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Lux Research

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DIRECT LITHIUM EXTRACTION

Innovations in Technology Development to Unlock New Opportunities

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ADD TITLE

01 | Landscape on the Lithium Extraction market

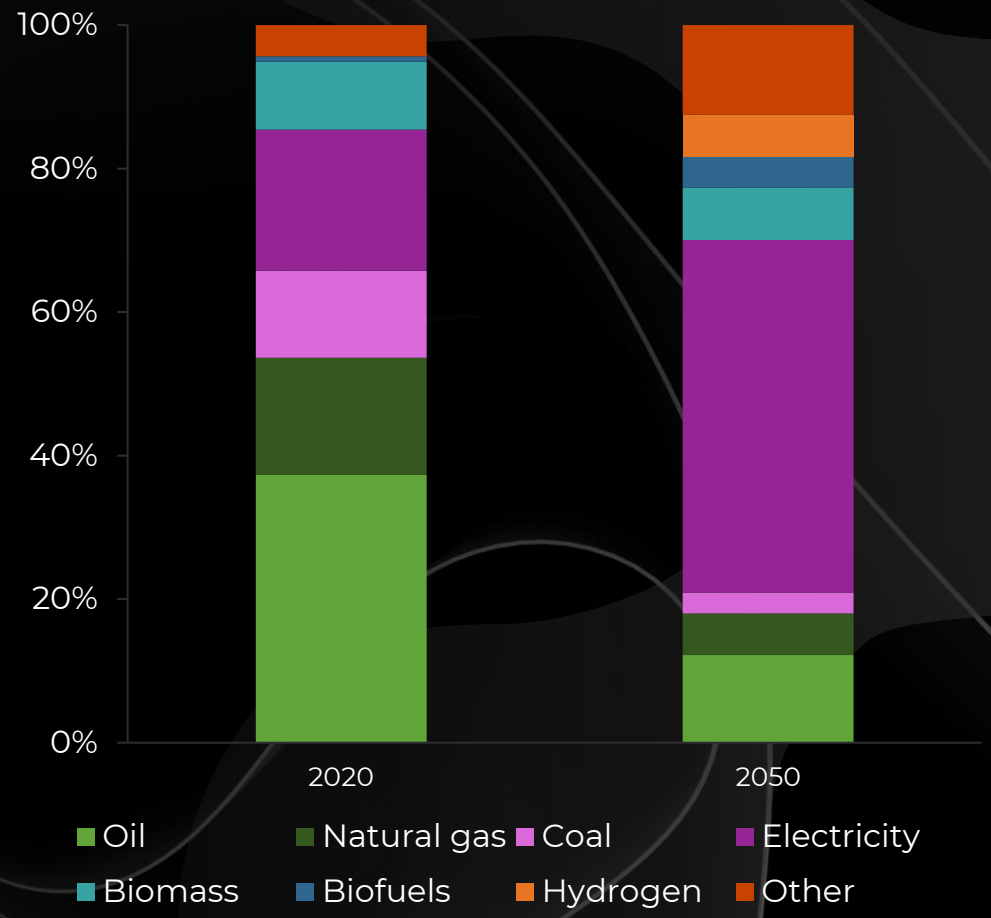
02 | Current & Emerging DLE technologies

03 | Key Takeaways

REACHING NZE

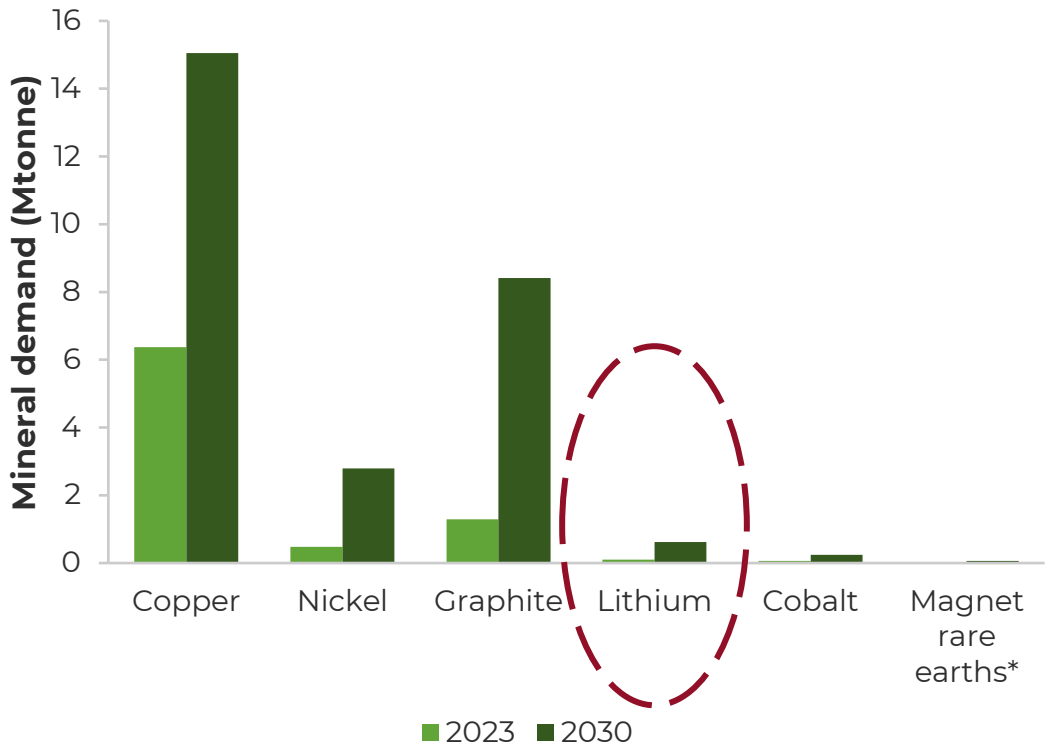
Requires a complete transformation of the global energy system

Energy demand in Net Zero scenario (NZE)
Share of final energy demand

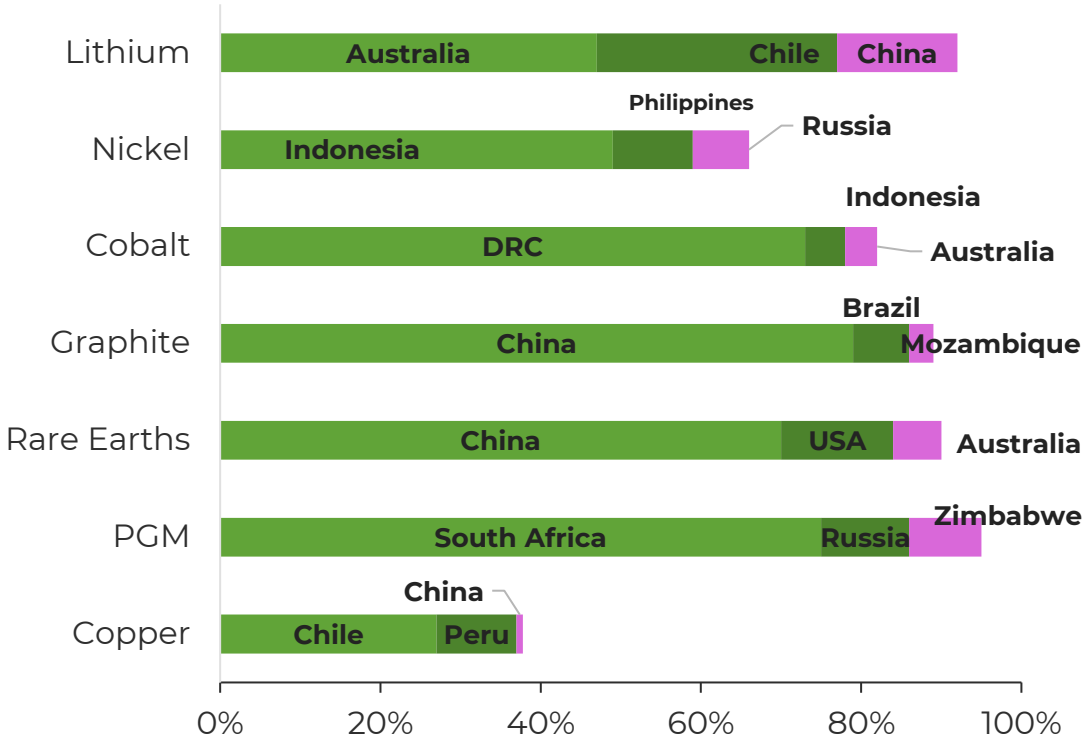


SHIFTING FROM A FUELS INTENSIVE TO A MATERIALS INTENSIVE ENERGY SYSTEM

Demand for Critical Minerals in IEA's NZE Scenario



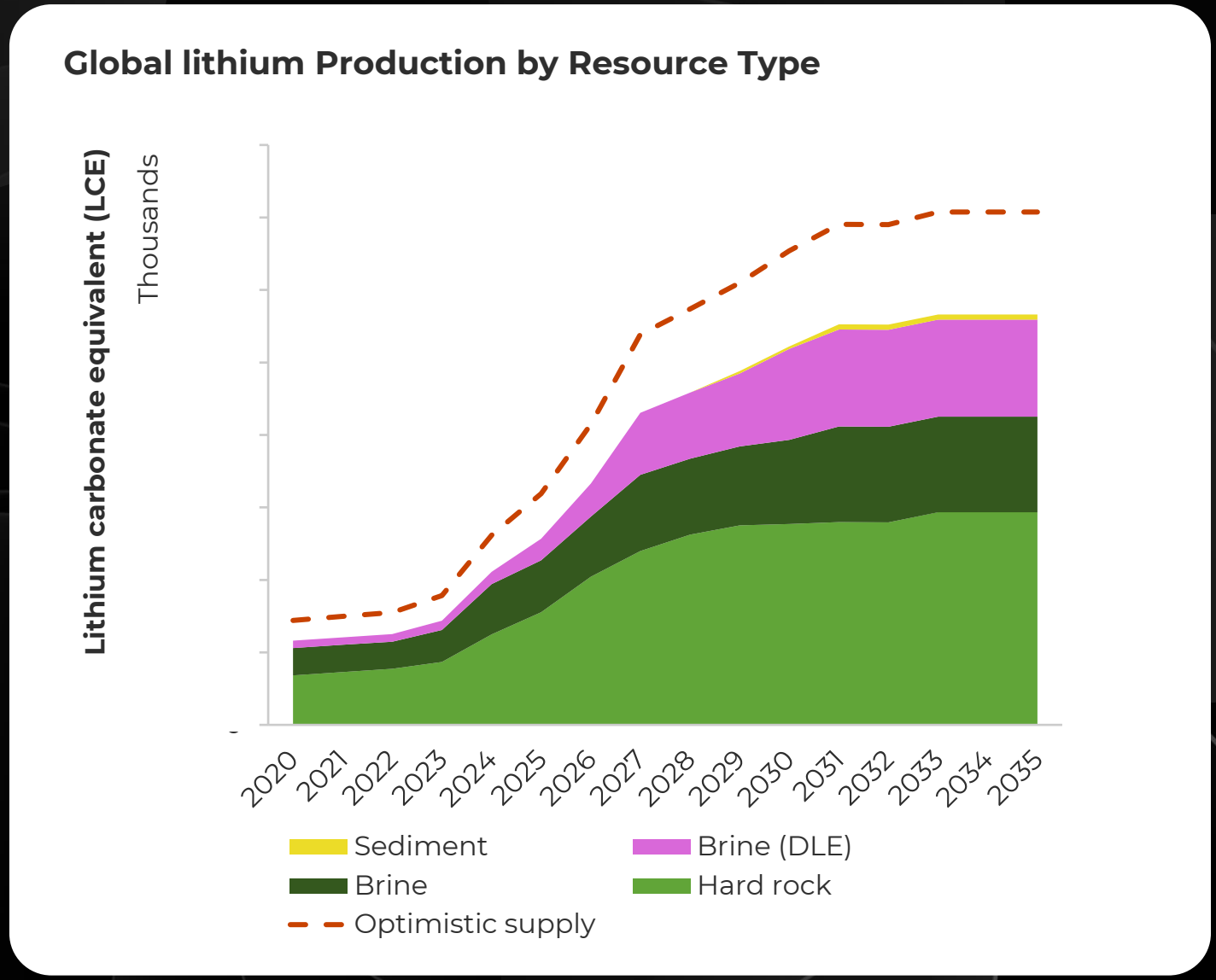
Share of top 3 producing countries in total production for critical minerals



The lithium industry is not on course to meet the projected demand from battery manufacturing over the next decade

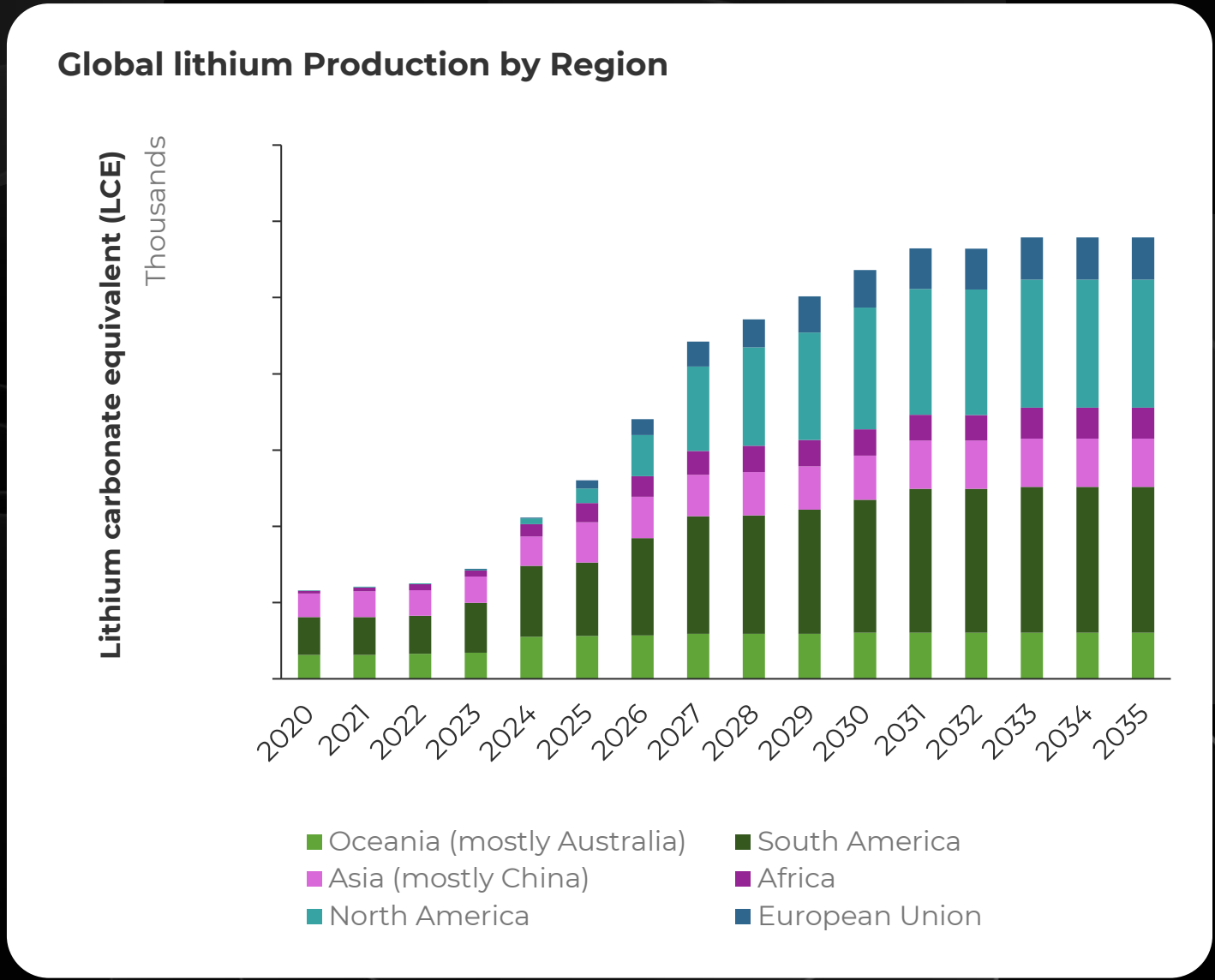
LITHIUM PRODUCTION FORECAST

- Even at a 12% CAGR lithium demand outpaces supply by 2030 – 1.2 Mtonne deficit
- Brine loses market share but makes a comeback through 2030
- Demand for sustainably sourced battery metals is expected to rise to meet future regulations



LITHIUM PRODUCTION FORECAST

- North America: lithium extraction and refining market is slowly awakening thanks to U.S. and Canadian regulatory mandates for self-reliance and attractive lithium resources. While current capacity is low ~7,000 tpy it is expected to grow to over 500,000 tpy by 2035

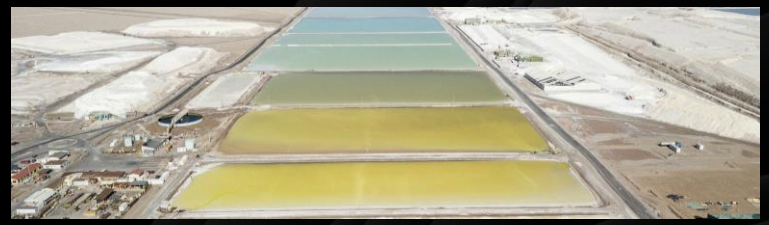


DLE reduces operational risk and expedites lithium to market

Time-to-market	A new evaporation-based brine resource requires between 12 and 18 months to get to market, not including the four- to five-year timeline to capitalize projects in the first place.
Environmental concerns	Concerns about hard-rock mining's high carbon footprint (around 15 tonne CO_2/tonne LiOH) and water loss to evaporation from traditional brines are forcing project developers to seek sustainable extraction processes
Reducing operational risk	DLE processes aren't weather dependent and operate continuously with shorter production time — days instead of months
Improved yield	DLE technologies can improve lithium recovery from 40% to 50% for evaporation ponds to over 85%.

DLE can target conventional and unconventional brines

Conventional Brines



Continental brines

Salars and salt pans in enclosed basins with lithium-enriched brines. These brines are some of the highest-grade brines in the world — 0.04% to 0.15% Li.

Stage of development

Continental brines are commercial today and predominantly located in South America.

Unconventional Brines

Oil field brines

Also known as petrobrines, these oil and gas waste products are some of the lowest-grade brines, containing as little as 0.007% to 0.02% Li.

Stage of development

These are precommercial brines. Extracted in conjunction with oil & gas or closed wells in North America.

Geothermal brines

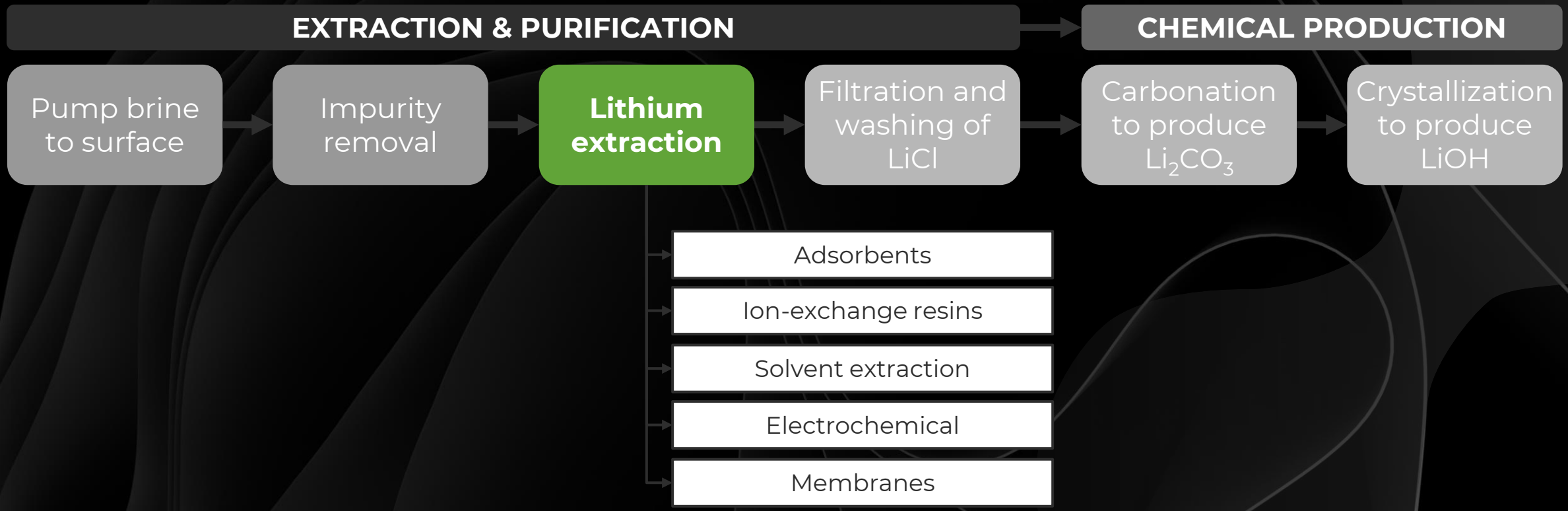
These brines come out of the ground hot, which facilitates certain DLE processes. These are low-grade sources containing as little as 0.01% to 0.04% Li.

Stage of development

Developers are scaling up from pilot production. Brines in geothermally active areas in California and the Upper Rhine Valley of Germany/France.

There are 5 main types of DLE technologies

Lithium extraction from brines
DLE replaces evaporation ponds in the **lithium extraction** step.



DLE comes in many approaches and scales; the main approaches are listed below

Adsorbents

Adsorbents physically capture LiCl molecules on their surface, while water acts as a stripping solution. This technology is at commercial scale and is used for select brines in South America and China.

Stage: Scale

Ion-exchange resins

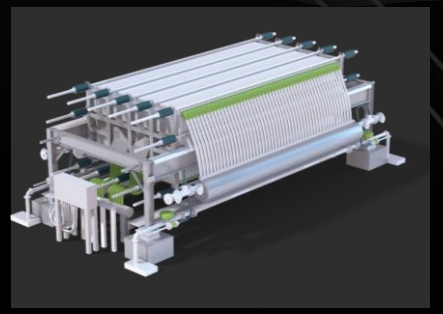
Lithium ions in the brine are chemically adsorbed onto the ion-exchange material and swapped for positive ions from the resin. Ion exchange uses acidic reagents like HCl to strip lithium.

Stage: Late-stage development

Solvent extraction

Not unlike the solvents used in hard-rock mining, DLE solvents are organic chemicals with absorptive or ion-exchange capabilities that strip the brine of lithium to form LiCl or lithium sulfate ions in solution.

Stage: Pilot (TRL6-7)



Electrochemical

Electrodialysis (ED) or bipolar ED (BPED) can extract lithium from brines using ion-selective membranes or adsorbents; electrolysis is used downstream of extraction to convert LiCl to LiOH and recycle water.

Stage: Pilot (TRL 5)

Membranes

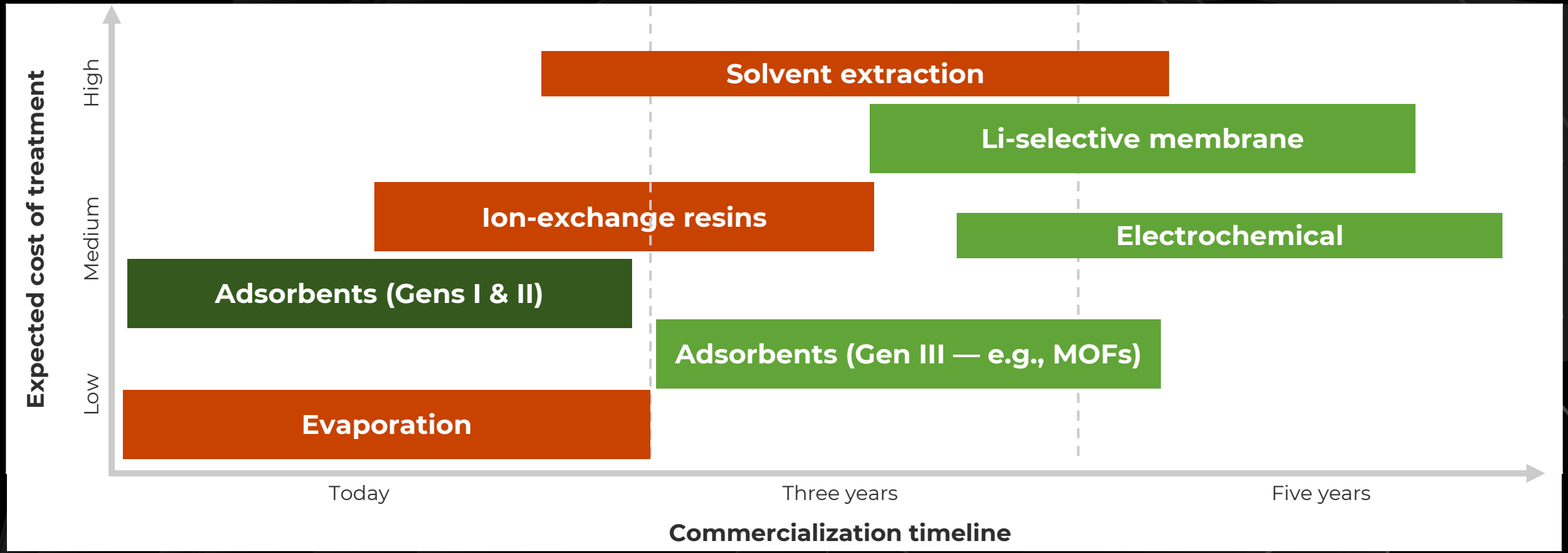
Lithium extraction relies on membrane selectivity and pore size. Innovations use metal-organic frameworks (MOFs*) infused with polymer substrates and chemically modified ion-exchange membranes.

Stage: Pilot (TRL 5-6)

*MOFs are porous, crystalline materials made of metal ions and organic ligands that can separate, transport, and isolate specific elements on an ionic level; image sources, left to right: Utility Engineering Company; Lanxess; ISP Fuel Systems; Thyssenkrupp; Envirogen Technologies

ANALYSIS

Adsorbents are the go-to-solution for DLE in the short to medium term, but next-generation technologies are on the horizon



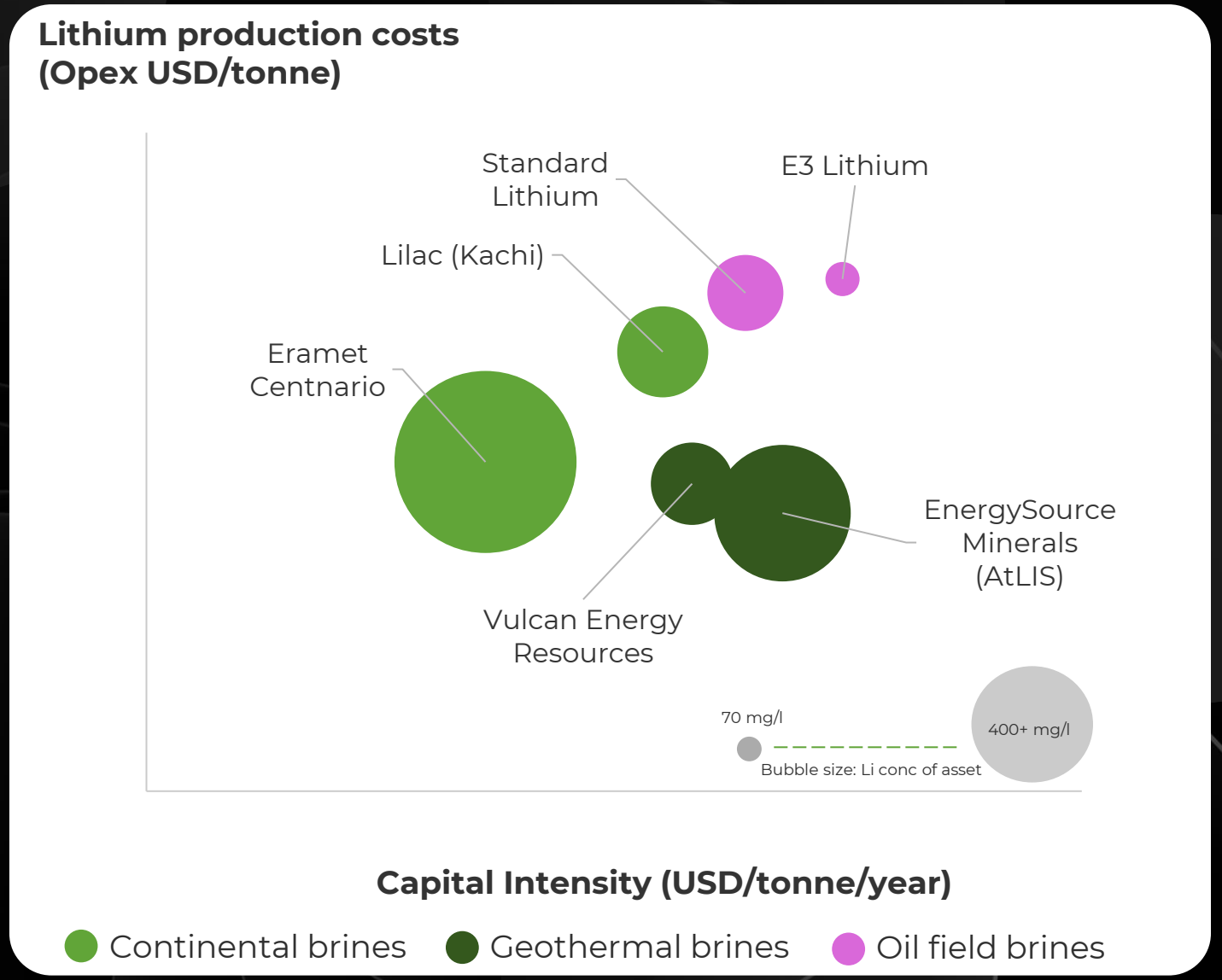
Environmental Impact: Low Medium High

"Environmental impact" refers to estimated water use/loss, reagent usage, and CO2 footprint.

DLE BY THE TYPE OF RESOURCE

Vulcan Energy is developing Europe's first geothermal brines, while EnergySource is exploiting North American geothermal resources.

Standard Lithium is completing North America's largest DLE facility commercial plant.



Source: Lux Research estimates; based on publicly available data

DON'T IGNORE REFINING!

While China only produces around 13% of the world's lithium, it is responsible for refining over 70% of the global supply

Look to companies that focus on traditional precipitation and crystallization but also to opportunities in electrolysis' as the technology can refine almost any lithium chemicals to a high-purity, battery grade material.

CONTINENTAL BRINES ARE MOST ECONOMICAL

But DLE can help reduce overall operational costs for geothermal

Geothermal brines have low production costs

- Project developers can power part of their operation with geothermal energy. These projects have operational cost comparable to traditional brines.
- Building greenfield geothermal plant plus DLE is capex intensive

Image source: Think Geoenergy

KEY TAKEAWAYS

1

No silver-bullet DLE technology

- Adsorbents and ion exchange lead the DLE race
- Projects with downstream water recycling and solvent recovery as well as cheaper refining will succeed

2

Commercializing geothermal

- Lithium is a strategic mineral
- Technology development for low-concentration brines
- Finding upstream and downstream partners lowers risk

3

Costs could trump sustainability

- DLE improve sustainability outcomes
- Success will depend on technoeconomic efficiency