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Zhejiang Province Lead-acid Battery Industry Synergistic Governance of Pollution and Carbon Reduction: Pathways and Policy Recommendations

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Abstract: Zhejiang Province is a vital production hub for lead-acid batteries in China and the nation's first pilot zone for "synergistic innovation in pollution and carbon reduction". Changxing County, known as the "Capital of China's Battery Industry," is central to this effort. The county commands an 80% market share in lead-acid batteries for light electric vehicles. It has established a complete supply chain covering production, sales, recycling, and regeneration. Currently, the industry faces economic headwinds and strict environmental regulations. However, new market opportunities are emerging, for example, the relaxed vehicle weight limits in the *Safety Technical Specifications for Electric Bicycles*. The critical challenge now is balancing the cost of environmental compliance with market profitability. Key solutions include upgrading to low-carbon production processes, building intelligent manufacturing systems, and optimizing battery recycling models.

Key words: Zhejiang province; Lead-acid battery industry; Synergistic governance of pollution and carbon reduction; Policy recommendations

1 Industry Status and Governance Foundation

1.1 Industry Overview

(1)Dominant Market Position

Since the 1980s, Changxing, Zhejiang, has leveraged industrial agglomeration and active transformation to become a vital national production base for lead-acid batteries and the largest base for recycled lead (hosting the province's only waste lead-acid battery disposal base). In the 1990s, Changxing's market share once accounted for 65% of the domestic total. Today, it remains pivotal in the national power battery market, with 65% of domestic electric bicycle plate enterprises and 75% of assembly enterprises originating from this region, cementing its status as the "Capital of China's

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Battery Industry".

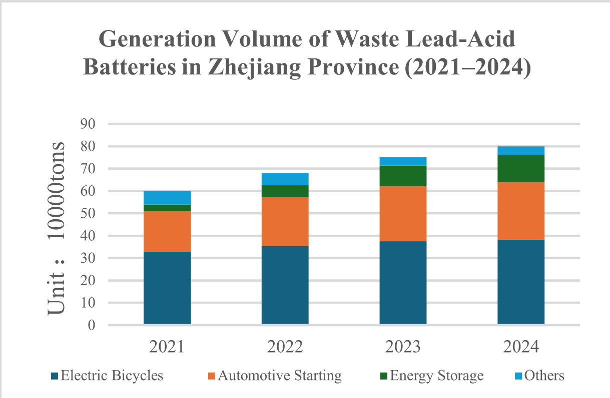

Figure 1 Generation volume of waste lead-acid batteries in Zhejiang province (2021-2024)

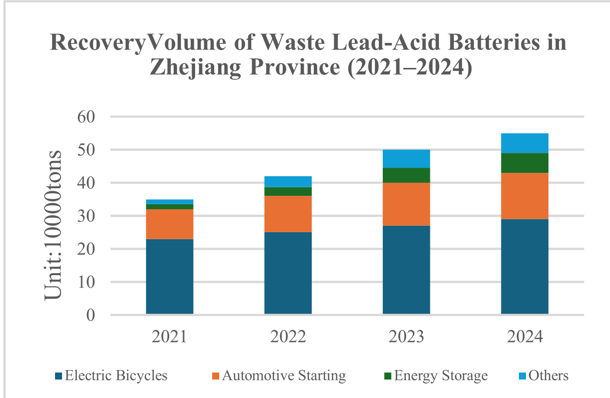

Figure 2 Recovery volume of waste lead-acid batteries in Zhejiang province (2021-2024)

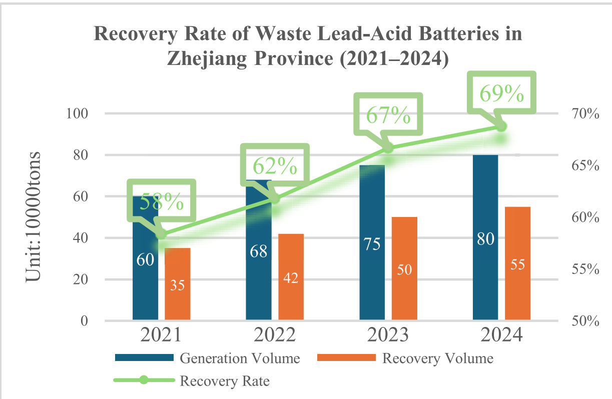

Figure 3 Recovery rate of waste lead-acid batteries in Zhejiang province (2021-2024)

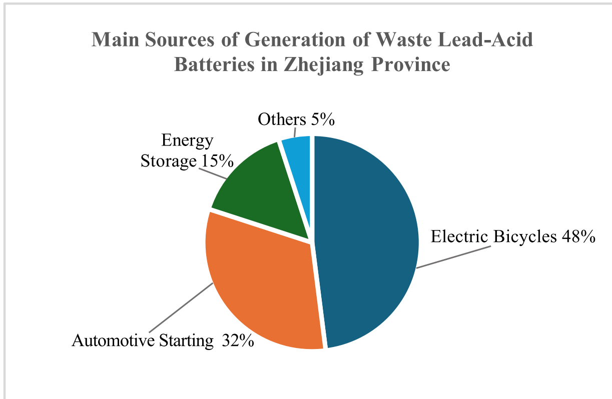

Figure 4 Main sources of generation of waste lead-acid batteries in Zhejiang province

Data Source: National Solid Waste and Chemicals Management Information System

(2)Leadership by Key Enterprises

Two local giants, Tianneng and Chilwee, were listed in the 2025 Fortune China 500. Specifically, Tianneng Group has focused on green low-carbon transformation, achieving exponential growth in revenue and profit up 130-fold and over 90-fold, respectively, since 2004 (Tianneng Co., Ltd., 2026). In 2022, it established its first overseas intelligent manufacturing base in Vietnam, exporting Changxing' s advanced technology and management globally. Chilwee Group has been listed in the Global New Energy Top 500 for six consecutive years - ranking 55th in 2024 (Chilwee Group, 2024), demonstrating strong industrial leadership.

(3)Closed-Loop Supply Chain

Changxing has integrated the entire value chain: design, raw material processing, manufacturing, recycling, and regeneration, laying a solid foundation for the circular economy. In particular, the "Lead Egg" (Qiandan) Platform, launched in 2022, is the first digital platform for comprehensive battery recycling services in China. It tracks batteries from production to disposal, solving the "last mile" collection problem. The platform covers 22 provinces and includes 443 recycling companies (50% of the national total) and 90,000 storefronts. It has facilitated the collection of 1.25 million tons of batteries and generated 15.4 billion RMB in transaction flow. This system increased disposal enterprise profits by 720 million RMB (People's Network, 2022; Zhejiang Provincial Department of Economy and Information Technology, 2023; Zhejiang Daily, 2024).

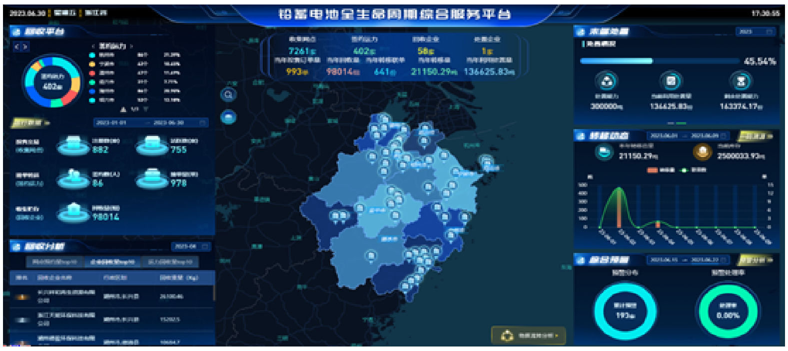

Figure 5 Homepage of the "Lead Egg" (Qiandan) platform

Figure 6 Recycling and regeneration of waste lead-acid battery

Figure 7 The "Lead Egg" (Qiandan) platform won the second prize in the national green and low-carbon development contest

Figure 8 The "Lead Egg" (Qiandan) platform won the first prize in the green and low-carbon development contest of Zhejiang province

Figure 9 *Forge an Optimal Ecosystem for Waste Lead-Acid Battery Recycling and Seize the Commanding Heights of the Segmented Industry* was shortlisted for the competition roadshow of the provincial best practice cases

Figure 10 *The establishment of Full-Chain Closed-Loop Management and Service System for Waste Batteries* was awarded the provincial reform breakthrough award (nomination award)

1.2 Foundation for Synergistic Governance

(1)Robust Policy Framework

Since being approved as the first national synergistic innovation zone in 2022, Zhejiang has built a policy system including synergy indices, carbon evaluation systems, and fiscal incentives. The “Comprehensive Deepening of Pollution and Carbon Reduction Synergistic Innovation Zone Construction New Three-Year Action” (China Environmental News, 2025) has been launched, listing the 650,000-ton/year waste lead-acid battery green recycling project as a key 2025 project (Zhejiang Provincial Department of Ecology and Environment et al., 2025).

(2)Technological Innovation

Changxing focuses on intelligent and green transformation, establishing a closed-loop lifecycle for power batteries. The region has been awarded titles such as “Zhejiang Provincial Demonstration Zone for Modern Industrial Cluster Transformation” and “China Green Power Energy Center”.

(3)Circular Economy Efficiency

Over 85% of raw materials for recycled lead come from waste lead-acid batteries (Chen & Li, 2012; Li, Li & Wang, 1999; Hou, 2001). Compared to primary lead smelting, recycled lead production reduces energy consumption and carbon emissions by approximately 90% (Qu,2019; Li, 2012). Changxing has built a “Production-Recycling-Regeneration-Reuse” green chain, achieving a unification of resource efficiency and pollution control.

Figure 11 The tianneng circular economy industrial park

In 2012, the Tianneng Circular Economy Industrial Park was put into operation. As the nation’s largest secondary lead production base to date, it has created a circular closed loop covering two key cycles: battery manufacturing → waste battery recycling → lead regeneration → battery manufacturing and production wastewater → reclaimed water reuse. All the recycled materials, ranging from secondary lead and sodium polysulfate to polypropylene plastic, can be directly used for manufacturing new batteries. The dismantling and recycling processes achieve nearly zero emissions, and the treated wastewater can even be directly used for watering flowers and raising fish.

2 Key Challenges in Governance

Deficiencies exist in carbon-pollution collaborative monitoring capacity. Enterprises above a designated size have established energy management systems, which support energy conservation and emission reduction via real-time monitoring and data analysis. However, they lack a full-process integrated mechanism of “real-time monitoring-intelligent analysis-collaborative optimization” for pollutants and carbon emissions. Inaccurate identification of key coordination links directly impairs the targeting precision and implementation efficiency of pollution reduction and carbon reduction governance.

The collaborative performance evaluation system remains unimplemented. No such index system has been built for the entire chain of lead-acid battery production, recycling and disposal, leaving no quantitative evaluation criteria or scientific assessment mechanisms. Linkages between enterprises' emission reduction outcomes, policy incentives and financial support are inadequate. This renders market-oriented incentive and restraint mechanisms ineffective, weakening enterprises' endogenous motivation for proactive emission reduction.

The cross-departmental collaborative supervision mechanism also needs refinement. Data interoperability across departments—including ecological and environmental protection, market supervision, transportation and taxation—is incomplete. Links such as store registration, contracted transportation capacity verification and cross-regional transportation are poorly coordinated. Consequently, the transportation trajectory of social-source waste lead-acid batteries fails to form a closed-loop with terminal disposal, creating regulatory blind spots.

3 Core Pathways for Improvement

3.1 Process Upgrades: Technology-Driven Reduction

(1) Green Manufacturing Processes

① Lead Powder: Adopt cold granulation technology (cold cutting + ball milling) to replace high-energy methods.

② Plates: Use continuous casting, rolling, and punching integrated processes to improve consistency.

③ Assembly: Implement fully automated assembly lines.

④ Disposal: Utilize oxygen-enriched side-blow dual furnace smelting. This optimizes heat transfer and reduces carbon intensity.

(2)Enhanced Resource Utilization

① Grid Smelting: Use closed, low-temperature continuous smelting furnaces (<450°C) to minimize lead volatilization and fuel use.

② Paste Smelting: Encourage “oxygen-enriched side-blow molten pool smelting” combined with waste heat recovery and acid making. This eliminates the need for pre-desulfurization and improves sulfur recovery.

③ Metal Recovery: Focus on high-efficiency recovery of lead, tin, and antimony.

④ Low-Carbon Material Substitution: Replace high-carbon fuels (bituminous coal, coke) with low-emission alternatives.

(3)Promote non-carbon reducing agents

① Guide enterprises to use low-emission raw materials, replacing high-carbon materials like bituminous coal and coke.

② Promote non-carbon-based reducing agents (e.g., hydrogen reduction technology) and use low-carbon slagging agents instead of limestone.

③ Encourage the use of sodium sulfate instead of sodium carbonate in separation processes.

3.2 Full-Chain Control: Closed-loop Governance

(1)Traceability Systems

Install data terminals with gravity sensors and image recognition at collection points. Upgrade the “Lead Egg” platform to track carbon footprints and warn of environmental risks.

(2)Deposit Refund System (DRS)

Pilot a deposit system for scattered sources like e-bike repair shops. Consumers pay a deposit (e.g., 30-50 RMB) when buying a battery, which is refunded digitally upon return to a compliant point.

(3)Data Integration

Link the "Lead Egg" platform with government systems for solid waste, tax, and transport. Create a “White List” for cross-province battery transport in the Yangtze River Delta to streamline approvals.

3.3 Digital Empowerment: Innovation in Regulation

(1)Synergistic Monitoring Platform

Encourage “One Enterprise, One Code” management. Systems should visualize the entire “Production-Emission-Reduction” process and automatically identify high-carbon steps.

(2)Differentiated Regulation (“Red-Yellow-Green”)

Classify companies based on performance (see Tables below).

① Green: Eligible for tax breaks and funding.

② Red: Subject to production limits and rectification.

Table 1 Synergy performance evaluation indicators for pollution and carbon emission reduction of lead-acid battery manufacturers in Zhejiang province

	Category	Weight of 1st-level indicators	Key Metrics		Units	Weight of 2nd-level indicators	Benchmark
1	Target Synergy	0.40	Degree of Synergy between Pollution Reduction and Carbon Emission Reduction		/	0.05	/
2			Production Capacity Utilization Rate		%	0.05	70
3			Carbon Emissions per Unit of Product	Plate Manufacturing and Assembly Assembly	kgCO2/kVAh	0.05	18 13
4			Comprehensive Energy Consumption per Unit of Product	Plate Manufacturing and Assembly Assembly	kgce/kVAh	0.05	4.2 2.7
5			Pollutant Emission Equivalent per Unit of Product	Plate Manufacturing and Assembly Assembly	AP/10000kVAh	0.05	50 15
6			Waste Water Discharge per Unit of Product	Plate Manufacturing and Assembly Assembly	m3/kVAh	0.05	0.015 0.005
7			Total Lead Discharge in Waste Water per Unit of Product	Plate Manufacturing and Assembly Assembly	mg/kVAh	0.05	1 0.5
8			Lead and Its Compounds Emissions in Waste Gas per Unit of Product	Plate Manufacturing and Assembly Assembly	mg/kVAh	0.05	40 20
9	Control Synergy	0.40	Advancement of Process Equipment		/	0.15	/
10			Proportion of Non-fossil Energy in Total Energy Consumption		/	0.05	2%
11			Reclaimed Water Reuse Rate		/	0.05	45%
12			Water Intake Volume per Unit of Product		m3/kVAh	0.05	0.1
13			Lead Consumption per Unit of Product	Plate Manufacturing and Assembly Assembly	kg/kVAh	0.05	18 1
14			Sulfuric Acid Consumption per Unit of Product		kg/kVAh	0.05	3
15	Management Synergy	0.20	Digital Management Platform		/	0.05	/
16			Management System		/	0.05	/
17			Implement the EPR System		/	0.05	/
18			Proportion of Enterprise R&D Costs		/	0.05	3%

Table 2 Synergy performance evaluation indicators for pollution and carbon emission reduction of lead-acid battery recycling and integration enterprises in Zhejiang province

	Category	Weight of 1st-level indicators	Key Metrics		Units	Weight of 2nd-level indicators	Benchmark
1	Target Synergy	0.40	Degree of Synergy between Pollution Reduction and Carbon Emission Reduction		/	0.05	/
2			Production Capacity Utilization Rate		%	0.05	/
3			Carbon Emissions per Unit of Product		tCO_2/t	0.05	/
4			Comprehensive Energy Consumption per Unit of Product	Pretreatment Process of Waste Batteries (Waste Batteries → Lead Paste and Lead Grid)	kgce/t	0.01	3
				Smelting Process of Lead Paste (Lead Paste → Secondary Crude Lead)		0.02	145
				Smelting Process of Lead Grid (Lead Grid → Secondary Crude Lead)		0.01	12
				Pyrometallurgical Refining Process (Secondary Crude Lead → Secondary Refined Lead)		0.01	10
				Secondary Lead (Waste Batteries → Secondary Lead)		0.01	120
						0.02	100
5			Pollutant Emission Equivalent per Unit of Product		AP/t	0.05	/
6			Waste water	Waste Water Discharge per Unit of Product	m3/t	0.01	1
				Total Lead Discharge per Unit of Product	g/t	0.01	2
				Ammonia Nitrogen Discharge per Unit of Product	g/t	0.01	10
				CODCr Discharge per Unit of Product	g/t	0.01	100
7			Waste gas	Flue Gas Emissions per Unit of Product	m3/t	0.01	10000
				SO2 Emissions per Unit of Product	kg/t	0.01	5
				NOx Emissions per Unit of Product	kg/t	0.01	1
				Smoke and Dust Emissions per Unit of Product	kg/t	0.01	5
				Lead and Its Compounds Emissions per Unit of Product	/	0.02	/
8			Waste residue	Waste Residue Generation per Unit of Product	kg/t	0.01	150
				Lead Content in Waste Residue	%	0.01	2
9	Control Synergy	0.4	Advancement of Process Equipment		/	0.15	/
10			Proportion of Non-fossil Energy in Total Energy Consumption		%	0.02	/
11			Crushing and Separation Process	Sodium Carbonate Consumption per Unit of Product	kg/t	0.01	150
			Lead Paste Smelting Process	Anthracite Coal Consumption per Unit of Product	kg/t	0.01	75
				Calcium Carbonate Consumption per Unit of Product	kg/t	0.01	/
			Lead Paste Smelting Process	Iron Filings Consumption per Unit of Product	kg/t	0.01	80
			Pyrometallurgical Refining Process	Sodium Carbonate Consumption per Unit of Product	kg/t	0.01	3
				Fluorosilicic Acid Consumption per Unit of Product	kg/t	0.01	2
			Electrolytic Refining Process	Anode Residue Rate	%	0.01	38
				DC Power Consumption per Unit of Product	kWh/t	0.01	120
				Caustic Soda Flakes Consumption per Unit of Product	kg/t	0.01	/
12			Waste Heat Utilization Amount per Unit of Product		kJ/t	0.03	/
13			Automation Level		/	0.02	/
14			Total Lead Recovery Rate		%	0.05	98
15			Fresh Water Consumption per Unit of Product		kg/t	0.02	300
16			Reclaimed Water Reuse Rate		%	0.02	100

Continued

	Category	Weight of 1st-level indicators	Key Metrics	Units	Weight of 2nd-level indicators	Benchmark
17	Management Synergy	0.2	Digital Management Platform	/	0.05	/
18			Management System	/	0.05	/
19			Implement the EPR System	/	0.05	/
20			Proportion of Enterprise R&D Costs	%	0.05	/

4 Strategic Recommendations

(1)Refine Policy

Publish technical guidelines and evaluation systems immediately. Update the Extended Producer Responsibility (EPR) rules to require annual recycling reports from manufacturers.

(2)Standardize Collection

Use digital platforms to integrate the manufacturing and recycling chains. Ensure recycling data is accepted by tax authorities to allow legitimate businesses to claim deductions and lower costs.

(3)Boost R&D

Fund research into recovering valuable metals and developing low-carbon reducing agents. Support collaboration between industry leaders (Tianneng, Chilwee) and universities (Zhejiang University) to achieve key breakthroughs by 2027.

(4)Expand Green Finance

Encourage banks to offer “Pollution and Carbon Reduction Loans” with interest rates below the Loan Prime Rate (LPR). Establish a provincial carbon neutrality fund specifically for the lead-acid battery sector.

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