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"Towards Sustainable Geographies with Net Zero Carbon Economy"

Co-organizers

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PRR Plano de Recuperação e Resiliência
REPÚBLICA PORTUGUESA
Financiado pela União Europeia NextGenerationEU
New Generation Storage
LNEG

Lithium Role in the Clean Energy Transition: Challenges and Prospects

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1. Introduction

Transportation represents more than 1/3 of global CO_2 emissions

- Achieving "Net Zero Emissions by 2050" needs the implementation of comprehensive policies
- This scenario requests to avoid 25% of the transport-related emissions by 2030

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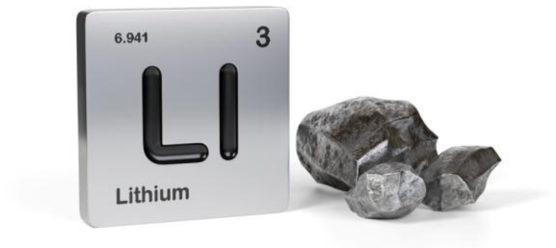

Lithium (Li) is a chemical element from Group 1 of the Periodic table
→ Alkali metal

- The lightest metallic element, with a low density (0.534 g/cm^3)
- Exhibits a high electrode potential (−3.05 V) and holds the highest specific heat capacity among all solid elements
- The low atomic mass (6.94 g/mol), high electrochemical potential and thermal capacity, promote a <u>superior ability for energy storage and transfer</u> → Li-ion batteries are currently the best electrochemical energy storage solution

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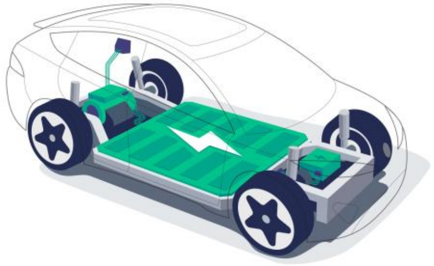


Batteries represent a strategic priority for EU in the clean energy transition

- Global demand for batteries is projected to increase 14-fold by 2030
- Electric vehicles (EV) production will increase demand for CRM* → **Li**, Co, Mn, Ni, C

Alternative sources and sustainable supply strategies are crucial to meet the raw material requirements of large-scale battery production

*Critical Raw Materials – resources economically vital and subject to supply risks in the EU

1. Introduction

Rising battery demand calls for rethinking this industry waste management

- Batteries may contain hazardous materials → can leach into soil and water causing long-term pollution
- **End-of Life (EoL) batteries offer a route for CRM recovery, supporting circular economy**

New markets	New jobs	Sustainable industry practices	Safe handling	Proper disposal routes

2. Goals

Analyze Li resources and role on the green energy shift

→ Li recovery processes and battery production

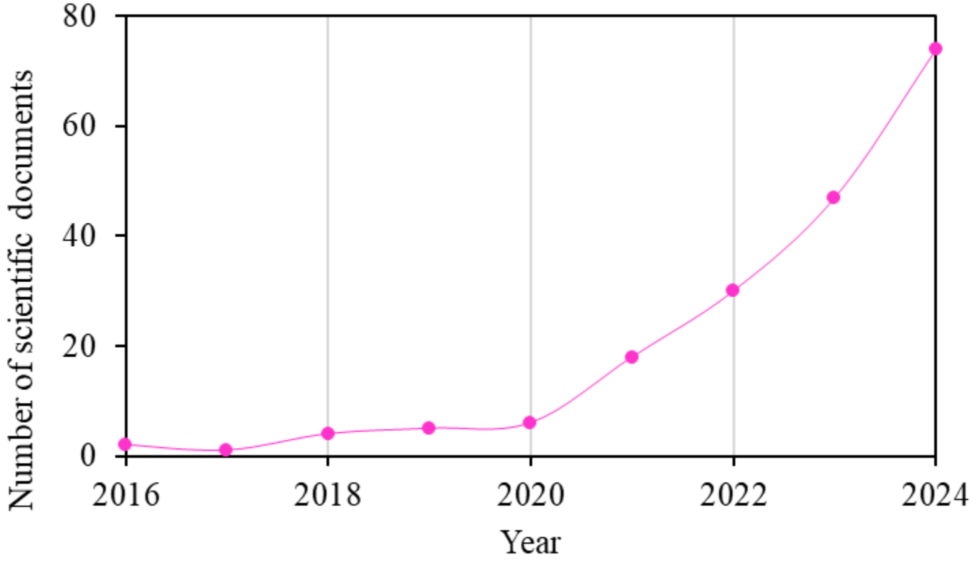
Identify key characteristics and limitations of methods

→ Environmental implications

3. Methodology

Bibliometric analysis conducted with ScienceDirect online database (04/2025)

→ Keywords: "lithium" AND "battery" AND "electric vehicle" AND "critical raw material" AND "clean energy"



- 187 scientific publications published (2016 -2024)
- 94% were released in the past 5 years
- 60% are original research articles, and 21% review articles

Primary subject areas

Energy (32%), **Environmental Science** (28%), and **Social Science** (17%)

4. Lithium resources – primary origin

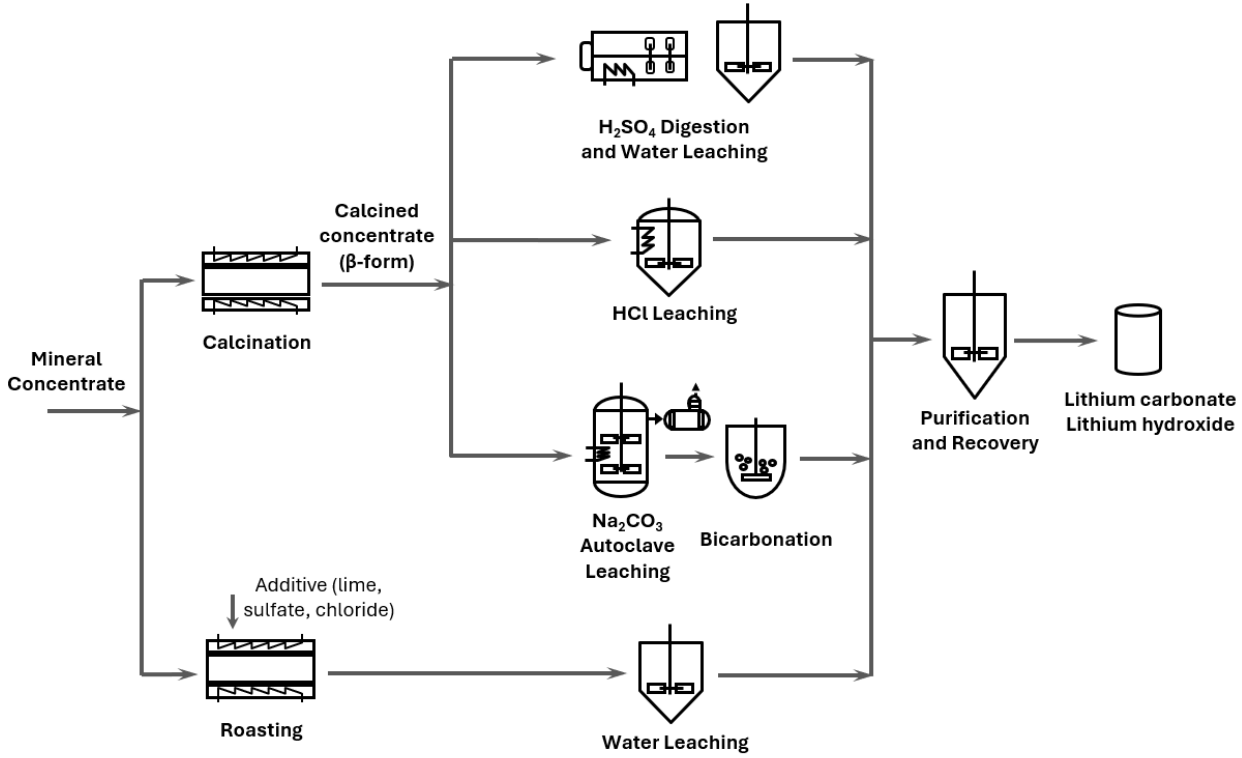
Primary resource		Chemical formula	Li content (%)
Brine		-	0.001 – 0.14
Sedimentary rock	Hectorite	$Na_{0,3}(Mg, Li)_3Si_4O_{10}(OH)_2$	1.2
	Jadarite	$LiNaSiB_3O_7(OH)$	1.4
Pegmatites	Amblygonite	$(Li, Na)AlPO_4(F,OH)$	3.4-4.0
	Eucryptite	$LiAlSiO_4$	5.5
	Lepidolite	$K(Li, Al)_3(Si, Al)_4O_{10}(F,OH)_2$	1.5-3.6
	Petalite	$LiAlSi_4O_{10}$	2.2-2.3
	Spodumene	$LiAlSi_2O_6$	1.9-3.7
	Zinnwaldite	$KLiFeAl(AlSi_3O_{10})(F,OH)_2$	2.0-4.0

- In 2024, top 3 countries in Li concentrate production were Australia (88,000 t/year), Chile (49,000 t/year) and China (41,000 t/year)
- For reserves, the leading countries are Chile (9.3 Mt), Australia (7.0 Mt), Argentina (4.0 Mt), China (3.0 Mt) and U.S.A. (1.8 Mt) → These reserves are estimated at ~30 Mt

5. Lithium resources – metallurgical treatment

After mining extraction, Li is concentrated by physical processing

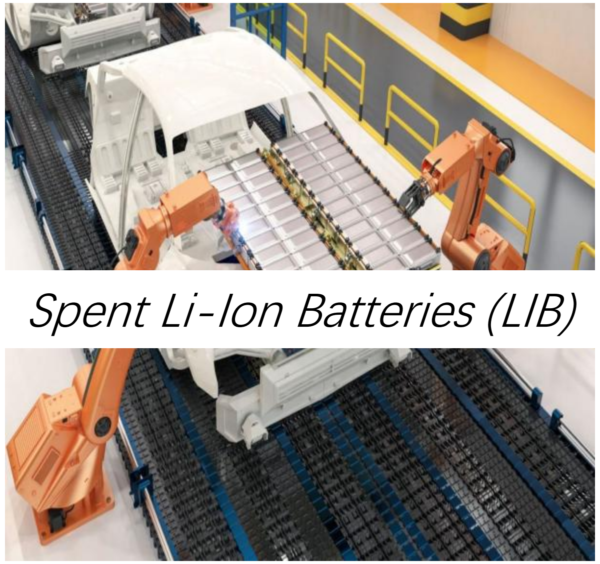
→ Grinding, flotation, density or gravity separation



Main steps of metallurgical processes

1. Thermal activation (with or without chemical reaction)
2. Li solubilization in aqueous media (leaching)
3. Purification, separation and recovery

6. Lithium recovery from secondary resources



Spent Li-Ion Batteries (LIB)

- High temperature **pyrometallurgical** or **hydrometallurgical** processes
- **Biohydrometallurgy** (microorganisms to recover metals in aqueous extractive metallurgy) → Yield = 80-90%
- **Solvent extraction** (differential solubility of compounds in two immiscible liquid phases) → Yield > 90%
- **Precipitation** methods for LIB recycling effluents → Yield = 88-95%

Oilfield brines

- **Precipitation** method ($AlCl_3$ and NaOH) → Yield =75.6%

Shale gas wastewater

- Two-phase **solvent extraction** → Yield = 30.8%

7. Battery technologies

1859 • Pb-acid battery

1866 • $Zn–MnO_2$ battery

1899 • Ni-based batteries

1960s • Li-metal systems

1980s • Ni–Zn and Ni–metal hydride batteries

1991 • **Li-ion batteries (LIB)**

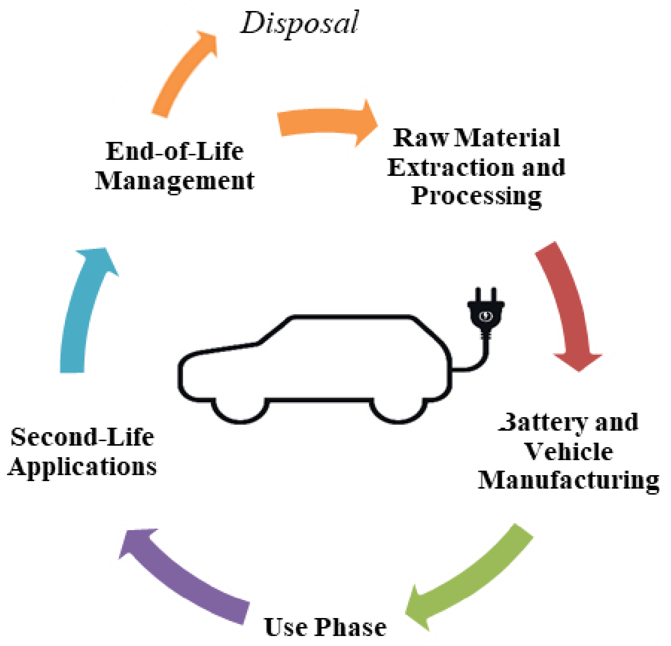
LIB became dominant due to superior energy density, safety, and life cycle

→ Anode, cathode, and electrolyte (with separator)

Post-Li technologies

- Metal–air batteries, Na-beta systems → Na/MCl_2 and Na/S batteries
- Alternative chemistries with Zn, Na, and Mg → Na-ion batteries show promising scalability
- Emerging technologies include Li metal, Na-ion, and Li–air ($Li–O_2$) batteries
- Dual-ion and dual-carbon batteries are being explored for stationary energy storage

8. Battery life cycle



1. Extraction and refinement of raw materials → Li, Co, Ni, Mn, and C

2. Materials processing for manufacture of battery cells

3. Production of LIB cells, modules, and packs

4. Assembly of vehicle glider and electric drivetrain

5. Operation → charging and discharging cycles, influenced by driving patterns, ambient conditions, and electricity mix

6. Battery degradation → EoL reached at 70-80% State of Health (SoH)

7. LIB no longer used for automotive applications can be repurposed for stationary energy storage

8. Batteries collected and processed according to regulatory frameworks → dismantling, material recovery, and safe disposal of non-recyclable components

9. Standards and guidelines

New Batteries Regulation in 2020

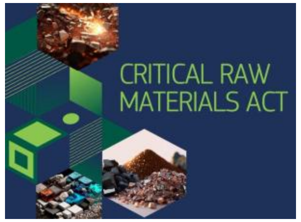
repealing Directive 2006/66/EC

EoL Vehicles - Directive 2000/53/EC

as amended by Directive 2018/849

The European Green Deal

adopted on 11 December 2019



The Critical Raw Materials Act

Four new EU targets to be met by 2030

10. Challenges and prospects

Energy consumption and efficiency

High temperature calcination/roasting required to improve minerals reactivity

Chemicals consumption

Acid digestion (H_2SO_4); neutralization ad purification (lime, soda, soda ash)

Need for high purity Li commodity for battery applications

High purity $LiOH.H_2O$ instead of Li_2CO_3; increase purity grade; more demanding and efficient purification/refining operations

Application to other mineral resources than spodumene / petalite

Lepidolite, zinnwaldite, ambligonite, Li-bearing clays

Environmental concerns - Green mining/green metallurgy

Green process design, wastewater management in hydrometallurgical operations, gas emissions in thermal treatment

11. Conclusions

Electrification of mobility is accelerating Li demand, driving transformations in extraction and refining processes

- Conventional methods, involving high-temperature calcination and acid-based hydrometallurgy, remain energetically and chemically demanding
- Emerging technologies face limitations in scalability, selectivity, and environmental performance
- EV involves substantial upstream environmental impacts (extraction and processing of Li, Co and Ni)
- Batteries are the most resource- and energy-intensive component of EV, where effective EoL treatment is essential
- A key pathway to improve sustainability lies in increasing the circularity of batteries
- Local involvement is imperative for transparent decision-making, equitable benefit-sharing, and socially responsible and environmentally sustainable resource management

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Thank you!

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