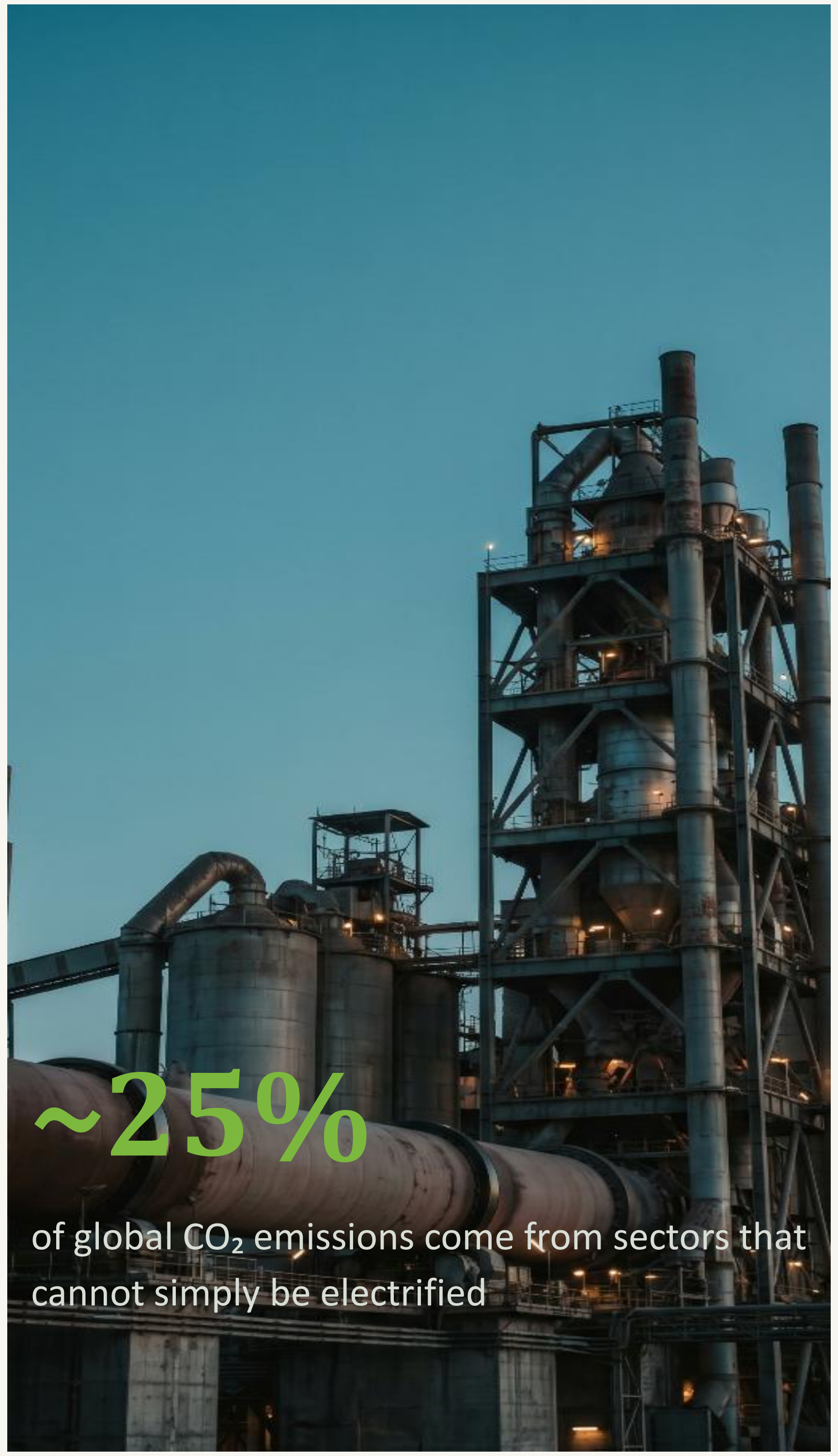
Carbon Capture, Utilization & Storage

Completing the decarbonization stack — where the residual emissions go.


CCUS
$12B
(Total Funding)
Direct Air Capture
Mission Zero (UK)
Funding: $32.8M
Carbon Capture (USA)
Funding: $115M
Heirloom (USA)
Funding: $203M
Point of Extraction
Svante (CAN)
Funding: $493M
Carbon Clean (UK+ IND)
Funding: $243M
Utilization
LanzaTech (USA)
Funding: $869M
CarbonCure (CAN)
Funding: $169M
CocoonCarbon (UK)
Funding: $15M
Storage
Carbfix (Iceland)
Funding: $117M
Carbon America (USA)
Funding: $30M

Why Decarbonization Alone Won't Be Enough

Renewables are scaling fast — but hard-to-abate sectors have no electric substitute.



Steel
~7% of global CO_2 emissions

Coal-based DRI. Process CO_2 is largely unavoidable with current routes; green hydrogen still needs 10+ years to scale.

Cement
~7% of global CO_2 emissions

CO_2 is released chemically during limestone calcination, not from combustion. CCUS is currently the only route to near-zero.

Chemicals
~4% of global CO_2 emissions

Feedstock carbon is locked into the process itself. Reforming and cracking generate structural CO_2, not just energy-related.

Shipping
~3% of global CO_2 emissions

Long-haul, energy-dense fuel requirements. Ammonia and hydrogen alternatives remain a decade or more from scale.

Aviation
~2.5% of global CO_2 emissions

Jet fuel's energy density has no battery substitute at scale. SAF plus CCUS is currently the only credible pathway.

Sources: IEA, Iron and Steel Technology Roadmap (2020) and Cement Technology Roadmap — steel & cement shares of global CO_2 · Our World in Data / Climate Watch, "Sector by Sector: Where Do Global GHG Emissions Come From?" — chemicals & petrochemicals · IMO Fourth GHG Study (2020) and IEA, International Shipping — shipping · IEA, Aviation, and Air Transport Action Group (ATAG), Aviation and Climate Change fact sheet — aviation · Energy Transitions Commission, "Mission Possible" (2018), for hard-to-abate framing

The CCUS Value Chain — Four Linked Stages

Each stage is a separate business with its own cost curve, risk profile and competitive moat.

Capture

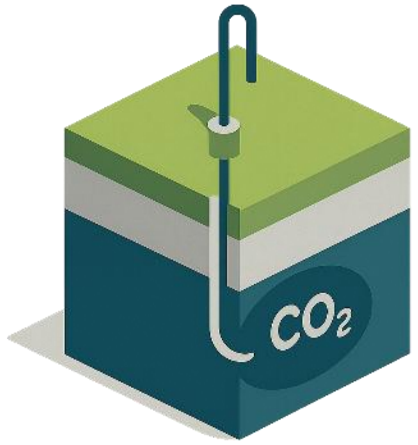
CO_2 separated from a flue stack, a process stream, or directly from ambient air via DAC.

→

Transport

Compressed to a supercritical state and moved by dedicated pipeline or ship to storage sites.

→



Utilize / Store

Locked into geology for permanence, or converted into fuels, chemicals and materials for use.

→

Net Reduction

Measured, reported & verified — the basis for compliance credits and voluntary offset revenue.

Carbon stops being waste and becomes a managed, monetizable resource — **that is the investment shift.**

VARANIUM

How Carbon Is Captured: Four Core Methods

Before it can be stored or reused, CO_2 has to be pulled out of a gas stream or the air itself — four technologies do the work.

Post-Combustion Capture

Most widely deployed today

CO_2 is scrubbed from flue gas after fuel burns, using amine solvents — the easiest method to retrofit onto existing plants.

Pre-Combustion Capture

Highest-purity CO_2 stream

Fuel is gasified into syngas, shifted with steam, and CO_2 is stripped out before combustion — used in IGCC power plants.

Oxy-Fuel Combustion

Skips the separation step

Fuel burns in pure oxygen instead of air, producing an almost-pure CO_2 exhaust stream ready for compression.

Direct Air Capture (DAC)

Fastest-growing pathway

Fans draw ambient air through sorbents or solvents, extracting CO_2 straight from the atmosphere at ~420 ppm.

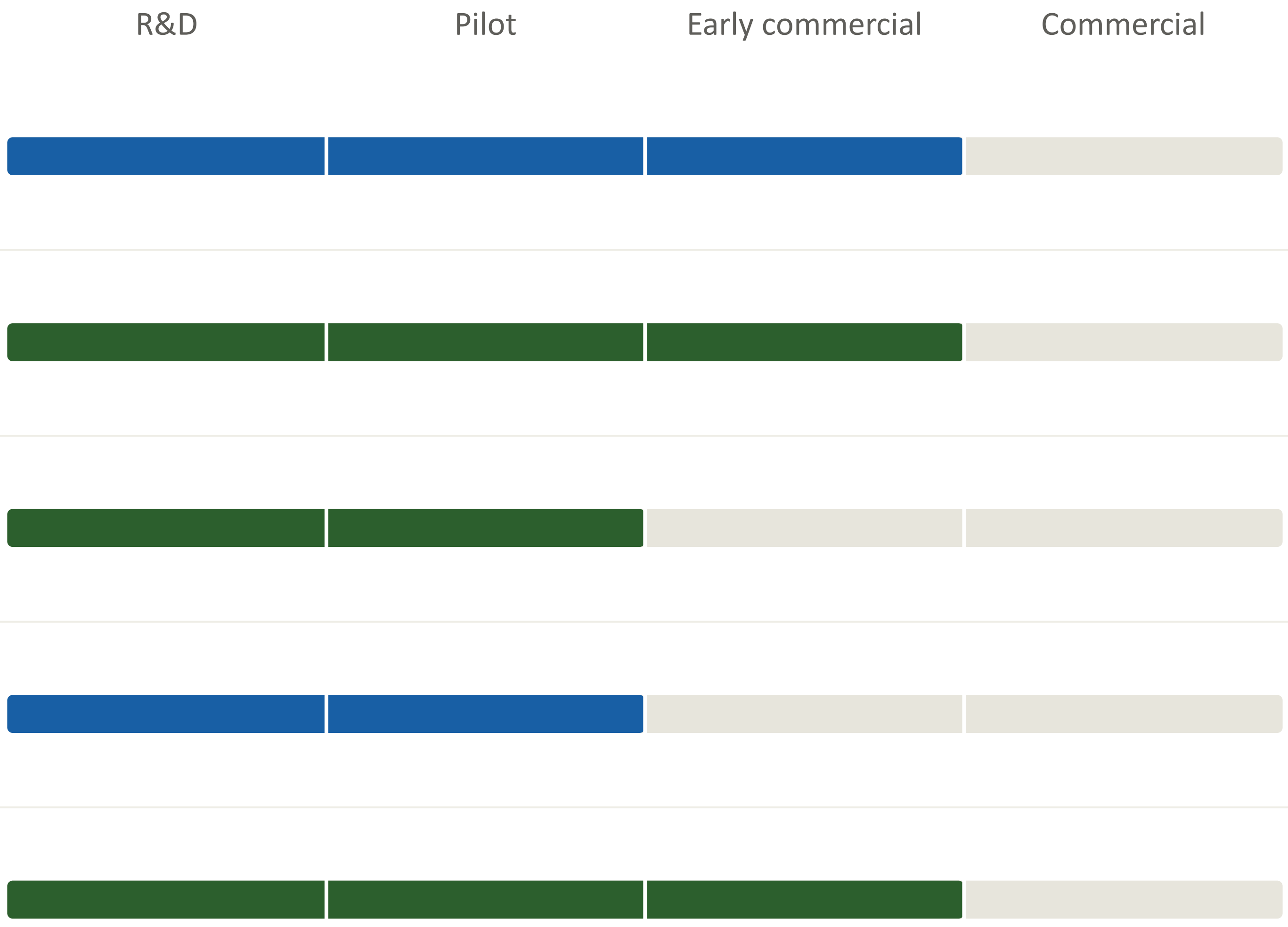
THE PIPELINE: Capture → Compress → Transport → Store / Utilize

Sources: IEA, "CCUS in Clean Energy Transitions" (2025); Global CCS Institute, "Global Status of CCS" (2025); IPCC AR6 WG3 Mitigation Report; BloombergNEF, CCUS Market Outlook Q4 2025

Emerging ways to capture carbon

Beyond point-source capture — a new wave of methods pulls CO_2 straight from air, rock, and ocean.

Maturity



Direct air capture $400–600/t$CO_2$ today

Fans pull ambient air through sorbents that bind CO_2 directly, then release it for storage.

Bioenergy with carbon capture (BECCS) Cheaper than DAC today

Burns biomass for energy and captures the CO_2 — net-negative, but land- and water-intensive.

Enhanced rock weathering Early pilot stage

Crushed basalt on farmland reacts with CO_2 over years, locking it into stable minerals.

Ocean alkalinity & direct ocean capture Early pilot stage

Boosts the ocean's carbon sink, or strips dissolved CO_2 from seawater directly.

Biochar & soil carbon Commercial at small scale

Converts crop waste into stable carbon char, mixed into soil for centuries-long storage.

Why it matters: these methods remove CO_2 already in the air or ocean, rather than at the smokestack — complementary to, not a substitute for, cutting new emissions.

Sources: IDTechEx, “Carbon Dioxide Removal (CDR) 2025–2035” (2025); PatSnap, “Direct Air Capture Technology Landscape” (2026); Frontiers in Climate, expert elicitation on CDR cost trajectories (2024); Carbon Herald, CCUS outlook (2026)

VARANIUM

Metal–Organic Frameworks: Molecular Sponges for CO_2

Engineered crystalline lattices, tunable pore by pore, to trap CO_2 with far greater precision than conventional sorbents.

6,000+ m^2/g

Internal surface area some MOFs achieve per gram — the equivalent of a football field folded into a sugar cube.

Lower Regeneration Energy

Weak, reversible CO_2 binding lets MOFs release captured gas with less heat than amine scrubbing.

Built from Metal Nodes + Organic Linkers

Metal ions or clusters bond with organic “linker” molecules, self-assembling into a rigid, highly ordered nanoporous crystal.

Tunable at the Molecular Level

Swapping linkers or adding functional groups (e.g., amines) tailors pore size and CO_2 affinity for specific gas streams.

Water Is the Main Obstacle

Humidity competes with CO_2 for adsorption sites, so current research centers on hydrophobic, moisture-resistant frameworks.

Status check: MOF-based CO_2 capture remains largely at lab and pilot scale today — a promising, high-precision complement to amine scrubbing rather than a wholesale replacement.

Sources: Carbon Research, “Next-Generation Metal–Organic Frameworks for CO_2 Capture, CH_4 Utilization, and H_2 Integration” (2026); ScienceDirect, “Direct Air Capture of CO_2 in Designed Metal-Organic Frameworks at Lab and Pilot Scale”; Matter / ChemRxiv, “Accelerating CO_2 Direct Air Capture Screening for Metal-Organic Frameworks” (2025)

Six ways to put captured carbon to work

Not all captured CO_2 is buried — a growing share becomes fertilizer, fuel, feedstock, or even food.

Ammonia & urea

~130 Mt CO2/yr

CO2 reacts with ammonia to make urea fertilizer — the single largest chemical use of CO2 today.

Building Materials

~Fastest-scaling in 2026

CO_2 reacts with ammonia to make urea fertilizer — the single largest chemical feedstock use of CO_2 today.

Enhanced oil recovery

~26% of CDU patents

CO2 injected into depleted wells to boost extraction — the largest volume use today, much of it permanently stored underground.

Algae cultivation

~16% of CDU patents

Flue-gas CO2 piped into ponds or photobioreactors accelerates algae growth for biofuel, animal feed, and protein.

Synthetic e-fuels

Largest capital inflow

CO2 combined with green hydrogen (Fischer-Tropsch) yields drop-in jet fuel and diesel — energy-intensive, still early-stage.

Polymers & chemicals

~53% of CDU patents (incl. above)

CO2 replaces fossil feedstock in plastics, polyols, and methanol — built into everyday materials rather than released.

IEA estimate: utilization pathways could absorb 5–10 Gt CO2/yr by 2050 if fully scaled — roughly 15–25% of today's global emissions.

Sources: IEA, “Putting CO2 to Use” & “CO2 Utilization in the Transition to Net Zero” (2025); C2ES, “Carbon Utilization — A Vital and Effective Pathway for Decarbonization”; CO2 from biogas patent analysis, Reviews in Environmental Science and Bio/Technology (2025); BloombergNEF, CCUS Market Outlook Q4 2025

VARANIUM

I-REC vs Gold Standard: two different tools

Often confused, but built for different problems — one tracks clean electricity, the other certifies emission reductions.

	I-REC · renewable energy certificate	**Gold Standard** · carbon credit standard
Certifies	1 MWh of renewable electricity generated	1 tCO_2e of emissions reduced or removed
Used for	Scope 2 claims — the electricity a company buys	Scope 1/3 offsetting and voluntary net-zero claims
Governed by	International Tracking Standard Foundation (I-TRACK); registry run by Evident	Gold Standard Foundation — WWF-backed, established 2003
Coverage	60+ countries, 18 issuers — mainly outside Europe/N. America	Global — renewable energy, forestry, cookstoves, and more
Rigor focus	Prevents double-counting of energy attributes	Additionality, permanence, and UN SDG co-benefits
Typical price	\$4–\$8 per MWh in oversupplied markets	Higher than I-REC

They're complementary, not competing — **a company can hold I-RECs for the electricity it buys and Gold Standard credits for residual emissions it can't yet eliminate.**

Sources: I-TRACK / trackingstandard.org; Evident (I-REC registry); Gold Standard Foundation; GHG Protocol Scope 2 Guidance; EcoHz, CCarbon “I-REC Standard” analysis (2025–26).

Carbon Credits: Trading & Exchange

CO_2 emissions now trade like any other commodity, with prices set daily across Europe, China, and beyond.

€

€81 / tonne

World's oldest and largest compliance market (since 2005). Prices hit multi-year highs in 2026, with ETS2 set to bring buildings and road transport into scope from 2027.

~8 Bn tCO_2

China National ETS

Now the largest carbon market by volume (~20% of global emissions) after adding steel, cement and aluminium. Allowances still trade far below EU levels, pending a shift to a hard cap by 2027.

$1 Trillion+

Global Market, 2025

Combined value of compliance and voluntary carbon trading worldwide. The voluntary segment alone is forecast to top $10B in annual traded value by 2030.

ICE

Leading global venue for compliance carbon futures; traded over $1 trillion in notional environmental-commodity value in 2025.

EEX

Europe's primary spot and derivatives market for EU ETS allowances (EUA, EUAA), underpinning daily price discovery.

Xpansiv CBL

Top voluntary carbon spot exchange; over 330M credits and environmental certificates transacted since 2020.

AirCarbon Exchange

Digital marketplace with 190+ global members, built to serve aviation offsets and cross-border voluntary trading.

Convergence ahead: the EU's CBAM (2026) and Article 6 of the Paris Agreement are pushing compliance and voluntary markets toward shared standards, pricing carbon consistently across borders for the first time.

Sources: European Commission, Climate Action (2026); ICAP, "EU ETS" & "China National ETS"; IEEFA, "China's ETS Reforms" (2025); CarbonCredits.com, "Top Carbon Credit Exchanges Driving Climate Markets in 2026"; Trading Economics, EU Carbon Permits (2026)

VARANIUM

Carbon becomes an asset class

Emission → **credit** → **trade** → **revenue** — three carbon-market structures, and why their prices differ by 100x.

Compliance (ETS)

€72/t

EU ETS, April 2026 · range €60–€95 over 2025–26

Legally mandatory — ~10,000 power and heavy-industry sites across the EU, Iceland, Norway, and Liechtenstein must surrender one allowance per tonne emitted. The annual cap shrinks 4.3%/yr, creating scarcity that sets a hard price floor. From 2026, CBAM charges importers a matching €75/t border fee, pulling non-EU demand into the same price band.

Voluntary (VCM)

$4–$500+/t

nature-based avoidance to engineered removal

No legal mandate — companies buy to back voluntary net-zero claims, so price tracks credit quality, not scarcity. Nature-based avoidance credits (forestry, Plan Vivo-type projects) trade around $4–$27/t; verified removals with high permanence and additionality push toward $60/t; engineered removal like direct air capture can exceed $500/t.

Article 6 (Paris)

Emerging — two-tier market

no single benchmark price yet

Cross-border trading between nations under the Paris Agreement (ITMOs). Two tiers are forming: **Authorized credits** carry a host-country letter, count toward national targets, and can settle international compliance obligations like CORSIA — commanding a premium. **Non-authorized credits** can only back voluntary claims and trade at a discount. The rulebook is still being built — long-dated optionality, high upside, high uncertainty.

The infrastructure beneath these markets — pipelines, storage, verification — behaves like a **regulated utility with first-mover moats.**

Source: ICE/EEX (EU ETS pricing); European Commission (CBAM); Ecosystem Marketplace, MSCI Carbon Markets; Sylvera, ICVCM, UNFCCC (Article 6 / PACM) — 2025–26.

European Standards — Timelines on CCUS

2009 CCS Directive → 2024 Net-Zero Industry Act → 2050 net zero: how EU policy is building the runway for carbon infrastructure.

2009 — CCS Directive
Directive 2009/31/EC creates the legal framework for permitted geological CO_2 storage across the EU.

2021 — CCUS Forum Launched
Commission convenes industry stakeholders; evolves into today's Industrial Carbon Management Forum.

Feb 2024 — ICM Strategy
Industrial Carbon Management Strategy sets out a roadmap toward a single EU CO_2 market.

Jun 2024 — Net-Zero Industry Act
Binding target of 50 Mtpa CO_2 injection capacity by 2030; oil & gas producers directly obligated.

Jun 2025 — Producer Plans Due
Obligated producers submit storage capacity plans and interim targets to the Commission.

2028 — First Review
Commission publishes its first progress evaluation on NZIA storage targets, repeating every 3 years.

2030 · BINDING TARGET

50 Mtpa

NZIA injection-capacity target. Oil & gas producers carry individual, legally binding contribution obligations.

2040 · PROJECTED NEED

~250 Mt/yr

Commission modelling of CO_2 that must be captured and permanently stored annually to stay on the 2040 pathway.

2050 · NET ZERO

~550 Mtpa

Estimated CO_2 managed each year at climate neutrality — CCUS shifts from compliance tool to core infrastructure.

Source: European Commission — Directive 2009/31/EC, Industrial Carbon Management Strategy (COM/2024/62, Feb 2024), Net-Zero Industry Act (Regulation (EU) 2024/1735), DG CLIMA (climate.ec.europa.eu).

Carbon Clean: modular capture at industrial scale

Founded in Mumbai(2009) then relocated to UK — industrial CCUS company known for CycloneCC, a columnless, skid-mounted capture unit.

The challenge

Conventional capture plants use large columns — bulky, capital-intensive, and slow to engineer and install on live industrial sites.

The approach

CycloneCC replaces columns with rotating packed beds and Carbon Clean's proprietary APBS-CDRMax solvent, built as a prefabricated, truckable, modular skid.

The result

The first industrial unit was installed on site in under a week — now scaling toward full commercialization across multiple industries.

50%
smaller footprint
vs. conventional plants

70%
shorter equipment
(height reduction)

100,000
tCO_2/yr captured
per CycloneCC unit

<1 week
on-site install time
for first deployment

First deployment — Fertiglobe, Al Ruwais Industrial Complex, Abu Dhabi: the mobile CycloneCC unit ran for roughly 4,000 operating hours over six months, reaching Technology Readiness Level 7 and validating the unit for scale-up. Carbon Clean is now exploring a 100,000 t/yr deployment with BHP and JSW Steel in India, and has been selected by ADNOC for further industrial rollout.

Company track record: over 2.9M cumulative operating hours across deployments, 110+ active patents, and 50 technology references worldwide.

Sources: Carbon Clean press releases and product pages (2025–2026); BHP–Carbon Clean–JSW Steel agreement announcement (2024); Carbon Capture Technology World Expo (2026)

VARANIUM

India — A Structural CCUS Opportunity

One of the world's largest industrial-emission bases, concentrated in CCUS-critical sectors.

SECTOR	EMISSIONS	CCUS FIT	WHY CCUS IS ESSENTIAL
Cement	~250 Mt/yr	★★★★★	World's #2 producer. Process CO_2 from calcination is unavoidable.
Steel	~200 Mt/yr	★★★★★	Coal-based DRI. Green steel needs a decade-scale CCUS bridge.
Refining	~70 Mt/yr	★★★★☆	State refiners under pressure; hydrogen co-benefits create economics.
Fertilisers	~50 Mt/yr	★★★★☆	Ammonia synthesis is CO_2-intensive; CCUS can enable blue hydrogen.

~450 Mt

Combined cement + steel emissions — India's core CCUS opportunity

Nascent

CCUS policy in India — significant first-mover advantage available

1 Gt

India's total industrial process CO_2 — among world's largest

Source: IEA, Global Carbon Project, Climate Policy Initiative, IEEFA, Ministry of Steel (GoI), CEEW — sector emissions estimates, 2023–2025.

The Deployment Gap Is Enormous

From 50 Mt operating today to a pipeline of ~430 Mt by 2030 — still less than half of the ~1 Gt/yr the IEA's Net Zero pathway requires.

~50 Mt
CO_2 captured & stored per year today (Q1 2025) — up only slightly from a year earlier

~430 Mt
Projected annual capture capacity by 2030 based on the current announced project pipeline

~1 Gt
Needed per year by 2030 under the IEA Net Zero Emissions (NZE) pathway

PROGRESS TOWARD THE 2030 TARGET (≈1 GT/YR) · SOURCE: IEA CCUS PROJECTS DATABASE, Q1 2025 (% CALCULATED VS. NZE BENCHMARK)

Operating today (~50 Mt) Announced pipeline adds (~380 Mt) Unaddressed gap to 1 Gt

Norway, 2025 — Heidelberg Materials' Brevik cement plant becomes Europe's first fully operational commercial CCS value chain, via Northern Lights storage.

Texas, 2025 — Occidental's Stratos plant comes online as the world's largest direct air capture facility.

Global, 2024 — Corporate CO_2-removal offtake deals reached ~6 Mt, nearly double 2023, giving DAC/BECCS developers FID-ready revenue certainty.

THE CASE FOR

- Only viable route for hard-to-abate industrial emissions — cement, steel, chemicals
- Enables carbon-negative systems via BECCS and direct air capture
- Backed by policy: 45Q tax credit (US), EU ETS, CBAM
- Voluntary CDR offtake demand nearly doubled in 2024, de-risking new projects

THE CASE AGAINST

- Costly vs. renewables; largely uneconomic without subsidy
- Unproven at gigatonne scale — operating base is 5% of the 2030 target
- Storage permanence and long-term liability remain uncertain
- 80% of 2030 pipeline capacity is in N. America/Europe, vs. under 60% today (IEA)

Sources: IEA, "CCUS Projects Around the World Are Reaching New Milestones" (May 2025), IEA CCUS Projects Database Q1 2025 update; IEA Net Zero Roadmap (2023 update); Clean Air Task Force, "Carbon Capture and Storage in Europe" (Nov 2025); TotalEnergies, Northern Lights project (2025).

SECTION 06

Circular Economy & CleanTech

Waste-to-resource loops, advanced materials, and the $5.8T regenerative economy.

Circular Economy

$28B
(Total Funding)

- Circular Economy Platforms & Infrastructure
  - Sortera (USA) — Funding: $89.3M
  - Olio (UK) — Funding: $51.2M
  - Recycleye (UK) — Funding: $30.5M
- Waste Management
  - LanzaTech (USA) — Funding: $869.3M
  - Enerkem (CAN) — Funding: $858.6M
  - Rubicon (USA) — Funding: $523M
- Water Treatment
  - Gradiant (USA) — Funding: $392M
  - Solugen (USA) — Funding: $656M
  - Twelve (USA) — Funding: $472.4M
- Sustainable Packaging
  - TemperPack (USA) — Funding: $234.2M
  - UBQ Materials (israel) — Funding: $240M
  - Oji Fibre Solutions (NZ) — Funding: $311.8M
- Recycling of General Materials
  - AMP Robotics (USA) — Funding: $268M
  - Noveon (USA) — Funding: $293M
  - PureCycle Technologies (USA) — Funding: 246M
- EV Battery Recycling
  - Lohum (India) — Funding: $87.7M
  - Ascend Elements (USA) — Funding: $1.10B
  - Redwood Materials (USA) — Funding: $2.29B
- Advanced Materials
  - Genomatica (USA) — Funding: $388.0M
  - Spiber (JAPAN) — Funding: $489.4M
  - Tidal Vision (USA) — Funding: $337.2M

Turning Waste Into Resource Loops

A closed loop where waste is input and products are resources — not disposal. Below: who is building each stage, in India and globally.

$5.8T

Global circular economy market opportunity by 2034 (8.2% CAGR)

$2.9T

Circular economy market size today — already one of the largest opportunity sets

	01 Design	02 Manufacture	03 Use	04 Recover	05 Recycle	06 Rebuild
Stage	For disassembly, repair and reuse — not disposal.	Resource-efficient, minimal waste, closed-loop inputs.	Extended lifetimes via servitization, leasing, repair.	Take-back, deposit systems, industrial symbiosis.	Advanced sorting, chemical recycling, hydrometallurgy.	Remanufacture & refurbish to original specification.
GLOBAL	**Fairphone** Netherlands — modular phone, user-replaceable parts	**Interface Inc.** USA — closed-loop nylon carpet tile yarn (ReEntry)	**Rolls-Royce** UK — "Power-by-the-Hour" jet engine leasing	**Loop (TerraCycle)** USA/EU — reusable packaging take-back platform	**TOMRA / Umicore** Norway/Belgium — AI sorting; battery hydrometallurgy	**Caterpillar Reman** USA — engines/parts remanufactured to OEM spec
INDIA	**Ather Energy** modular, swappable EV battery & component design	**Dalmia Bharat** waste-derived fuels + fly ash/slag replace clinker	**Cashify** refurbished device resale & buyback, extends device life	**Recykal** digital EPR marketplace linking brands, waste, recyclers	**Attero** e-waste & battery recycling; recovers Li, Co, Au	**Lohum** EV battery remanufacturing & second-life repurposing

India context: 930+ active circular-economy companies have raised $708M to date; the sector could unlock ~$45B in annual value and 1.4M jobs by 2050, as India's 62 Mt of annual waste is projected to double by 2030.

Sources: Global Market Insights, "Circular Economy Solutions Market Size" (2025–34); Tracxn, "Circular Economy in India" (Feb 2026); Earth5R circular-startups analysis (2025); Gravita India, Race Eco Chain, company disclosures (Fairphone, Interface, Rolls-Royce, TerraCycle Loop, TOMRA, Umicore, Caterpillar); Attero, Lohum, Recykal, Cashify, Dalmia Bharat, Ather Energy public materials (2025–26).

EV Battery Recycling — The Loop Closes Here

The fastest-growing sub-segment of circular economy; +55% CAGR, driven by EV scale.

$15B
Market today — growing +55% CAGR

11M+
EV batteries end-of-life by 2030

80%+
Li/Co/Ni recovery, best-in-class

KEY PLAYERS — EV BATTERY RECYCLING

OUTSIDE INDIA

Redwood Materials
USA · **$2.29B** · Li recycling

Northvolt
Sweden · **$13.0B** · Cell + recycling

Umicore
Belgium · **$4.44B** · Cathode + recycling

INDIA

Lohum
Noida · **$109M raised**
~70% domestic share; hydrometallurgy + CAM

Attero
Uttarakhand · **₹8,300 Cr planned**
98%+ extraction efficiency

Recyclekaro
Maharashtra · **$18.3M raised**
10,000 MT/yr, 95%+ recovery

Investment in recycling infrastructure today is a **call option on the EV supercycle** with commodity exposure — without the mining risk. It sits at the intersection of EV adoption, critical-mineral security, and corporate circular mandates.

India adds a second angle: Battery Waste Management Rules mandate 90% material recovery by FY 2026–27 and a domestic recycled-content quota from 2027–28 — turning compliance into guaranteed feedstock for Lohum, Attero, and Recyclekaro alike.

Source: Mordor Intelligence / Global Market Insights, "EV Battery Recycling Market" report; company data from Redwood Materials, Northvolt, Umicore; PS Market Research, "India Battery Recycling Market" (2026); DIYguru, "Battery Recycling India 2026"; Tracxn company profiles (Lohum, Attero, Recyclekaro, Feb 2026); Central Pollution Control Board, Battery Waste Management Rules (2022, amended 2025).

Inside the Life of a Recycled Battery

From a dead EV pack to fresh cathode powder — six steps, one closed loop.

1 Collect & sort

Spent packs from EVs, phones, and grid storage are gathered and sorted by chemistry (LFP vs. NMC) and charge state.

2 Discharge & dismantle

Packs are safely discharged to prevent thermal runaway, then dismantled into modules and individual cells.

3 Shred

Cells are mechanically or wet-shredded, separating steel casings, plastics, and copper/aluminum foils.

4 Black mass

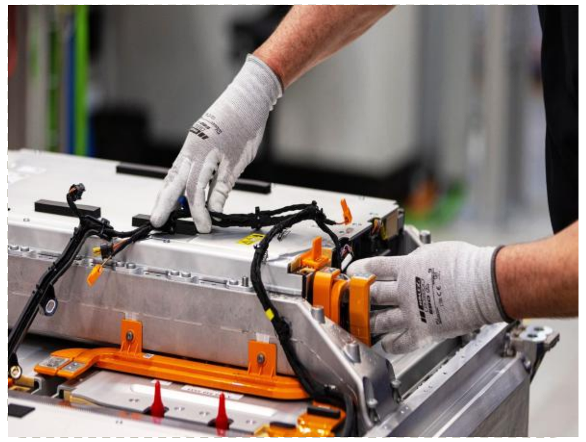
What's left is "black mass" — a dark powder packed with cathode and anode material. This is the prize.

5 Extract

Acid leaching (hydrometallurgy) or smelting (pyrometallurgy) pulls lithium, cobalt, nickel, and manganese out of the black mass.

6 Refine & reuse

Purified metal salts become battery-grade precursors — shipped back to cathode makers to build the next generation of cells.



95–99%
Ni & Co recovery rate via hydrometallurgy

85–95%
Lithium recovery rate (harder to reclaim)

~5%
of Li-ion batteries recycled globally today

70%
EU-mandated Li-ion collection rate by 2030

Sources: C&EN, "Lithium-ion battery recycling goes large" (2025); Green Li-ion, "Step-by-Step Guide to the Li-Ion Battery Recycling Process" (2026); Energy Solutions, "EV Battery Recycling 2026"; Umicore public disclosures; EU Battery Regulation (2023/1542).

VARANIUM

Waste, Water & Sustainable Packaging

Large, fragmented markets undergoing technology-driven transformation at scale.

Waste Management

$1.2T
TAM

Growing 5.6% CAGR. AI-powered sorting, chemical recycling, waste-to-energy. Emerging-market municipal contracts are the opportunity.

Water Treatment

$372B
TAM

Desalination, zero-liquid discharge, industrial wastewater. India's urban water gap is a structural investment thesis.

Advanced Materials

$847B
TAM

Bio-based polymers, recycled carbon fibre, low-carbon cement. Performance parity with conventional materials increasingly achieved.

Sustainable Packaging

$327B
TAM

Transitioning to recyclable, compostable and refillable formats. Regulatory mandates (EU SUP Directive) are the demand engine.

Sources: MarketsandMarkets, "Waste Management Market" (2024); Fortune Business Insights, "Water and Wastewater Treatment Market" (2025); Grand View Research, "Sustainable Packaging Market Report" (2024); BCC Research, "Advanced Materials Markets" (2025)

Waste Management — Deep Dive

How a $1.2T, 5.6% CAGR market is being rewired by sorting automation, chemical recycling and formalization of the informal sector.

Core Techniques

Mechanized segregation: AI-optical & NIR sorters separate mixed materials recovery facility streams, lifting recovery purity above 90%.
Chemical recycling: Pyrolysis and depolymerization convert mixed/contaminated plastics back to virgin-grade feedstock.
Waste-to-energy: Incineration, gasification and biomethanation turn residual and organic waste into power and bio-CNG.
EPR-linked formalization: Digital credit trading brings informal waste-pickers into traceable, compliant supply chains.

Emerging Technology

Robotic dismantling: Computer-vision robotic arms recover gold, silver and palladium from e-waste at over 99% precision.
IoT-enabled logistics: RFID bins, GPS fleets and blockchain tracking give municipalities real-time proof-of-processing.
Battery urban mining: Hydrometallurgical lithium-ion recovery is scaling fast as India's first EV fleets reach end-of-life.
Carbon-capture pairing: WtE plants are being retrofitted with pilot carbon-capture units to push toward negative emissions.

Key Players — India

Antony Waste Handling & A2Z Green: Listed municipal-concession incumbents running mechanized collection fleets.
Attero & RecycleKaro: Battery and e-waste specialists using AI-based sorting and lithium-ion recovery at scale.
Recykal: Digital EPR marketplace and AI recognition engine across 180+ cities; closed a $22M Series B in 2025.
Saahas Zero Waste: Corporate-facing traceable sorting and zero-landfill diversion programs.

Key Players — Global

Waste Management Inc. (US): Largest North American operator, scaling waste-to-energy and recycling technology.
Veolia (France): Global leader expanding resource-recovery and recycling service lines across 190+ countries.
AMP Robotics (US): AI robotic sorters (Cortex platform) processing ~62,000 t/yr, cutting MRF contamination 30–50%.
SUEZ & LanzaTech: Incineration carbon-capture pilots and syngas fermentation pushing chemical-recycling frontiers.

Sources: Mordor Intelligence, "India Waste Management Market" (2026); RecycleKaro, "Top E-waste Recycling Companies in India" (2025); Earth5R, "Top Waste-to-Energy Companies" (2025); Trade.gov, "India Recycling Technologies Opportunities" (2025).

Water Treatment — Deep Dive

A $310B market where India's urban water gap meets desalination, zero-liquid-discharge and AI-optimized plant operations.

Core Techniques

Reverse osmosis desalination: SWRO/BWRO membranes remain the workhorse for coastal municipal and industrial supply.
Zero/minimal liquid discharge: Multi-effect evaporation and crystallization recover near 100% of industrial effluent as reusable water.
Membrane bioreactors (MBR): Combine biological treatment with ultrafiltration for tertiary reuse and potable-reuse-grade output.
Ion exchange & electro-dialysis: Used for demineralization and targeted contaminant removal in industrial process water.

Emerging Technology

Forward osmosis & membrane distillation: Lower-energy osmotic and thermal separation pilots (e.g., vacuum MD at IOCL Panipat).
AI-optimized plant operations: Predictive dosing and fouling-detection software (e.g., WABAG–Pani Energy partnership).
Direct potable reuse (DPR): Multi-barrier treatment trains now push treated wastewater straight back into drinking supply.
PFAS & micropollutant removal: Advanced oxidation and specialty resins target pharmaceuticals, pesticides and "forever chemicals".

Key Players — India

VA Tech WABAG: Chennai-based, 100-yr-old technology base; 6,500+ projects in 25+ countries, strong ZLD and desalination order book.
Ion Exchange (India): Six-decade water & environment player spanning engineering, chemicals and the Zero-B consumer brand.
Thermax: Energy-and-environment major known for turnkey ZLD systems integrating heat recovery.
Enviro Infra Engineers & TRL Krosaki: Government infrastructure execution and patented nature-inspired "TRL Rain" distillation.

Key Players — Global

Veolia & SUEZ (France): Diversified water majors spanning desalination, reuse and municipal operations worldwide.
Xylem (US): Water technology and smart-metering leader focused on treatment and network efficiency.
Aquatech International (US): Specialist in ZLD and water-recycling systems for pharma, power and refining clients.
ACCIONA & ACWA Power: Large-scale desalination developers active across the Middle East and Asia-Pacific.

Sources: VA Tech WABAG corporate disclosures & Grokipedia (2026); SUSBIO, "Top 10 Wastewater Treatment Companies in India" (2026); Tradebrains, "Water Management Stocks" (2026); Mind2Markets, "Water Treatment Chemicals Manufacturers" (2024).

VARANIUM

Advanced Materials — Deep Dive

Bio-based polymers, recycled carbon fibre and low-carbon cement are reaching performance parity with conventional materials.

Core Techniques

PLA & bio-polyol synthesis: Fermentation of sugars/starch into lactic acid feeds industrial-scale PLA bioplastic plants.
Supplementary cementitious materials: Fly ash, slag (GGBS) and calcined clay (LC3) substitute clinker to cut embodied carbon.
Recycled carbon fibre recovery: Pyrolysis and solvolysis reclaim fibre from aerospace/automotive composite scrap.
Geopolymerization: Silicon-aluminium activation creates cement-free binders with a fraction of the CO2 footprint.

Emerging Technology

Bio-based PAN precursors: Projects like OSCAR derive carbon-fibre precursor from glycerol and lignin instead of petroleum.
Carbon capture & utilization in cement: Direct CO2 injection into curing concrete (e.g., CarbonCure) locks carbon permanently into the material.
Automated composite manufacturing: Automated fibre placement and 3D-printed continuous-fibre parts cut waste and production cost.
Agri-waste & bamboo composites: Bagasse and bamboo-fibre composites (e.g., IIT Guwahati) target automotive and construction use.

Key Players — India

JSW Cement: Green-cement leader; Scope 1+2 carbon intensity ~40% below the global average via slag-based products.
Balrampur Chini Mills: Building India's first industrial-scale PLA bioplastic plant (~80,000 t/yr) beside its sugar operations.
UltraTech Cement & ACC: Large-scale adopters of blended and low-carbon cement formulations across India.
Kiran Global Chem: Geopolymer "Geocement" made from fly ash and furnace-slag by-products.

Key Players — Global

BASF & Dow: Chemical majors leading bio-based and recycled-content polymer platforms for packaging and automotive.
Holcim & CEMEX: Global cement leaders scaling ECOPlanet/Vertus low-carbon ranges and carbon-capture pilots.
Toray & Teijin (Japan): Carbon-fibre giants investing in recycled-fibre and bio-based precursor technology.
Corbion (Netherlands): Global leader in PLA bioplastics (Luminy®) via a joint venture with TotalEnergies.

Sources: GMI, "India Bio-based Construction Materials Market" (2025); CompositesWorld / Nova-Institut, "Bio-based Polymer Report" (2026); Spherical Insights, "Top Green Cement Companies" (2026); JSW Cement disclosures; Allied Market Research, "Carbon Fiber Market."

VARANIUM

Sustainable Packaging — Deep Dive

A $400B transition to recyclable, compostable and refillable formats, with the EU PPWR and India's EPR rules as demand engines.

Core Techniques

Mono-material design: Single-polymer structures replace multi-layer laminates so packs can actually be recycled at scale.
Bagasse & agri-fibre moulding: Sugarcane-residue tableware and trays substitute single-use plastic food packaging.
Recycled-content integration: Post-consumer resin (PCR) blended into new packaging to meet recycled-content mandates.
Refill & deposit-return systems: Reusable containers with return logistics cut per-unit packaging material entirely.

Emerging Technology

PHA & next-gen PLA: Higher-performance bio-polymers extend compostable formats into food-contact applications.
Mycelium & seaweed packaging: Mushroom-root and seaweed-derived materials (e.g., Notpla) fully biodegrade, even in water.
Digital product passports & QR tracking: Embedded codes verify recyclability and material composition at point of disposal.
Barrier-coating innovation: Recyclable fibre-based barrier films (e.g., Amcor AmFiber) replace foil/plastic laminates.

Key Players — India

Pakka Limited (CHUK): Bagasse-based compostable tableware for restaurants, cafes and food-delivery platforms.
UFlex & EPL (Essel Propack): Large flexible-packaging manufacturers shifting toward recyclable and mono-material tubes/films.
ITC (Filo Series): Industrially compostable, soil-biodegradable paperboard for food-service packaging.
Huhtamaki India & Ecoware: Fibre-based and agri-waste packaging serving FMCG, hospitality and QSR brands.

Key Players — Global

Amcor (Switzerland/Australia): Recycle-ready paper-based refill packaging (AmFiber) and recycled-plastic (AmFiniti) programs with Mondelez.
Tetra Pak (Sweden): Aseptic carton systems built on renewable paperboard and plant-based polymers.
Novamont & NatureWorks: Leading compostable-bioplastic producers holding a combined share of the global market.
Notpla (UK): Seaweed-based packaging pioneer targeting single-use sachets and films.

Sources: Earth5R, "Sustainable Packaging: Top 20 Innovations for 2025"; The Sustainable Brands Journal, "Top Sustainable Packaging Companies in India" (2026); GMI, "Eco-friendly Food Packaging Market" (2026); EUR-Lex, Regulation (EU) 2025/40 (PPWR).

SECTION 07

Energy Storage & Efficiency

Technology landscape, company map, and the enabling layer of the clean economy.

VARANIUM


Storage Tech
$55B
(Total Funding)
Pneumatic & Compressed Air Storage
Hydrostor (Canada) — $565M
Augwind (Israel) — $150M
Storelectric (UK) — $1.34M
Mechanical & Flywheel Storage
Energy Vault (Switzerland) — $260M
Advanced Rail Energy Storage (USA) — $50M
Thermal Energy Storage
Malta Inc. (USA) — $122M
Antora Energy (USA) — $272M
Rondo Energy (USA) — $352M
EV Battery Storage & Recycling
Redwood Materials (USA) — $2.39B
Northvolt (Sweden) — $15.0B
Umicore (Belgium) — N/A (public co.)
Home & Distributed Energy Storage
SpanIO (USA) — ~$419M
Sonnen (Germany) — $180M
Enphase Energy (USA) — $121M
Grid-Scale Chemical Battery Storage
ESS Inc (USA) — $46.2M
Ambri (USA) — $222M
Form Energy (USA) — $1.2B+
Hydrogen Based Energy Storage
Neom Green Hydrogen (KSA) — $8.4B
Electric Hydrogen (USA) — $603M
Sunfire (Germany) — $1.0B

Zinc-Based Batteries & Green Hydrogen

Zinc-Based Batteries

TRL 6–7 Early Commercial

Zinc-air and zinc-bromine cells use water-based electrolytes and abundant zinc instead of scarce lithium or cobalt — eliminating fire risk and scaling modularly from 10 kW microgrids to 200 kWh+ grid systems.

EVOLUTION

- *2019* — *IIT Madras R&D*
- *2021* — *HZL × IIT MoU*
- *2024* — *Offgrid ZincGel*
- *2025* — *Offgrid $15M*
- *2026* — *Sthyr $1M seed*

INDIA

Sthyr Energy — Chennai; IIT Madras zinc-air spin-out

Offgrid Energy Labs — IIT Kanpur; zinc-bromine ZincGel

Hindustan Zinc — zinc feedstock & R&D partner

Godrej Enterprises — zinc-manganese dioxide cells

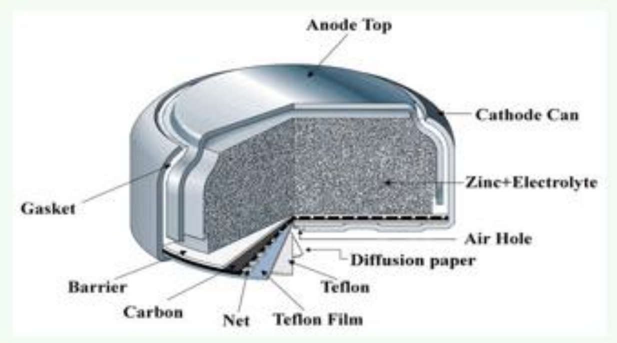
GLOBAL

NantEnergy — USA; rechargeable zinc-air

Zinc8 Energy Solutions — Canada; long-duration zinc-air

Mitsubishi Heavy Ind. — Japan; "e-zinc" systems

Urban Electric Power — USA; Godrej's tech licensor



Green Hydrogen Storage

TRL 9 Commercial

Electrolysers split water into hydrogen using renewable power, storing energy for weeks or months rather than hours — serving hard-to-electrify sectors like steel and refining, and cutting India's 85% petroleum import dependence.

EVOLUTION

- *2023* — *Nat'l H2 Mission*
- *2024* — *Adani 5MW pilot*
- *2025* — *JSW mega plant*
- *2026* — *Reliance 3GW/yr*
- *2030* — *Target 5 MMT/yr*

INDIA

Reliance Industries — Jamnagar; 3 MMT/yr target by 2032

Adani (ANIL) — $50bn/10-yr plan with TotalEnergies

Larsen & Toubro — electrolyser manufacturing & EPC

NTPC / JSW Energy — hydrogen hubs, steel-sector supply

GLOBAL

Air Products & Linde — industrial gas majors

Shell — integrated hydrogen production

Bloom Energy — solid-oxide electrolysers

Plug Power — electrolyser & fuel-cell tech

Source: National Green Hydrogen Mission, Hindustan Zinc, TechCrunch, Blackridge Research — compiled July 2026

India's Storage Stack Is Diversifying

Policy, capital and cost curves are pulling every chemistry forward at once — lithium-ion for scale today, sodium and zinc for cost and safety tomorrow, hydrogen and gravity for the long-duration edge cases lithium can't reach.

2021
PLI scheme for Advanced Chemistry Cells, ₹18,100 cr

2023
National Green Hydrogen Mission launched

2024
First VRFB & zinc-bromine pilots go live

2026
Sodium-ion & zinc-air reach India pilot scale

2031
India BESS market projected at $8.59bn

33.2%
India BESS market CAGR, 2026–31

$10B+
India's existing lithium storage market

5 MMT
Green hydrogen target by 2030

55%+
EV battery recycling CAGR

Source: NREL, Mordor Intelligence, National Green Hydrogen Mission, company disclosures — compiled July 2026

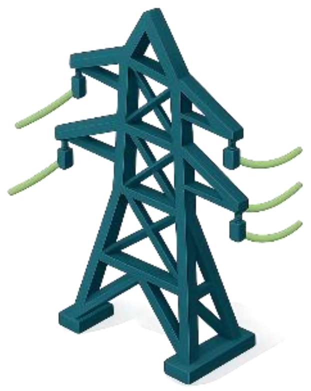
The Cheapest Unit of Energy

Building management, grid management and industrial electrification as investable verticals.

Building Management

Span.IO (USA) — **$419M** tado° (Germany) — **$245M**

Smart thermostats, building energy management, AI-driven HVAC. ESG mandate drives adoption. Recurring SaaS model.



Grid Management

Landis+Gyr (CH) — **$1.03B** Stem (USA) — **$229M** Enel X (Italy) — **$168M**

Advanced metering, demand response, smart-grid software. Tailwinds from FERC 2222 and EU Smart Grid Directive. Data moats compound.

Industrial Efficiency

Turntide (USA) — **$544M** Phononic (USA) — **$230M** Carbon Lighthouse — **$112M**

Motor efficiency, industrial cooling, building decarbonization. Hard-to-reach emissions, large fragmented market, deep ROI.

Source: Tracxn

SECTION 09

About Varanium Capital Advisors

Our promoters, investment team, and track record — managing ~$1B across debt, equity and venture capital.

Promoters — Varanium Group

30+ years of global financial-markets experience from Goldman Sachs, Citibank and Shinsei.

T S Anantakrishnan

FOUNDER & MANAGING PARTNER

30+ years in Portfolio & Risk Management across global asset-management firms including Goldman Sachs and Shumway Capital. Former CEO of Religare Portfolio Managers; previously headed Portfolio Management at Prime Securities.

MBA NYU Stern · MS Stony Brook · BE IIT Roorkee · CFA & FRM

Sajeeve K Thomas

PROMOTER

30+ years in Consumer & Corporate Banking, Capital Markets, Treasury and Risk across Shinsei & Citibank. Country Treasurer & Head of Capital Markets and Head of Risk APAC at Citi Japan; Head of Retail Banking at Shinsei Bank, Japan.

PGDBA — IIM Ahmedabad (1975)

Global Multi-Asset Management Firm Managing ~$2 billion in Assets Under Management (AUM) with offices in Mumbai, Singapore and Mauritius.

- Listed Equities
- Private Equity
- Venture Debt
- Fixed Income

Investment Team — Onshore

Experienced professionals spanning investment banking, fund management and technology.

Aparajit Bhandarkar

PARTNER · ALTERNATIVE ASSETS

22+ yrs in Investment Banking, IR & startup investments. Ex-CEO Dice Fintech Ace; Head of Strategy at Jio Payments Bank; among the first 50 at Yes Bank.

MBA NYU Stern · CFA · CA

Nawal Bachhuka

PRINCIPAL · VENTURE DEBT FUND

23+ yrs across NBFC & corporates, 15+ in underwriting & risk. Managed a ₹3,500 Cr MSME book (West) at Aditya Birla Finance. Ex-ABFL.

Chartered Accountant

Vikram Pandya

FUND MANAGER · VENTURE CAPITAL

21+ yrs in Banking, Technology & Fintech. Director – Fintech at SP Jain School of Global Management. Ex-Strategic Advisor at Yes Bank; AI specialization.

CA · CFA (USA) · CISA

Aman Jain

VP · ALTERNATIVE ASSETS

7+ yrs across start-up investments, strategy, research & valuations. Prior to Varanium, a research analyst at Evalueserve covering US consumer & auto.

CA · CFA (USA) · BFM, H.R. College

VARANIUM

Varanium...

Inspired by the timeless wisdom of the Gayatri Mantra

Where *'Varanium'* signifies the pursuit of excellence and perfection. This philosophy guides everything we do.