Cleantech HERO

JUL - AUG 2026

Issue no. 09

Dr. Avishek Kumar

Quality control in Renewable Energy:

From Manufacturing to Deployment | P 03

Alexander Enulescu

The Hidden Challenge of Clean Energy

Storage Infrastructure | P 09

Avnish Bagaria

No Longer Scrap:

How Spent EV Batteries are Powering Circular Economy | P 14

Pradyumna Gupta

Cleantech Industry Supply Chain's Quiet Problem:

Component Qualification in the Rush to Deploy | P 06

Bidisha Banerjee

Beyond Electrolysis:

Bringing Biomass into India's Hydrogen Future | P 17

INSIGHT. INNOVATION. IMPACT

What's INSIDE

Avishek Kumar

Founder and Director, Sunkonnect

Quality Control in Renewable Energy: From Manufacturing to Deployment

***Dr. Avishek Kumar** is the founder and director of **Sunkonnect**, a Singapore-based sustainability consultancy offering services in ESG, net zero, climate, carbon auditing, and green building.*

1. Where in the supply chain do you see the most quality failures: raw material sourcing, in-process manufacturing, pre-shipment, or post-installation?

Quality challenges can emerge at every stage of the supply chain, but in my experience, the most critical failures often surface during in-process manufacturing and pre-shipment. Raw material inconsistencies, especially in glass, EVA, or backsheet for solar modules, and steel quality for wind components, can set the stage for downstream issues.

However, it is during in-process manufacturing that lapses in process control, inadequate traceability, or improper calibration of equipment tend to lead to structural or performance-related non-conformities. Pre-shipment inspections then become the last line of defence to catch such issues before deployment. Post-installation failures are rarer but can be severe, usually tied back to earlier lapses that went undetected. This is why a holistic quality assurance programme across the entire value chain is vital.

2. Solar and wind equipment is increasingly sourced from global manufacturers. How does Sunkonnect ensure inspection rigour when equipment is manufactured in, say, China, Vietnam, or Denmark before shipping to India?

Sunkonnect operates with a global network of technical experts and accredited inspection partners, allowing us to deploy independent teams at manufacturing facilities regardless of geography. Our approach combines rigorous on-site inspections with digital monitoring tools.

We tailor our checklists to international and client-specific standards, focus on process audits, and conduct random sampling for destructive and non-destructive testing. For critical components, we also use data-driven analytics to flag anomalies in real time. This hybrid model, combining boots-on-the-ground expertise with digital oversight, ensures that quality and compliance are upheld even across complex, multi-country supply chains.

3. What are the most common deviations or non-conformities you encounter during pre-shipment inspections? Have you identified any recurring issues specific to Indian EPC projects?

During pre-shipment inspections, common deviations include inconsistencies in labelling, incomplete documentation, and minor cosmetic defects. More serious issues, such as improper lamination in solar modules, micro-cracks, or non-conformance to electrical safety standards, occasionally surface and require immediate corrective action.

In the context of Indian EPC projects, we often observe gaps in adherence to project-specific specifications, as well as challenges with last-minute design changes or incomplete type testing. These issues are sometimes amplified by aggressive timelines and cost pressures. Early engagement with EPCs and suppliers, coupled with a robust documentation process, helps mitigate these risks.

4. There's growing interest in BESS in India. How different is the inspection and quality assurance challenge for storage compared to solar PV or wind?

Battery energy storage systems (BESS) present a new layer of complexity compared to traditional solar or wind assets. The inspection scope expands beyond mechanical and electrical quality to include a deep dive into battery chemistry, thermal management, software controls, and safety protocols. Unlike solar modules, where visual inspection and electrical tests are standard, BESS requires cell-level traceability, end-of-line testing, and validation of software algorithms that manage charging, discharging, and fire suppression. Our teams undergo specialised training for BESS audits, and we place a strong emphasis on lifecycle testing and cybersecurity, given the integration with digital grids.

5. You've also co-founded VFlowTech (Vanadium Flow Batteries). How do you foresee the usage of vanadium batteries in a lithium-dominated BESS market?

Lithium-ion will remain the mainstream choice for short-duration, high-density applications, but vanadium flow batteries are gaining traction for grid-scale, long-duration storage due to their inherent safety, scalability, and ability to handle deep cycling without degradation. In markets like India, where renewable penetration is increasing and grid stability is crucial, vanadium flow batteries can complement lithium systems by providing **long-duration backup, frequency regulation, and integration with renewable assets.**

As costs decline and local supply chains for vanadium mature, I believe we will see a hybridisation of storage portfolios, with vanadium flow batteries playing a key role in large-scale and industrial applications.

6. With the rise of domestic solar manufacturing under the PLI scheme, do you see Indian manufacturers improving quality benchmarks, or is there still a significant gap compared to global standards?

The PLI scheme has catalysed significant investments in automation, R&D, and process upgrades among Indian manufacturers, and we are witnessing genuine improvements in quality benchmarks, particularly among Tier 1 players. **India's solar module manufacturing capacity has grown remarkably — exceeding 120 GW as of mid-2025, representing over 200% growth since 2022.**

However, it is equally important to acknowledge that implementation has not been without challenges. Capacity additions in certain upstream segments remain below targets, and manufacturers continue to navigate dependencies on imported equipment, raw materials, and technical expertise. Bridging the gap with global leaders will require sustained focus on process discipline, workforce training, and ongoing investment in advanced testing infrastructure.

The most successful manufacturers are those who embed quality into their organisational culture, not just their production lines. With continued policy support, greater upstream integration, and industry collaboration, I am cautiously optimistic that Indian solar manufacturing will progressively move towards global parity.

7. Given that you've built battery analytics, AI and IoT capabilities at your other venture, Datakrew, it would seem natural to bring those into Sunkonnect's inspection work. Has that integration happened in practice, or do the realities of field inspection, remote sites, inconsistent connectivity, and client conservatism make it harder than it sounds?

We have made significant strides in integrating AI-driven analytics and IoT-based monitoring into Sunkonnect's inspection and quality assurance processes, particularly in environments where connectivity and client readiness permit.

For instance, our digital twin solutions and remote monitoring systems allow real-time tracking of equipment performance and predictive maintenance. However, adoption varies by region and project type.

In remote sites with limited connectivity or where clients prefer traditional approaches, we adapt by using hybrid models, combining on-site inspections with periodic digital assessments. Change management and demonstrating clear ROI are key to driving wider adoption of these advanced tools across the sector.

8. What advice would you give to renewable energy developers to avoid quality pitfalls early in their projects?

Start with a quality-first mindset from day one. Engage experienced technical partners early in the design and procurement process. Insist on robust supplier qualification, independent testing, and clear documentation of standards. Invest in digital tools for traceability and real-time quality monitoring. Most importantly, **create a culture of transparency and accountability across stakeholders — developers, EPCs, and suppliers alike.** Early diligence, paired with ongoing oversight, will save time and cost in the long run, while ensuring that your assets deliver reliable and sustainable performance throughout their lifecycle.

Pradyumna Gupta

Founder and Chief Scientist of Infinita Lab and Infinita Materials

Cleantech Supply Chain's Quiet Problem: Component Qualification in the Rush to Deploy

*This article is authored by **Dr. Pradyumna Gupta**, Founder and Chief Scientist of **Infinita Lab and Infinita Materials**. In this article, he explores the importance of bridging materials science, reliability engineering, and system-level safety to enable more resilient and sustainable next-generation technologies.*

Something is quietly failing in cleantech deployments: there's a trend the cleantech industry has so far not wanted to talk about, or even acknowledge publicly. **Solar arrays are failing at rates faster than their expected lifetimes. Battery energy storage systems are being swapped out long before their estimated service lives are up. Electric vehicle charging stations in commercial settings are experiencing failure rates beyond the initial equipment manufacturer's design specifications.** Individually, these failures are not headline-catching, in the way a grid failure might be, but they rather become the cost of warranty work, operational write-offs, or adjusted performance guarantees. Individually, these are relatively small, but collectively, they point to **an industry-wide systemic failure:** an industry that has the capacity to deploy technology faster than it has the means to qualify that technology.

The Pressure to Deploy

India's cleantech sector has reached an inflection point. Ambitious BESS procurement targets from the Ministry of Power, the National Green Hydrogen Mission, and massive expansion in utility-scale solar amount to hundreds of billions of rupees in near-term commitments. Worldwide, the **energy storage market is projected to surpass $500B in cumulative investment** by the end of the decade. Pressure to deploy is real, and coming from all sides at once: from policy mandates, investor timelines, and procurement officials scrambling to meet tender deadlines.

Under this pressure, component qualification gets compressed. Whether a certain cell chemistry, enclosure polymer, busbar coating, or thermal management material is viable for a 15–20 year project life takes a back seat to whether enough inventory can be procured, certified on paper, and shipped on schedule. This compression is understandable. It is also among **the most costly decisions the industry is currently making,** though the tab won't hit the balance sheet for five more years.

Quality Control Is Not Qualification

The key misconception to address is that component qualification is a quality control function at the tail of the supply chain. **It is a risk management decision at the head of the supply chain.** Quality control asks: Does the batch of components conform to the specs against which it was shipped? Qualification asks: **Is the specification itself sufficient for the environment in which it will actually operate for the life of the system?** These are not the same question, and when they get confused, that's how what looked like a compliant system on paper turns into a field liability.

A component that meets an IEC standard under laboratory conditions has established a baseline of conformity; that is all. It has not been established that it will perform according to specification for a decade of thermal cycles within a coastal industrial environment, or after 3000 charge/discharge cycles at elevated temperature due to installation in an inadequately ventilated tropical enclosure. The discrepancy between standard certification and actual field conditions is where premature failures have their roots.

What the Datasheet Does Not Tell You

Let's look at the materials science of a utility-scale BESS system. We select lithium-ion cells based on datasheets that describe behavior at an ideal temperature and at a defined charge/discharge rate. They don't describe what happens to the cell's electrochemistry at 2000 cycles under elevated temperature, how the separator material's structure and function respond to thermal cycling, or what the rate of electrolyte decomposition is at temperatures the cell was never designed to tolerate on a continuous basis. These aren't edge cases. They are the actual operating conditions under which the system will operate while connected to the grid in Chennai, Jaipur, or Ahmedabad.

This problem is systemic. Polymer enclosures used in outdoor electrical assemblies simultaneously experience UV exposure, humidity cycling, and thermal cycling. A material passing a standard weathering test in an environmental chamber may still experience surface degradation, micro-cracking, and dielectric drift under operating conditions not accurately represented by the test protocol. Connector interface surfaces increase contact resistance with each cycle via fretting corrosion, particularly in locations subject to vibration.

The viscosity and conductivity of thermal interface materials used between power electronics and heat sinks will change over their lifespan. Individual materials science literature describes each of these failure mechanisms. What's missing is the aggregation of this knowledge into a structured qualification process prior to procurement decisions in the cleantech supply chain.

Multi-Supplier Trap

The problem is exacerbated by the nature of global supply chains. As Indian cleantech procurement grows, increasing numbers of components—particularly cells, power semiconductors, and specialized polymers—are being supplied from a range of international sources whose manufacturing methods and material compositions may differ in ways not visible in formal documentation.

Cell A and Cell B, despite meeting the same IEC specification, may show very different electrochemical aging responses under the same cycling routine. Qualification test results obtained using Supplier A's component do not necessarily apply to Supplier B's components, even when the specification appears identical. “Same spec means same performance” is often a false assumption. The substitution of one supplier for another mid-project for reasons of availability has led to some of the most expensive and unpleasant shocks in cleantech project delivery in recent years.

Qualification as a Procurement Gate

What changes is the organizational mindset regarding ‘when qualification is intended to occur’ and ‘what it is intended to accomplish’. Leading cleantech operators around the world regard qualification as an input gateway rather than an afterthought. Any new supplier, cell chemistry, or enclosure material, before entering the bill of materials for a project at scale, undergoes a structured process involving accelerated life testing, material characterization, and failure mode analysis.

That process has a cost; however, that cost is a fraction of the cost of a field failure, an early replacement cycle, or a performance guarantee dispute on an asset intended to operate for two decades as a cash-generating system.

Building that capability in India creates a competitive advantage beyond risk reduction. As India seeks to compete for green financing, exports, and foreign infrastructure contracts, strong qualification capabilities may become a source of competitive differentiation. Investors and off-takers in advanced economies demand answers regarding suppliers, materials, and testing history. Those answers either exist inherently within the supply chain from the outset or must be scrambled for later.

The Foundation Beneath the Transition

The energy transition is, at its core, a materials problem as much as it is an engineering or policy problem. The ambition is right. The policy frameworks are improving. The capital is beginning to flow. What cannot be outsourced or deferred is the technical rigor required to ensure that deployed systems actually perform to the standards the transition demands.

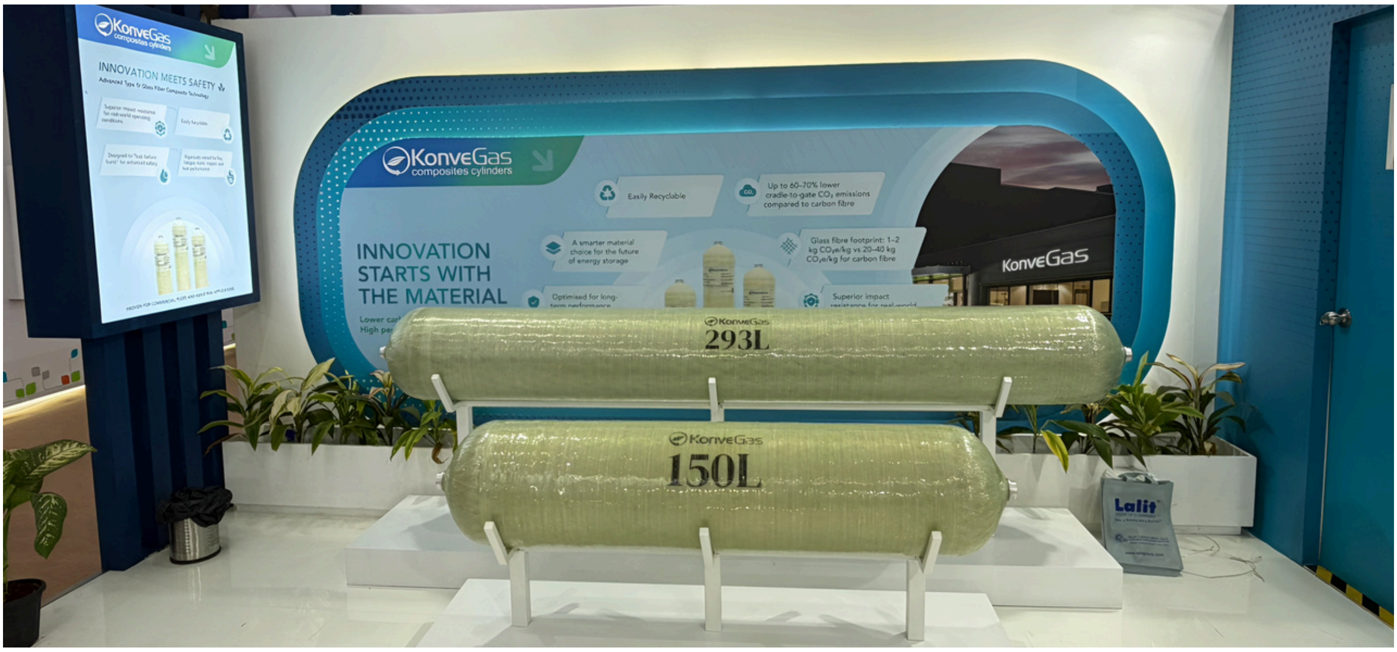
Getting the materials right—and knowing they are right before deployment at scale—is not a technical formality. It is the foundation upon which the reliability of the entire cleantech infrastructure transition will ultimately depend.

Alexander Enulescu

Founder- KonveGas

The Hidden Challenge of Clean Energy: Storage Infrastructure

*The interview with **Alexander Enulescu**, founder of **KonveGas**, looks at the importance of storage systems for making cleaner gases like CNG, biogas, and hydrogen practical and widely usable. It also explains that to truly understand how "green" these technologies are, we need to look at things like what materials they use, how they are manufactured, the emissions involved, and their overall impact across their full life cycle—not just how they perform when in use.*



1. You've described storage as "the primary bottleneck" for clean gas adoption. Specifically, what part of the storage chain—vessel cost, weight, regulatory approval, or local manufacturing capacity—is the biggest constraint today, and how does that vary between CNG, biogas, and hydrogen?

It varies by fuel, but there's a constraint people often overlook: **the vessel itself.**

For **CNG and biogas,** the technology is mature, so the visible constraints are weight and cost. But the deeper issue is the embedded carbon in the storage vessel. If you run renewable biogas but store it in cylinders made from fossil-based, high-emission materials that are produced through energy-intensive manufacturing, you haven't eliminated emissions—you've simply relocated them from the tailpipe to the factory. **The fuel is clean; the storage isn't**.

For hydrogen, the technical bar is higher still. Its physical properties demand more from materials, liner design, and pressure capability. But the same principle applies: a hydrogen vessel produced from fossil-based, energy-intensive materials carries the same embedded-emissions problem. Storing a zero-emission fuel in a high-carbon vessel undermines the very reason for switching to hydrogen in the first place.

So the real bottleneck isn't a single cost line. It's whether the entire storage chain, including the vessel, is genuinely low-carbon. Otherwise, clean gas becomes a way of relocating emissions rather than reducing them.

2. KonveGas builds Type 4 glass fiber composite cylinders rather than Type 3 (carbon fiber) or steel. For a business audience weighing total cost of ownership, what's the economic case for glass fiber over carbon fiber, beyond the headline price difference?

The discussion should focus on **total value rather than material cost alone.**

Different materials bring different advantages. Some chase the lowest possible weight; others rely on established manufacturing routes. For gas storage, KonveGas advanced glass fiber composite cylinders strike the balance: weight savings, cost efficiency, durability, and proven high-pressure performance in one solution.

They also bring local and environmental advantages. KonveGas advanced glass fiber composite cylinders require lower energy use in production than more energy-intensive alternatives, which means lower embedded emissions. And because glass fiber can be sourced locally, it reduces dependence on imported materials, strengthens supply chain resilience, and keeps more value in the local economy.

This matters because total cost of ownership is never set by cylinder price alone. It is shaped by weight, payload, fuel efficiency, production energy, supply chain risk, service life, and the ability to deploy across a fleet or network in a financially realistic way. So the case is not that glass fiber simply costs less. It is that it combines performance, safety, cost efficiency, and local value creation, while keeping embedded emissions lower than more energy-intensive alternatives.

3. Your cylinders are rated for over 25 years of service life. How does that durability translate into a concrete ROI argument for fleet operators or infrastructure developers comparing it against steel's lower upfront cost?

When evaluating storage systems, the conversation should move beyond **initial acquisition cost** and focus on **lifecycle economics**.

A longer service life reduces replacement cycles, minimizes operational disruptions, and lowers long-term asset management costs. Combined with weight reduction and corrosion resistance, this can significantly improve the total cost of ownership over the life of the asset.

For fleet operators, higher efficiency and lower maintenance requirements contribute to stronger operational economics. For infrastructure developers, long-life storage systems provide greater asset utilization and investment stability.

The real value emerges when **durability, operational performance, and lifecycle cost** are evaluated together rather than focusing solely on upfront expenditure.

4. KonveGas serves three very different use cases—onboard vehicle storage, stationary storage, and transport modules. Do these require fundamentally different engineering approaches, or is it largely the same core technology adapted to different certifications?

The core technology platform remains similar, but each application requires dedicated engineering optimization and certification.

The fundamental challenge is always the same: storing gas safely, efficiently, and reliably under pressure. Onboard vehicle storage requires a strong focus on packaging, weight, crash safety, vibration, thermal exposure, and vehicle integration.

Stationary storage systems typically focus on capacity, long-term durability, and infrastructure integration. Transport modules must address logistics efficiency, transportation regulations, and repeated loading and unloading cycles.

While the underlying composite technology is shared, each application involves different performance requirements, regulatory frameworks, and certification standards.

5. Hydrogen storage carries different pressure and embrittlement challenges than CNG or biogas. What design or material adjustments does KonveGas make specifically for hydrogen applications, and is that market currently ahead of or behind CNG/biogas in commercial readiness?

Hydrogen introduces unique engineering challenges because of its **small molecular size, high diffusivity, and demanding storage requirements.**

This requires **specialized liner technologies, optimized composite structures, advanced sealing solutions, and rigorous validation processes** designed specifically for hydrogen service conditions.
From a market perspective, hydrogen remains behind CNG in terms of commercial maturity and infrastructure deployment. CNG has decades of operational experience, while biogas is benefiting from growing policy support and production investments.

Hydrogen’s long-term potential is significant, but the industry is still in the ecosystem-building phase. Storage technology, distribution infrastructure, and refueling networks will all need to expand substantially before hydrogen reaches widespread adoption.

6. You're pursuing local manufacturing in India under the "Make in India" framework. What's driving that decision—import costs and logistics, regulatory requirements, or proximity to OEM customers—and what's your realistic timeline for a local production line?

India represents **one of the world's most dynamic clean-energy and mobility markets.** Local manufacturing supports multiple strategic objectives. It strengthens supply-chain resilience, reduces logistics complexity, improves responsiveness to customers, and aligns with national industrial-development priorities.

Proximity to OEMs, infrastructure developers, and clean-energy projects also enables stronger collaboration and faster market responsiveness.

We continue to evaluate opportunities and partnerships that support long-term manufacturing localization. The objective is to build a sustainable and scalable presence that grows alongside India's clean-energy ecosystem.

7. India's Compressed Bio-Gas and Green Hydrogen infrastructure is scaling quickly. From your vantage point at events like India Energy Week and the BBB Summit, where specifically is India's storage infrastructure lagging behind the pace of production and demand?

India has made remarkable progress in supporting alternative fuel production, particularly in compressed biogas and hydrogen initiatives. The next challenge is ensuring that storage, transportation, and distribution infrastructure expand at a comparable pace.

One area that requires attention is the movement of fuel between production centers and consumption hubs. Another is the continued expansion of refueling and distribution networks that can support growing demand from the transportation and industrial sectors.

The opportunity is significant because infrastructure investments made today will directly influence how rapidly clean fuels can achieve nationwide adoption.

8. You've claimed composite cylinders can cut logistics-related carbon footprint by up to 70%. Can you break down where those emissions savings actually come from—vehicle payload efficiency, fewer transport trips, manufacturing process, or end-of-life impact?

The reduction comes from several factors working together. A major part is the **choice of raw materials** and the energy intensity behind producing those materials. Advanced glass fiber composite technology can offer lower embedded energy and lower embedded emissions compared with more energy-intensive or fossil-based material alternatives.

Weight is another important factor. Compared with heavier storage solutions, a lighter composite cylinder system can improve payload efficiency, reduce fuel or energy use during transport, and, in some cases, reduce the number of trips required for the same delivered gas volume.

Manufacturing also matters. When glass fiber can be sourced locally, it can reduce dependence on imported high-energy materials, shorten supply chains, and support more local value creation.

End-of-life is part of the lifecycle discussion, but the main savings usually come from the combination of lower-impact raw materials, lower energy intensity in material production, lower cylinder weight, better transport efficiency, and longer service life.

The exact reduction depends on the application, cylinder size, transport distance, vehicle configuration, material sourcing, and local energy mix.

9. What does KonveGas's testing and certification process look like in practice—fire, fatigue, burst, impact—and how do you communicate that safety profile to risk-averse industrial buyers who are used to steel?

Safety is the foundation of everything we do.

Composite cylinders undergo extensive testing and certification procedures designed to validate performance under demanding operating conditions. These evaluations typically include **burst testing, pressure cycling, fatigue testing, impact resistance, environmental exposure assessments, and fire-related safety evaluations**, depending on the applicable standards and intended application.

For industrial customers, transparency is essential. Safety is not communicated through marketing claims but through internationally recognized certifications, documented test results, engineering validation, and demonstrated operational performance.

At KonveGas, the objective is to ensure customers have confidence that advanced composite technologies can deliver both superior performance and uncompromising safety.

10. Looking three to five years out, what needs to happen at the policy or infrastructure level—in India or globally—for storage to stop being the bottleneck you describe?

The most important requirement is a **coordinated ecosystem approach.** Governments, industry stakeholders, technology providers, and infrastructure developers must **align investments across the entire value chain.** Fuel production capacity alone is not enough. **Storage, transportation, refueling infrastructure, standards, and certification frameworks** must scale simultaneously.

Stable policy support, long-term infrastructure planning, and continued investment in advanced storage technologies will all play important roles. Over the next three to five years, the countries that successfully integrate production, storage, and distribution into a unified clean-energy ecosystem will be the ones that achieve the fastest and most sustainable adoption of alternative fuels. For India, that opportunity is particularly significant given the scale of its energy transition ambitions.

Avnish Bagaria

Co-Founder and Director of NavPrakriti Green Energies Pvt. Ltd

No Longer Scrap: How Spent EV Batteries Are Powering the Circular Economy

*This article is authored by **Avnish Bagaria**, Co-Founder and Director of **NavPrakriti Green Energies Pvt. Ltd.** In this article, he explores how end-of-life EV batteries are driving the circular economy through recycling, second-life applications, and closed-loop supply chains, highlighting their role in advancing resource security and sustainable mobility.*

The emergence of the EV has precipitated a secondary revolution, one that has garnered considerably less attention but is no less important. As the number of electric cars on the planet begins to increase, a new question arises: What will be done with the batteries when their lifecycle expires? The answer to this question has significant implications for the development of global industrial ecosystems. Rather than being wasted, used EV batteries are becoming an integral part of a developing circular economy.

The Scale of the Opportunity

First, let us talk about **how big this problem is going to become** and why there is such a need to develop a sustainable solution. According to estimates, **worldwide battery demand exceeded 1 TWh in 2024, with over 85% of that coming from EVs.** Given the current rate of growth, **the number of available batteries is likely to increase sevenfold by 2030 and may approach millions of tonnes by 2040.**

There is more than just waste involved here, since **a 75 kWh EV battery cell contains more than $2,000 worth of valuable metals, including lithium, cobalt, nickel, and copper.**

Markets are already beginning to respond to this trend. **The global EV battery recycling market, forecast to be worth under $1 billion in 2024, could grow to almost $24.5 billion by 2035, marking an astonishing compound annual growth rate** (CAGR) **of over 40%.** It seems that **battery recycling will be among the fastest-growing sectors within the overall clean energy economy.**

Turning Waste Into a Resource: The Circular Economy Approach

Historically, battery production and supply chains have followed a linear pattern: **mine, produce, consume, and dispose.** This model is becoming less and less viable. In addition to being resource-intensive, **mining lithium, cobalt, and nickel carries serious geopolitical risks and has substantial negative environmental impacts.** Recycling breaks the mold, reimagining **"waste" as a sustainable source of vital minerals.**

Thanks to advanced technological methods, **95-99%** of cobalt and nickel and up to **95% of lithium can be extracted from batteries.** What sets these materials apart from fossil fuels and allows for their effective recycling is their **capacity for indefinite reuse without any decline in performance.**

Second-Life Battery Economy

While recycling can serve as the end of a battery's life, many batteries are currently finding a new lease on life through "second-life" applications. **Despite having completed their lifecycle inside vehicles, EV batteries usually still retain around 60-80% of their original capacity**, making them suitable for different purposes.

As a result, a second-life battery economy is emerging, in which EV batteries find a new home in stationary power storage units. There have already been initiatives aimed at using recycled EV batteries in microgrids powering thousands of people or stabilizing renewable energy generation.
Importantly, as renewable energy sources such as wind and solar become increasingly prevalent, grid storage is becoming crucial.

Industrial and Economic Changes

The circular battery economy goes beyond sustainable practices by reshaping industrial value chains. **In the circular battery economy market, electric vehicles account for over 53%,** demonstrating that they play an important role as both sources of waste and demand drivers.

A whole new ecosystem based on battery lifecycle management is developing, including collecting, analyzing, repurposing, recycling, and reusing materials within production processes. **More than 90 recycling facilities have already been built, with a combined capacity of 1.6 million tonnes per year.**

Both startups and well-established companies are investing in such practices, establishing closed-loop systems, in which materials obtained through recycling are reused to produce new batteries. Such an approach helps both conserve resources and strengthen supply chains amid the industry's geopolitical fragmentation.

Structural Challenges on the Path to a Circular Economy

Though the concept holds promise, there are a number of structural challenges to the transition to a circular EV battery economy.
First, there is an obvious issue of timing, since **battery production cycles typically last 8-12 years**, meaning there will not be sufficient volumes available for recycling until at least a decade from now.

Second, economic considerations remain a major hurdle. The recycling process is capital-intensive, and price fluctuations could affect its cost efficiency. At the same time, the logistics of transporting and handling batteries also incur considerable costs.

Third, technological obstacles exist because there are many different EV batteries using various chemistries and technologies. Newer chemistries, such as LFP, are even less economically feasible to recycle because they contain fewer valuable materials.

Finally, even under optimistic assumptions, recycling will still contribute only a relatively modest share of the materials needed by 2040.

Policy, Innovation, and What Comes Next

It is only now that governments and policymakers have started playing an integral role in accelerating the adoption of circular solutions. For example, **the European Union has mandated minimum recycling efficiency levels and increased recycled content requirements for future batteries.** Policies of this nature are necessary to establish **a market that supports and rewards recycling.**

Moreover, **innovation is progressing rapidly.** The use of technologies such as **battery passports and AI-driven diagnostics** is enhancing the traceability and efficiency of the recycling process. Additionally, **new technologies for more efficient and cost-effective material recovery** continue to be researched and adopted.

Finally, businesses are also adapting their models. **Automakers are exploring battery leasing and take-back programs** that help ensure a steady supply of batteries for recycling.

From Liability to Resource

The story of used battery packs from electric vehicles is changing in a fundamental way. **What was once viewed as a liability is becoming a valuable resource.**

Circular thinking is about creating economies where growth does not depend on the continual consumption of new resources. When it comes to electric vehicles, this means creating **a closed-loop system**, where batteries are continuously repurposed and recycled.

With the emergence of the mass EV market, **companies and countries that succeed in building this circular model will gain a significant competitive advantage.** Not only will they reduce their environmental impact, but they will also secure long-term access to critical resources.

Bidisha Banerjee

Research Associate - Indian Council for Research on International Economic Relations

Beyond Electrolysis: Bringing Biomass into India’s Hydrogen Future

*The article, written by **Bidisha Banerjee**, Research Associate at **Indian Council for Research on International Economic Relations**, explores how agricultural biomass can be integrated into India’s green hydrogen strategy. It highlights the role of crop residue utilisation in reducing stubble burning and supporting a decentralised and inclusive clean energy transition.*

Two Unfinished Revolutions

Every winter, a familiar crisis overtakes northern India as smoke from burning crop residues blankets cities, becoming an all-too-common sight. The result, as we all know, is air pollution reaching hazardous levels. However, what is widely treated as an environmental inconvenience is, in fact, a vast untapped energy resource. **India produces over 228 million tonnes of surplus agricultural biomass annually**—an enormous resource that is routinely burnt, wasted, or underutilised.

At the same time, the country is exploring new opportunities in advanced renewable energy technologies through green hydrogen, **targeting the production of 5 million tonnes of green hydrogen annually by 2030.** However, this strategic priority remains largely centralised and capital-intensive. **Can these unresolved crises and extraordinary opportunities be brought together?**

The Ignored Biomass Problem

Most agricultural biomass consists of residues from rice, wheat, and sugarcane, followed by other crops that remain after harvest. Burning these residues is a major contributor to ambient particulate matter. While schemes such as **Sustainable Alternative Towards Affordable Transportation** (**SATAT**) **and Galvanizing Organic Bio-Agro Resources Dhan** (**GOBARdhan**) offer alternatives, they absorb only a fraction of the available supply and remain insufficient in scale.

The existing biomass utilisation pathways—which focus on power generation, compressed biogas, and pelletisation for co-firing—also absorb only a small share of the available biomass. Moreover, they offer limited farmgate returns, despite biomass having the potential to strengthen rural energy security rather than remain a pollution liability.

The Hydrogen Ambition

India's National Green Hydrogen Mission (NGHM) emerged from the growing need to promote advanced renewable energy technologies. The rationale is clear: hydrogen is essential for decarbonising fertilisers, refineries, steel production, and long-haul transport, where direct electrification is not viable.

However, the Mission is currently designed almost entirely around large-scale electrolysis powered by solar and wind energy. Projects are concentrated in renewable-rich industrial corridors across Andhra Pradesh, Gujarat, Rajasthan, and Tamil Nadu, with the primary focus on industrial consumption and export markets.

In addition, **electrolysis-based hydrogen remains expensive, with production costs currently ranging from INR 397-560 per kilogram of hydrogen.** This pathway also requires significant land, water, grid infrastructure, and capital investment. Consequently, India's hydrogen ambition, as presently structured, generates almost no direct rural linkage. Farm households, which constitute a major share of India's workforce, have little stake in this transition—neither as producers, suppliers, nor beneficiaries.

The Convergence in Need

There is, indeed, a **thermochemical pathway** capable of integrating these two fragmented sectors into a single technical and strategic opportunity. **Agricultural biomass can serve as a feedstock for hydrogen production.** Depending on the conversion technology employed, **one tonne of dry biomass can produce approximately 40-100 kilograms of hydrogen**.

The principal advantage of biomass over other renewable feedstocks is that the resource is already geographically distributed across virtually every agricultural state in India, enabling decentralised production close to the source.

Technologies Worth Betting On

Not all biomass-to-hydrogen pathways are equally suited to Indian conditions. **Three technologies stand out.**

First, biomass gasification is the most mature technology. Agricultural residues are converted into syngas at high temperatures, followed by hydrogen separation. It integrates well with agri-processing clusters and, when combined with carbon capture, can produce carbon-negative hydrogen.

Second, anaerobic digestion with biogas reforming is the most immediately deployable option. Wet organic wastes—including cattle dung and agro-industrial effluents—are converted into biogas, which is subsequently reformed to produce hydrogen. This pathway builds directly on India's existing compressed biogas infrastructure, requires moderate capital investment, and aligns naturally with village-scale energy systems.

Third, **pyrolysis reforming** offers a modular approach in which biomass is thermally decomposed to produce hydrogen precursors while generating biochar as a valuable co-product. Biochar improves soil fertility, can qualify for carbon credits, and transforms a hydrogen production facility into a regenerative agriculture asset.

All three technologies share a critical advantage over electrolysis: **they are inherently decentralised and scalable through replication rather than concentration.**

The Missing Middle

The opportunity for convergence exists, but **the policy architecture does not—yet**.
India's **National Green Hydrogen Mission remains overwhelmingly focused on renewable electricity-based electrolysis, while existing bioenergy schemes do not treat hydrogen as a priority end-use**. There are no standardised biomass procurement contracts, no floor prices for hydrogen-oriented residue markets, and no dedicated financing mechanisms for decentralised biomass-to-hydrogen systems.

Meanwhile, the Ministry of New and Renewable Energy (MNRE), Ministry of Agriculture and Farmers Welfare (MoAFW), Ministry of Petroleum and Natural Gas (MoPNG), and Ministry of Power (MoP) each hold a part of the solution, yet no integrated coordination mechanism exists to bring these efforts together.

What Must Change

Four interventions are essential.

First, the National Green Hydrogen Mission must move beyond pilot projects and establish dedicated incentive streams for biomass- and waste-based hydrogen.

Although these pathways are recognised in principle, financial support and deployment remain overwhelmingly focused on electrolysis.

Second, a dedicated component for decentralised hydrogen, analogous to SATAT for compressed biogas, should be established, with cooperative ownership at its core rather than as an afterthought.

Third, targeted financial instruments—including viability gap funding, credit guarantees, and interest subvention—should be specifically designed for small- and medium-scale biomass-to-hydrogen plants.

Fourth, a cross-ministerial coordination platform should be established to bring together all relevant ministries under a common deployment framework.

The Way Forward

India's hydrogen future need not be confined to large industrial hubs. It can begin in its fields.
The biomass exists. The hydrogen ambition exists. What is needed now is the policy resolve to connect them.

The same seasonal cycle that engulfs northern India with particulate matter every winter can, with the right policy architecture, contribute to a decentralised hydrogen economy that reaches where electrolysers never will—the farm, the cooperative, and the rural cluster.

India has never lacked resources. It has often lacked the imagination to see them as assets rather than problems.

Crop residue is the latest test of that imagination. **The resource is renewable. The policy window is not.**

Yamaha Launches FZ Blue Flex to Advance Ethanol-Based Sustainable Mobility

India Yamaha Motor Pvt. Ltd. has introduced the **Yamaha FZ Blue Flex**, a flex-fuel motorcycle designed to support India's transition toward cleaner and more sustainable transportation. The launch marks Yamaha's entry into ethanol-compatible mobility solutions, aligning with the country's efforts to reduce dependence on fossil fuels and promote renewable energy in the transport sector.

The motorcycle is powered by a **149cc air-cooled, fuel-injected engine** and is engineered to operate on **ethanol-blended fuels ranging from E20 to E85**. This flexibility enables the use of higher ethanol blends while maintaining the performance and reliability expected from everyday commuter motorcycles.

The introduction of the FZ Blue Flex reflects India's broader strategy to expand the use of biofuels and accelerate the adoption of low-carbon mobility solutions. By encouraging the use of renewable fuels, flex-fuel vehicles like the Yamaha FZ Blue Flex can contribute to lower vehicle emissions, improved energy security, and a more sustainable transportation ecosystem.

Maruti Suzuki Expands Biogas Infrastructure to Strengthen Sustainable Manufacturing

MARUTI SUZUKI

Maruti Suzuki India Limited has announced two new biogas initiatives as part of its efforts to strengthen sustainable manufacturing and integrate renewable energy into its operations. These projects support the company's commitment to environmentally responsible practices while aligning with India's clean energy objectives.

The company will establish a **10 tonnes per day biogas plant** at its **Kharkhoda facility**, with commissioning scheduled for **FY 2026-27**. In addition, Maruti Suzuki will expand the capacity of its existing **Manesar biogas plant** from **0.2 tonnes per day to 0.7 tonnes per day**, increasing its renewable energy generation capability.

Maruti Suzuki has committed an investment of **INR 150 crore** for the two projects. The initiatives are aligned with the Government of India's **Waste-to-Wealth** mission and are expected to promote efficient waste utilization, support cleaner energy adoption, and enhance sustainability across the company's manufacturing operations.

Investments & Project Financing

Company	Update	Key Figures	Location
Sunsure Energy	Secured project financing from FMO & Axis Bank for a 75 MWp open access solar project; FMO's first India Group Captive C&I financing.	₹262 crore	Ilayangudi, Tamil Nadu
Inox Clean Energy	Received investment from Adar Poonawalla Family Office at a ₹70,000 crore valuation, following 10 acquisitions in 10 months.	₹700 crore	-
Continuum Green Energy	Secured investment from a Chubu Electric Power Co., Inc. affiliate via equity subscription & share acquisition to expand wind, solar, hybrid and BESS portfolio.	₹1,350 crore	Pan-India
SolarSquare (led by B Capital)	Raised a funding round to expand its full-stack residential rooftop solar platform.	$53 million	-
DCM Shriram	Approved investment to expand renewable energy capacity at its manufacturing facility; expected completion June 2027.	₹217 crore / 48 MW	Bharuch, Gujarat
Karo Sambhav	Raised a pre-Series A round led by Rainmatter by Zerodha to expand recycling infrastructure.	₹56 crore ($6M)	-
Roofsol Energy	Secured funding from Aseem Infrastructure Finance to expand solar IPP & C&I solar projects, incl. JK Tyre installations.	₹260 crore / 100 MWp	-
Serentica Renewables	Secured financing led by the Asian Development Bank (ADB) for a hybrid renewable project supplying to BALCO.	395.4 MW (191.4 MW solar + 204 MW wind)	Koppal, Karnataka
Black Mass Energies	Raised pre-seed funding from a US-based angel investor to support battery-recycling R&D and sales expansion.	$114K (₹1.1 crore)	-
GPS Renewables	Completed a Series C round to accelerate its compressed biogas (CBG) project pipeline; investors include PixelSky Capital, Sojitz Corp & IOC.	₹635 crore	-
Granarium Technologies	Raised pre-seed funding led by BSV Ventures to industrialise nanocellulose-based supercapacitor storage tech.	€1 million+	-

Projects, Contracts & Tenders

Company	Update	Key Figures	Location
Hartek Group	Secured a utility-scale solar EPC project (two 200 MW plants); scope covers engineering, procurement, construction, commissioning & grid interconnection.	400 MW (299.2 MWac)	Rajasthan
ACME Group	Developing a green ammonia project with supply commitments through SECI and Japan's LTDA program.	800,000 TPA	Paradip, Odisha
Prozeal Green Energy	Developing a captive solar power project in partnership with a steel & mining company for industrial decarbonisation.	60 MWp	Uttar Pradesh
NTPC Renewable Energy Ltd (NTPC REL)	Invited EPC bids for grid-connected solar PV; contractor to handle execution, commissioning & 3 yrs O&M via reverse auction.	600 MW (300/600 MW packages)	Dhule, Maharashtra
Solex Energy Limited	Secured an order from a global renewable energy group to supply N-Type TOPCon G12R Glass-to-Glass solar modules (615/620 Wp).	₹628.37 crore	Manufactured near Surat, Gujarat
Pace Digitek Limited	Secured a contract for a BESS project covering design, engineering, supply, installation, testing, commissioning & 12 yrs O&M.	250 MW / 500 MWh	Maithan, Jharkhand
Suzlon Group	Secured an EPC contract from Tata Power Renewable Energy (TPREL) for a wind project; will install 127 S144 turbines (3.15 MW each) incl. BoP & O&M.	400 MW	Anantapur, Andhra Pradesh
Sterling and Wilson Renewable Energy	Secured the West Minya Solar Power Project order via its 50:50 joint venture with Hassan Allam Construction, incl. solar PV plus Battery Energy Storage System capacity.	USD 560 million (1,000 MWac + 600 MWh BESS)	Egypt
Ayana Renewable Power Ltd.	Emerged successful bidder in MPPMCL's e-reverse auction for wind power procurement, with a greenshoe option for expansion.	800 MW (expandable to 1,600 MW)	Madhya Pradesh
RENA Technologies	Secured a contract to supply solar cell production equipment to EMMVEE Energy for TOPCon manufacturing, incl. wastewater systems & technical support.	6 GW	India
Bondada Group	Secured an EPC contract from NTPC Renewable Energy for a solar project with BESS, to supply power to defence establishments.	₹1,338 crore (250 MW + 50 MW/200 MWh BESS)	Sitapur, Uttar Pradesh

MoUs, Strategic Partnerships & PPAs

Company	Update	Key Figures	Location
ACME Group & IHI Corporation	Developing a Japan-certified green ammonia project under Japan's CfD & LTDA hydrogen support programs; targeted commissioning July 2030.	405,000 TPA	Gopalpur, Odisha
Meta Platforms & CleanMax	Announced a partnership to develop solar & wind capacity; Meta to procure environmental attributes, expanding collaboration beyond 900 MW.	837 MW	Rajasthan & Karnataka
ONGC Green Limited & NHPC Limited	Signed an MoU to collaborate on pumped hydro storage and renewable energy projects, supporting ONGC's energy transition goals.	-	-
Havells India Ltd. & Pixii AS	Signed an MoU to develop & introduce Battery Energy Storage Systems for India, incl. pilots, co-development & local manufacturing.	-	-
Hindustan Zinc, Advantek Associates & Aeroeagle Automobiles	Signed an MoU to explore hydrogen fuel & clean energy solutions for mining operations, supporting net-zero target by 2050 or earlier.	-	-
Lineage Power (Pace Digitek) & Bondada Group	Signed an MoU to supply integrated Battery Energy Storage System solutions for future projects — LPPL's third MoU during IESW 2026.	-	-
Lineage Power (Pace Digitek) with Onward Solar Power & Kalpa Power	Signed two MoUs to serve as preferred BESS supply partner for utility-scale and C&I energy storage projects.	-	-
Inox Wind & Inox Clean Energy	Signed an MoU to supply wind turbines, supporting INOXGFL Group's integrated renewable strategy and strengthening Inox Wind's order pipeline.	1,500 MW	Pan-India
Ceigall Morena Solar BESS Park & Rewa Ultra Mega Solar Ltd	Signed a PPA for a solar power project with battery storage, incl. construction and long-term operations.	220 MW / ₹1,700 crore	Morena Solar Park, Madhya Pradesh
BluPine Energy, Craftsman Automation & Sunbeam Lightweighting Solutions	Signed long-term Open Access PPAs to supply solar power for manufacturing operations under the Electricity Act, 2003 captive provisions.	21 MWp	Rajasthan project
Hexa Climate & NHPC	Signed a 25-year PPA for an FDRE project to supply PSPCL, supporting grid reliability and avoiding ~7.47 lakh tonnes CO2 annually.	160 MW / ₹4.33 per kWh	-

Commisionings, Acquisitions, & Milestones

Company	Update	Key Figures	Location
Jupiter International	Inaugurated a TOPCon solar cell facility to expand solar manufacturing and boost high-efficiency cell production.	1.25 GW	Baddi
KP Group (KP Energy Limited)	Commissioned Phase 1 of a wind power project (16 Suzlon turbines, 3.15 MW each), developed for NTPC Renewable Energy Limited; achieved COD.	50.4 MW	Vanki, Nakhatrana, Kutch, Gujarat
Hexa Climate	Commissioned the Wardha Solar Plant, expected to generate ~180 million units annually and avoid ~147,000 tonnes CO_2 per year.	80 MW	Wardha, Maharashtra
Radiance Renewables	Commissioned a solar project supporting its target of 2 GW operational capacity; designed for future BESS integration.	87 MWp	Korwar, Karnataka
Ministry of Petroleum and Natural Gas	Approved assistance for India's first private-sector Hybrid 2G Ethanol Project; the biorefinery will convert agri-residues into ethanol.	₹150 crore / 91 KLPD	Uttar Pradesh
Adani Energy Solutions Ltd. (AESL)	Agreed to acquire 100% of IntelliSmart Infra Pvt Ltd (subject to approvals), expanding its smart meter portfolio to over 4.7 crore meters.	₹3,050 crore	-
Saatvik Green Energy Limited	Acquired an equity stake in MELCON Transformers and Electricals to strengthen transformer manufacturing & energy infrastructure.	80% stake	-
Nexgen Exhibitions	Survey projects a rise in drone deployment across India's logistics, security & cleantech sectors over the next three years.	55% increase (3-yr outlook)	India
Sunkonnect's Sunsol Cleantech	Plans to deploy solar capacity across India through 5,000 projects by 2030, offering end-to-end solar solutions.	2 GW+	Pan-India
Sanwaliya Windtech	Installed wind turbine generators across projects for Vibrant Energy, JSW Energy, ReNew Power & BluPine Energy, expanding wind infra.	126 WTGs	Multiple states