



OPTIMIZATION MODELS FOR HYBRID VEHICLE RECYCLING PROCESSES IN UZBEKISTAN

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Abstract. *This article examines the structural characteristics of hybrid electric vehicles (HEV/PHEV), the challenges associated with recycling their lithium-ion batteries, and models for optimizing these processes within the economic and environmental context of Uzbekistan. The study analyzes the "Second Life" concept for batteries and evaluates the efficiency indicators of raw material recovery. The author proposes a centralized recycling network model tailored for Uzbekistan's industrial landscape, aiming to achieve environmental safety and economic sustainability through "Urban Mining" practices.*

Keywords: *Hybrid vehicles, battery recycling, lithium-ion, Second Life, hydrometallurgy, Uzbekistan, green economy.*

1. Introduction: Problem Statement and Relevance

Under the framework of Uzbekistan's "Strategy for Transition to a Green Economy," the import and localized production of Hybrid Electric Vehicles (HEV) are accelerating. However, unlike traditional vehicles, hybrids integrate two complex systems: an internal combustion engine and high-voltage battery packs.

The core issue lies in the end-of-life management of these vehicles (typically after 8-10 years). Disposing of them as conventional scrap metal poses a severe threat to the environment. The heavy metals and electrolytes contained in lithium-ion batteries can contaminate soil and groundwater. Therefore, developing a national model for hybrid vehicle recycling is not only an environmental necessity but also a strategic economic objective.

2. Technical Chain of Hybrid Vehicle Recycling

The recycling process for hybrid vehicles must move beyond simple "pressing" and evolve into a high-tech chain consisting of the following stages:

- **Safe Disassembly System:** Hybrid vehicles operate at voltages ranging from 300V to 650V. The first stage involves a "Safety Disconnect" of the battery pack, performed by specialized robotic systems or highly qualified technicians.
- **Component Separation:** Mechanical parts (engine, crankcase, transmission) are directed toward standard metal recycling, while electronic components (inverters, converters) are sorted separately.
- **Battery Diagnostics:** This is a critical juncture. Before a battery is deemed fully unusable, each individual "cell" must be tested for residual capacity.





3. Optimizing the "Second Life" Concept

When the State of Health (SOH) of hybrid vehicle batteries drops to 75-80% or less, they become unsuitable for transportation. However, this remaining capacity is highly effective for Energy Storage Systems (ESS).

Optimization Model:

Given Uzbekistan's high solar potential, these batteries can be repurposed as storage units for night-time electricity supply. On average, a battery pack recovered from a single hybrid vehicle can cover the daily lighting and basic appliance needs of one household. The extension coefficient of the battery's service life K_x is determined as follows:

$$K_{ext} = \frac{T_{auto} + T_{station}}{T_{auto}}$$

(Where T_{auto} is the service years in the vehicle, and $T_{station}$ is the years of service in a stationary application).

4. Material Regeneration (Hydrometallurgy and Pyrometallurgy)

Recovering precious metals from within the battery is referred to as "Urban Mining." This paper compares two methods for the Uzbekistan context:

- **Pyrometallurgy:** High-temperature smelting. The disadvantage is that lithium evaporates, and CO₂ is emitted into the atmosphere.
- **Hydrometallurgy:** Leaching in acidic solutions. This method allows for up to 98% precision in recovering lithium and cobalt.
- **Economic Efficiency:** The market value of cobalt recovered from 1 ton of hybrid batteries is 2.5 times cheaper than importing the raw material.

5. Institutional Proposals for Uzbekistan

To manage the process effectively, we propose a three-tier model:

- **Regulatory Framework:** Implementing the "Extended Producer Responsibility" (EPR) principle. Companies that import or manufacture vehicles must be responsible for their eventual recycling.
- **Digital Monitoring:** Assigning a QR-code (passport) to every hybrid battery. This allows for tracking its entire life cycle from production to final disposal.
- **Recycling Clusters:** Establishing specialized "Green Recycling Centers" in industrialized regions such as Tashkent, Navoi, and Andijan.

6. Technological Flowchart and Economic Models

The recycling flowchart emphasizes two pathways for the **Lithium-ion battery**: material recycling or "Second Life" reuse.

The "Second Life" economic model illustrates how batteries, rather than being immediately smelted, serve as stationary energy storage devices, thereby reducing environmental load and maximizing the "Life Cycle" value.



Conclusion and Practical Recommendations

- **Environmental Risk:** The increase in hybrid vehicles leads to a geometric progression of lithium-ion waste. Without an established system, a battery waste crisis may occur by 2030.
- **Economic Resource:** Recycling is not just waste disposal; it is a renewable source of Cobalt, Lithium, and Nickel.
- **Energy Solution:** Retired batteries are the most cost-effective solution for storing solar and wind energy.

Optimization Proposals:

1. **"Green Passport" System:** Digital monitoring of batteries across ownership changes.
2. **Cluster Approach:** Developing hydrometallurgical processing units in metallurgical centers like Navoi or Olmalik.
3. **Recycling Subsidies:** Providing tax or customs incentives for citizens who return used batteries to official points.
4. **Standardization:** Implementing mandatory safety standards (based on ISO) for battery disassembly in service centers.

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