ICLEI
Local Governments for Sustainability

Battery Recycling and end of life - *Current State, Preparedness, and Entrepreneurship for Himachal Pradesh*

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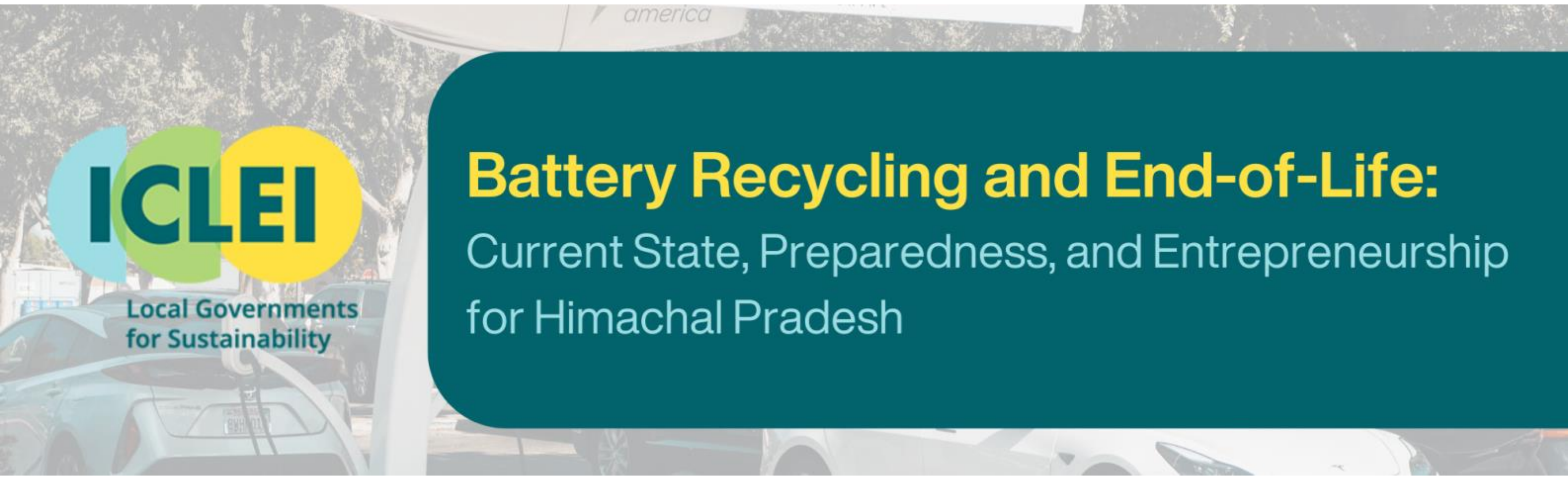


1. Executive Summary

The rapid adoption of electric vehicles (EVs), propelled by the need to reduce carbon emissions, has significantly increased the demand for lithium-ion batteries. While EVs offer an environmentally cleaner alternative to internal combustion engines, their batteries pose considerable environmental challenges due to toxic components and complex end-of-life (EoL) management. This report examines the **lifecycle of EV batteries, focusing on extraction, usage, second-life applications, and recycling, with an emphasis on India's evolving EV ecosystem and the unique context of Himachal Pradesh**.

Despite government policies and increasing EV usage in semi-urban regions like Paonta Sahib, Himachal Pradesh lacks the necessary infrastructure for safe and effective battery recycling. Field research reveals **gaps such as poor subsidy awareness, limited recycling units, and over-reliance on informal waste handlers**. However, the state's renewable energy potential and industrial clusters like Baddi present an *opportunity to develop a circular battery economy through localized collection hubs, refurbishment centres, and strategic public-private partnerships.*

Second-life applications for EV batteries such as *grid storage, telecom tower backup, and EV charging support* are particularly viable in Himachal's context, given its dispersed geography and reliance on hydroelectric power. Additionally, a single **77kWh recycled battery** can generate an **economic benefit exceeding ₹1.1 lakh**, demonstrating the untapped financial and environmental potential of battery circularity. Global best practices, including Tesla's modular battery designs and Japan's centralized tracking systems, offer replicable models for India.

The report recommends integrating battery lifecycle management into Himachal Pradesh's EV policy, initiating pilot projects for battery passports and localized refurbishment, and establishing a single-window clearance for recycling startups. By formalizing informal sectors, promoting second-life battery use, and investing in skill development, *Himachal Pradesh can position itself as a leader in India's sustainable mobility transition and battery circular economy.*

2. Introduction to EVs & Batteries

The sudden surge in the market of Electric Vehicles (EVs) is an outcome of the growing threat of carbon emissions that has surfaced worldwide. Taking a leap into the same, India has been no exception in rapidly pacing the adoption of EVs in Indian markets. This rampant adoption triggers great pressure on the manufacturers to fulfil the demand that has suddenly shot up, which eventually trickles down to the massive demand for the energy sources required to power EVs, i.e., EV Batteries. These batteries comprise rare-earth metals such as lithium, nickel, cobalt, manganese, etc., which are sourced via extensive mining processes, making it an environmentally hazardous method to save the environment.

Some of the EV battery types are lead-acid, Ni-Cd, Ni-Zn, Zn/air, Ni-MH, Na/S, Li-polymer, and Li-ion batteries. **Lithium-ion batteries** have gained significant popularity amongst OEMs (Original Equipment Manufacturers) due to their manufacturing and scale-friendly properties. Today, nearly all the EVs produced worldwide use lithium-ion batteries, making them synonymous with EV batteries in the industry.

Even before the advent of EVs, Lithium-ion batteries have been an integral part of routines in almost all the electronic battery-operated devices available out there. May it be mobile phones, laptops, tablets, or electronic toothbrushes, lithium-ion batteries are the power sources for all these consumer electronics. With such a dominant usage, these batteries pose an equally severe environmental risk.

The **disposal of lithium-ion batteries** has been discussed and questioned for decades. The following is the world's view on the same:

> "Improper disposal of lithium-ion batteries increases the risk of health, water, and land degradation. Overall, it harms human health and the ecosystem."
>
> **— *Marching Ants, 2024***

> "Even the smallest amount of water, or water-based liquid, will be enough to ignite a damaged lithium battery. Not only is this highly dangerous, but if it happens during the transportation or recycling process, then the damage could be extensive, and lives could be put at risk."
>
> **— *Grundon, 2022***

> "Lithium-ion (Li-ion) batteries and devices containing these batteries should not go in household garbage or recycling bins. They can cause fires during transport or at landfills and recyclers. Instead, Li-ion batteries should be taken to separate recycling or household hazardous waste collection points."
>
> **— *"Frequent Questions on Lithium-Ion Batteries | US EPA," 2020***

> "Improperly disposed vape batteries not only pose a fire risk but also contribute to environmental pollution. These batteries contain valuable materials that can be recycled and reused, preserving natural resources. Additionally, the financial cost of battery fires is significant. Insurance claims related to lithium battery fires can reach up to £20 million, highlighting the economic impact of these preventable incidents."
>
> **— *Lampropoulos, 2024***

Also, the batteries used in EVs are significantly larger than those found in regular consumer electronics. For instance, **a single 77 kWh EV battery** contains approximately the same energy capacity as about **4,162 mobile phone batteries**, each with a capacity of 5,000 mAh. This, in turn, points to the rising concern about EV battery disposal, given the rising demand for EVs in the market.

EV batteries are designed to retain a significant portion of their capacity throughout their lifespan. Typically, an EV battery is considered to have reached its end of life (EoL) when its **efficacy drops down to about 70-80% of its original value**. This means that during its operational life in the vehicle, approximately 20-30% of the battery's initial capacity is utilized before it is deemed unsuitable for automotive use.

Quick Fact!

Tesla's 2023 Impact Report indicates that the average battery capacity loss for **Model 3 and Model Y** Long Range versions is about 15% after 200,000 miles, suggesting that 85% of the battery's capacity remains usable at that point. *(Kane, 2024)*

EV batteries are engineered for durability, most lasting **7 to 10 years** before requiring replacement. Post replacement, these batteries still hold 70%-80% of their original capacity, which builds the potential for its **second-life applications (reuse)** and subsequent recycling.

India's growing EV market, fuelled by government initiatives like **PM E DRIVE and state-level EV policies**, highlights the urgent need for a **robust end-of-life (EoL) battery ecosystem**. The country's dependency on imported lithium, cobalt, and nickel not only exacerbates supply chain vulnerabilities but also poses a strategic challenge to energy security. With projections of over **70 GWh of waste batteries by 2030**, India has a unique opportunity to establish itself as a global leader in battery circularity by developing advanced recycling infrastructure, fostering second-life applications, and creating awareness about sustainable disposal practices.

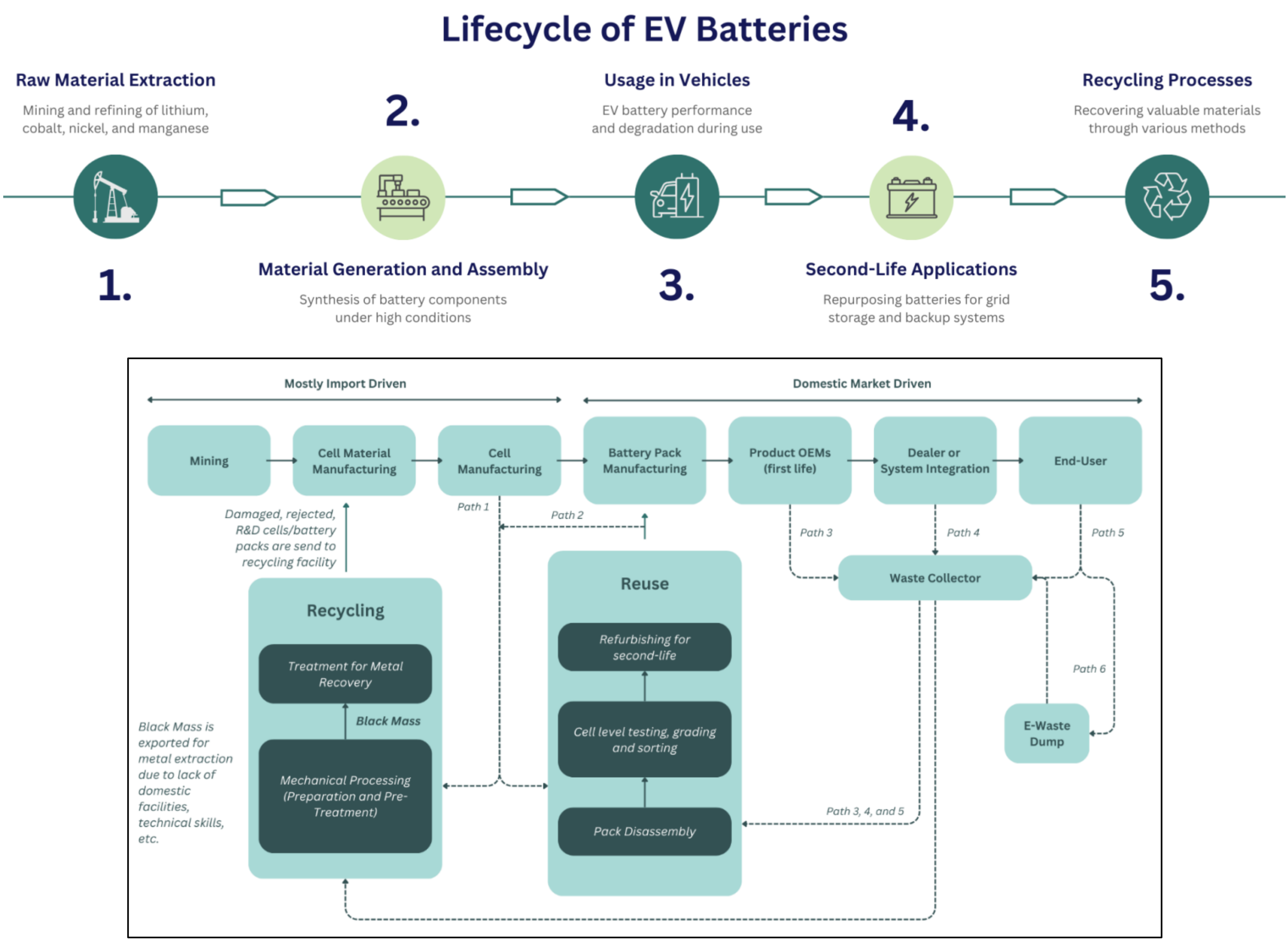
This report explores the **EV battery EoL ecosystem from a managerial, entrepreneurial, and policy viewpoint**. The importance of an EoL treatment of EV batteries in the details of repurposing these batteries will be discussed, keeping India's practicalities in check. The report further dives deeper into the current state, preparedness, and entrepreneurial opportunities for EV battery EoL treatment in the state of Himachal Pradesh. The report concludes with suitable recommendations to enhance the EV battery EoL ecosystem for Himachal Pradesh as a whole.

3. Lifecycle of EV Batteries and End-of-Life (EoL) Considerations

3.1 Lifecycle of EV Batteries:

The lifecycle of an electric vehicle (EV) battery is characterized by five critical phases: raw material extraction and refining, material generation and assembly, usage within vehicles, second-life applications, and recycling. Each stage is crucial to understanding EVs' environmental and economic impact and assessing their cycle's sustainability.

Fig: India-specific detailed life cycle of EV Batteries (NITI Aayog)



Raw Material Extraction and Refining

EV batteries primarily consist of lithium, cobalt, nickel, and manganese, requiring extensive mining and refining processes before manufacturing. The extraction process is notably energy-intensive and ecologically invasive.

Material Generation and Assembly

After raw materials are refined, these components are synthesized into battery elements, including cathodes, anodes, and electrolytes.

Usage in Vehicles

EV batteries, typically lithium-ion-based, are engineered to provide high energy density, efficiency, and longevity. During initial vehicle usage, they undergo charge and discharge cycles that gradually reduce capacity. This degradation is influenced by factors such as:

- **Charging Practices**: High charging rates or frequent fast charging can accelerate capacity loss.
- **Temperature Variations**: Extreme high and low temperatures negatively impact battery chemistry, speeding up degradation.
- **Usage Patterns**: High demand driving scenarios, such as heavy acceleration or towing, strain the battery, reducing its lifespan.

A typical EV battery can maintain its operational capacity for approximately **8–10 years or around 3000 to 5000 full charge cycles** *(Casals, Amante García, Aguesse, & Iturrondobeitia, 2017)*. Effective monitoring of the State of Charge (SoC) and temperature during charging is vital for maximizing battery lifespan.

3.2 Second-Life Applications:

Post-vehicular use, EV batteries often retain between 60% and 80% of their original capacity, making them suitable for secondary applications. Common second-life utilizations include grid energy storage, backup power systems, and renewable energy storage, wherein high-power density is not as critical *(Ahmadi, Yip, Fowler, Young, & Fraser, 2014)*. By facilitating secondary use, the lifespan of the batteries can be extended by an **additional 5 to 10 years**, thereby reducing the environmental footprint associated with producing new batteries *(Casals et al., 2017)*.

3.3 Recycling:

Recycling processes play a pivotal role in recovering valuable materials such as lithium, cobalt, and nickel, reducing the dependence on raw material extraction. Several established and emerging methods are used for recycling, each with distinct advantages and limitations:

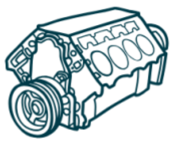
Method	Mechanical Recycling	Pyrometallurgy	Hydrometallurgy	Direct Recycling
Description	Shredding and crushing processes to separate black mass (metal oxides, graphite, etc.).	High-temperature process that smelts materials into metal alloys and slag.	Leaches metals (e.g., lithium, cobalt) using chemical solutions for high-purity recovery.	Refurbishes electrode materials (e.g., cathodes) without reducing them to elemental forms.
Advantages	Simplifies material recovery and prepares for further processing.	Short process flow, low equipment requirements, strong operability	Low energy consumption, great versatility, high product purity, high recovery efficiency	Energy-efficient and preserves material integrity.
Disadvantages	Generates impurities requiring further treatment.	High energy consumption, poor metal purity, difficulty in lithium recovery	Need to dispose of large amounts of acid and toxic wastewater, long recovery process	Complex regeneration process; not yet industrialized.
Main Source of Pollution	Dust generation; energy consumption	Emission of polluting gases and production of slags	Release of toxic gases (e.g., NO_x, SO_x, CO)	Minimal; focused on preserving material integrity

Some processes which are not yet applicable in the industry but are giving promising results:

- **Biometallurgy**: Microorganisms, such as bacteria, extract metals from battery materials.
- **Solvometallurgy (DES)**: Deep Eutectic Solvents selectively dissolve and recover metals from battery materials.
- **Solvometallurgy (Ionic Liquid)**: Ionic liquids extract metals with high selectivity and efficiency.

3.4 Strategic Initiatives for Himachal Pradesh:

Electric vehicle (EV) deployment in mountainous and cold-climate regions like Himachal Pradesh demands a **region-specific strategic framework** to ensure performance, sustainability, and long-term adoption. Unlike urban centres, the **state faces unique environmental and infrastructural constraints,** from sub-zero temperatures to limited recycling capabilities, that directly impact battery performance and end-of-life (EoL) handling. To navigate these challenges, it is essential to explore innovative thermal management systems, adopt cutting-edge battery technologies, and invest in localized infrastructure.



Advanced Thermal Management Systems

Adoption of All-Solid-State Batteries (ASSBs)

Recycling Infrastructure Development

Localized Battery Aggregation Hubs

Advanced Thermal Management Systems:

- Liquid cooling and phase-change materials (PCMs) are critical for maintaining battery efficiency in cold weather experienced by Himachal Pradesh.
- Preconditioning techniques can enhance battery longevity, ensuring reliability in high strain driving scenarios.

Adoption of All-Solid-State Batteries (ASSBs):

- ASSBs offer broad temperature resilience and better reliability, making them ideal for the region's demanding applications.

Recycling Infrastructure Development:

- Himachal Pradesh lacks an advanced recycling framework, making infrastructure development a priority.
- A hybrid recycling strategy (mechanical pre-processing + hydrometallurgical extraction) is suitable, as seen in China and South Korea.
- This method recovers valuable metals and supports local cell and component manufacturing.

Localized Battery Aggregation Hubs:

- Establishing battery aggregation hubs streamlines collection logistics and improves efficiency.

By adopting a **hybrid recycling model**, the state can reduce dependency on external sources and foster economic growth in renewable energy in the region of Himachal Pradesh.

4. Second Life of Batteries (SLB)

With the increasing reliance on battery technology, managing batteries after reaching the end of their useful life is becoming a growing concern. The current recycling capabilities for modern battery chemistries, particularly lithium-ion cells, are insufficient, leading to many discarded batteries being sent to landfills without recycling.

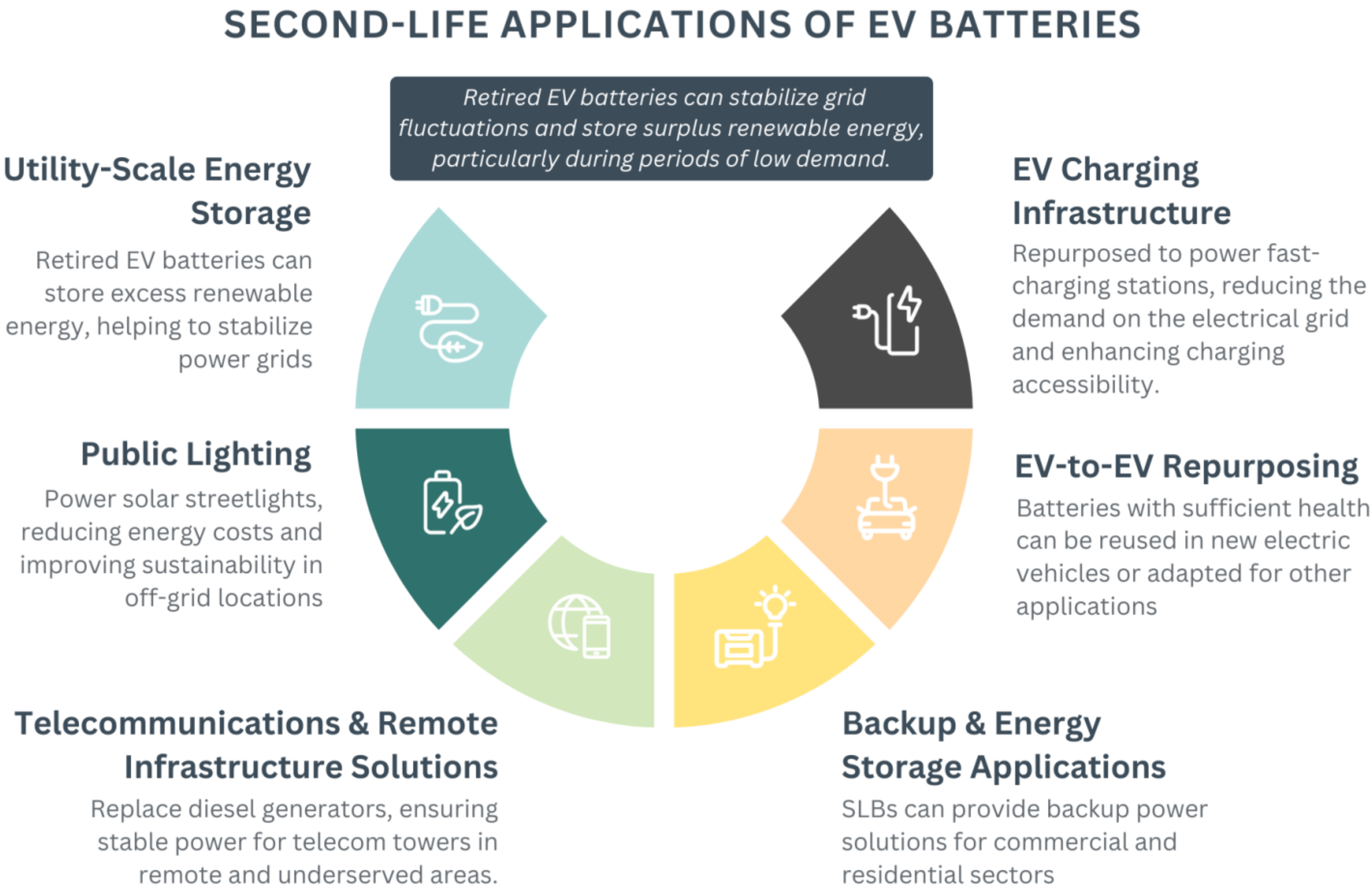
Considering these challenges, repurposing used batteries for secondary applications is gaining considerable attention. This trend is partly influenced by the rising adoption of electric vehicles, which will produce a large volume of old batteries once their operational lifespan has elapsed. Retired EV batteries retain approximately 80% of their original capacity, making them suitable for various energy storage system (ESS) applications, particularly within the utility sector, despite being less effective for traction use *(Hossain et al., 2019)*.

Psychological factors, such as "**range anxiety**" *(Un-Noor et al., 2017)*, can also contribute to the premature disposal of EV batteries when their capacity diminishes by around 20%. The potential for utilizing EV batteries for second-life applications will be explored further, as most of the existing literature tends to focus on the enhanced usability of these batteries beyond their initial purpose. In this context, the term "second life" will be consistently used throughout this paper to refer to repurposed batteries after their original intended functionality has concluded.

4.1 Potential Markets for SLB:

From an economic point of view, the second-life battery applications can be categorized into two business options. The first option corresponds to using the batteries for large applications such as providing support to renewable energy sources such as wind or solar, etc., and transmission. The second option is the smaller energy applications, which include residential consumers, commercial consumers such as telecommunication companies, food distribution centres, and light commercial buildings.

4.2 Second Life Applications of EV Batteries:



Utility-Scale Energy Storage: The India energy storage market is projected to grow **from 233.78 MWh in 2024 to 6,637.31 MWh by 2033, with a CAGR of 41.70% during 2025–2033**. Retired EV batteries play a crucial role in grid energy storage by stabilizing power grids and storing surplus energy from renewables like wind and solar. The **"RMI Winery Microgrid Project"** successfully incorporated second-life Nissan Leaf batteries into a microgrid framework *(Colthorpe, 2018)*. Similarly, BMW, Vattenfall, and Bosch used batteries from over **100 vehicles in Germany to build a 2 MW, 2800 kWh storage system** further validate the use of second-life batteries for managing peak loads and frequency regulation.

Backup and Energy Storage Applications: Second-life EV batteries are increasingly being used in **commercial, industrial, and residential** sectors to ensure reliable backup power and enhance energy autonomy. In commercial settings, GM and ABB developed a 25-kWh energy storage prototype using Chevrolet Volt batteries to provide robust backup solutions (e.g., in San Francisco). Similarly, in residential areas, these batteries store solar energy for use during peak demand and power microgrids in remote locations. For instance, **Toyota repurposed 208 NiMH batteries** from hybrid vehicles to build an **85-kWh energy storage system**, powering a **40-kW solar PV system** at Yellowstone National Park *(Gordon-Bloomfield, 2018)*.

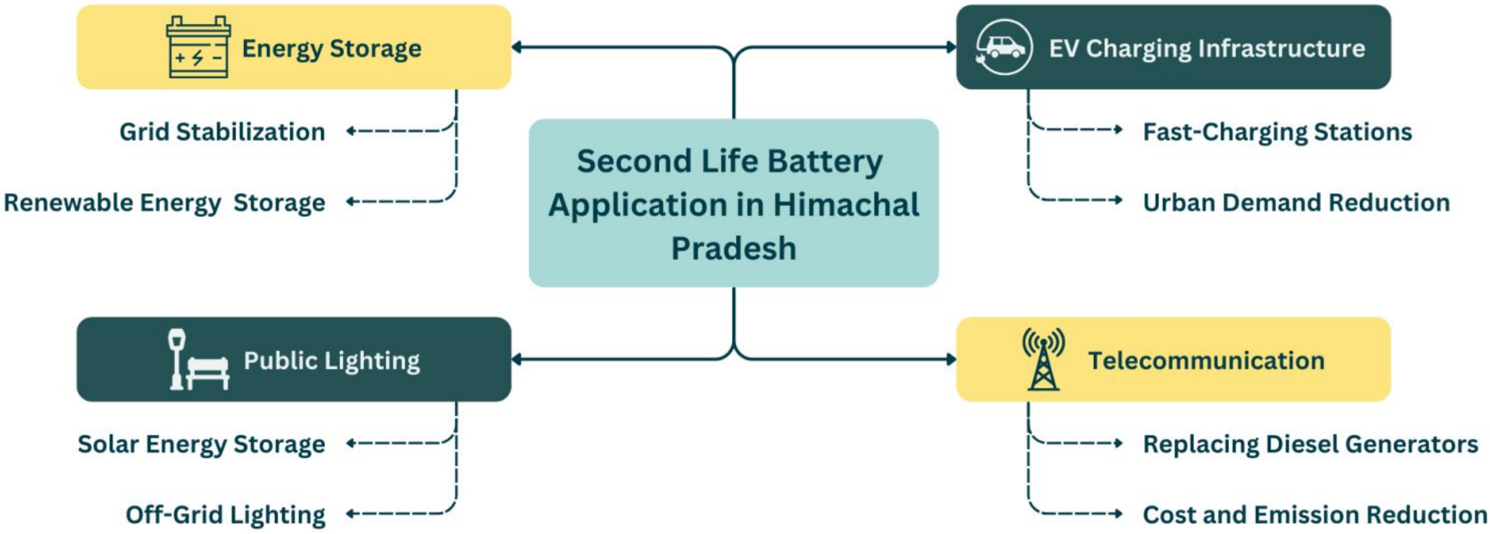
Telecommunications and Remote Infrastructure Solutions: The telecommunications industry, particularly in remote or underserved regions, relies on consistent energy sources to maintain service continuity. Second-life batteries have proven to be reliable **replacements for diesel generators**, as seen in projects across Africa and Asia. These batteries ensure stable power for telecom towers, reducing reliance on fossil fuels and promoting sustainable practices in off-grid environments *(Union of Concerned Scientists, 2018)*. **Himachal Pradesh has a total of 1,039 telecom towers operated by Bharat Sanchar Nigam Limited** as of October 2024 (Press Information Bureau, 2024).

Public Lighting and Infrastructure: The India solar street lighting market is projected to grow from **USD 1.07 billion in 2024 to USD 3.54 billion by 2033**, at a **CAGR of 14.21%** during 2025–2033. Second-life EV batteries can transform public infrastructure, such as street lighting, by reducing energy costs and fostering sustainability. **Nissan's "Reborn Light" project** in Japan exemplifies this application, where solar energy stored in repurposed batteries powers streetlights in areas with limited grid access *(The Reborn Light, 2018)*.

EV-to-EV Repurposing: In EV-to-EV repurposing, modules with over 80% State of Health (SoH) are reused in new EVs, as seen in Nissan's LEAF program with Sumitomo's module testing technology. This approach offers a second life of **5–10 years**. For **other vehicle applications**, modules with less than 80% SoH are repurposed for use in forklifts, airport carts, and electric bikes. Renault, for instance, uses end-of-life (EOL) batteries in boats operating in Paris, with these applications extending battery life by 10–20 years. (NITI Aayog)

EV Charging Infrastructure: Another promising reuse is in EV charging infrastructure, where EOL batteries power fast-charging stations, reducing the demand for additional grid supply. EVgo repurposes BMW i3 battery packs, while Renault's Connected Energy initiative employs E-STOR technology for similar purposes, offering a second life of **10–12 years**.

4.3 Suitability in Himachal Pradesh:



Geographic and Economic Advantages for Second-Life Battery Applications:

- Himachal Pradesh's hydroelectric resources provide a strong foundation for utility-scale energy storage.

Grid Stabilization and Renewable Energy Integration:

- Retired EV batteries can help stabilize grid fluctuations and store surplus renewable energy during periods of low demand.
- Microgrid systems in rural areas can enhance energy reliability while reducing infrastructure expansion costs.
- This approach aligns with the state's renewable energy reliance and potential for solar and hydroelectric integration.

Second-Life Batteries in EV Charging Infrastructure:

- With India's growing EV adoption, Himachal Pradesh can integrate second-life batteries into charging stations.
- Fast-charging stations using these batteries reduce grid dependency, especially in urban centres like Shimla and Manali, where tourism and urbanization increase electricity demand.
- This enhances the scalability of EV infrastructure in the region.

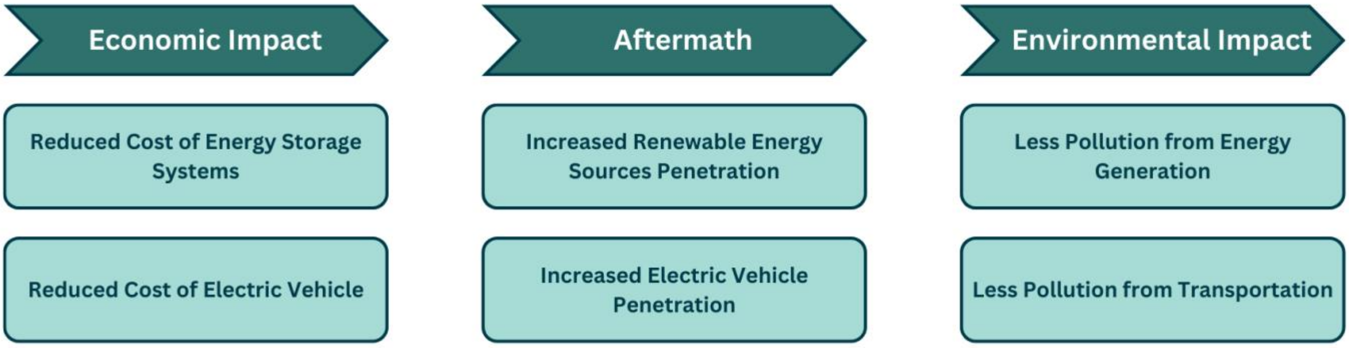
Telecommunications Support in Remote Areas:

- Mountainous terrain and remote locations challenge telecom connectivity in Himachal Pradesh.
- Replacing diesel generators at telecom towers with second-life batteries ensures stable service, lowers operational costs, and reduces carbon emissions.

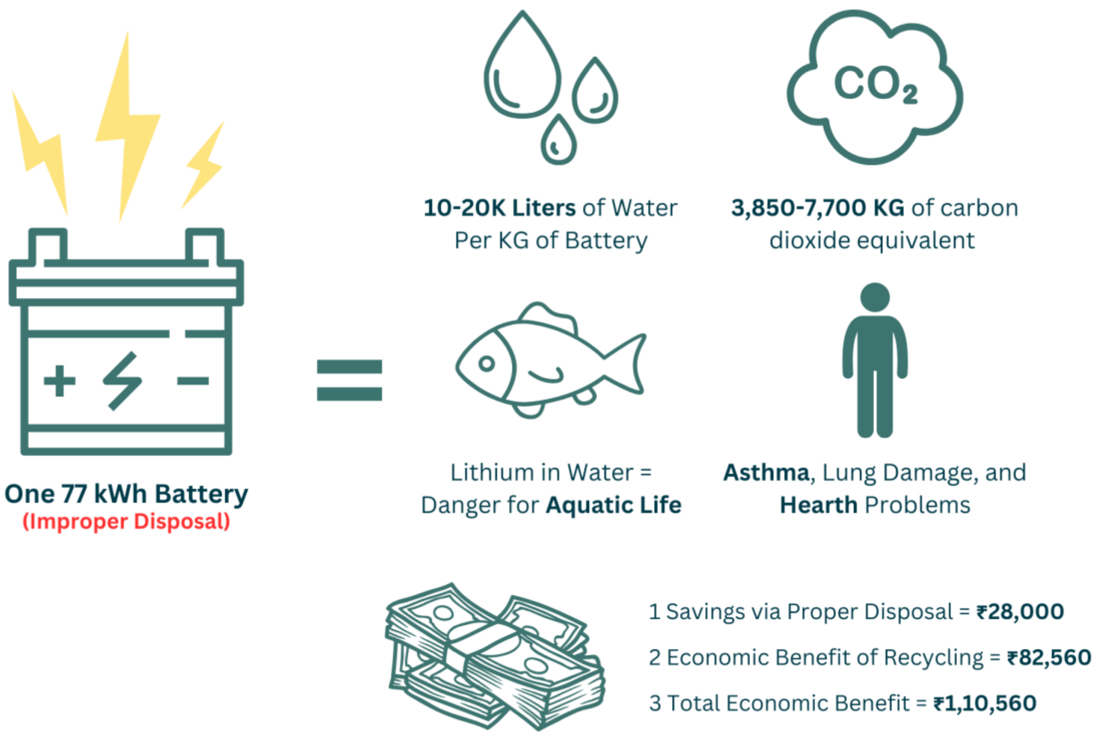
Public Lighting and Solar Energy Storage:

- Second-life batteries can store solar energy to power streetlights, particularly in off-grid or underserved areas.
- This enhances public safety and reduces energy costs for remote communities.

4.4 Impacts of Second-Life Battery Energy Storage Systems (SLBESS):



5. The Importance of Battery Recycling: Environmental and Economic Impact



EV battery recycling plays a crucial role in mitigating environmental risks and maximizing economic benefits. With the rising adoption of electric vehicles, the demand for lithium-ion batteries is surging, bringing concerns about their end-of-life disposal. These batteries contain **valuable metals** such as *cobalt, nickel, and lithium*, alongside other materials that pose significant environmental hazards if improperly discarded. The uncontrolled disposal of batteries leads to *soil and water contamination, air pollution, and landfill congestion, exacerbating ecological damage*. Additionally, improper disposal results in the loss of recoverable materials, increasing dependence on costly mining operations and hindering the growth of the recycling industry.

Recycling not only **prevents environmental degradation** but also **creates substantial economic value** by recovering high-value materials, reducing production costs, and fostering job creation in the circular economy. The analysis below quantifies both the environmental and economic consequences of improper disposal and presents a financial case for battery recycling. By considering real-world estimates, it demonstrates how recycling a single **77kWh EV battery** can prevent pollution, save remediation costs, and generate significant economic returns. This underscores the urgent need for robust recycling infrastructure and policies to ensure sustainable battery management.

5.1 Environmental Impact:

The uncontrolled disposal of lithium-ion batteries poses severe environmental hazards due to their toxic components and potential for harmful degradation. Heavy metals like cobalt, nickel, and copper can leach into soil, reducing fertility and harming ecosystems, while lithium compounds **contaminate groundwater** by forming corrosive substances. Toxic runoff from improperly discarded batteries pollutes rivers and lakes, endangering aquatic life, and fires caused by flammable electrolytes release hazardous gases like hydrogen fluoride and dioxins, contributing to **air pollution and respiratory risks**. Composing components such as polyethylene and polypropylene separators emit greenhouse gases like methane and carbon dioxide, accelerating **climate change**. Wildlife exposed to contaminated environments faces poisoning, developmental issues, and reproductive harm, while aquatic ecosystems suffer from oxygen depletion and algal blooms. The non-biodegradable nature of these batteries further exacerbates **waste management challenges**, occupying landfill space and leading to long-term environmental damage. These risks underscore the need for effective recycling and proper disposal of lithium-ion batteries to mitigate their environmental impact.

Taking an example of a **77kWh battery**, it holds the capacity to pose the following environmental hazards*:

Particulars	Impact
Toxic Chemical Leakage	Contamination of 10,000-20,000 liters of water per kg of battery material.
Greenhouse Gas Emissions	3,850-7,700 kg of CO_2 equivalent from potential fires or decomposition.
Resource Wastage	Loss of 1,000–2,000 worth of materials and 10,000-15,000 kWh of embedded energy.
Ecosystem Damage	Lithium concentrations >2.5 mg/L in water can be lethal to aquatic life.
Human Health Risks	Cobalt exposure can cause asthma, lung damage, and heart problems.

**The calculations assume a 77-kWh battery contains 15-20 kg lithium, 5-10 kg cobalt, 10-15 kg nickel, and 5-10 kg manganese, with leaching potentially contaminating 10,000-20,000 liters of water per kg. A battery fire could release 50-100 kg CO_2 equivalent per kWh (totalling 3,850-7,700 kg CO_2). Resource wastage estimates include 1,000–2,000 in material value and 10,000-15,000 kWh of embedded energy. Ecosystem impacts are based on toxicity thresholds, e.g., >2.5 mg/L lithium being lethal to fish. Data is sourced from scientific studies, industry reports, and lifecycle assessments.*

5.2 Economic Impact:

The uncontrolled disposal of EV batteries leads to greater economic concerns, primarily through the loss of valuable resources such as cobalt, nickel, and lithium, which are essential and finite. Without proper recycling, these **materials are practically wasted**, increasing reliance on energy-intensive and costly mining operations to meet the growing demand for raw materials in battery production. This **inefficiency** also hampers the development of the recycling industry, which could otherwise recover these resources, reduce production costs, and create jobs, fostering innovation and supporting a circular economy. Also, improper disposal results in significant **environmental cleanup costs**, as contaminated soil and water require expensive remediation efforts, diverting public and private funds from other critical development projects. The **scarcity of raw materials** due to wasteful practices further raises production costs for EV batteries, leading to higher prices for electric vehicles and potentially slowing their adoption, thereby impeding progress toward a sustainable future of mobility.

Again, taking an example of a **77kWh battery**, the following can be the associated economic benefit of proper disposal of this battery:

5.2.1 Savings Economics via Proper Disposal:

1. **Environmental Cleanup Cost:**
    a. During improper disposal, toxic metals like cobalt, nickel, and lithium leach into soil and water. On average, cleanup costs for contaminated soil or water can range from **$12 to $60 (₹1000 to ₹5000)** per kg of leached material.
    b. A typical EV battery contains approximately:
        i. Cobalt: ~10 kg
        ii. Nickel: ~30 kg
        iii. Lithium: ~8 kg
        iv. Assuming improper disposal leads to 20% leaching of these metals:
            1. Leached Material = (10 + 30 + 8) x 20/100 = 9.6 Kgs
            2. Cleanup cost = 9.6 x ₹2500 per Kg (Average) = **₹24,000**
2. **Landfill Cost:**
    a. Batteries occupy significant landfill space and may require special handling. Disposal costs can reach **$50 (₹4000)** per battery due to handling hazardous waste.
3. **Total Avoidable Cost = ₹24000 + ₹4000 = ₹28,000**

5.2.2 Economic Benefit from Recycling:

Recycling enables the recovery of up to 99% of valuable materials, which can be reused in battery production or other industries. For a conservative calculation, we here assume a recovery rate of **95%**. Here's the potential economic benefit visible considering the *latest per kg pricing of the metals mentioned below as of 6th January 2025*:

1. **Recovered Material Value:**
    a. Cobalt = 10 kg x $24 x 95% = $228 (₹18,240)
    b. Nickel = 30 kg x $15 x 95% = $428 (₹34,240)
    c. Lithium = 8 kg x $10 x 95%= $76 (₹6,080)
    d. Copper, Aluminium, Graphite, and others = $300 (₹24,000) (combined estimate)

e. Total Recoverable Value: ₹18,240 + ₹34,240 + ₹6,080 + ₹24,000 = **₹82,560**

2. **Recycling Industry Multipliers:**
   a. Beyond raw material recovery, recycling generates economic activity through jobs, equipment manufacturing, and technological innovation. For this, a multiplier could be further added to the final calculations to come up with a more detailed economic impact of recycling a battery.

5.2.3 Total Economic Impact:

1. Savings Economics via Proper Disposal = ₹28,000
2. Economic Benefit from Recycling = ₹82,560
3. **Total Economic Benefit Expected from Recycling a 77kWh battery = ₹1,10,560**

**The above estimates are rough estimates to depict the scale of the economic impact of recycling EV batteries. The following numbers should not be considered for any further calculations.*

6. Financial Analysis of Battery Cost Post-Warranty

Electric vehicle (EV) batteries represent a significant share of a vehicle's cost, typically accounting for 50–60% of the total price. As the industry evolves, understanding the financial implications of battery depreciation, repair, replacement, and resale becomes crucial for stakeholders.

6.1 Battery Depreciation and Residual Value Challenges:

Battery depreciation remains a complex financial element for EVs. Unlike internal combustion engine (ICE) vehicles, where residual value has a predictable depreciation curve, EV batteries experience distinct patterns influenced by technological advancements and market forces. Early-generation EVs depreciated rapidly as newer models with extended ranges and faster charging capabilities made older versions obsolete. For example, Tesla Model S retains around 57% of its value after three years, compared to an ICE vehicle average of 60% (Recurrent, 2020). This trend created uncertainty around long-term residual values, particularly given the **absence of a mature secondary market** for used batteries.

EV batteries' disintegration curves also vary based on usage patterns and maintenance. Factors such as frequent fast charging, exposure to extreme temperatures, and high mileage accelerate capacity loss, reducing the resale value of both the battery and the vehicle. Despite warranties covering up to eight years or **160,000 kilometres**, concerns about battery longevity persist. Surveys indicate that only 2.5% of batteries have been replaced outside recalls, suggesting slower-than-expected degradation. However, technological risk and the introduction of affordable EVs from China amplify depreciation issues *(The Financial Express, 2023)*.

6.2 Replacement Costs of EV Batteries:

The cost of replacing an EV battery remains high, varying significantly by model, capacity, and market. In India, replacement costs typically range from **₹15,000–₹20,000 per kWh**, with the total cost for a **30–40 kWh battery unit** falling between **₹3 lakh** and **₹4.5 lakh**. High-capacity models like the Hyundai Kona and Tesla Model S incur even higher costs, often exceeding **₹12 lakh**.

Model	Battery Capacity (kWh)	Replacement Cost (INR)
Tata Nexon EV	30–40.5	₹3.33–₹7 Lakhs
Tata Tiago EV	24–30	₹4.1–₹5.1 Lakhs
Hyundai Kona EV	40	₹11.9 Lakhs
Tesla Model S	75	₹10–₹20 Lakhs

Replacement costs also include labour charges and taxes, which add **₹10,000–₹2.3 lakh** depending on the complexity of the replacement process *(Economic Times, 2023)*.

6.3 Insurance and Warranty Options:

Insurance solutions are critical for mitigating the financial risks associated with battery failures. These products fall into two main categories:

1. **Battery Warranty**: Offered by manufacturers, warranties cover premature failures or capacity loss during the specified period. For instance, *Tata Nexon EV provides a three-year or 1.25 lakh-kilometre warranty*. Warranties often eliminate the need for additional expenses during the coverage period.
2. **Battery Insurance**: Specialized insurance policies safeguard against risks like theft, accidental damage, and capacity loss due to unforeseen events. Premiums vary based on vehicle make, battery capacity, and insurer. *In India, IRDAI offers discounted premiums for EVs, with rates ranging from ₹1,780 for small cars (<30 kWh) to ₹6,712 for larger models (Business Today, 2022)*.

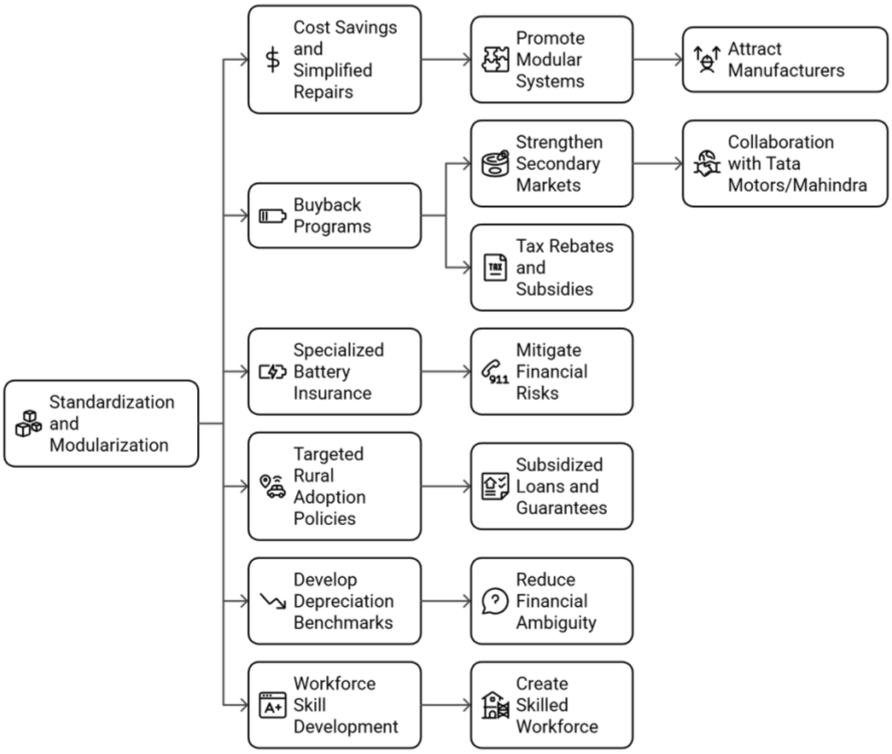
Insurance products like **"Battery Secure Add-On"** also cover surge damage during charging, water ingress, or short circuits, providing comprehensive protection against operational risks.

Coverage Type	Cost Range (INR)	Key Features
Battery Warranty	Typically included	Covers failure or degradation
Battery Insurance	₹1,780–₹6,712 Annually	Protects against theft/damage

6.4 Factors Influencing Financial Viability:

1. **Battery Degradation** depends on several variables, including temperature exposure, charging frequency, and driving patterns.
2. **Technological Advancements**: As newer, more efficient batteries enter the market, older models depreciate faster due to reduced demand and perceived obsolescence.
3. **Labor Costs** and **Supply Chain** constraints also affect replacement prices. In India, delays in sourcing components and skilled technicians increase the total replacement expense. Additionally, third-party battery recycling and refurbishment markets need expansion to reduce costs for consumers.

6.5 Strategic Insights for Himachal Pradesh Based on EV Battery Financial Insights:



Standardization and Modularization for Cost Efficiency:

- Uniform battery packs across EV models simplify repairs, enable modular upgrades, and enhance value retention.
- Targeted incentives for modular battery systems can attract manufacturers to establish assembly plants in Himachal Pradesh, fostering local job creation and reducing import dependency.

Buyback Programs and Public-Private Partnerships (PPPs):

- Government-subsidized buyback programs can strengthen secondary markets for EV batteries.
- Collaboration with Tata Motors, Mahindra, and others can ensure second-life applications in grid storage, telecom, and public lighting.
- South Korea's success with subsidized battery recycling serves as a model, reducing costs and increasing adoption.
- Tax rebates and subsidies for recyclers and EV owners can foster circular economy initiatives.

Specialized Battery Insurance for Risk Mitigation:

- Battery insurance products like "Battery Secure Add-On" can cover risks such as theft, power surges, and water ingress.
- Collaboration with insurers can introduce affordable premiums for both rural and urban consumers, promoting EV adoption and addressing long-term battery concerns.

Targeted Rural Adoption Policies for EVs:

- Subsidized loans, extended battery warranties, and buyback guarantees can make EV ownership viable for rural communities.

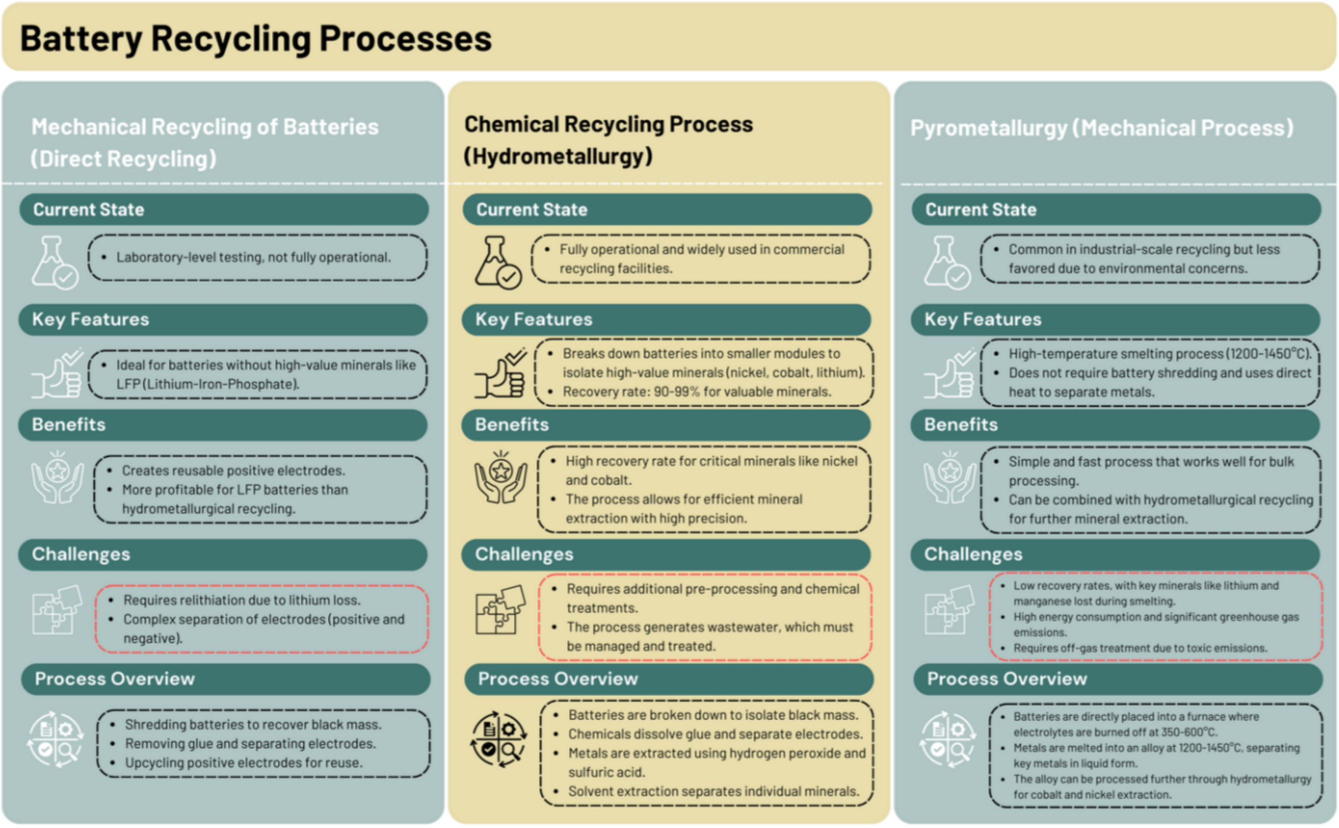
Depreciation and Residual Value Benchmarks:

- Working with Bureau of Indian Standards (BIS) to establish depreciation guidelines will reduce financial ambiguity in EV financing.
- Standardized depreciation will help lenders and consumers assess EV battery values accurately, positioning EVs as lower-risk assets and encouraging financing.

Workforce Skill Development for Battery Ecosystem:

- Training programs in battery recycling, repair, and refurbishment are essential to support Himachal Pradesh’s EV ecosystem.
- Collaborations with manufacturers and educational institutions can create a skilled workforce, reducing labour costs and driving down battery replacement expenses.

7. Battery Recycling Process & Infrastructure



EV Battery recycling goes beyond following waste management rules, as it also holds various environmental and social benefits. Creating a circular economy to manage EV batteries will help the country and the industry meet critical global greenhouse gas/carbon dioxide reduction targets and secure a long-term supply of battery minerals. Recycling EV batteries will help reduce the associated mining pollution. There are more benefits that EV recycling delivers, which we can divide into environmental and social benefits. Environmental benefits include conserving natural resources by recycling lithium batteries, reducing greenhouse gas emissions, reducing electronic waste generation, and preventing soil and water contamination. Moreover, the environment and society are key areas that benefit from EV Battery recycling. The process required manpower. Hence, it creates jobs across multiple fronts. Unsafe working conditions and human rights concerns often mar the extracting industry. Lithium-Ion Battery recycling can reduce this burden by fulfilling the demand for cobalt. EV Battery recycling also supports renewable energy by storing energy from renewable sources such as solar and wind power. By creating a lithium-Ion battery recycling value chain, we can make a supply chain that values ethical practices and promotes transparency. Each benefit from recycling paints a path for a sustainable and equitable future, from conservation to taking care of social factors. Multiple recycling methods exist for EV batteries; this research covers the mechanical, chemical and thermal processes. Table above explains the three processes and their key features and challenges. The best method has a high mineral recovery rate and lower environmental impact.

The Table below compares the advantages and disadvantages of all the above recycling methods. Hydrometallurgical recycling is considered the better method of EV Battery recycling as it has a high mineral recovery rate, lower environmental impact, and the ability to extract a broader range of materials at high purity levels compared to other methods.

Recycling Method	Advantages	Disadvantages
Pyrometallurgy	• Versatile process, compatible with all battery chemistries and configurations. • Eliminates the need for sorting or mechanical pre-treatment. • Achieves high metal recovery, including cobalt, nickel, and copper. • Well-established technology, adaptable to existing pyrometallurgical facilities.	• Unable to recycle lithium, aluminum, or organic materials and not suitable for LFP batteries. • Requires costly gas treatment to prevent toxic air emissions. • High energy consumption and significant capital investment needed. • Additional processing required to extract pure metals from alloys formed during smelting.
Hydrometallurgy	• Compatible with all battery chemistries and configurations. • Adaptable separation and recovery methods to extract specific metals. • Achieves high recovery rates, particularly for lithium. • Produces high-purity materials, suitable for cathode precursor production. • Energy-efficient process with no air emissions.	• Battery cells require crushing, posing safety risks. • Acid treatment degrades the cathode structure. • Generates a large volume of process effluents, requiring treatment, recycling, or disposal. • Not cost-effective for LFP batteries. • Does not recover anode materials, such as graphite and conductive additives. • High operational costs make large-scale adoption challenging.
Direct recycling	• Preserves the valuable cathode structure during the process. • Enables recovery of nearly all battery materials, including anode, electrolyte, and foils. • Effective for recycling LFP batteries. • Energy-efficient method with minimal waste. • Well-suited for processing manufacturing scraps.	• Requires intricate mechanical pre-treatment and separation processes. • Recovered materials may have lower performance compared to virgin materials or become outdated before market entry. • Mixing different cathode materials can reduce the quality and market value of the recycled product. • Regeneration techniques are still under development. • Not yet scaled for large-scale industrial implementation.

Although the concept is new for the Indian market, some companies are working towards recycling lithium-ion batteries. Companies like Attero, Recyclekaro, BatX Energies, ReBAT, and LOHUM are some players in the India market working towards recycling lithium-Ion Batteries and, primarily, contributing to SDG goals and the national objective of reaching Net Zero emissions by 2070.

To talk about the infrastructure, we can first delve into the stakeholders involved in the EV Battery recycling process and then discuss the current state of the infrastructure in India and Himachal Pradesh. Stakeholders are listed in the table below:

Stakeholder
HPDT (Himachal Pradesh Department of Transport)
Electricity Board

Vehicle Manufacturer
Battery Manufacturer
Battery Dealers
Service Centre & Workshop

In India, the rapid adoption of electric vehicles (EVs) is supported by national policy and when we focus on the state of Himachal Pradesh. The state policy supports it. Moreover, there is a requirement for a robust infrastructure to manage end-of-life (EOL) batteries effectively. With actional insights, this section explores infrastructure readiness for EV battery recycling in India and Himachal Pradesh.

The share of the total battery market as of 2021 was 48.98% (lead acid batteries (LABs) and 51.01% Lithium-ion batteries (LIBs). Moreover, the global annual demand for batteries was around 933 GWh, which is expected to grow fivefold to reach 5100 GWh by 2030. The national waste management policy required producers to establish collection centres. The deadline for producers to do so was 2025. The policy also aims to develop licensed facilities for recycling lithium-ion batteries adhering to environmental norms. Moreover, the benchmarks set are to achieve a recovery efficiency for valuable materials like lithium, cobalt, and nickel by 2027. The national policy targets recycling facilities near major EV manufacturing hubs (Delhi NCR, Bengaluru, Pune). The transportation and logistics that a producer or collection unit can use are specified in the policy, and a dedicated transport vehicle and GPS tracking are mandated for monitoring.

To understand state preparedness, we can look at the proposed plan in the **Himachal Pradesh Electric Vehicle Policy, 2022**. The state planned to establish **collection centres in key locations such as Shimla, Mandi, Baddi, and Dharamshala**. The policy **incentivises businesses** to return used batteries to **authorised recyclers** under the **Extended Producer Responsibility (EPR) framework**. Moreover, the policy proposed the **development of licensed battery recycling facilities** in the state (**specific locations and capacity are not explicitly mentioned in the policy**). The state also suggested **collaborating with urban local bodies** to integrate battery waste collection into **existing waste management systems**. According to primary research conducted by the team, there are no EV Battery recycling units in place in the state of Himachal Pradesh. Moreover, this can be verified on the official website of the CPCB (Central Pollution Control Board). It is mandatory for recyclers to register with the regulatory authorities, and the board also keeps a record of credits availed by OEMs on collecting the used batteries from the market. As mentioned in the field visit section, when asked about the battery dealers in the city of Ponta Sahib, the battery dealers send all the lead acid batteries to the manufacturers. Concluding the section about the current preparedness of the state for recycling Electric Vehicle Batteries, the state does not have any facility currently in place or in the process of establishment. Therefore, the state should propose and incentivise the establishment of recycling units in the state and promote lithium-ion battery recycling businesses.

8. Challenges in EV Battery Recycling

This section will identify the challenges associated with recycling EV batteries, categorising them into infrastructure, technical expertise, and public awareness. This section will delve into the regulatory hurdles and examine the gaps within the current system that hinder the efficiency of recycling practices.

After discussing what is EV battery recycling, the process involved, and the infrastructure capabilities required and the current state preparedness of Himachal Pradesh for Battery recycling and waste management.

The successful implementation of EV battery recycling in Himachal Pradesh depends on policy implementation and the state's preparedness to address emerging challenges. While the Himachal Pradesh Electric Vehicle Policy, 2022 outlines key measures, such as establishing collection centres and incentivising responsible disposal, we have yet to examine the state's current on-ground preparedness.

Challenges arise across multiple stakeholders, including **producers, recyclers, regulatory bodies, and consumers**. Ensuring compliance with Extended Producer Responsibility (EPR) mandates, setting up a functional collection and recycling network, and addressing logistical constraints in a hilly terrain present significant barrier. Financial viability, technological readiness, and public awareness influence the state's ability to recycle and repurpose EV batteries efficiently.

This section examines the key challenges affecting EV battery recycling in Himachal Pradesh, considering national-level obstacles and state-specific limitations that hinder progress.

Let us now understand these barriers at the national and state level.

1. **Infrastructural Deficiencies:** Talking about infrastructure deficiencies in EV battery recycling refer to the lack of adequate physical, logistical, and technological resources needed to efficiently collect, store, transport, and process end-of-life vehicle (EV) batteries. These deficiencies create bottlenecks in the recycling ecosystem, making it challenging to achieve high recovery rates of critical materials like lithium, cobalt, and nickel while ensuring safe and environmentally compliant disposal, according to the Niti Ayog report on Advanced Chemistry Cell Battery Reuse and Recycling Market in India and India's Battery waste management rules, 2022, we can highlight key barriers across collection, processing, logistics, and policy implementation. India as a country, according to reports till 2021, does not have a **nationwide collection mechanism** for end-of-life batteries, making it challenging to direct used batteries to formal recycling channels. Moreover, **informal and unregulated collection methods** lead to improper disposal and lower recycling efficiency. The storage of used EV batteries causes significant concern due to fire hazards and chemical leaks. There is an absence of standard **protocols for battery handling**,

which results in unsafe stockpiling and informal processing. Although the Battery Waste Management Rules 2022 mandate producers to take back used batteries, enforcement remains weak, leading to non-compliance by many OEMs. ***As per the current state, India's lithium-ion battery (LIB) recycling capacity is below 2000 tons per year, whereas Europe has over 52,000 tons per year, and China has more than 30,000 tons per year.*** Due to this limited domestic infrastructure, India exports black mass (a mixture of critical battery materials) to countries with advanced recycling capabilities. When talking about Himachal Pradesh, we can refer to the primary research and conclude that there are no recycling facilities in the state for lithium batteries, and there has been no initiation to push such efforts by the decision-makers. Adding to this, the state of lead acid battery recycling units is also unsuitable for employees as they do not provide healthy working conditions. However, the Central Pollution Control Board (CPCB) has designed and published a standard operating procedure for recycling lead-acid batteries. During the primary research, it was also highlighted that transportation of batteries across the country is also a challenge for the recyclers and battery providers.

2. **Regulatory and Policy Challenge:** The regulatory and policy framework for EV battery recycling in India has evolved with the **introduction** of **the Battery Waste Management Rules in 2022,** but implementation challenges persist at national and state levels. The gaps in enforcement, clarity in compliance, and financial incentives affect the effectiveness of battery waste management in India and Himachal Pradesh. While the Battery Waste Management Rules 2022 mandate **Extended Producer Responsibility (EPR)** for battery manufacturers, their **on-ground implementation remains weak**. **The lack of strict penalties and enforcement mechanisms** has led to low compliance among battery producers and recyclers. **The absence of regulatory standards** for testing and classifying **batteries with a secondary life** creates confusion regarding whether they should be recycled or repurposed. **The lack of specific guidelines for EV batteries** leads to confusion in the industry regarding **collection, transportation, and recycling methods.** Himachal Pradesh has adopted the **Himachal Pradesh Electric Vehicle Policy, 2022**, which incorporates elements of battery waste management. However, several challenges exist. The policy mentions **setting up battery collection centres** in **Shimla, Mandi, Baddi, and Dharamshala**, but implementation has to be ascertained. **The absence of a licensed recycling facility** in the state forces used EV batteries to be **transported to other states**, increasing costs and inefficiencies; this question has to be reviewed again after understanding the current preparedness of the state.
3. **Technological Challenges:** A major challenge for **EV Battery recycling** in India is the lack of adequate supply of used batteries ready for recycling. EV batteries in India vary significantly by **chemistry, shape, size, and configuration**, making disassembly and recycling **complex**

and inconsistent. This increases the cost for recycling batteries and processing difficulties. Himachal Pradesh, while it has a forward-looking electric vehicle policy strategy, still faces significant technological challenges in establishing a lithium-ion battery (LIB) recycling industry. As per the Himachal Pradesh EV Policy of 2022, the state will have collection points in urban areas like Shimla, Mandi, Baddi, and Dharamshala. However, the lack of an existing LIB recycling plant in the state compels the state to rely on using external space for processing. This reliance not only increases the logistical costs but also poses risks related to the safe transportation and segregation of toxic battery waste. Also, the state lacks the technical expertise and infrastructure required for the functioning of sophisticated recycling technology. The NITI Aayog report on the ACC Battery Recycling Market in India brings out the fact that the country, in general, is limited in the establishment of hydrometallurgical and direct recycling processes. Himachal Pradesh, lacking local research and development centres as well as modular systems suitable to its geography of hills, is much less equipped to implement such technologies. Another urgent problem is the lack of decentralised pre-treatment centres for essential processes like battery discharge, dismantling, and sorting. Without them, end-of-life batteries are shipped in bulk to distant centres, slowing processing and creating safety issues.

9. On-Ground Study (Field Visits & Online Interviews)

After theoretically understanding EV Batteries and their applications, primary research was carried surveying all kinds of stakeholders involved in the value chain to solidify the context of the research and build a strong base for upcoming recommendations. Below mentioned are the field insights gathered from the primary research.

9.1 Insights from Automobile Showrooms

As part of our field research, we conducted interviews with representatives from two key automobile showrooms in Paonta Sahib: TATA Commercial Showroom and Bajaj Showroom. These interviews revealed critical ground-level perspectives that help explain the current state of Electric Vehicle (EV) adoption and the challenges therein.

TATA Commercial Showroom (Paonta Sahib):

The showroom staff highlighted that **government subsidies**, although well-intentioned, often **fail to reach the end consumer**. This creates a disconnect between policy formulation and its actual impact on adoption. Moreover, while incentives for selling EVs are available, they tend to benefit the showroom owners rather than incentivizing frontline salespersons. Another major barrier identified was the **high fixed cost associated with EVs**, which deters the public from considering them as viable alternatives to internal combustion engine vehicles. Additionally, the lack of a widespread and reliable **charging infrastructure** was cited as a significant reason for the slow uptake of commercial EVs.

Bajaj Showroom (Paonta Sahib):

Discussions with the Bajaj showroom team, particularly around the Bajaj Chetak model, brought out a different facet of subsidy distribution. It was noted that **subsidies are extended to the company for replaced EV batteries**. While this reduces operational costs at the firm level, the benefit does not directly translate to consumer incentives or affordability enhancements.

These findings point to the need for a **more targeted and transparent incentive mechanism** that addresses end-user affordability and infrastructure readiness, both of which are critical for accelerating EV adoption.

9.2 Insights from EV Service Centres

The field research also encompassed interactions with service providers to understand the ecosystem supporting post-sale operations of electric vehicles. Two service centres in Paonta Sahib: Shabas Automobile (a third-party service centre) and the TATA Commercial Service Centre, provided vital insights into the emerging dynamics and limitations in the EV servicing landscape.

Shabas Automobile – Third-Party Service Centre (Paonta Sahib):

The representative noted that electric vehicles are **unlikely to reach third-party mechanics** for servicing during the initial **3–4 years of ownership**. This delay is largely due to **warranty coverage** and **specialized servicing protocols** mandated by manufacturers. Additionally, in the case of battery replacements, the old battery is collected by the dealer responsible for supplying the new unit. This bypasses independent mechanics entirely, indicating a service structure still tightly controlled by OEMs (Original Equipment Manufacturers).

TATA Commercial Service Centre (Paonta Sahib):

The authorized TATA service centre offered a more structured perspective. Replaced EV batteries are sent back to battery vendors, often located in urban centres such as Chandigarh and Dehradun. **Warranty claims** for EV batteries are also routed through these vendors, reflecting a multi-tiered **after-sales support system**. Importantly, TATA Motors has instituted regular **training programs** for service technicians to build capacity in EV diagnostics, repair, and maintenance. This suggests a concerted effort by OEMs to develop internal servicing capabilities rather than depending on the broader automotive repair market.

These insights underscore the nascency of third-party EV servicing and highlight the role of OEMs in maintaining control over post-sale services, particularly in the early years of vehicle ownership. Such a structure, while ensuring quality and safety, may inadvertently **limit the growth of a decentralized EV maintenance ecosystem**.

9.3 Insights from EV Two-Wheeler Dealer (XIDAA)

XIDAA is an emerging Indian electric vehicle (EV) manufacturer focused on providing affordable, sustainable mobility solutions, particularly in the electric two-wheeler segment. The company's offerings, such as electric scooters equipped with lithium-ion batteries, cater to semi-urban and rural markets seeking cost-effective EV alternatives.

At the XIDAA dealership in Paonta Sahib, several **operational and market-level insights** were gathered. The dealer highlighted that vehicles typically come with a one-year **warranty** for lead-acid batteries and a three-year warranty for lithium-ion batteries. The **cost** of a lithium-ion battery is approximately ₹30,000 (including GST), while individual cells are priced at ₹400, indicating a significant expenditure on battery components for users.

A key policy-level insight was that although **subsidies are announced** under various government schemes, there is a **lack of formal notification or clarity at the ground level**, creating uncertainty for both sellers and buyers. Additionally, the battery disposal process is evolving. Currently, lead-acid batteries are collected by **informal waste handlers** (unorganised scrap dealers), and a similar trend is expected for lithium-ion batteries. These vendors, often traveling from locations like Yamunanagar, represent an **unorganized yet critical component of the EV waste management chain**.

Market demand for electric scooters is reportedly increasing, but the dealer emphasized the urgent need for a more **robust charging infrastructure** to support this growing interest. Without adequate public charging stations, the scalability of EV adoption remains limited.

These insights underline **systemic gaps** in subsidy implementation, battery disposal logistics, and infrastructure; key areas that require attention to unlock the full potential of EVs in smaller towns.

9.4 Insights from EV Battery Dealers

Battery dealers form a critical link in the electric vehicle (EV) value chain, influencing both supply continuity and end-user affordability. Field interactions with authorized and specialized battery dealers (both Lead-Acid and Lithium-Ion) in Paonta Sahib provided the following insights about the EV battery ecosystem.

Shital Authorized Battery Dealer (Paonta Sahib):

At present, this dealer does not source EV batteries from Exide, citing that electric vehicles are still in the trial phase and do not yet constitute a significant market segment. However, batteries from internal combustion engine (ICE) vehicles and inverters, irrespective of brand (e.g., Exide, Luminous) are regularly routed to Exide for processing or replacement. This suggests that the **infrastructure and vendor linkages for EV-specific batteries are yet to be integrated** into traditional battery distribution networks.

Exide Authorized Battery Dealer (Paonta Sahib):

The dealer confirmed that lithium-ion batteries which are central to most EV models are currently imported from China, indicating India's ongoing dependence on global supply chains. However, Exide has initiated the process of setting up a lithium-ion battery manufacturing unit in Kolkata. This development, once operational, could improve domestic sourcing and reduce cost and lead times, thus positively impacting EV adoption.

E-Rickshaw Battery Dealer – Neeraj Garg (Paonta Sahib):

This dealership is presently the only one in the region solely dedicated to EV batteries, specifically catering to the e-rickshaw segment. Established in 2020, the business was spurred by government-led EV initiatives. Batteries are currently sourced from China and routed through Delhi-based supplier

Trontek. This case reflects how focused demand segments like e-rickshaws have catalyzed the emergence of dedicated battery supply chains in smaller towns.

Overall, these insights reveal a **fragmented yet evolving battery ecosystem**. While general battery dealers remain cautious about EV integration, niche players and upcoming domestic manufacturing suggest a **transition is underway**. Bridging the gap between traditional and EV-specific battery networks will be essential for scaling the EV ecosystem beyond metropolitan centres.

9.5 Insights from E-Rickshaw Drivers

To understand real-world user experiences and battery performance over time, interactions were conducted with e-rickshaw drivers operating in Paonta Sahib. These drivers represent early adopters of electric mobility in semi-urban areas.

A consistent insight from the field was that even after **4–7 years** of ownership, most drivers reported no major issues with their e-rickshaw batteries. This suggests a relatively **high level of durability and operational reliability**, especially in a segment that sees daily and intensive usage.

Another practical observation was related to battery maintenance: drivers mentioned that when performance issues did arise, they were often due to faulty individual cells within the battery. These **cells could be replaced independently**, allowing the overall battery lifespan to be extended without necessitating complete battery replacement. This practice not only helps reduce operational costs but also reflects the drivers' adaptability and informal knowledge of EV upkeep.

These findings point to a promising user experience in the e-rickshaw segment, where battery **longevity** and modular **repairability** contribute to sustained vehicle usage. Such grassroots-level evidence reinforces the viability of electric mobility for commercial last-mile transport in smaller towns.

9.6 Insights from Omega Seiki Mobility (OSM)

ICLEI South Asia facilitated an online interaction between our research team and **Omega Seiki Mobility (OSM)**, a leading Indian electric vehicle (EV) manufacturer. This session provided us with valuable, on-ground insights into the challenges and opportunities in the EV landscape, particularly from a manufacturing and supply chain lens.

OSM, a part of the Anglian Omega Group, has emerged as a key player in India's EV sector, known for its focus on electric cargo vehicles, technological innovation (such as 15-minute fast charging), and its vertically integrated approach to EV manufacturing. The company is actively engaged in R&D, localized manufacturing, battery technology advancement, and creating a robust servicing ecosystem across India.

Our interaction with senior representatives at OSM offered nuanced perspectives on the evolving EV ecosystem in India, particularly from a manufacturing and supply chain standpoint. The following insights were derived:

a. Battery Supply Chain Risks and Evolution

- Initially, the EV supply chain was constrained by **high lithium prices** and **limited suppliers**. However, global oversupply has reduced costs, stabilizing sourcing.
- Safety and regulatory compliance remain critical. The shift from **NMC to LFP chemistries** reflects efforts to enhance stability and localization.
- Emerging domestic players are entering cell manufacturing, yet major components are still **largely imported** (especially cells), though packs and BMS are now largely **assembled in India**.

b. Reverse Supply Chain and Recycling Readiness

- Currently, EV batteries have **not reached their end-of-life** in significant volumes. However, a reverse logistics system is evolving, driven by **Extended Producer Responsibility (EPR)** norms.
- Recyclers like **Lohum (Noida)** and **Tata Chemicals (Gujarat)** are beginning to operationalize recycling processes.
- Swappable battery models are already deployed in OSM's 3-wheelers; their future depends on region-specific use cases and fast-charging trade-offs.

c. Service, Range Anxiety, and Infrastructure Gaps

- The biggest psychological and infrastructural challenge remains **range anxiety**, especially in remote terrains like Himachal. However, modular supply chains and regional servicing are maturing.
- **Fast-charging infrastructure** and **high-range models** are expected to address many current concerns.
- OSM claims a **proprietary 15-minute charging system** for commercial vehicles, leveraging cooling systems and high-discharge BMS design.

d. ICE vs EV Supply Chains

- **EV supply chains** are **relatively simpler** due to a lighter Bill of Materials (BOM) and fewer precision components compared to ICEs.
- Fundamentals like planning, lead time, and supplier relationship management remain **identical**.
- **Buffers**, **JIT (Just-in-Time)** methods, and **risk resilience** (e.g., dealing with disruptions like protests or fog) are critical across both supply chains.

e. Policy Recommendations

- Ongoing FAME subsidies are crucial for affordability and market penetration.
- There's a **strong push for policy continuity** to support infrastructure (especially charging stations) to **reduce range anxiety**.
- **Mandates** around safety, localization, and recycling are already **shaping manufacturer behavior**.

f. EV Workforce and Just Transition

- Components like **wiring harnesses** and **electronics** are already heavily **female-led in manufacturing**.
- OSM supports service **upskilling programs** through its dealer and technician networks.

- The EV industry requires new skill sets: **diagnostics, software understanding, and electronics**—not traditional mechanical expertise.

g. Himachal's Role in the Value Chain

- While current EV servicing in Himachal is limited, the terrain offers strategic use cases like **clean mobility in ecologically sensitive zones**.
- Himachal can benefit from localized EV assembly units, service hubs, and possibly renewable-powered charging stations, especially due to hydropower availability.

h. Emerging Business Models

- Commercial EV adoption is led by sectors like pharma, groceries, and logistics with **short-range but high-frequency routes**.
- TCO (Total Cost of Ownership) advantages are strong drivers for EV trucks, buses, and last-mile delivery fleets.
- Fast-charging-enabled fleet vehicles can significantly improve asset utilization by enabling two-shift operations.

9.7 Insights from Himachal Pradesh Pollution Control Board

To further contextualize the implementation challenges and regulatory readiness surrounding EV battery recycling, we conducted an in-depth discussion with an **official from Himachal Pradesh State Pollution Control Board (HPPCB)**. This conversation provided clarity on the on-ground realities, compliance mechanisms, and existing bottlenecks in enforcing battery waste management norms in the state.

a. Current Regulatory Framework:

The official highlighted that battery waste management in Himachal Pradesh is governed by national-level policies, specifically the *Battery Waste Management Rules*, applicable across all states. These rules stipulate the responsibilities of manufacturers, recyclers, and other stakeholders, emphasizing **Extended Producer Responsibility (EPR)** mechanisms. Each manufacturer is mandated to **recycle a fixed percentage of the batteries** they introduce into the market, either through their own channels or by partnering with authorized recyclers.

b. State-Level Infrastructure and Gaps:

Currently, Himachal Pradesh does not have a state-specific EV battery recycling policy. The state primarily follows the Central Pollution Control Board (CPCB) guidelines. While lead-acid battery recycling is active in regions like Baddi and Paonta Sahib, **lithium-ion battery recycling facilities** are yet to be established within the state. The recyclers operating in Himachal mostly source their input from other states, with local waste forming a very small percentage of their intake.

c. Operational and Logistical Challenges:

A significant challenge highlighted was the *transportation of hazardous waste*. Movement of used batteries i.e. classified as hazardous waste must occur through authorized vehicles, which poses a **logistical constraint for recyclers** who source material from across India. Furthermore, challenges such as **manual battery dismantling** and limited purification infrastructure for recovered materials like lead create occupational and financial strains for recyclers.

d. Worker Safety Concerns:

The **official from HPPCB** also addressed the occupational **health risks posed** by the manual dismantling of batteries in the recycling process. Workers are exposed to **hazardous materials** such as lead, which can result in **long-term health complications**. While regulations allow for manual dismantling of smaller batteries, safety protocols are often insufficient, posing significant risks to worker health. The HPPCB's regulatory framework currently focuses more on environmental compliance and less on specific worker safety standards, which remain a **critical gap**.

e. Role of the Pollution Control Board:

The HPPCB’s role is regulatory, focused on ensuring that recycling units comply with **environmental standards**, operate within capacity limits, and follow **CPCB-prescribed SOPs**. It **does not directly offer incentives or subsidies** for setting up or expanding facilities. However, approvals for establishing recycling units are granted based on CPCB's technical standards.

f. Potential Policy Enhancements:

When asked about potential reforms, the official emphasized the need for **greater awareness, inter-agency coordination, and investment in local infrastructure**. Additionally, developing standardized cell dismantling and material recovery mechanisms, aligned with CPCB SOPs, would facilitate safer and more scalable operations. He acknowledged that state departments such as Industries would play a key role in providing targeted policy support or financial incentives to attract battery recycling ventures to the region.

HPSPCB

10. Best Practices and Case Studies

To overcome a few listed challenges with EV Battery second-life application and recycling, industry best practices and case studies from around the world can be looked into in order to get a better understanding of how can India and Himachal Pradesh come up with better policies, regulations, and practices to provide a push to this budding sector.

10.1 Industry Best Practices:

- ### Battery Design for Recycling:
  - **Modular Battery Design for Standardization by Tesla:**
    - In an ideal world, all phones would use the same Li-ion battery type, making them easier to produce, cheaper, and more efficient. Tesla applied this idea of standardization to their electric vehicles (EVs). Inspired by Elon Musk's focus on simplicity and modular design, Tesla abandoned complex, custom battery designs. Instead, they used a standard **"18650" battery cell**, a common off-the-shelf option. They connected hundreds of these cells to power the Model S into a flat, slab-like pack that fits neatly into the car's floor. This design streamlined production, **simplified battery recycling**, and improved performance without needing a fully custom solution.
    - Modular standardization improves battery recycling by simplifying the process. When batteries are built using standard, widely available components like Tesla's "18650" cells, recyclers can handle them more efficiently. They don't have to deal with complex, custom designs that require specialized tools or methods to dismantle. Instead, standardized batteries allow for **easier disassembly, sorting, and recovery** of valuable materials like lithium, cobalt, and nickel.
    - Additionally, since these standardized cells are produced in large volumes, recyclers can develop scalable and cost-effective recycling techniques tailored to these **common components**. This reduces waste, lowers recycling costs, and promotes the reuse of materials, ultimately leading to a more sustainable battery lifecycle.

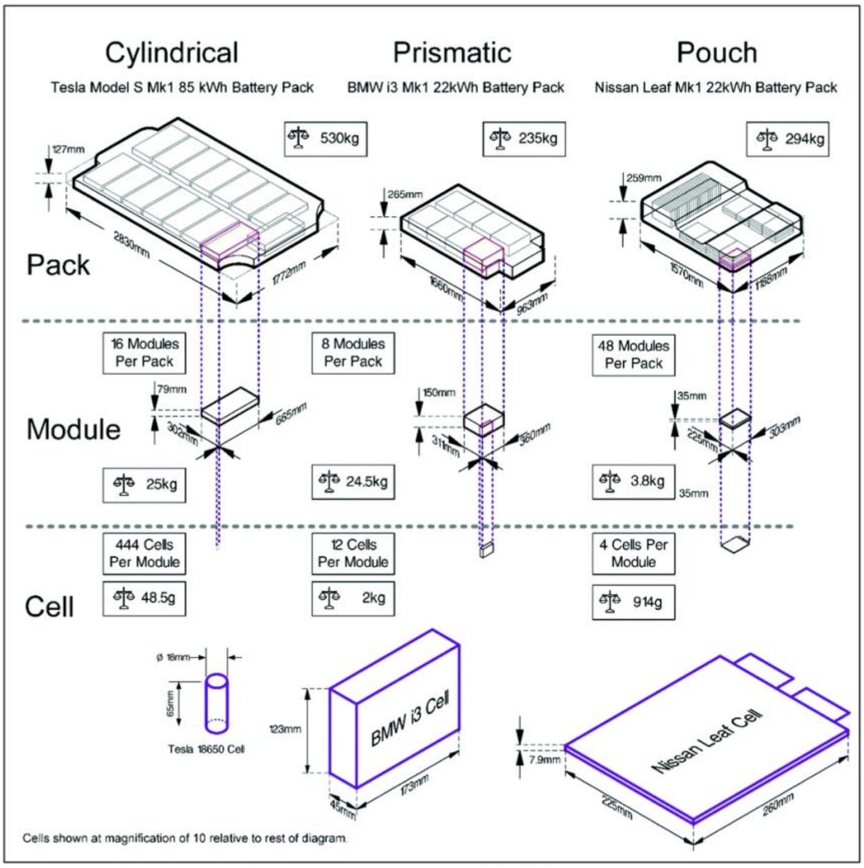


Fig: The importance of design in lithium-ion battery recycling

- **European Union's Battery Regulation (EU) - Standardization:**
    - The **European Union's Battery Regulation (EU) 2023/1542**, adopted on 12 July 2023, promotes **standardization** to enhance battery sustainability and recycling.
    - The EU Battery Regulation (EU) 2023/1542 emphasizes the importance of a harmonized regulatory framework to enhance battery sustainability and recycling. Recital 2 of the regulation states:

      "It is necessary to create a harmonized regulatory framework for dealing with the entire life cycle of batteries placed on the Union market."
    - This harmonization aims to **standardize battery design, labelling, and performance requirements** across EU member states, simplifying the recycling process and promoting environmental sustainability.

- **Lifecycle Assessment of EV Batteries:**
    - **Battery Passport:**
        - A battery passport is a **digital document or system that tracks and records the life cycle of a battery**, from production through usage to recycling or disposal. It is designed to provide transparency, traceability, and accountability throughout the battery's lifecycle, especially in industries like electric vehicles (EVs), renewable energy storage, and consumer electronics.
        - The key elements of a battery passport typically include *manufacturing details, performance data, environmental impact, and EOL management*.
        - Battery passports will be a core tool in enabling a **circular battery value chain**, allowing all stakeholders to cooperate and share relevant information to maximize safety, optimize battery use, and ensure responsible recycling. *("Battery Regulation EU: Learn about Battery Passports," 2022)*

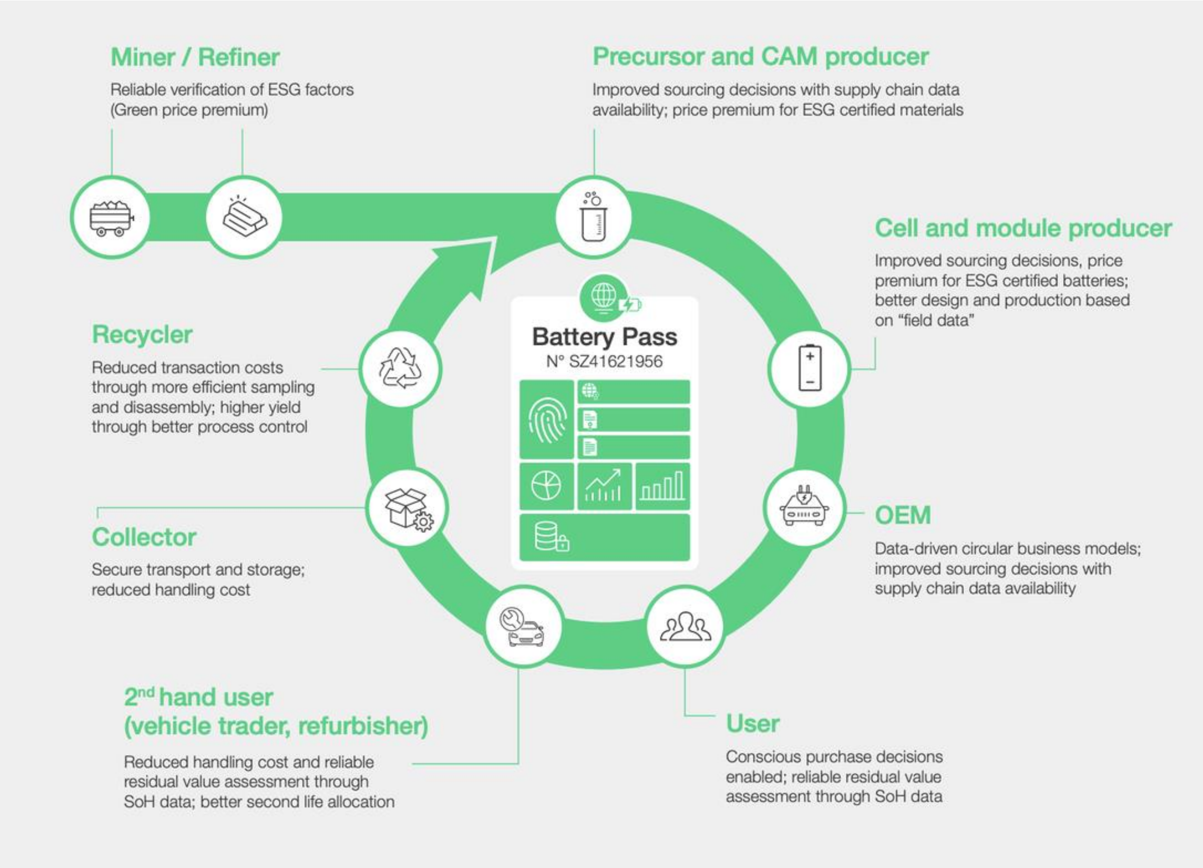
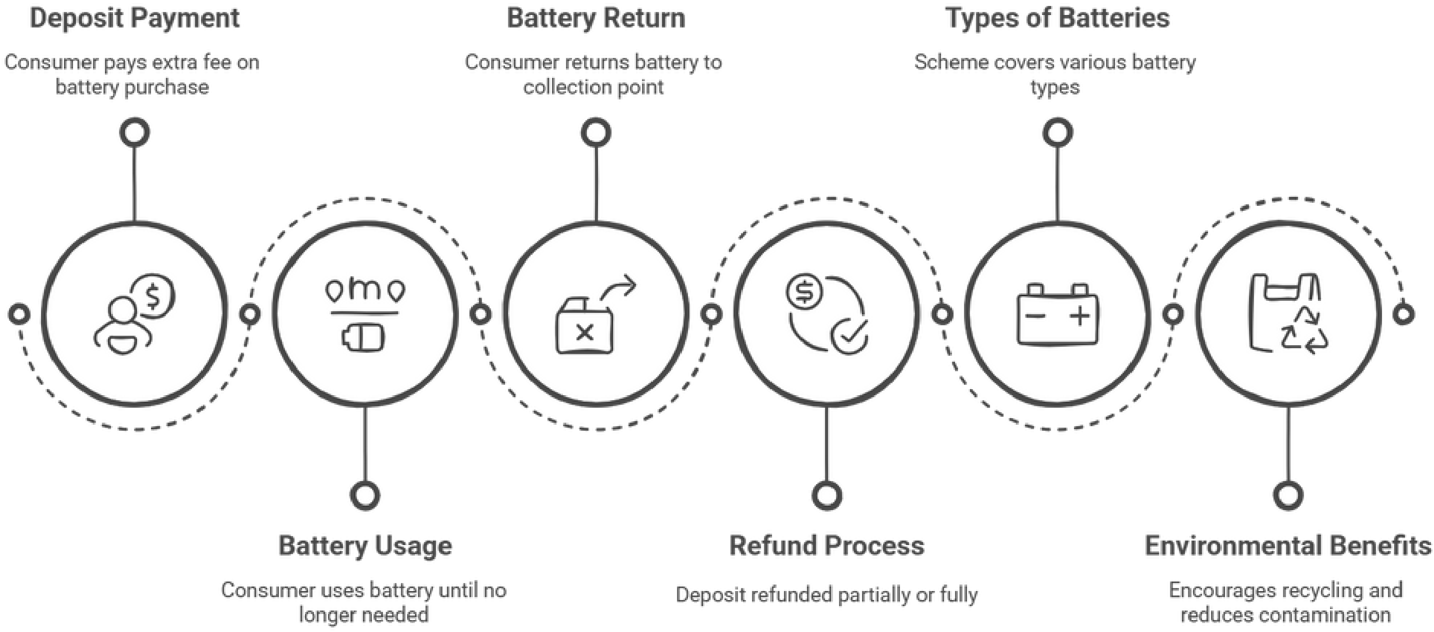


Fig: The digital battery passport will unlock major value at industry and society alike

- **Collaboration or Vertical Integration:**
  - **Volkswagen's Salzgitter:**
    - Volkswagen's Salzgitter plant in Germany is a facility that recycles electric car batteries. The plant aims to create a **closed-loop process** that recovers valuable raw materials from lithium-ion batteries.
    - Firstly, the plant process will analyze if the battery has enough power to be used in mobile storage systems and if it is given a second life. If enough power is available within the battery, it will be recycled for use in mobile storage systems, like the mobile charging robot and the flexible, rapid charging station. However, the returns of larger volumes of batteries are not expected until at least the late 2020's.
    - During the pilot phase, the plant will recycle **3,600 batteries per year**, approximately **1,500 tonnes**. There are also tonnes of CO2 savings calculated, which is a step towards Volkswagen making a more sustainable stance, contributing to climate protection and the supply of raw materials. As the plant becomes more efficient, the system can be scaled up to process larger volumes.

Fig: Volkswagen AG Salzgitter Plant

- ## Policy Frameworks:
  - ### Deposit Refund Schemes:
    - Deposit refund schemes for consumers returning used batteries are initiatives designed to encourage the recycling of batteries by **offering a refund or incentive when consumers return their used or spent batteries**. These programs help promote responsible disposal, reduce environmental impact, and ensure that hazardous materials like heavy metals in batteries are properly managed.
    - Here's how these schemes generally work:



- Countries like the **EU, USA, and Germany** are great examples of such schemes where these schemes are used to incentivize the general public to deposit their used EV batteries.
- In India, **lead battery deposit refund systems** are already in place.

- **Producer Responsibility Organization (PRO):**
  - A Producer Responsibility Organization is a company or entity established by manufacturers to **fulfil their legal obligations** related to the **collection, recycling, and disposal of waste generated by their products**. PROs can operate independently from the parent company, ensuring compliance with recycling laws and regulations. They may serve a single company or multiple firms within an industry, functioning under various names such as industry exemption companies, third-party organizations, or designated bodies.
  - By partnering with PROs, companies can streamline waste management and recycling processes, reducing their environmental footprint and enhancing their **corporate social responsibility (CSR)**.
  - By aligning with PROs, companies can support the circular economy, fostering innovation in developing durable, reusable, and recyclable products. This strengthens the brand reputation and leads to more sustainability, which resonates with environmentally conscious customers.

- **Extended Producer Responsibility (EPR):**

- The Waste Management Rules 2022, mentions about Extended Producer Responsibility (ERP), which mandates the producers of Electric Vehicle (EV) Batteries to become accountable for collecting, recycling, and refurbishment of waste batteries. This initiative ensures environmentally sound management of battery waste and also promotes circular economy.

- Its producers responsibility to register with Central Pollution Control Board (CPCB) via their centralised ERP portal.

- The policy also mentions specific collection and recycling targets to be achieved by producers every year.

- Producers are also prohibited from disposal of waste batteries in landfills and shall direct the collected the batteries to authorized recyclers or re-furbishers.

- The ERP System also facilitates the exchange of ERP certificates between the producers and registered recyclers/re-furbishers.

10.2 Case Studies:

- **Company Specific Case Studies:**

  - **Redwood Materials (Headquarters: Carson City, Nevada, United States):**
    - Founded by a former Tesla executive, Redwood Materials leads the battery recycling space by using **advanced hydrometallurgical processes** to recycle lithium-ion batteries, recovering 95-98% of nickel, cobalt, and lithium.
    - Collaborates with Ford, Panasonic, and Amazon to build a closed-loop battery supply chain.
  - **CATL (Headquarters: Ningde, China):**
    - CATL repurposes used EV batteries for **stationary energy storage systems (ESS)**.
  - **Umicore (Headquarters: Brussels, Belgium):**
    - Belgian company Umicore operates one of the world's largest battery recycling plants.
    - Focuses on **pyrometallurgical recycling** with a recovery rate exceeding 95%.
    - Plays a central role in the EU's circular battery supply chain, collaborating with automakers like Audi and Volvo.
  - **Nissan's 4R Energy Corporation (Yokohama, Kanagawa Prefecture, Japan):**

    - Nissan pioneered the reuse of EV batteries in projects like **residential energy storage systems**.
    - Its partnership with 4R Energy Corporation uses second-life batteries for **off-grid solar systems** and **EV charging stations**.
  - **Lithium Australia (Australia):**
    - Lithium Australia focuses on innovative **sodium-sulphur battery technologies** and recycling lithium-ion batteries.
    - **Partners with the University of Melbourne** to create low-cost recycling solutions.

- **Country Specific Case Studies:**
- **Japan:**
  - Japan mandates **manufacturers like Nissan and Toyota** to collect end-of-life EV batteries.
  - Infrastructure Highlight:
    - Japan uses a **centralized digital system** to track battery lifecycles.
    - The government **incentivizes** recycling plants that **meet high recovery rate** standards.
  - Second-Life Usage:
    - Large-scale **off-grid energy solutions** using repurposed EV batteries, such as **disaster recovery centres**, are widely adopted.
- **South Korea:**
  - South Korea has established state-of-the-art recycling plants collaborating with companies like **LG Chem** and **Samsung SDI**.
  - Infrastructure Highlight:
    - **Jeju Island** is a battery collection and recycling model integrating second-life batteries into the island's **renewable energy microgrid**.
  - Second-Life Usage:
    - Second-life batteries are repurposed for **electric scooters and energy storage in rural areas**.
- **China:**
  - Infrastructure Highlight:
    - State-supported companies like **CATL and BYD** operate **extensive battery recycling networks** with government incentives.
    - A **centralized tracking system** ensures efficient collection and compliance.

- Second-Life Usage:
  - Second-life batteries **power public transportation systems** and are used in **grid stabilization projects**.
- **United States:**
  - Infrastructure Highlight:
    - California grants EV battery recycling startups and integrates them into the **state's green energy initiatives**.
    - The **state collaborates with Redwood Materials** to develop closed-loop recycling ecosystems.
  - *Nevada: Tesla Gigafactory*
    - Nevada's Gigafactory **integrates recycling systems within production facilities**, showcasing a circular economy model.
    - Second-life batteries are used in **solar energy farms**.
- **Nordic Countries (Sweden, Finland, Denmark):**
  - Finland and Denmark collaborate on **cross-border recycling networks**, leveraging economies of scale.
  - Sweden's **Northvolt Revolt Plant** runs on 100% renewable energy and achieves material recovery rates exceeding 95%.
  - Norway integrates a **deposit-refund system** for EV batteries, incentivizing returns.
- **Netherlands:**
  - **Battery-as-a-Service (BaaS) model** in The Netherlands: users do not own EV batteries outright. Instead, they lease or subscribe to the battery as a service, enabling easier management of the battery lifecycle and enhancing sustainability.

10.2.1 Success Metrics and KPIs:

Country	Key Metric	Success Indicator
Japan	Recycling Rate	Over 90% recovery of lithium-ion battery materials
	Second-Life Usage	20% of second-life batteries used for grid storage and energy solutions
	Recycling Facilities	20+ active recycling facilities processing 100,000+ tons of batteries annually
South Korea	Recycling Rate	88% recovery rate for lithium-ion batteries
	Second-Life Batteries in Storage	500 MWh of second-life batteries for grid stabilization
China	Recycling Network Size	10,000+ EV battery recycling centers established
	Recycling Rate	50% and rising for spent EV batteries
	Second-Life Usage for Transportation	1 GWh of second-life batteries repurposed for electric buses and charging stations
United States	Recycling Capacity	Over 90% material recovery in pilot projects
	Waste Reduction	30,000+ tons of battery waste diverted from landfills
	Grid Storage	200 MWh of second-life batteries deployed in California's grid energy storage
Netherlands	BaaS Adoption	20% EV owners using Battery-as-a-Service (BaaS)
	Collection Points Density	500+ battery collection points nationwide
	Second-Life Batteries in Storage	100 MWh of second-life batteries in residential and commercial energy storage

11. Policy & Regulatory Framework

The EV Battery market in India is expected to grow at a CAGR of 10.56%, from 16.77 billion dollars in 2023 to 27.70 billion dollars by 2028. A robust policy and regulatory framework are required to set standards to incentivise the recycling infrastructure development, ensuring proper collection and disposal of used EV Batteries, responsible battery waste management, and synergy between various stakeholders contributing to the value chain, to establish a sustainable circular economy for EV Batteries. This section aims to study the policies and regulations issued by the Indian government and analyse them to recommend policy amendments.

Key National Policies and Regulations Governing the EV and Battery Industry

The very first policy to govern EV batteries was launched in 2015 by the Indian government under the name FAME: Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME) scheme. The policy was designed to promote electric and hybrid vehicle technology manufacturing and to ensure a robust infrastructure for a sustainable business environment. It was done to achieve the vision of the National Electric Mobility Mission Plan 2020 (NEMMP), which focussed on faster adoption of EVs and promoted manufacturing in the country. Phase 1 focused on four areas: demand creation, technology platform, pilot project, and charging infrastructure. Demand incentives were planned to provide buyers with an upfront reduction in the purchase price of the vehicle of any category. In this phase, 2.78 lakh EV vehicles were supported with an incentive of approximately Rs. 343 Crores. Moreover, 465 buses were sanctioned across various cities/states. The scheme did not talk about EV battery recycling, as its primary focus was more on EV adoption and building the country's infrastructure.

Although there was an update in FAME I, there needed to be a discussion about EV Battery recycling or related infrastructure in FAME II. It was also designed to promote EV adoption by providing demand incentives and building the manufacturing infrastructure in India. The policy was from 2019 to 2022. The policy has an outlay of 10,000 crores, 86% of which was allocated to demand incentives focused on the adoption of various kinds of Electric Vehicles such as 7000 E-Buses, 5 Lakhs E-3 wheelers, 55000 E-4 wheeler (passenger cars) and 10 lakh E-2 wheelers. Moreover, only advanced batteries and registered vehicles were eligible under the scheme. The scheme mentioned various subsidies for different categories of vehicles during adoption. Additionally, on 1st October 2024, PM - E Drive was launched in succession of FAME II, which also focused on the adoption of Electric vehicles in India. The scheme is a part of governments broader push to promote clean energy and sustainable transportation by promoting adoption of electric Vehicle in the country. It focuses on incentivizing the adoption of EVs, providing subsidies to buyers of electric two-wheelers, cars, buses and charging infrastructure. One of the major focus area of PM -eDrive is the enhancement and expansion of EV charging infrastructure, ensuring that consumers have more access to charging stations. The initiative is aligned with the country's broader environmental goals and it will play a vital role in India's commitment to achieving net-zero emissions by 2070.

To talk about battery recycling, in 2021, Prime Minister SHRI NARENDRA MODI introduced the Battery Waste Management Rules 2022, which overrides the 2001 rules. It governs various kinds of batteries, such as electric vehicles, portable, automotive, and industrial batteries. The main function mentioned in the rule was ERP (Extended responsibility of the producer), where the producer (including the importers) is responsible for collecting and recycling/refurbishing waste batteries and recovering materials. The rule prohibits the disposal of used batteries in landfills and mandates waste battery collection and recycling/refurbishment. It also proposes setting up an online portal for issuing ERP certificates between producers and recyclers. Moreover, the rules mentioned duties of the producer as below:

1. Schedule 1 of Waste Management Rules 2022 prescribes adherence to prohibitions and labelling requirements.
2. A producer has to ensure the safe handling of the waste battery so that it does not cause harm to health and the environment.

There were other obligations also set by the WMR 2022, as the producer has to use a minimum amount of material in new batteries that have been domestically recycled. The assessment of the same shall be in respect of the total dry weight of the battery. Moreover, in the case of an imported battery, the producer must meet this obligation by getting recycled material used by other businesses or exporting a similar quantity.

S No.	**Type of Battery**	**Minimum use of the recycled materials out of total dry weight of a Battery (in percentage)**			
1		**2027-28**	**2028-29**	**2029-30**	**2030-31 and onwards**
2	**Portable**	5	10	15	20

	Electric Vehicle	5	10	15	20
3		**2024-25**	**2025-26**	**2026-27**	**2027-28 and onwards**
4	**Automotive**	35	35	40	40
	Industrial	35	35	40	40

The minimum target is the percentage of the total weight of the material recovered out of dry weight of the battery, and recyclers are mandated to follow the below minimum recovery targets.

S.No.	**Type of Battery**	**Recovery target for the year in percentage**		
		2024-25	**2025-26**	**2026-27 and onwards**
1	**Portable**	70	80	90
2	**Automotive**	55	60	60
3	**Industrial**	55	60	60
4	**Electric Vehicle**	70	80	90

There are penalties and environmental compensations imposed on non-adherence to the policies drafted by the government of India. CPCB is the authority that imposes environmental compensations for noncompliance by any stakeholders. These ECs are imposed under two regimes. Firstly, the cost of handling, collection, and transportation of waste batteries, plus the cost of processing to recover metal. Secondly, the application fee for registering as a producer, recycler, or refurbisher.

As discussed above, PM E-Drive and Battery Waste Management Rules 2022 govern the electric vehicle industry at the central level. State-level policies are designed to regulate and control business activities in various states. Himachal Pradesh also introduced an H.P. State EV Policy, 2022, to promote the adoption of Electric Vehicles in the state and the building of infrastructure for EV charging.

This policy was designed to address the deteriorating air quality of the hill ecology. It also states that Himachal Pradesh has an **energy surplus,** and **90%** of the energy generation is from hydropower. The policy also mentioned that adopting electric vehicles and building the infrastructure will improve the number of jobs and address the issue of climate change. According to the policy, the state's government aims to become the leader by decarbonising its transport sector and promoting ecotourism via combined efforts in renewable energy supply and EV adoption.

The objectives of the policy are as follows:

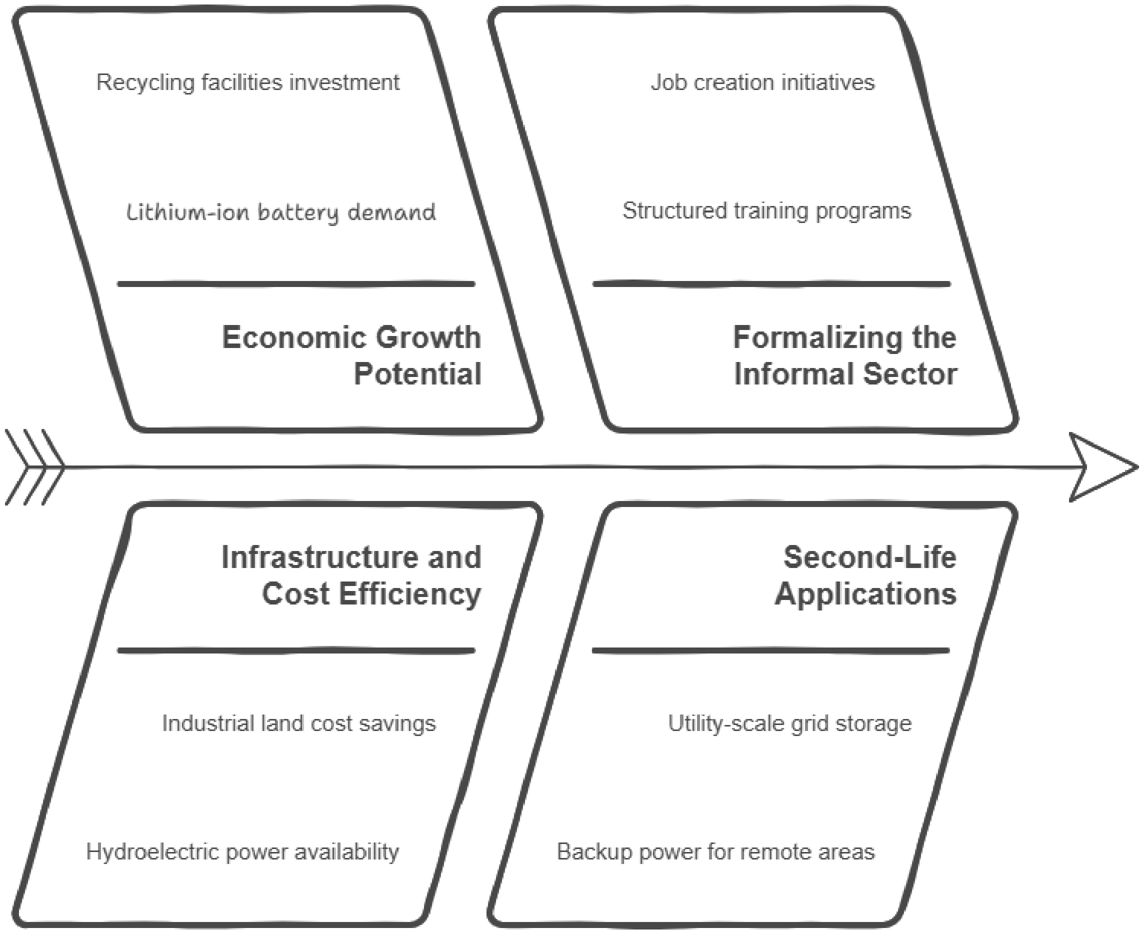
1. Electric Vehicle adoption in the state, achieving a target of 15% vehicle registrations by 2025.
2. Promoting a sustainable transport system, making the state a global hub for electric mobility development and manufacturing electric vehicles.
3. Setting up charging infrastructure via public and private collaborations to provide infrastructure to manufacturers to set up EV manufacturing facilities.
4. Providing subsidies and incentives for EV adoption and manufacturing was also one of the objectives to promote electric mobility in the state.
5. Declaring and working towards making Shimla, Mandi, Baddi, and Dharamshala model cities for EV readiness and adoption.

To achieve these objectives, the government proposed strategies to promote demand for EVs through fiscal and non-fiscal incentives, incentives for purchasing EVs, and tax/fee waivers (waiving off the annual permit fee on commercial EVs). The government also proposed to exempt EVs from road tax and toll taxes for the duration of the policy. Moreover, the government mandated the use of EVs in institutional areas and aimed to start with public transport and government vehicles. The authority also proposed the development of EV Industrial parks and manufacturing firms by allocating 100 to 200 acres of land. In addition, infrastructure support, such as land, water, electricity, and road connectivity, is also promised as per the State Industrial Policy 2019 provisions.

Himachal Pradesh State Board Electricity has been designated the Nodal Agency for charging infrastructure. The cities targeted are Shimla, Mandi, Baddi, and Dharamshala. It aimed at achieving the target of 1 charging station on each side of the Highway at every 25 km on state highways and at least one on each side at every 50 km on National Highways. Moreover, Incentives were set up as a claim from the PLI scheme for the National Programme on Advanced Chemistry Cell (ACC) battery Storage of the Ministry of Heavy Industries for approx 18100/- crores.

The state policy supports the early adoption of EVs and the building of a strong infrastructure to support the same by growing entrepreneurship and regulations in the state. Hence, the current preparedness is being mapped across Himachal Pradesh. In the city of Poanta Sahib, there are currently no EV battery dealers, and the lead acid battery dealers have not yet procured EV batteries as the demand has not yet hit the initial stage in the city.

12. Opportunities in Himachal Pradesh



Himachal Pradesh, with its unique topography and emerging EV ecosystem, presents a timely opportunity to develop a regionally attuned battery recycling and second-life battery value chain. The concentration of early EV adoption in commercial segments, particularly **e-rickshaws and two-wheelers** in towns like Paonta Sahib demonstrates grassroots-level interest that is currently underserved by formal collection or disposal systems. Given the state's strategic location **near industrial hubs like Chandigarh** and its **robust hydroelectric base**, Himachal can position itself as a clean-tech corridor by leveraging its existing pharmaceutical and electronics manufacturing sectors (especially in **Baddi-Barotiwala-Nalagarh**) to pilot scalable battery recycling and refurbishment units. These can be powered sustainably and positioned to serve both the local and adjoining North Indian markets.

Furthermore, the state's informal sector comprising **kabaadis and small battery dealers** already engages in unregulated collection and resale, particularly of lead-acid batteries. With minimal state-level infrastructure for lithium-ion recycling currently in place, formalizing these actors through structured training, safe logistics protocols, and EPR-backed aggregation centres offers a dual opportunity: **enhancing environmental compliance while generating local employment**. Himachal's terrain and dispersed settlements also make it an ideal candidate for second-life battery applications like **telecom backup, solar street lighting, and rural electrification**. By rooting such initiatives in localized needs, the state can simultaneously address waste management gaps and strengthen its renewable energy ambitions.

Below mentioned are the opportunities presented to Himachal Pradesh by this EV Revolution in detail:

1. Economic Growth Potential: India's demand for lithium-ion batteries is projected to reach approximately 260 GWh by 2030, driven by accelerated EV adoption and renewable energy integration (Casals et al., 2017). HP can leverage this growth by developing dedicated battery recycling facilities that use advanced hydrometallurgical technology—capable of recovering up to 90% of valuable metals such as lithium, cobalt, and nickel (Ahmadi et al., 2014). In addition, similar projects in nearby regions have attracted investments of around ₹7.5 crores per plant, suggesting that with targeted viability gap funding, HP could support multiple recycling startups by 2026 (iPower Batteries, 2024; Reuters, 2025). Furthermore, HP's successful Extended Producer Responsibility (EPR) initiatives have diverted over 1,300 tonnes of plastic waste annually, generating approximately ₹4.8 crores in revenue (WRI India, 2023). By integrating battery recycling into these established frameworks, HP can enhance its circular economy model while reducing environmental hazards.

2. Infrastructure and Cost Efficiency:

- The **Baddi-Barotiwala-Nalagarh (BBN) industrial belt** offers a significant advantage with industrial land costs approximately 30% lower than Shimla, providing an ideal setting for new recycling units (Economic Times, 2023).
- Cluster-based processing models from the Mandi-Dharamshala region have demonstrated transportation cost reductions of about ₹3.6 per ton per kilometre (Statista, 2024), offering a replicable model to boost efficiency in battery recycling hubs.
- Additionally, HP's extensive hydroelectric capacity—currently around 3,300 MW (MNRE, n.d.)—can power recycling plants at low cost, further reducing operational expenses and bolstering the state's competitiveness.

3. Formalizing the Informal Sector: HP's informal waste sector includes thousands of scrap dealers who currently operate under unregulated conditions. Structured training programs and community engagement initiatives could formalize these roles, potentially generating over 1,200 new jobs while establishing a systematic battery collection network. This not only improves operational efficiency but also enhances environmental compliance and worker safety.

4. Second-Life Applications and Local Partnerships: After their primary use, EV batteries typically retain 60–80% of their capacity, making them ideal for various secondary applications. HP can repurpose these batteries for:

- **Utility-Scale Grid Storage:** Stabilizing power grids by storing surplus renewable energy, which is particularly valuable given HP's hydro and solar potential.
- **Backup Power for Remote Infrastructure:** Powering telecom towers in remote Himalayan regions, thereby reducing diesel dependence and ensuring consistent service (Union of Concerned Scientists, 2018).
- **Public Lighting and Rural Electrification:** Supporting solar streetlights and off-grid electrification in underserved areas to improve public safety and reduce energy costs.
- **EV Charging Infrastructure:** Deploying repurposed batteries in fast-charging stations to mitigate grid strain and enhance charging efficiency (Renault, 2018).

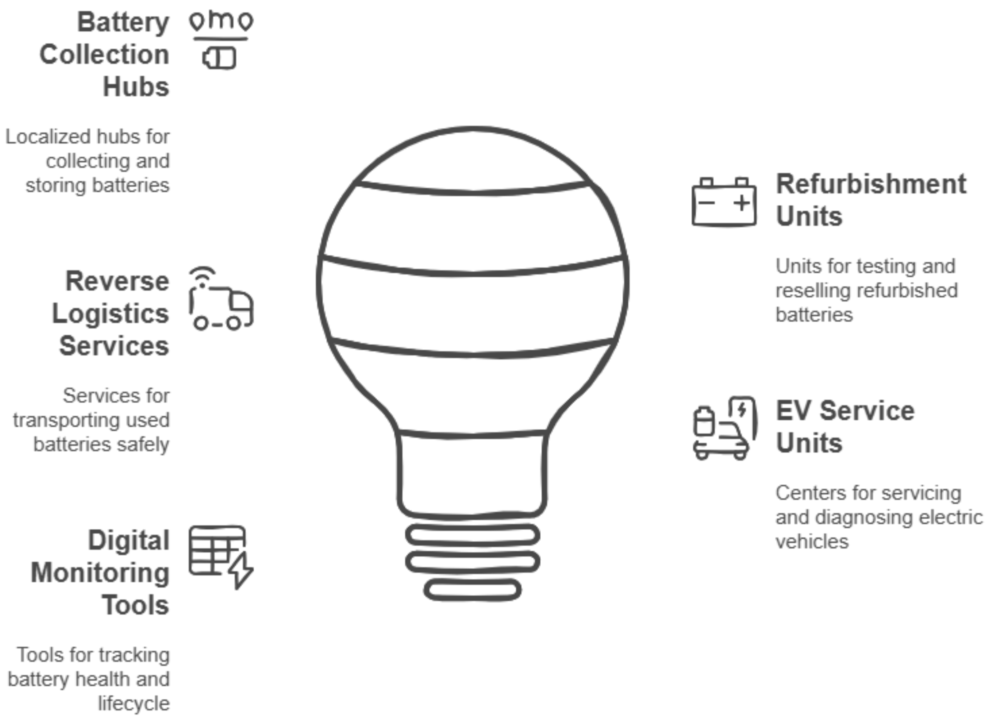
Local partnerships, including collaborations with academic institutions (e.g., CSIR-NEERI, IIT Mandi) and domestic manufacturers (e.g., Exide, Tata, Amara Raja), will be critical in driving research and ensuring a steady supply of end-of-life batteries. A short-term collaborative platform among these stakeholders could boost second-life battery deployments by an estimated 20% within two years (NITI Aayog, 2022).

5. Collaborative Platforms for Second-Life Applications

As a **short-term measure**, HP can:

- Encourage collaboration among automotive, recycling, and energy sectors to scale second-life battery applications.
- **Projected Impact**: This initiative could **increase deployments by 20% within two years**, reducing battery waste while enhancing energy storage capabilities (NITI Aayog, 2022).

13. Entrepreneurial Opportunities in Battery Recycling



Based on field visits to Paonta Sahib and stakeholder discussions across the EV ecosystem, the following are a few **highly context-specific entrepreneurial opportunities** in Himachal Pradesh's battery recycling space:

1. Battery Collection & Aggregation Hubs in Semi-Urban Centres

The absence of formal collection points in smaller towns like Paonta Sahib has resulted in informal players dominating the value chain, especially for lead-acid batteries. Lithium-ion battery collection is still nascent but expected to rise as EV adoption grows. Entrepreneurs can create **localized hubs** that partner with OEMs, service centres, and municipal bodies to **collect, record, and safely store end-of-life (EoL) batteries**, forming the first link in a compliant reverse supply chain.

2. Battery Refurbishment Units for E-Rickshaws and Off-Grid Storage

Interviews with e-rickshaw drivers revealed that battery issues often stem from specific faulty cells, not the entire unit. Local workshops already replace individual cells informally. Entrepreneurs can formalize this by setting up **small refurbishment units that test, replace, and resell batteries with quality control**. These refurbished batteries can power off-grid solar lights, telecom towers, or backup systems in rural Himachal, supporting energy resilience and income diversification.

3. Reverse Logistics Services for Hazardous Battery Transport

Transporting used lithium-ion batteries is logistically difficult due to their hazardous classification and regulatory requirements. Entrepreneurs can fill this gap by offering **certified reverse logistics services** using **authorized vehicles** and **CPCB-compliant packaging**, especially from interior districts to industrial hubs like Baddi or to out-of-state recyclers. *With recyclers like Lohum operating in nearby Noida, this business model ensures material recovery without violating safety norms.*

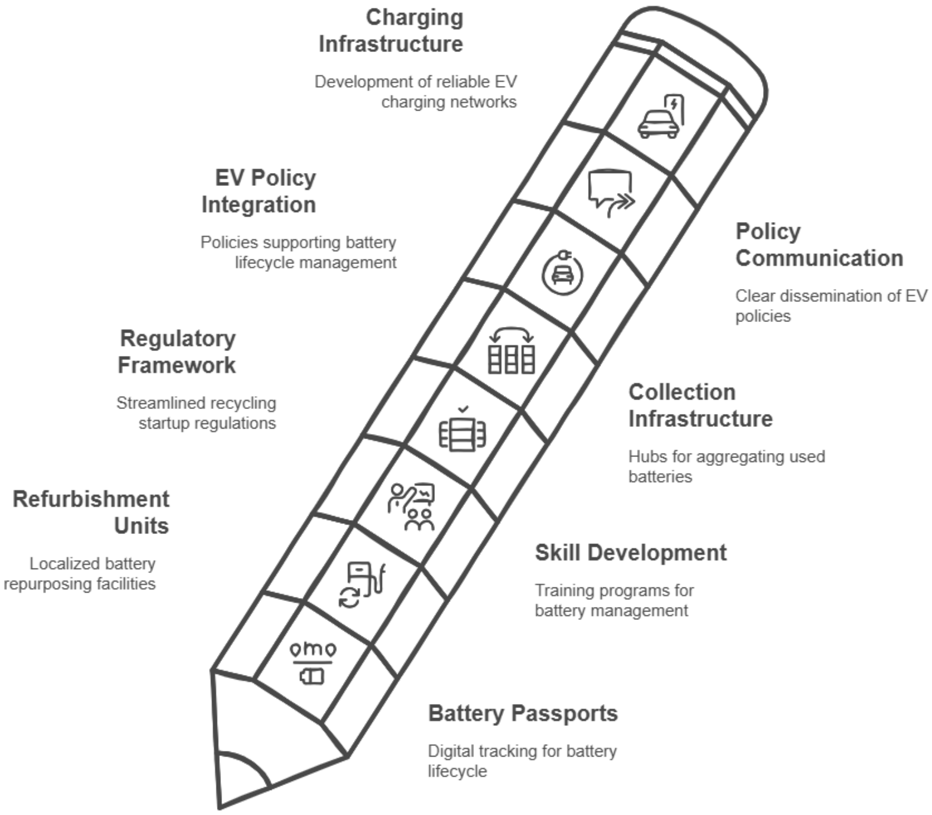
4. Decentralized EV Service and Diagnostics Units

TATA and other OEMs currently centralize service operations, and independent mechanics in Himachal lack access to EV-specific training and tools. Entrepreneurs can establish **authorized third-party EV servicing centres**, especially in regions with growing EV use. These centres can offer diagnostics, minor battery repairs, and interface with OEMs for warranty processing. These service centres can also be integrated into the existing third-party service centres for better synergy and profitability for individual entrepreneurs.

5. Digital Battery Health Monitoring & Lifecycle Management Tools

As battery life-cycle traceability becomes important especially with the push for battery passports, there is a strong opportunity for tech-driven entrepreneurs to develop **localized digital tools**. These platforms can **track battery usage data, enable predictive maintenance, and signal end-of-life timelines**. For small fleet operators (e.g., delivery vehicles, e-rickshaws), such solutions can reduce downtime and increase ROI. In the Himachal context, where terrain-induced range anxiety is common, battery performance visibility can build trust in EV adoption. These tools can be integrated into state-supported battery passport pilots, creating new B2B offerings for OEMs and regulators. This remains a far-fetched solution that might turn out to be a start-up venture in the future. Participation of institutions like **IIT Mandi** and **IIM Sirmaur** in such initiatives can lead to active participation of young minds in solving real-time problems and exploring booming opportunities.

14. Recommendations & Action Plan



Himachal Pradesh's economy is on a dynamic growth path with a projected GDP growth of **7.1% for FY 2023–24** and a **per capita income approaching ₹2.35 lakh**, and its strengths in hydroelectric power, pharmaceutical manufacturing, and horticulture provide a solid foundation for sustainable industrial initiatives. Building on these advantages, the following data-driven recommendations offer a comprehensive roadmap for developing a sustainable battery recycling and second-life ecosystem in the state.

1. Integrate Battery Passports into EV and Recycling Pilots

In Himachal Pradesh, the lack of traceability in battery life cycles—highlighted by the HP Pollution Control Board—is a major barrier to enforcing safe recycling and EPR mandates. Given that **commercial EVs** in sectors like logistics, e-rickshaws, and institutional fleets (e.g., pharma transport in Baddi or municipal EVs in towns like Paonta Sahib) follow defined service routes and are linked to OEMs or fleet operators, they provide an **ideal starting point for deploying battery passports**. A battery passport can digitally capture battery health, usage cycles, ownership history, and end-of-life status, making reverse logistics and safe disposal more manageable at the local level. This can be **executed manually in the beginning** where all the identified touchpoints can be used to collect necessary updates about the battery which can later be put to use.

In the **long run**, Governments can make reporting of this information about the batteries in the market a **mandate to the OEMs** as it is very much possible for them to integrate IoT with already existing BMS during the manufacturing and assembly for such data collection purposes. This way the data will be collected and will also be at disposal to the government which can then be used for a greater good. It also satisfies the environmental aspect of running EVs using lithium-ion batteries. Additionally, it does not pose any pressure of data collection on the Government bodies. Starting with commercial EVs in Himachal Pradesh, Battery Passport can become a **national policy amendment for a much bigger impact**.

Action Plan: Launch a pilot in the Baddi-Barotiwala-Nalagarh (BBN) industrial belt, mandating OEMs and fleet operators to integrate battery passports for all new commercial EVs. This can be supported through a simple, app-based tracking system co-developed with a local tech partner or institute like **IIT Mandi**. *For initials, the pilot can be supported by on-paper/on-card entries as well which can be formalized using standardized seal tags.*

2. Create a Network of Battery Refurbishment Micro-Units for Second-Life Applications

Field interactions with e-rickshaw drivers and service centres indicate that many batteries retain high residual capacity (60–80%) even after years of usage. Informal practices such as replacing faulty cells already exist, but **without safety controls or quality standards**. Himachal can leverage this insight by encouraging **localized refurbishment units** that test, reassemble, and repurpose batteries for *off-grid solar lighting, telecom backups, and micro-grid storage*. These units need not be independent refurbishment units but rather can also be integrated with existing **third-party service centres** which will make this model more feasible and practically doable. This particularly stand very relevant for **regions with low grid connectivity**.

Action Plan: **Incentivize** refurbishment units' setup and integration in Paonta Sahib and Solan through skill development and financial support, targeting secondary use-cases for rural electrification.

3. Expand Targeted Skill Development Programs for Battery Recycling and Repair

The field study revealed that OEMs like TATA conduct in-house technician training, but third-party mechanics remain excluded. Simultaneously, unsafe manual dismantling persists in unregulated units. Addressing these gaps through **government organized structured, regionally distributed training programs** especially in areas like Hamirpur, Solan, and Baddi can build a future-ready workforce for battery testing, disassembly, and recycling. This can be facilitated by initiatives like **Skill India and Start Up India**, where such issues can be addressed on ground.

OEMs seem to be contributing to this cause even further by providing employment as well as training in **EV repair and maintenance space** which in-turn is very beneficial from the point-of-view of EV adoption in India.

Action Plan: **Skill India** initiative can integrate courses on EV repairing and EV Battery Refurbishing to bring this mainstream and help in a smooth transition towards an EV driven future and this can start by spreading awareness about EVs and the threat it posses to ICE enabled workers in the future, which will then provide a push towards proactive instinct and upskilling of these workers.

4. Establish a State-Facilitated Single-Window Framework for Recycling Startups

One of the consistent themes across discussions with battery dealers and pollution control authorities was the procedural complexity in setting up recycling or battery management businesses. Issues like hazardous waste transport permits, land acquisition, and pollution clearances often deter new ventures. A dedicated, **state-level single-window mechanism** streamlining approvals and offering regulatory guidance can significantly **reduce entry barriers**. This will in-turn provide a better platform for EV related businesses to flourish in a state like Himachal Pradesh.

Action Plan: Operationalize this mechanism through the **District Industry Centre (DIC)** in coordination with **HPPCB and CPCB**, initially focused on lithium-ion recycling projects in specific regions of Himachal Pradesh.

5. Develop Localized Battery Collection and Aggregation Infrastructure

Himachal Pradesh currently lacks a formal network for aggregating used EV batteries, especially lithium-ion variants. As revealed in Paonta Sahib, the informal sector, comprising local kabaadis and battery dealers, plays a significant but unregulated role in battery disposal. This fragmented approach limits traceability, undercuts safety standards, and fails to meet Extended Producer Responsibility (EPR) goals. Establishing **localized battery collection hubs by the state government** in towns such as Mandi, Kangra, and Paonta Sahib can integrate these informal actors into **formal supply chains**, improve battery tracking, and ensure safer handling. Moreover, this can also work together with the **Battery Passport mechanism** that the report suggests above making these localized battery collection centre a core touchpoint in the entire value chain.

Action Plan: Set up pilot battery aggregation centres with standardized protocols and **tie-ups with OEMs and municipal bodies** under the EPR framework.

6. Incorporate Battery Lifecycle Management into HP's EV Policy Framework

One of the critical gaps in Himachal Pradesh's current EV policy is the absence of clear directives around battery lifecycle management, despite the policy's broader push for electric mobility through macro-level incentives. As the state witnesses a gradual uptake of EVs, there is an urgent need to pre-emptively address the **environmental and infrastructural challenges** posed by end-of-life batteries. Incorporating battery lifecycle management into the policy framework would ensure a more sustainable and future-ready EV ecosystem. This entails moving beyond vehicle-centric incentives to mandating practices that span the entire battery value chain including *eco-friendly design standards, structured take-back mechanisms, refurbishment guidelines, and scientifically managed recycling processes*. Such provisions would not only **reduce the burden on landfills and mitigate environmental risks** but also support the circular economy by enabling **second-life battery to use and material recovery**. Moreover, integrating these elements would send a strong signal of regulatory commitment and policy continuity, encouraging startups and investors to explore innovation in battery reuse, recycling technologies, and service logistics within the state.

Action Plan: Revise the Himachal EV Policy to include *measurable targets and incentives for battery recycling, with provisions for battery swapping, second-life applications, and producer responsibility organizations (PROs)*.

7. Improve Policy Communication and Ground-Level Rollout Mechanisms

A significant barrier to the effective implementation of Himachal Pradesh's EV initiatives lies in the weak communication and rollout of policies at the ground level. Insights from field interviews revealed that many stakeholders, ranging from EV dealers and workshop technicians to drivers and rural users, were either **misinformed or unaware** of crucial aspects such as **subsidy eligibility, battery return protocols, and new government schemes**. This disconnects between policy formulation and on-ground awareness undermines the impact of otherwise progressive interventions. To ensure that incentives reach their intended beneficiaries and regulations are uniformly followed, the state must strengthen its **policy dissemination mechanisms**. This includes not only improving the clarity of communication but also tailoring outreach strategies to suit diverse regional and socio-economic contexts. By ensuring that timely information reaches rural sellers, mechanics, and end-users in formats they can easily understand and access, the state can **build trust**, encourage wider EV adoption, and reduce misinformation.

Action Plan: Conduct periodic **awareness drives**, translated materials in local languages, and digital updates via **panchayat and municipal networks** to ensure wider and consistent reach.

8. Invest in a Robust and Region-Sensitive Charging Infrastructure

Both dealers and users in Paonta Sahib emphasized the lack of reliable charging infrastructure as a major bottleneck in EV adoption. The challenge is amplified by the hilly terrain and dispersed population clusters. For Himachal to unlock its full EV potential, especially in commercial segments like e-rickshaws and delivery vehicles, a decentralized yet reliable charging network is critical which can be created using **local partnerships with public and private properties**. Few examples can be notes across Paonta Sahib and Kala Amb where **private hotels have set up EV Charging Infrastructure** free of cost in order to serve the tourist better as well as earn some extra cash in commissions. This will help in reducing the 'Range Anxiety' as well which has today become one of the biggest barriers in the wider adoption of EVs in Himachal Pradesh.

Action Plan: **Solar-powered and hydro-backed public charging stations** can be prioritized in semi-urban and rural areas; incentivize private players to deploy chargers at commercial and transport hubs.

15. Conclusion

The rise of electric vehicles (EVs) presents Himachal Pradesh with a unique dual challenge: **managing environmental externalities and maximizing economic potential across the EV battery value chain**. While the state's EV adoption is still nascent, particularly in commercial and semi-urban segments, the projected volume of end-of-life (EoL) batteries in the coming years **necessitates urgent preparation**. This report demonstrates that beyond environmental stewardship, *battery recycling and second-life applications offer a compelling opportunity to drive innovation, generate employment, and improve rural energy access* especially when embedded in local contexts like those of Paonta Sahib or the Baddi-Barotiwala-Nalagarh (BBN) industrial corridor.

To capitalize on these opportunities, Himachal Pradesh must evolve from a passive policy adopter to an **active enabler of the circular battery economy**. Building integrated systems such as *localized aggregation hubs, refurbishment micro-units, and reverse logistics networks* will lay the foundation for long-term resilience. Moreover, the convergence of policy innovation (e.g., EPR enforcement and battery passports), private sector involvement, and community-level engagement is critical to transform informal practices into regulated, safe, and scalable models. Collaboration with institutions like **IIT Mandi, CSIR, and skilled OEMs** can further propel Himachal into a knowledge-driven battery ecosystem.

By **aligning policy with on-ground realities and local capacities**, Himachal Pradesh can build a resilient and inclusive battery recycling ecosystem. Leveraging tools like battery passports, localized refurbishment, and targeted training will enhance compliance and unlock new economic opportunities.

"With focused action, the state is well-positioned to lead India's transition toward a circular and sustainable EV future."

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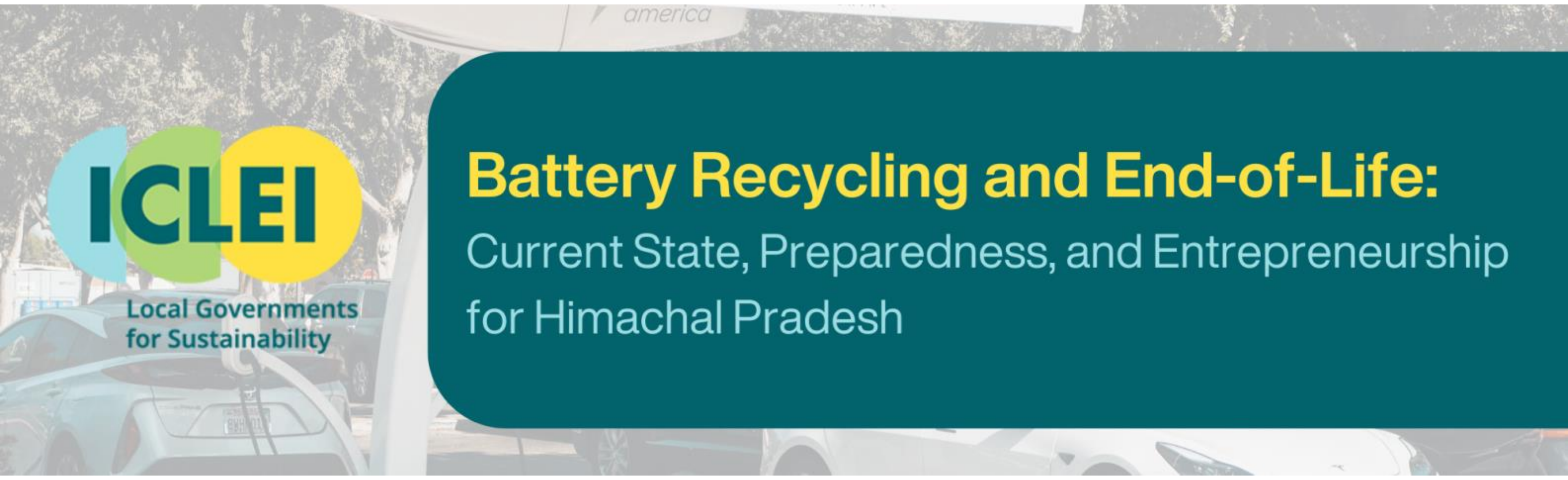

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