

The Lithium Standoff: Geopolitics, Ecology, and Physics

A field report on the minerals, bottlenecks, and environmental trade-offs behind the battery transition

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1 I. The Geopolitical Bottleneck

Scheyder (2023) identifies two critical choke points in the Western supply chain: **Permitting Speed** and **Refining Capacity**.

1.1 1. The “Time Tax” on Mining

While Australia and Canada function as “fast lanes” for resource extraction, the United States permitting process acts as a bottleneck. According to Scheyder (2023), US mine permitting averages 7-10 years compared to 2-3 years in peer nations. A 2023 study in *Science of the Total Environment* examining 72 proposed US lithium sites provides peer-reviewed context for the regulatory complexity driving these delays (“Potential Impacts of Proposed Lithium Extraction on Biodiversity and Conservation in the Contiguous United States” 2023).



Figure 1: Average Mine Permitting Times (Years). Source: Scheyder (2023), investigative journalism. Peer-reviewed regulatory context: Science of the Total Environment (2023).

Key Finding

As shown in Figure 1, the US takes **3-4x longer** to permit a lithium mine than Australia or Canada. This regulatory gap is a strategic vulnerability in the energy transition (Scheyder 2023).

Data source: Permitting time estimates are from investigative journalism (Scheyder 2023), not peer-reviewed research. The 72-site regulatory analysis in “Potential Impacts of Proposed Lithium Extraction on Biodiversity and Conservation in the Contiguous United States” (2023) provides peer-reviewed evidence for the structural causes of US permitting delays.

1.2 2. The Refining Monopoly

While lithium is found globally, the capacity to turn it into battery-grade chemicals is centralized. China accounts for almost two-thirds of the world’s lithium processing, while only **2.1% is refined in the US**. Beyond lithium, China controls **75% of cobalt processing**, **95% of manganese capacity**, and nearly all graphite capacity (APM Research Lab 2024).

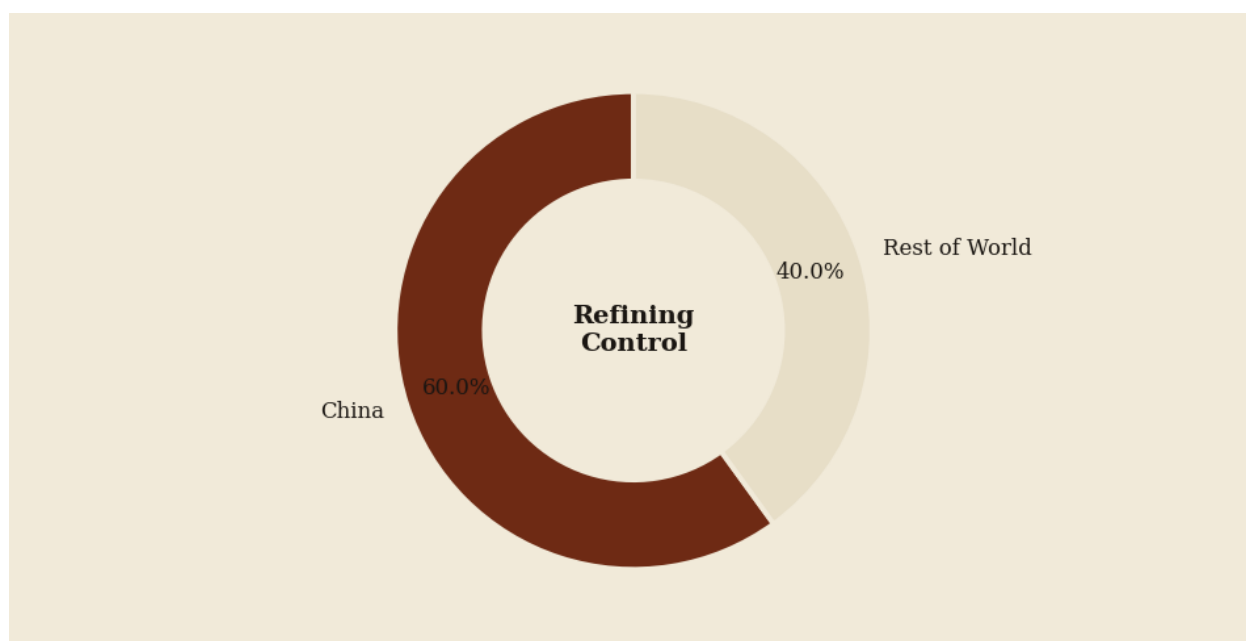


Figure 2: Global Lithium Refining Capacity Share. Source: APM Research Lab (2024) citing Reuters. Industry/gray literature.

Strategic Risk

Figure 2 shows that China controls **60%** of global lithium refining capacity. Even if the West mines more lithium, it still depends on Chinese processing infrastructure to produce battery-grade material (Scheyder 2023).

Data source: Refining capacity share from APM Research Lab (2024) citing Reuters (APM Research Lab 2024). This represents processing/refining capacity, not raw material extraction. Note: this is industry reporting (gray literature), not peer-reviewed data.

1.3 3. Global Reserves: Where the Lithium Actually Is

The geopolitical map has shifted. South America’s “Lithium Triangle” holds the largest reserves, but the US has moved up significantly following the Salton Sea discovery – the U.S. Department of Energy revealed the

region contains over **3,400 kilotons** of lithium, enough for over 375 million EV batteries (U.S. Department of Energy 2024; U.S. Geological Survey 2025).

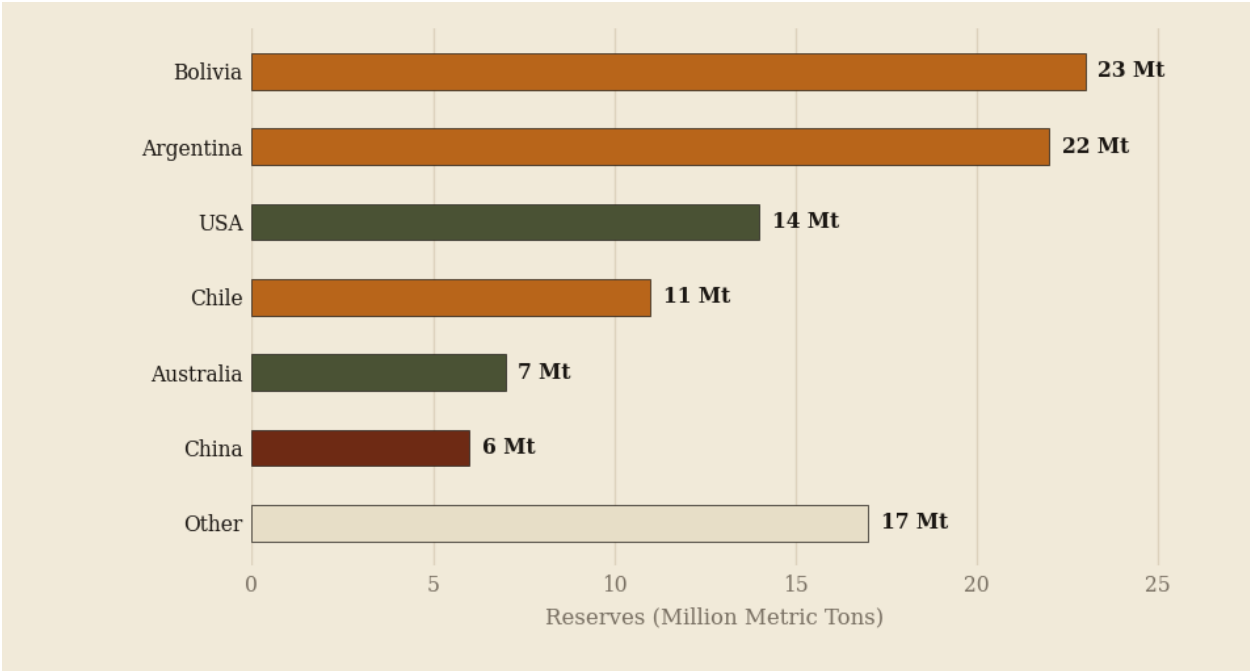


Figure 3: Global Lithium Reserves by Country (Million Metric Tons). Source: USGS Mineral Commodity Summaries (2025). Government data.

💡 The Salton Sea Factor

The US now holds an estimated **14 million metric tons** of lithium reserves – more than Chile. However, reserves do not equal production. Australia dominates extraction at **86,000 metric tons** (47% of global output) despite ranking 5th in reserves (U.S. Geological Survey 2025).

Data source: USGS Mineral Commodity Summaries (U.S. Geological Survey 2025). Government data, updated annually. Salton Sea figures from DOE (U.S. Department of Energy 2024).

1.4 4. Production vs. Reserves: The Extraction Gap

Global lithium production increased **18% to approximately 240,000 tons** in 2024, up from 204,000 tons in 2023 (U.S. Geological Survey 2025). But the countries with the most lithium in the ground are not the ones pulling it out the fastest.

⚠️ Bolivia’s Paradox

Bolivia sits on the world’s largest lithium reserves (**23 Mt**) yet produced only **600 metric tons** in 2024. Political instability, lack of infrastructure, and state control of mining have created a bottleneck that no amount of geology can fix (Scheyder 2023; U.S. Geological Survey 2025).

2 II. Scientific Literature: The Hidden Trade-offs

Recent high-impact studies reveal that “green” technology often involves complex environmental swaps.

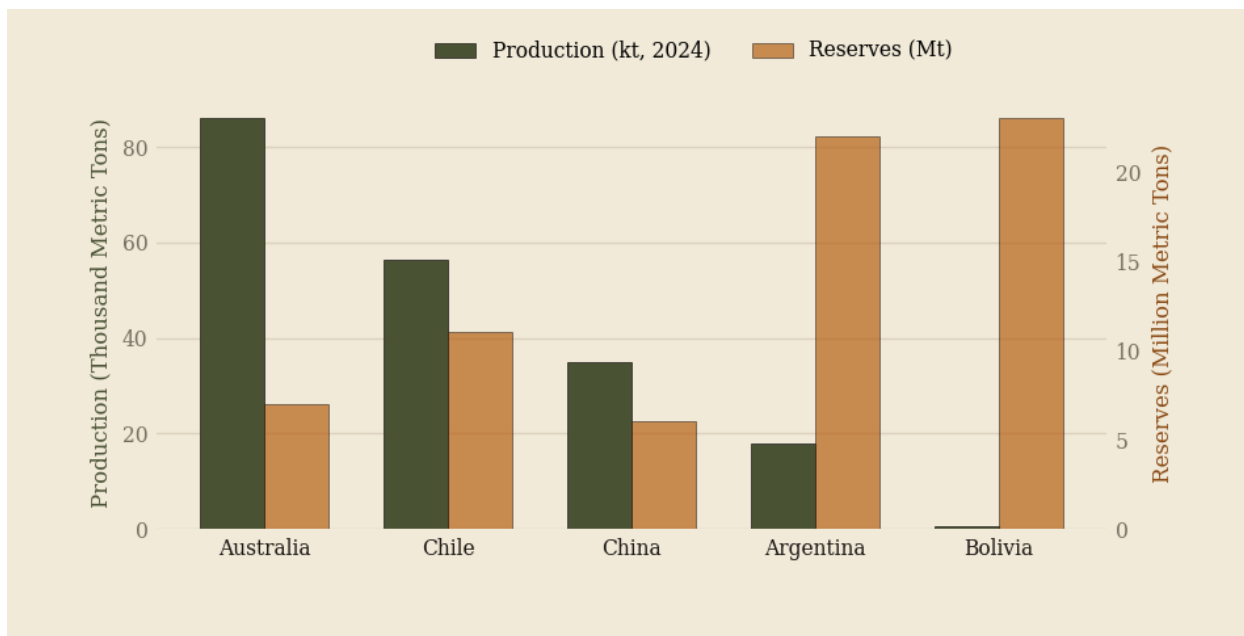


Figure 4: Top Lithium Producers (2024) vs. Reserves. Source: USGS Mineral Commodity Summaries (2025). Government data.

2.1 5. Direct Lithium Extraction (DLE) vs. Brine Ponds

A 2023 review in *Nature Reviews Earth & Environment* (IF: 42.7) (Vera et al. 2023) found that while DLE technologies achieve **95%+ lithium recovery rates**, only **30% have been tested on real-world brines** – the rest are lab-scale only.

A 2024 study in *Environmental Science & Technology* (IF: 11.4) (“Direct Lithium Extraction: Environmental Life Cycle Assessment” 2024) and *Resources Conservation & Recycling* (“Life Cycle Comparison of Lithium Extraction Methods” 2024) highlights a massive divergence: DLE saves land but costs carbon.

- **Land Use:** DLE uses **97% less land** than evaporation ponds.
- **Carbon Intensity:** DLE can have **7x higher** climate impacts due to energy consumption.
- **Water Savings:** DLE achieves up to **81% reduction** in water consumption vs. conventional methods (“Water Consumption in Lithium Mining: A Comparative Analysis” 2024).

⚠ The Trade-off

Figure 5 shows there is no free lunch. DLE dramatically reduces land footprint but shifts the burden to carbon emissions. A 2025 study in *ES&T* (IF: 11.4) found that environmental impacts vary **4x for GHG emissions** and an astonishing **2,885x for land use** between different mining sites globally. Furthermore, 56-68% of environmental impacts generated in mining countries are embodied in internationally traded lithium flows (Liu et al. 2025).

Data source: Synthesized from *Environmental Science & Technology* (2024) and *Resources, Conservation and Recycling* (2024) comparative studies, with additional context from Vera et al. (2023). All peer-reviewed. Values normalized to 1.0 for visualization; actual impacts vary by location and specific extraction technology.

2.2 6. The Carbon Cost of Lithium

Extraction is energy-intensive. According to MIT Climate Lab, one ton of mined lithium emits nearly **15 tonnes of CO2** (MIT Climate Lab 2024). Hard rock mining can reach **20.4 tonnes CO2** per tonne of

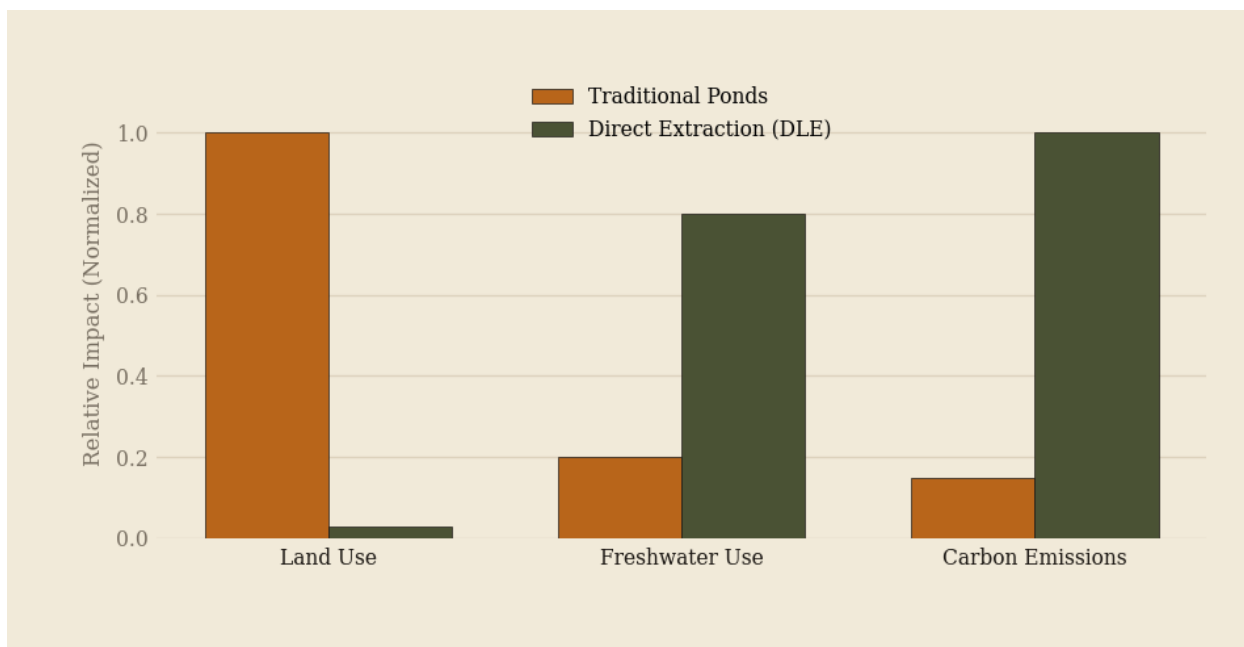


Figure 5: The Environmental Trade-off: DLE vs. Evaporation Ponds. Sources: ES&T (2024); Resources, Conservation and Recycling (2024); Vera et al., Nature Reviews Earth & Environment (2023). All peer-reviewed. Values normalized to 1.0 for comparative visualization.

lithium. But this varies dramatically by method.

💡 The Recycling Dividend

Figure 6 shows that recycled lithium produces roughly **8x less CO2** than hard rock mining. This is the strongest argument for building recycling infrastructure now, before the first wave of EV batteries reaches end-of-life.

Data source: Brine evaporation baseline (~15 t CO2) from MIT Climate Lab (MIT Climate Lab 2024) (gray literature, not peer-reviewed). Hard rock figure (~20.4 t) from industry analysis. DLE and recycling estimates are modeled projections. The Liu et al. (2025) study (peer-reviewed, IF: 11.4) confirms that carbon intensity varies significantly by site.

2.3 7. The Physics of Future Density

Battery technology is advancing on two fronts. A 2025 Tsinghua University breakthrough published in *Nature* (IF: 64.8) achieved **604 Wh/kg** gravimetric and **1,027 Wh/L** volumetric energy density in solid-state cells – more than twice today’s top commercial batteries at ~255 Wh/kg (Tsinghua University 2025). A separate study in *Nature Sustainability* confirmed batteries exceeding 500 Wh/kg (“Batteries Achieving Specific Energy Exceeding 500 Wh/Kg” 2025). Meanwhile, lithium-sulfur batteries offer a theoretical ceiling of **2,600 Wh/kg**, roughly 10x current Li-ion, according to *Communications Materials* (IF: 7.9) (“Assessing the Practical Feasibility of Solid-State Lithium–Sulfur Batteries” 2025).

i Two Horizons

Near-term (2025-2030): Solid-state batteries at 604 Wh/kg are real – prototyped and measured, published in *Nature* (Tsinghua University 2025). Commercialization is the challenge. **Long-term (2030+):** Lithium-sulfur at 2,600 Wh/kg remains theoretical (“Assessing the Practical Feasibility of

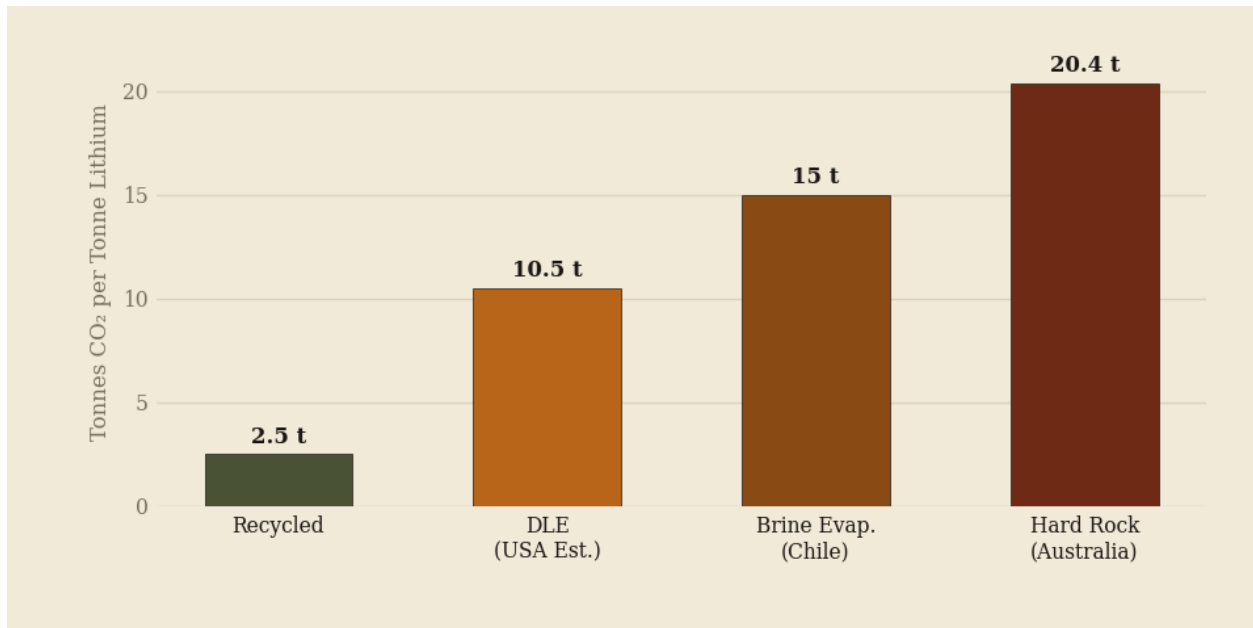


Figure 6: Carbon Intensity by Extraction Method (Tonnes CO₂ per Tonne Li). Sources: MIT Climate Lab (2024, gray literature) for brine baseline; industry estimates for DLE and recycling; peer-reviewed literature for hard rock.

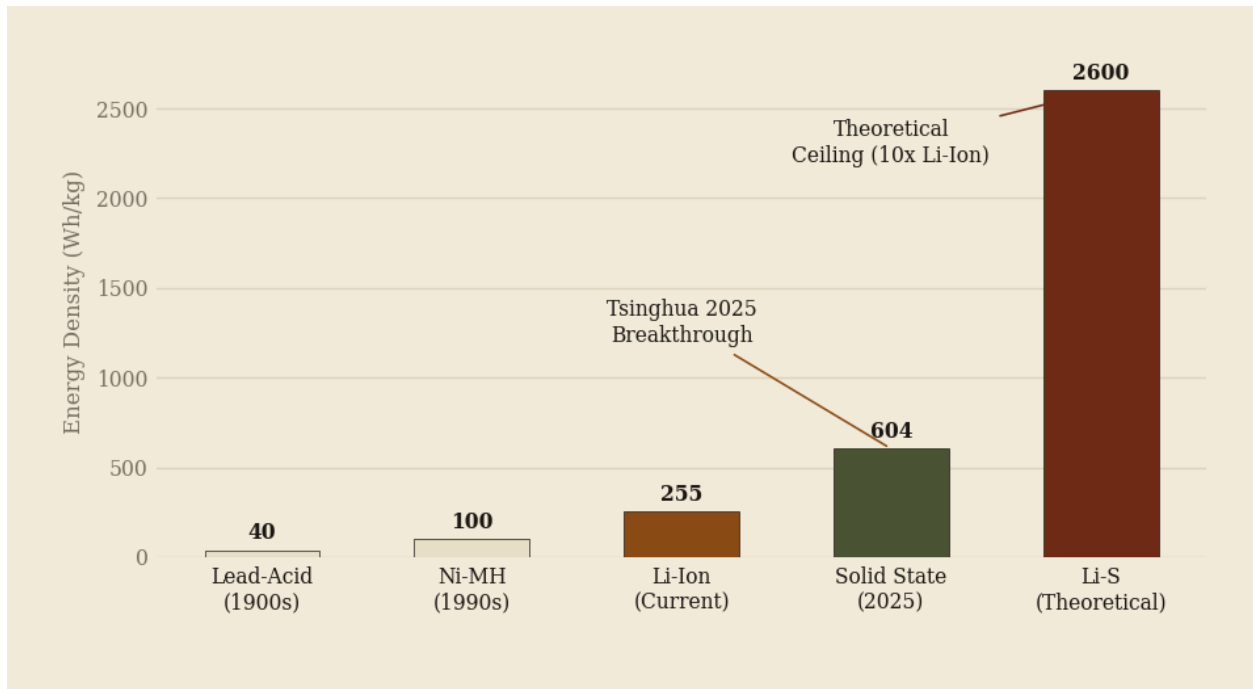


Figure 7: Evolution of Battery Energy Density (Wh/kg). Sources: Lead-acid and Ni-MH are industry standard benchmarks. Current Li-Ion: Communications Materials (2025), peer-reviewed. Solid-state: Nature (2025), Tsinghua University, peer-reviewed. Li-S theoretical: Communications Materials (2025), peer-reviewed.

Solid-State Lithium–Sulfur Batteries” 2025), but if achieved would make EVs lighter than gasoline cars. **Data source:** Historical values (lead-acid, Ni-MH) are industry standard benchmarks, not from the cited journal articles. Current Li-ion (~255 Wh/kg) and Li-S theoretical from *Communications Materials* (2025) (peer-reviewed). Solid-state from *Nature* (2025) (peer-reviewed). Additional confirmation from *Nature Sustainability* (2025).

3 III. The Recycling Imperative

Currently only **1-3% of lithium** is recovered globally from recycled batteries, mainly due to high costs. Yet a 2025 *Nature Communications* (IF: 16.6) study found that a minimum **84% collection rate** is needed to stabilize lithium supply by 2060 (“Lithium-Ion Battery Recycling Relieves the Threat to Material Scarcity” 2025).

3.1 8. Recovery Rates by Recycling Method

Not all recycling is equal. The three main approaches recover different materials at very different rates.

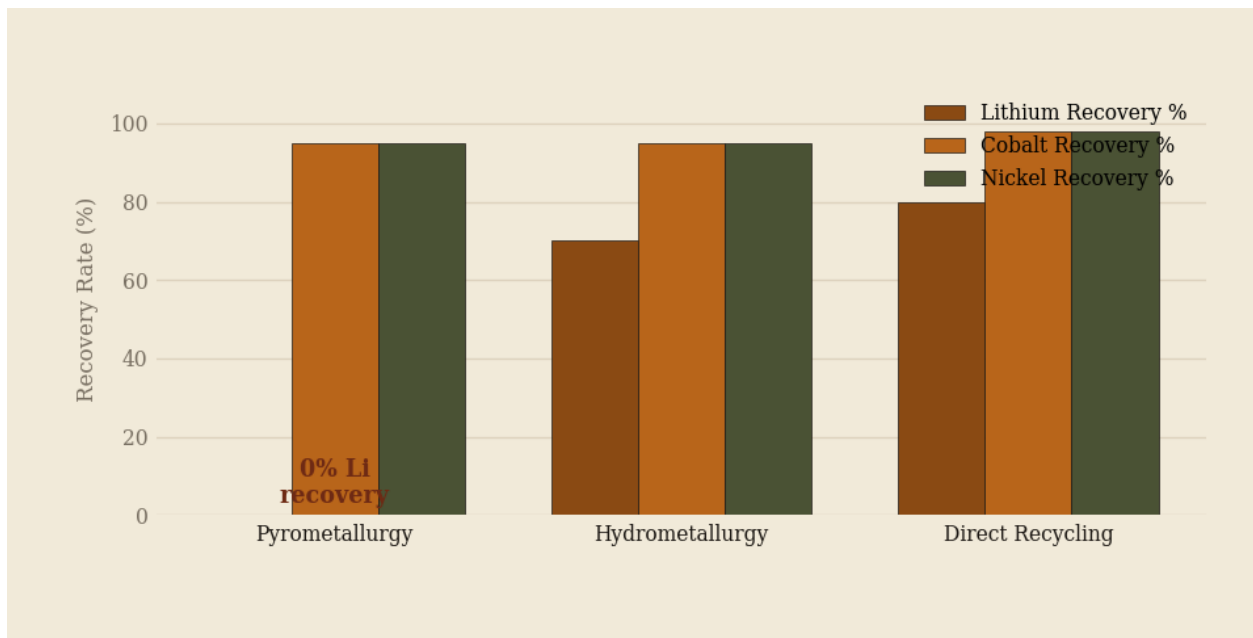


Figure 8: Battery Recycling Recovery Rates by Method. Source: Industry data and peer-reviewed literature. Recovery rates represent current technological capabilities.

! The Pyrometallurgy Problem

Figure 8 reveals a critical flaw: **pyrometallurgy recovers zero lithium**. It’s the cheapest method but treats lithium as slag waste. The industry must shift toward hydrometallurgy and direct recycling to close the loop (“Lithium-Ion Battery Recycling Relieves the Threat to Material Scarcity” 2025).

Data source: Recovery rates from industry analysis and *Nature Communications* (2025) (peer-reviewed, IF: 16.6). The 84% collection rate target is a modeled finding from the same study.

3.2 9. The Recycling Market Outlook

The global lithium battery recycling market is valued at **\$5.4-16.2 billion** (2024) and projected to reach **\$24-47 billion by 2032**, growing at a **17-20.6% CAGR**. The EU has mandated that EV batteries must contain a minimum **6% recycled lithium and nickel by 2030** (European Union 2023).

4 IV. Demand Outlook

4.1 10. What’s Eating the Lithium?

In 2024, **87% of global lithium** went to batteries. The remaining 13% was split across ceramics, lubricants, and industrial applications (U.S. Geological Survey 2024).

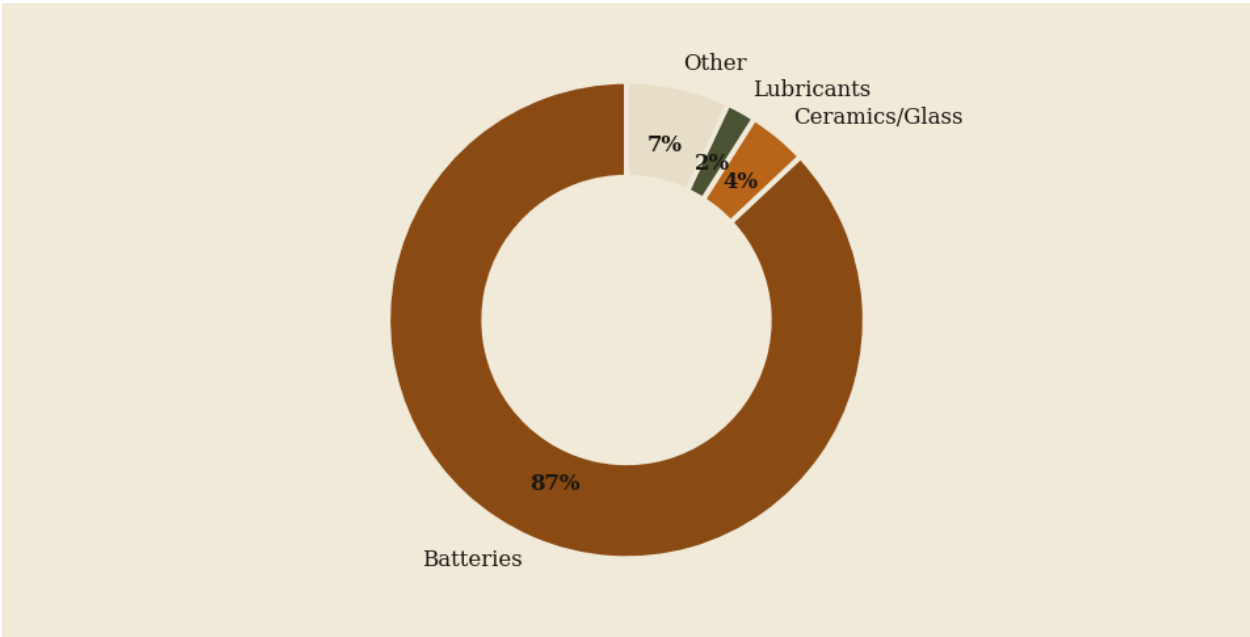


Figure 9: Global Lithium Demand by Application (2024). Source: USGS Mineral Commodity Summaries (2024, 2025). Government data.

i Demand Scale

An average EV uses **8 kg of lithium** (a Tesla Model S uses 62.6 kg). Global demand is forecast to reach **1 million metric tons by 2025** and **surpass 2 million tons by 2030** (U.S. Geological Survey 2025).

5 V. Summary Data Tables

5.1 Water Intensity Reference

Multiple sources converge on these ranges (U.S. Geological Survey 2025; “Water Footprint Assessment of Lithium Production in the Salar de Atacama” 2024; Vera et al. 2023; Wetlands International Europe 2023; “Water Consumption in Lithium Mining: A Comparative Analysis” 2024)

Extraction Method	Water Usage (per Tonne Li)	Source Type	Primary Region
Brine Ponds	~500,000 gal / 2M liters	Multiple (industry + gray lit.)	Chile/Argentina
Hard Rock DLE	100,000-300,000 gal Up to 81% reduction vs. conventional	Industry analysis Industry analysis	Australia USA (Proposed)
Salar de Atacama	442 m ³ world equiv. (AWARE)	Peer-reviewed (JCP, IF: 11.1)	Chile

5.2 Carbon Intensity Reference

Source	CO2 per Tonne Li	Source Type
Recycled	~2.5 tonnes	Industry estimate
DLE	~10.5 tonnes	Modeled projection
Brine Evaporation	~15 tonnes	Gray lit. (MIT Climate Lab)
Hard Rock Mining	~20.4 tonnes	Industry analysis

Note: MIT Climate Lab baseline (~15 t) is gray literature (MIT Climate Lab 2024). The Liu et al. (2025) ES&T study (peer-reviewed, IF: 11.4) confirms significant site-by-site variation but does not provide single-point estimates.

5.3 Key Statistics at a Glance

Metric	Value	Source	Type
Global reserves	28 million metric tons	USGS 2025	Gov.
Salton Sea lithium	3,400 kilotons	DOE 2024	Gov.
Global production (2024)	240,000 t (+18% YoY)	USGS 2025	Gov.
Battery share of demand	87%	USGS 2024	Gov.
Lithium per average EV	8 kg	Industry data	Gray lit.
Current recycling rate	1-3% globally	Industry estimates	Gray lit.
Required recycling rate	84% by 2060	Nature Comm. 2025	Peer-rev.
EU recycled content mandate	6% by 2030	EU Reg. 2023	Gov.
Solid-state prototype	604 Wh/kg	Nature 2025	Peer-rev.
Li-S theoretical ceiling	2,600 Wh/kg	Comm. Materials 2025	Peer-rev.
Site-to-site GHG variation	4x	ES&T 2025	Peer-rev.
Site-to-site land use variation	2,885x	ES&T 2025	Peer-rev.

5.4 Source Quality Legend

Tag	Meaning	Examples in This Report
Peer-rev.	Published in peer-reviewed journals with editorial review	Nature, ES&T, Nature Comm., Comm. Materials, NREE
Gov.	Government agency data, publicly audited	USGS, DOE, EU Regulation

Tag	Meaning	Examples in This Report
Gray lit.	Industry reports, think tanks, journalism – not peer-reviewed	MIT Climate Lab, APM Research Lab, Reuters, Scheyder (2023)
Industry	Corporate/trade analysis	Lithium Harvest, SolarTech, market research firms

APM Research Lab. 2024. “Lithium Processing and Refining: Global Capacity Analysis.” APM Research Lab, citing Reuters.

“Assessing the Practical Feasibility of Solid-State Lithium–Sulfur Batteries.” 2025. *Communications Materials*. <https://doi.org/10.1038/s43246-025-00918-9>.

“Batteries Achieving Specific Energy Exceeding 500 Wh/Kg.” 2025. *Nature Sustainability*.

“Direct Lithium Extraction: Environmental Life Cycle Assessment.” 2024. *Environmental Science & Technology*.

European Union. 2023. “EU Battery Regulation 2023/1542.” Official Journal of the European Union.

“Life Cycle Comparison of Lithium Extraction Methods.” 2024. *Resources, Conservation and Recycling*.

“Lithium-Ion Battery Recycling Relieves the Threat to Material Scarcity.” 2025. *Nature Communications*.

Liu, W. et al. 2025. “Robust Assessments of Lithium Mining Impacts Embodied in Global Supply Chain Require Spatially Explicit Analyses.” *Environmental Science & Technology* 59 (14): 7081–94. <https://doi.org/10.1021/acs.est.4c12749>.

MIT Climate Lab. 2024. “Lithium Mining for EVs: Sustainability Considerations.” APM Research Lab.

“Potential Impacts of Proposed Lithium Extraction on Biodiversity and Conservation in the Contiguous United States.” 2023. *Science of the Total Environment*.

Scheyder, Ernest. 2023. *The War Below: Lithium, Copper, and the Global Battle to Power Our Lives*. New York: Atria Books.

Tsinghua University. 2025. “Solid-State Battery Achieving 604 Wh/Kg Gravimetric Energy Density.” *Nature*.

U.S. Department of Energy. 2024. “Salton Sea Lithium Resource Assessment.” DOE Report.

U.S. Geological Survey. 2024. “Mineral Commodity Summaries 2024: Lithium.” USGS Annual Report. <https://pubs.usgs.gov/periodicals/mcs2024/mcs2024-lithium.pdf>.

———. 2025. “Mineral Commodity Summaries 2025: Lithium.” USGS Annual Report. <https://pubs.usgs.gov/periodicals/mcs2025/mcs2025-lithium.pdf>.

Vera, M. L., W. R. Torres, C. I. Galli, A. Chagnes, and V. Flexer. 2023. “Environmental Impact of Direct Lithium Extraction from Brines.” *Nature Reviews Earth & Environment* 4: 149–65. <https://doi.org/10.1038/s43017-022-00387-5>.

“Water Consumption in Lithium Mining: A Comparative Analysis.” 2024. Lithium Harvest / SolarTech Industry Analysis.

“Water Footprint Assessment of Lithium Production in the Salar de Atacama.” 2024. *Journal of Cleaner Production*. <https://doi.org/10.1016/j.jclepro.2024.140848>.

Wetlands International Europe. 2023. “Water Impacts of Lithium Brine Extraction.” Wetlands International.