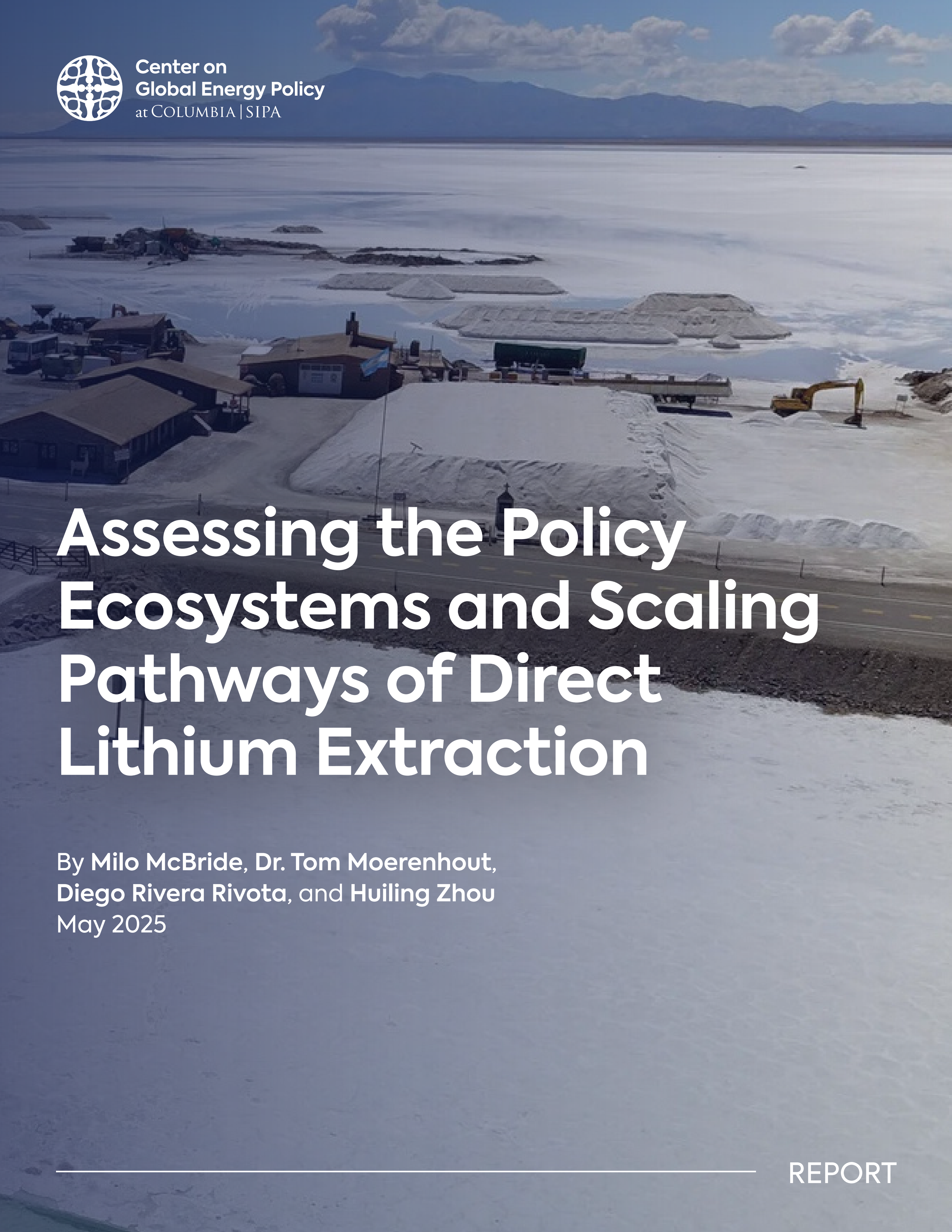

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Assessing the Policy Ecosystems and Scaling Pathways of Direct Lithium Extraction

By **Milo McBride**, **Dr. Tom Moerenhout**,
Diego Rivera Rivota, and **Huiling Zhou**

May 2025

REPORT

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Acknowledgements

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He has advised and consulted for various stakeholders, including the White House, Departments of Energy and State, USTR, and policymakers in several other countries, including the EU, Canada, India, Indonesia, Nigeria, DRC, Egypt, Iraq, Chile, and Brazil. His collaborative efforts span organizations such as the OECD, IEA, World Bank, UNCTAD, UNEP, OPEC, IRENA, and several philanthropic foundations.

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She is now an electric vehicles analyst at BloombergNEF, where she covers the economics, policy developments, and company strategies shaping EV markets in North America and globally.

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Executive Summary

Lithium plays a critical role in the global energy transition. It is the core ingredient of lithium-ion batteries that power electric vehicles (EVs) and are used in stationary energy storage systems. Due to its unique properties, lithium cannot be easily substituted when high performance is required—and that is unlikely to change with technological developments in the foreseeable future. For these reasons, forecasters expect lithium demand to rise precipitously through 2030 and then remain on an upward trajectory.

Meeting this fast-growing demand will require the development of many new lithium extraction projects. Developing any type of mine is a complex endeavor that often requires considerable time. But the lithium industry faces a set of structural, economic, and environmental challenges that compounds the difficulty of scaling production. Specifically, the lithium sector is small relative to many other mining industries, and fluctuating lithium prices are making it hard to attract investment. This in combination with long lead times can make it complicated to respond to short-term demand fluctuations.

This report, part of the Critical Materials program at the Center on Global Energy Policy at Columbia University SIPA, explores the policy ecosystems supporting the development of a newer set of lithium production technologies based on direct lithium extraction (DLE), which involves the selective extraction of lithium ions from subsurface brines. If DLE technologies are scalable and mature, they could help meet lithium demand in the medium and especially the long term. In theory, DLE can be more efficient, effective, and sustainable than conventional lithium mining technologies, though more research is needed to demonstrate when and how.

The report focuses on the fiscal and regulatory mechanisms in place in the countries or regions that are developing DLE technologies, including the US, Canada, Chile, Bolivia, China, and Europe. These mechanisms have been effective in driving DLE development and deployment to date, but higher levels of support and novel policy maneuvers will be needed if governments want to continue to support efforts to scale DLE and potentially make it competitive with legacy forms of lithium production.

Other findings of the report are as follows:

1. Research and development policies and early pilot incentives have helped developers realize site-specific DLE projects, particularly in California (US), Alberta (Canada), Qinghai (China), and Saxony (Germany).

2. Numerous DLE projects have reached the pilot stage, several of which are moving toward large, commercial demonstration scale. But others may face challenges from downward pressure on lithium prices and uncertainty over project financing costs for first-of-a-kind developments.
3. A hindrance to DLE development more broadly is regulatory policy uncertainty. Efforts in Canada and the United States to harmonize DLE regulations with oil and gas processes and in China to shorten permitting timelines have helped. In Chile and Argentina, procedural questions about water reinjection practices could complicate DLE's outlook.
4. To fully understand DLE's potential, further research is needed on its impact on freshwater resources and its cost compared to conventional lithium production.

The report concludes with a set of recommendations for policymakers in the countries or regions mentioned previously who wish to bolster support for DLE project development. These are followed by an appendix that maps existing DLE pilot and demonstration projects around the globe.

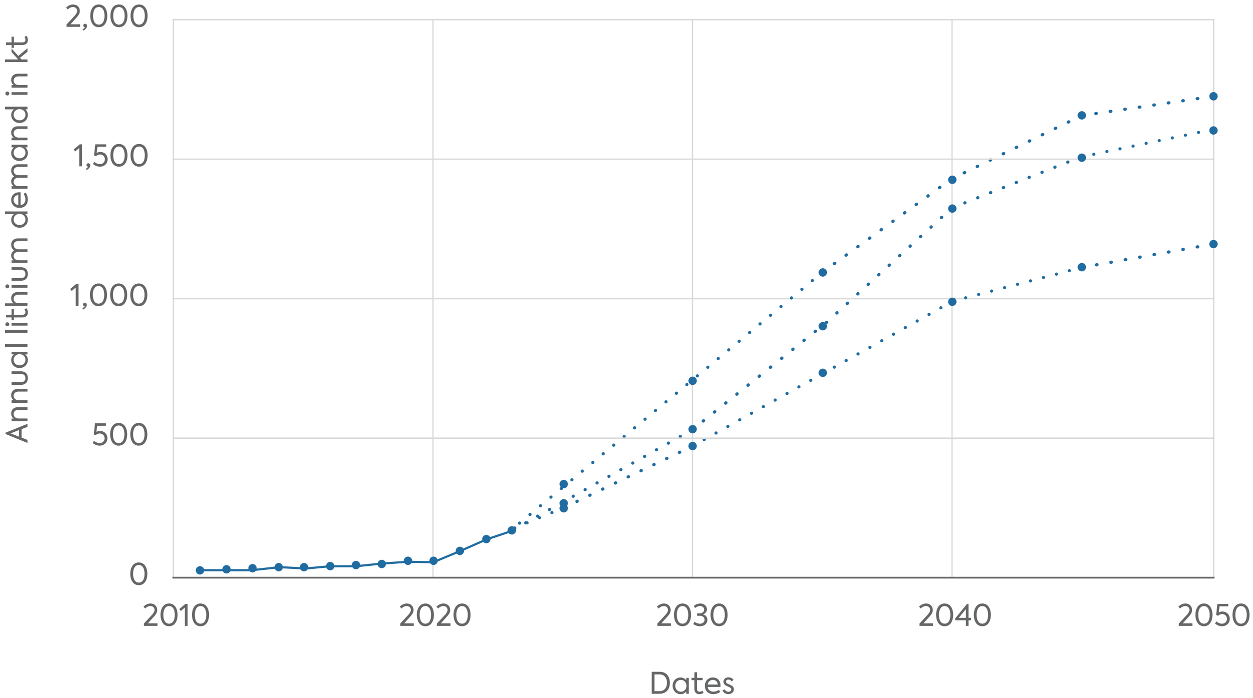
Introduction

Lithium is essential for the energy transition, particularly for lithium-ion batteries used in electric vehicles (EVs) and stationary storage systems. Given its low weight and superior energy and electrochemical properties, lithium is difficult to replace in settings where high performance is required, making alternatives such as sodium-ion (Na-ion) batteries and other new technologies, though important, mostly complementary in the medium term (S&P Global 2024; Stoikou 2024). While Chinese companies have recently shown the ability to increase the energy density potential of sodium-ion batteries, these still remain below the energy density used in the most high-performance lithium-ion batteries (CATL 2025).

For this reason, most forecasters expect that lithium demand will more than triple from 2023 levels by 2030 (International Energy Agency 2024; Energy Transition Commission 2023; BloombergNEF 2024; Seetharaman et al. 2024). This demand is currently being propelled by EV sales growth and the correlated production of battery manufacturing infrastructure, with nearly eight terawatt hours (TWh) of lithium-ion battery factories under construction by 2025—roughly fourfold the expected battery demand for the same year (BloombergNEF 2024). Although EV demand risks being asymmetric across markets, signs point to significant growth globally (Figure 1).

Lithium demand beyond 2030 is harder to predict but is expected to remain on a strong upward trajectory, especially if the present downward pressure on lithium prices challenges the economic advantage of Na-ion (International Energy Agency 2024). Technological pathways seem to reinforce lithium's long-term importance and potential growth: lithium can offset graphite as an anode material and will remain important to the cathode. Even for the most mineral-reducing next-generation battery designs, such as lithium-sulfur and lithium-air chemistries (the latter being at early-stage research and development [R&D]), lithium remains critical (Harmon 2023; Lynch 2023). If these novel technologies eventually deliver on their potential, they could help to penetrate new facets of the transportation sector such as some types of aviation (Bills et al. 2020), their growth will reinforce lithium's importance.

Figure 1: Global lithium demand in the IEA's stated policies and accelerated and net-zero scenarios



Note: Annual lithium demand is listed in kilotons (kt), not lithium carbonate equivalent (LCE). Consumption for 2011 is based on the average estimates from that year listed by the United States Geological Survey (USGS). Data for 2010 is not available.
Source: USGS, International Energy Agency.

Lithium demand growth therefore has an air of inevitability—but this leaves the question of scale. Structurally, even low-growth scenarios represent an enormous level of new project development, especially for a relatively small, boutique industry like lithium. For example, under the International Energy Agency's (IEA) business-as-usual and net-zero scenarios, meeting 2030 lithium demand will require 30 or 50 new average-size lithium mines, respectively (Moerenhout et al. 2023). This comes at a time when the industry is facing economic and environmental challenges. Simply put, how can the industry balance the imperative to meet demand growth with that of social and environmental stewardship?

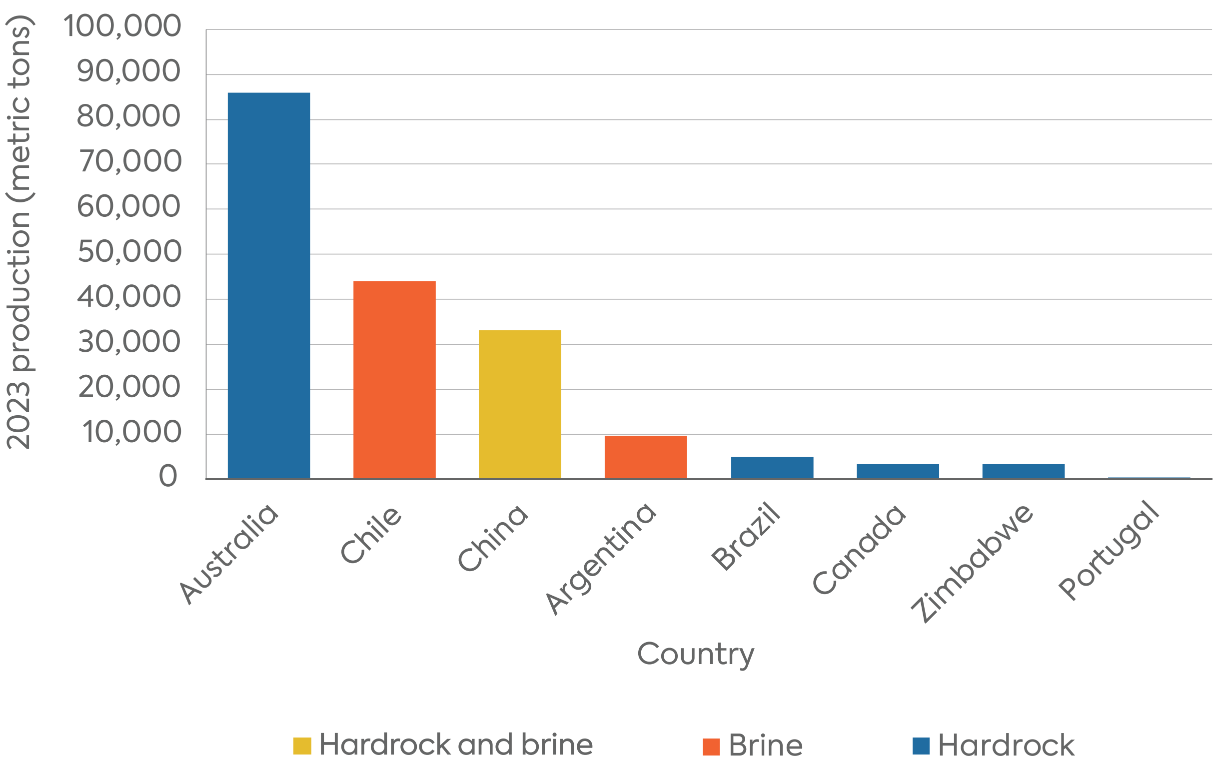
This report explores the potential contribution of direct lithium extraction (DLE) technologies, which allow for the selective extraction of lithium ions from subsurface brines, to striking that balance. It finds that government support—both regulatory and fiscal—has been a driver of technology development and advancing deployment. However, if governments wish to develop this potentially groundbreaking technology, more support will be needed, as it remains unclear whether DLE projects will prove competitive against legacy production.

The report begins by analyzing the advantages and disadvantages of DLE production, including relative to competitor lithium mining technologies. It then assesses the policy mechanisms—both fiscal and regulatory—that DLE technologies face in the countries where they are being developed. The report concludes with policy recommendations should policymakers in these countries wish to continue developing DLE technologies. An appendix provides the most up-to-date (January 2025) information available on key DLE pilot and demonstration projects currently underway around the globe.

Lithium Production Technologies

Traditional lithium extraction is geographically concentrated in South America, where for the most part brine evaporation is used; Australia, where hardrock mining is used; and China, where lithium is produced from both hardrock and brine resources (USGS 2024; McKinsey 2023; Barbosa and Carvalho 2024; Hotter 2024; Benchmark Mineral Intelligence 2024). The top three global lithium producers are currently Australia, Chile, and China, but other players, such as Argentina, Brazil, Canada, and Zimbabwe, are entering the race (Figure 2) (USGS 2024). While lithium in Brazil and Zimbabwe is mined from hardrock, Canada has both hardrock and brine projects underway, which are described at length in this report.

Figure 2: Lithium production by country and method in 2023



Note: Some small production estimates were omitted in the source and US domestic production data were withheld to avoid disclosing company proprietary data (USGS, 2024).
Source: USGS, International Energy Agency, S&P Global, and Canadian Mining Journal.

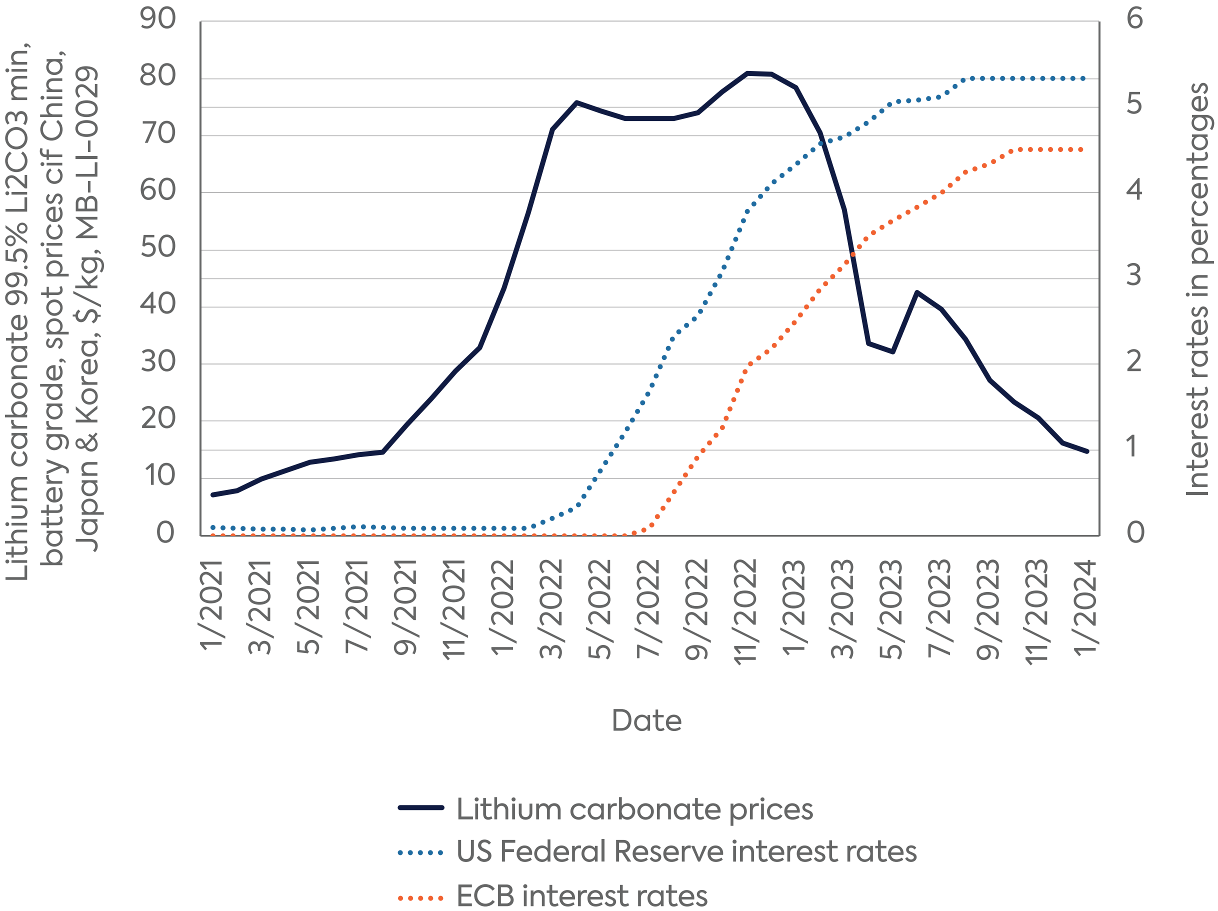
Brine and hardrock extraction both come with trade-offs. Conventional lithium brine evaporation entails seven times the land of hardrock mining (Kushner and Talbot 2023), potentially impacting local ecosystems, especially in arid regions such as Chile's Salar de Atacama (Liu et al. 2019; Kushner and Talbot 2023). This process is also slow, taking up to two years to complete, and results in the loss of more than 90 percent of the extracted water through evaporation (Vera et al. 2023). Moreover, economically recoverable evaporation ponds are currently found predominantly in Chile and Argentina, which host brines with high thresholds of lithium concentration, potentially limiting the geographical diversity of conventional brine-based production (Munk et al. 2016). These regions are also subject to increasing levels of drought and water stress, which could put lithium producers at odds with other water consumers, creating conflict or at least jeopardizing the social license to mine (S&P Global 2022). That said, most of the water involved in lithium brine extraction is already highly saline and not suitable for agriculture. Still, even limited use of freshwater—or the perception of high water consumption—can trigger local backlash.

Hardrock mining uses more fresh water and emits at least three times as much carbon dioxide as conventional brine production (Benchmark Mineral Intelligence 2023)—with some studies suggesting as much as six or seven times greater (Pell et al. 2020). In theory some of these emissions could be abated through fuel switching. Hardrock resources also require energy-intensive processing that uses chemicals, leading to waste streams with heavy pollutants, particularly with the incumbent sulfuric acid method (Gao et al. 2023).

Developing any type of mine is a multistage process that includes discovery and exploration, feasibility assessments, and later the construction of the mining operation and necessary adjacent infrastructure. Developing a lithium project could take between four and seven years (Energy Transition Commission 2023). In some analyses lithium brine project development is placed at the upper bound of this time range at seven years, while hardrock plays are placed lower at about four years (Kushner and Talbot 2023). Given these timelines, some jurisdictions, such as Western Australia, have recently issued frameworks to expedite mineral permitting (Claughton 2024), which can help quickly ramp up supply.

However, price volatility can complicate investment decisions. In 2021 lithium carbonate and hydroxide prices skyrocketed about fourfold, before collapsing to their pre-hype range in early 2024 (Koralewski 2024). In recent years this volatility has been compounded by elevated interest rates in the United States and European Union, which increase project financing costs, a particular challenge for so-called junior miners entering the lithium space with weaker balance sheets (Figure 3). Further, the nicheness of the global lithium market comes with downside challenges to scaling investment, such as nascent future pricing mechanisms and their subsequent lack of liquidity (Benchmark Mineral Intelligence 2024; Ouerghi et al. 2024). Environmental, social, and governance expectations of nature-based disclosures could increase pressure on accessing capital (Taskforce on Nature-Related Financial Disclosures 2024).

Figure 3: Falling lithium prices amid elevated interest rates (2021–24)



Source: Fastmarkets and US Federal Reserve Bank.

The challenges of scaling lithium—whether environmental, social, financial, or economic—have raised concerns about underinvestment everywhere besides China or Chinese plays abroad. Most creditors and miners are not incentivized to take on the risks of developing new projects, despite clear demand signals beyond the coming years of excess supply (Wood Mackenzie 2024). This is in sharp contrast to only two years ago, when the base scenario of Benchmark Mineral Intelligence's demand projections had a 12.5 percent supply deficit by 2030—the equivalent of at least six lithium mines, or 50 percent of the entire industry's size in 2022 (Moores 2024). Others expected a 30 percent supply deficit by this time (Energy Transition Commission 2024).

While some today assert that demand will be sufficiently supplied from new mines and recycling capacity, even modest supply deficits toward or beyond 2030 could risk triggering price shocks—for example, an estimated 0.5 percent supply deficit in 2022, alongside a surge in EV demand, helped catalyze the aforementioned price surge of an astounding 500 percent (S&P Global 2022). Given that minerals are now a large cost component of cathodes, these price shocks will be passed on to batteries, EVs, and the energy transition writ large.

DLE Technologies: Advantages and Challenges

DLE technologies are being developed as a potential solution to some of these challenges. In the DLE process, brine is pumped from the earth, sent through a filtration system, and in many cases reinjected into the ground (Nicolaci et al. 2023). In theory this offers a more sustainable and efficient means of producing lithium. Although hybrid DLE methods—where DLE is used alongside evaporation ponds—have been used in Argentina and China for decades (Grant 2020), pure-play DLE is relatively new and moving toward commercial scale.

DLE can be applied to various subsurface brines, some of which are conveniently located in brownfield oil sites or in situ geothermal plants that naturally produce saline brine and steam at high temperatures for power generation (Iyer and Kelly 2022). DLE can also process brines with lower concentrations of metal, differentiating it from the incumbent salar brine evaporation method, which is solely applicable to brines without certain chemical impurities and ultrahigh lithium concentrations (Vera et al. 2023). Thus, whereas Chile's Salar de Atacama, with its world-leading average lithium concentration of over 1,400 mg/L, uses evaporation ponds, the Great Lake Salt, with its average lithium concentration of only 52 mg/L, is the site of a DLE pilot project (Munk et al. 2016).

DLE technologies are not monolithic or universally applicable. Today four primary technologies are being pursued to pull lithium ions from brine: adsorption, ion exchange, solvent extraction, and membrane separation. Adsorption is the incumbent technology that is in commercial use (Nikkhah et al. 2024). Some start-ups are currently pioneering ion-exchange techniques that could prove more efficient (Patel 2023). Solvent extraction and membrane separation both theoretically offer their own functional advantages but are likely further from commercialization. Table 1 lists the various existing DLE technologies ranked by technological readiness level (TRL) and potential to recover lithium.

Table 1: Existing DLE processes

Technology	Description	Technology maturity	Lithium recovery
Adsorbents	Adsorption process using sorbents	TRL 9 (commercial)	80%–99.9%
Ion exchange	Ion exchanger using resins, aluminates, or ceramics	TRL 8	80%–99.9%
Solvent extraction	Fluid solvent mixture blended with brine to extract water	TRL 7	99.9%
Membrane separation	Often used in conjunction with ion-exchange and adsorbents/solvent extraction; promising processes are nanofiltration or reverse osmosis	TRL 4–5	>99.9%
Electrochemical separation	Electrochemical extraction of lithium from brines by adsorption or intercalation	TRL 1–3	>90%

Note: TRL stands for technology readiness levels, a measurement system that assesses the maturity of a technology on a scale of 1 to 9, where 1 is basic research stage and 9 is commercial deployment stage.

Source: McKinsey, International Lithium Association.

DLE's potential to help balance lithium demand and supply is significant. Based solely on company projections of stage 1 production capacity in the coming two to five years, current DLE production plays around the globe could cover almost all lithium demand for EVs once operational. Of course, not all these projects will come online, and forecasters generally assign weights to such projections that account for other demand- and supply-side factors, making the true impact of DLE smaller than if one relies on company estimates. More measured outlooks for DLE production place it between 470 kt and 526 kt from 2030 to 2035 (depending on the source), up from about 124–140 kt of LCE production in 2024 (BloombergNEF 2024; Benchmark Mineral Intelligence 2024). Some forecasters expect that about half of all lithium brine production could be from DLE by 2030, which represents a rapid and market-shifting development (BloombergNEF 2024; Benchmark Mineral Intelligence 2023; Benchmark Mineral Intelligence 2024). It should be emphasized that this is solely in the context of brine resources. Hardrock lithium will also expand geographically.

Compared with conventional evaporation methods, DLE could prove effective in extracting lithium. Studies suggest that traditional evaporation ponds have a recovery rate of 40 to 60 percent, while DLE can achieve as much as 90 percent, if not higher in isolated cases (Iyer and Kelly 2022; Controlled Thermal Resources n.d.). Some in the private sector have asserted that the DLE process could yield as much lithium in days as is produced from evaporation in over a year (Nicolaci et al. 2023). Others have challenged these claims, arguing that doubling production efficiency would not inherently necessitate such a parabolic shift in production times, especially given the challenges surrounding DLE development. Economically, DLE will need to contend with an expanding hardrock market across Brazil, Sub-Saharan Africa, and especially China, though these resources can be high on the cost curve (Yao 2022; Barbosa et al. 2024; S&P Global 2023).

The development of DLE faces three main obstacles: scale, cost, and environmental impact. In regard to scale, DLE technologies are not a "one stop" fix to the filtration process; they are part of a multistage chain that must be tailored to the chemical properties of each individual brine (Vera et al. 2023; Razmjou 2024). For example, different resources may hold varying levels of minerals such as silica or magnesium, as well as differing concentrations of lithium, necessitating an individually tuned DLE system (Razmjou 2024). This dynamic means that DLE systems are unlikely to be interchangeable between geographies, highlighting the importance of pilot-stage production, where firms take the time to tune their filtration systems to specific brines before scaling.

Turning to cost, it has not yet been proven that DLE technologies can be competitive with incumbent evaporation processes and especially hardrock mining. Some private sector analyses suggest that DLE will widen the lithium cost curve through levels of capital intensity comparable to conventional brine evaporation (Nicolaci et al. 2023). However, more recent analyses from leading industry forecasters illustrate an expensive pathway to market: commercial-stage developments are almost twice as capital intensive as early-stage pilot projects, indicating a potential oversight in initial forecasts of equivalent capital costs to incumbent technology (Benchmark Mineral Intelligence 2024). DLE may have operational costs potentially analogous to evaporitic processes, but its capital costs could prove higher (possibly the result of specialized machinery for the DLE process) (Razmjou 2024). Geothermal DLE projects could potentially yield unforeseen economic benefits, such as the ability to self-supply low-carbon power and carbonate from steam, as well as extract other minerals such as silica (Warren 2021).

In terms of environmental impact, while some have asserted that all DLE processes inherently reduce water impact, recent literature suggests that some processes could require more water than evaporation and that further research based on proprietary data and field tests is needed (Stower 2023; Vera et al. 2023). Site-specific analysis of California's Salton Sea finds the impacts to be modest (Busse et al. 2024), but past studies have found a wide range of DLE water consumption both above and below incumbent lithium methods (Razmjou 2024).

Critical questions remain about the sustainability of reinjecting spent brines following the DLE process. In theory DLE could redirect the spent brine into brine-bearing aquifers, in contrast to evaporation ponds, where the water is left to evaporate. But this should be done with caution so as not to impact the environment or production wells. Further research is needed to understand the impacts of these practices (Razmjou 2024; Vera et al. 2023). While this report does not address the technological pathways for DLE, water use will be an important determinant of which pathway becomes predominant and thus how policy ecosystems can support less water-intensive DLE technologies.

DLE Policy Ecosystems

Summary of Findings

As illustrated in Figure 4, DLE is slowly but surely breaching the market across North America, Latin America, China, and potentially parts of Europe. This report finds that government support—both regulatory and fiscal—has been a driver of technology development and advancing deployment. This trend is observed in numerous locations, including California's geothermal DLE, Alberta's oil field DLE, and Qinghai's salar DLE. DLE plays are also emerging without fiscal incentives, relying instead on the help of pro-extraction local policies, as observed in various Argentine provinces and Arkansas. Even in regions that offer subsidy regimes, support mechanisms vary among loans, grants, and tax credits. Most countries offer support for R&D, while loans for project finance are primarily limited to Europe, and grants are typically limited to North America. Chile, Argentina, and Bolivia lack clear policies, regulations, and support mechanisms to drive widespread adoption of DLE, which is instead emerging through private sector initiatives and foreign partnerships.

Figure 4: Map of DLE projects globally

Note: This list is not exhaustive and includes some DLE projects at early stages of development as well as projects that could be hybrid DLE and evaporation.
Source: Authors' analysis of existing DLE projects.

Concerted and long-standing policy efforts are helping bring DLE technology closer to commercialization. On the domestic front, this report finds that, based on analysis of E3's Alberta project, Vulcan Energy's Germany project, and Controlled Thermal Resources' California project, DLE resources are being scaled through multifaceted support mechanisms. The latter project, as discussed in the US section of this report, received the most comprehensive and multifaceted funding measures, including infrastructure grants, academic hubs, and funding to help address, and hopefully remediate, historical environmental injustices. Since their start in the late 2010s, DLE projects have generally begun with early-stage R&D funding to help professionalize ideal filtration technologies. Additional financing has then been issued to develop pilot production facilities, which helps achieve scale and keep DLE start-ups afloat as they professionalize the extraction and filtration processes.

Later-stage funding avenues vary by region. In Europe, Brussels and London authorized low-interest, one-off, multimillion-dollar loans from the European Investment Bank and the UK Infrastructure Bank to scale German and British DLE facilities. Canada's Strategic Innovation Fund has authorized up to C$27 million in funding for the E3 oil field brine system. Similarly, the US Department of Energy (DOE) and the California Energy Commission (CEC) have both unleashed more modest grants in the million-dollar range to the Salton Sea geothermal play. While the Europeans do not offer tax credits, both Canada and the US rely on them heavily to bolster domestic clean energy production. However, Canada's tax credit is higher than that of its US equivalent, which initially omitted DLE (and critical mineral extraction more broadly).

While Chile's public-private lithium strategy has prompted some state-owned enterprises (SOEs) to embrace DLE, the country does not offer binding or durable policy measures that can drive broad DLE adoption. DLE could instead emerge there as a way of tapping lower-quality brines or potentially as a hybrid process that complements existing evaporitic methods. Argentina has observed several key DLE plays from French, Chinese, and US firms, but these cases represent corporate ambition and geologic necessity, not policy support per se. While Argentina has two projects with DLE as part of their operations—Fenix and Centenario-Ratones—both it and Chile lack clear regulations regarding brine reinjection, a potential facet of DLE production. Bolivia's lithium brine is notoriously difficult to filter, and the country has not developed the necessary capacity for the innovation needed to stimulate DLE domestically. Such production is thus contingent on partnerships with Chinese and Russian firms. Like Argentina, Bolivia does not appear to have offered subsidies or support mechanisms for DLE.

On the regulatory side, certain provinces have made clear strides in outlining potentially supportive policies for DLE, while others trail behind. For example, the Canadian provinces of Alberta and Saskatchewan have amended local regulatory rules to include lithium brines in the traditional process used for oil and gas extraction. This could prove helpful, especially given that many companies and engineers in these regions are leveraging expertise in hydrocarbon production and are thus likely familiar with incumbent legal processes. The EU has promised expedited permitting, but this will likely be project specific and will not guarantee short timelines to market.

China's unique political economy likely offers some of the most advantageous support measures for DLE production. The Qinghai central government has a long-standing strategy to develop the region's brine resources into a commercial industry—a clear signal of ongoing policy support. The region's DLE producers also have access to widespread funding mechanisms, such as R&D grants, low-interest rate loans, and tax rebates. Most importantly, DLE projects in Qinghai may be able to enjoy ultrafast permitting timelines—as short as 40 days. For context, the EU's Critical Raw Materials Act pledges to expedite strategic permitting timeframes to two years. Qinghai DLE also benefits from local demand drivers with China being the largest lithium refiner and battery producer in the world.

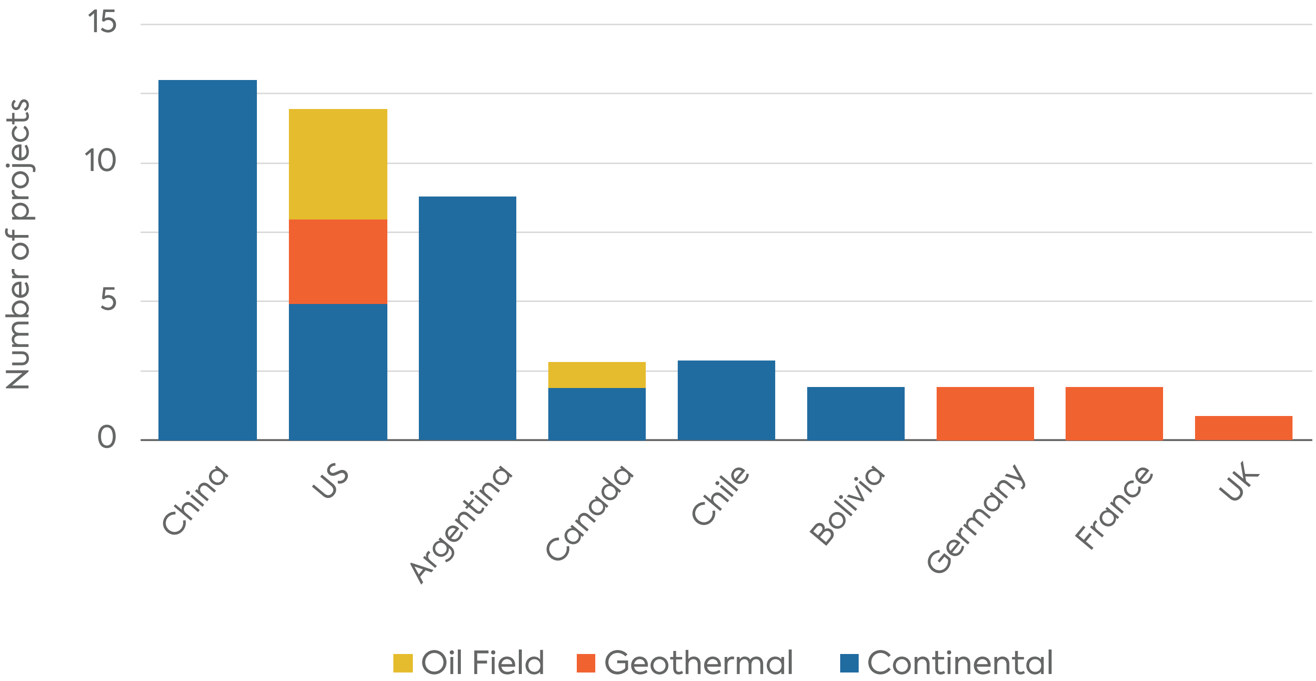
Policies related to intellectual property (IP) for DLE were identified in both Chile and China. In China the Qinghai province and the Salt Lake Institute have begun tracking both domestic and international patents filed for DLE processes. Similarly, Chile's National Institute for Intellectual Property (INAPI) has tracked all DLE patents since 2000. Other markets in North America and Europe have no observed analogs. In terms of requests from countries of origin in the Chilean database, Canada leads with 30, followed by the US and China with 25 and 22, respectively. Finally, in terms of companies, both Korean-based POSCO and Canadian Nemaska Lithium have the most requested patents with a total of eight each, followed by US-based Albemarle with seven (INAPI 2023).

Despite these strong support indicators, many of the observed DLE sites are in areas with increasing levels of water stress, which could impact DLE prospects. Some DLE-producing regions, such as Utah, have already adopted regulatory measures to constrain industries with high water consumption. These challenges could impact DLE technology pathways, with the lowest water-consuming filtration and processes possibly proving the most resilient in the long term.

But there are also unconventional DLE plays emerging outside of so-called continental brines (Figure 5). For instance, Europe and the US have several geothermal DLE projects, which may be high risk, high reward, as they face technical challenges in commercializing production but would reap the sustainability benefits of on-site, zero-carbon, and baseload power. Germany's and California's geothermal DLE projects are expected to begin commercial operations in the coming years. Other DLE plays are emerging in oil field brines across southern Arkansas and Alberta, where subsurface brine deposits with high lithium concentrations are located in or near former oil fields.

These projects potentially come with added benefits, such as access to historical geological research.

Figure 5: DLE projects by region



Note: This list is not exhaustive and includes some DLE projects at early stages of development as well as projects that could be hybrid DLE and evaporation.
Source: Authors' analysis of existing DLE projects.

Country-by-Country Analysis

The United States

Although historically home to hardrock lithium production, the US has relegated lithium production to a niche industry, with demand being met through rising imports (USGS 2024). This trend could soon change, however. Since 2022, significant investments have been made in both the comprehensive US battery supply chain and some upstream mineral production (Clean Investment Monitor 2025). Recent government estimates put US battery cell capacity at 1.2 TWh by 2030, enough for at least 12 million EVs annually (Gohlke et al. 2024), with some estimating US demand at about 412,000 tons LCE of lithium chemical (Peters 2024). That said, the second Trump administration could introduce policy shifts ranging from subsidy alterations to permitting reform that could further incentivize mining but reduce battery demand compared with the counterfactual.

While the US is home to multiple hardrock lithium plays, some have struggled with permitting, local community opposition, and financing (L 2024; Sainato 2023). Given the demand-side drivers in the US as well as regulatory and social backlash to some open-pit projects, DLE projects could prove attractive in the US market as a complement to the high-quality hardrock plays.

With diverse brines located across the US, both federal and state governments have passed funding and regulatory clarity to advance domestic DLE production. Most of this funding has gone to advancing geothermal DLE production in the Salton Sea, California, where legacy geothermal plants are being retrofitted to process lithium from production well brine and new power plants are being proposed to combine energy production with lithium and other critical mineral production from geothermal brines (Warren 2021).

Outside California, several states, including Arkansas, Louisiana, Texas, Nevada, and Utah, are developing DLE plays while advancing or deliberating new regulatory frameworks. In the Western regions of the US, DLE projects will increasingly need to contend with those regions' ongoing drought and the prospect that water risks could trigger local concerns and subnational government intervention in the most severe cases.

The US is home to multiple locations with brine suitable for DLE methods, including the Smackover Formation between East Texas and Arkansas, the Salton Sea in California, the Clayton Valley in Nevada, and even the Great Salt Lake in Utah. The US DLE outlook is further strengthened by the presence of relevant private sector firms with skills transferable to pumping and purifying subsurface fluid. Thus far, the types of firms involved in these projects are in oil field servicing, oil and gas, geothermal power, downstream chemicals, legacy lithium, and technology-specific industries focused on filtration techniques. On the demand side, US automobile makers are positioned to varying degrees as first movers to secure equity and offtakes in California's Salton Sea geothermal DLE and oil brine projects in Arkansas (General Motors 2021; Stellantis 2023; SK On 2024).

The US also has significant opportunities to extract lithium from "produced" or "flowback" wastewater at hydraulic fracking sites, though this is at a preliminary stage and outside the scope of this report. An Oklahoma-based lithium processing plant is exploring these resources (Stardust Power, 2024), while government and academic researchers have corroborated high lithium volumes in the Marcellus Shale (Mackey et al. 2024).

Fiscal Analysis

Significant funding mechanisms have been authorized for the Salton Sea of California, and several grants have been issued for DLE projects in Arkansas (though the fate of some of these mechanisms remains unclear, given the potential policy shifts under the Trump administration) (California Governor 2023; Department of Energy 2024). Much of this funding is in the form of state-level grants toward R&D and infrastructure and tax development grants and rebates, and less so federal tax credits—the typical fiscal mechanism in US clean energy incentives. California, which has a GDP comparable to a G7 country (California Governor 2023), has unleashed unparalleled levels of state funding to develop its lithium resources. Other states with high DLE potential, such as Arkansas, are finalizing their own lithium tax royalty structure to help provide market clarity to developers. The following section addresses federal incentives and then primarily focuses on mechanisms to stimulate DLE development in the Salton Sea.

US federal industrial policy in both the clean energy and fossil fuel sectors has some support measures that include or apply to DLE. For example, the Inflation Reduction Act (IRA) 45X tax credit extends to mineral extraction or processing at a modest 10 percent (Department of Treasury 2024). Much of the 45X subsidy for clean energy manufacturing provides a 30 percent production tax credit, including other upstream processes such as polysilicon production in the solar supply chain (Department of Treasury 2023). Given the geological similarities between lithium-rich brine and oil and gas deposits, DLE may qualify for tax architectures used to subsidize conventional energy extraction, such as drilling, though this is not certain (Congressional Research Service 2021). According to the USGS, lithium qualifies for a 22 percent depletion allowance, similar to the 15 to 25 percent allowance awarded to oil and gas production (USGS 2024; Internal Revenue Service 2023).

While no DOE loans to DLE projects have been finalized, the DOE Loan Programs Office (LPO) has opened its Title 17 funding to all facets of mineral production, including lithium extraction (Loan Programs Office 2024). The DOE LPO has also funded other non-DLE lithium projects, such as the Thacker Pass play and Rhyolite Ridge in Nevada (Loan Programs Office 2024). In the final days of the Biden administration, a conditional loan of $1.36 billion was extended to EnergySource Minerals in the Salton Sea, but the fate of this funding remains unclear amid spending freezes by the Trump administration (Salata 2025).

California's geothermal-related DLE projects received the most comprehensive federal and state funding of all the DLE projects analyzed in this report. This includes R&D awards from the DOE and the CEC and reflects the Salton Sea's production potential and technical challenges: the DOE expects the region to be capable of producing 3,400 kt of ultralow carbon lithium—enough to power 375 million EV batteries (Office of Energy Efficiency and Renewable Energy 2023). For context, US EV sales in 2023 were just shy of 1.2 million (Brinley 2024) out of about 15 million total car sales (Walz 2024). Previous studies estimate that with the present 400 MW of installed geothermal capacity in the Salton Sea, annual lithium production could range between 127,000 and 150,000 metric tons LCE (Dobson et al. 2023). But purifying high-temperature geothermal brines is a technological and economic challenge compared with purifying conventional brines because of complex chemistry, high salinity, scaling, material corrosion, and energy demands (Stringfellow and Dobson 2021).

Because of the perceived high-risk, high-reward potential of geothermal DLE, R&D and pilot programs have received state and federal backing. Since 2017, the CEC has awarded over $27 million in research funding to help develop geothermal projects (California Governor 2023). In 2020 the state deployed grants worth $6 million to Berkshire Hathaway Renewables, the owner of 10 out of the 11 Salton Sea geothermal plants, and $1.46 million to Controlled Thermal Resources, another DLE player in the region (Chao 2020). At the federal level, the DOE's Geothermal Technologies Office funded nearly $17 million in geothermal DLE research grants through a three-round prize competition to academic institutions and private companies to advance improvements in extraction processes that will reduce costs and limit environmental impacts. (Department of Energy 2022; Office of Energy Efficiency and Renewable Energy 2023; Advanced Materials and Manufacturing Technologies Office 2022). Previously, the DOE had rescinded a $14.9 million grant to a DLE project in the Salton Sea, likely because of legal disputes with the company (Scheyder 2022).

On top of R&D funding, state and federal governments have supported economic development–related infrastructure that helps ensure the Salton Sea's long-term commercialization. This is an important consideration, especially given the historical, environmental, and social injustices that the Imperial Valley has endured. In the early 1900s, the terminal lake or "sea" was created by the flooding of the Colorado River, which helped foster economic development and regions important for avian biodiversity. But inflows from the Colorado River have decreased and been replaced by agriculture drain water, resulting in toxicological impacts amid increasing water precarity (Bardeen 2022). To address these environmental issues, the US Department of the Interior has promised $250 million from the IRA to promote water conservation (California Natural Resources Agency 2022). To date, about $70 million of that total has been authorized (California Natural Resources Agency 2023).

To remediate these economic injustices and prepare the region for a potential lithium boom, the US Department of Commerce's Economic Development Administration (EDA) awarded a planning grant of $500,000 to develop the Lithium Valley Tech Hub (Economic Development Administration 2024; University of California, Riverside 2023). Additionally, the region is a finalist for the EDA's Distressed Area Recompete Pilot Program, from which $65 million has been requested (Economic

Development Administration 2023). The state of California is also committing funds to support the Salton Sea's economic development. The 2023–24 California budget earmarked $3 million for the Imperial Safety Corridor, which develops adequate road infrastructure (Padilla 2023). The previous year's budget included $80 million for a STEM program at San Diego State University's Brawley campus, located near the Salton Sea (San Diego State University 2022).

State-level tax schemes are also being deployed to promote economic development and redistribution efforts. California's recent budget includes a new excise tax on lithium extraction that ranges from $400 per metric ton for smaller projects (20,000 metric tons LCE or lower) to $800 per metric ton for larger projects (30,000 metric tons LCE or higher) (California Legislative Information 2022). The state has pledged to allocate 80 percent of these tax revenues to the county where extraction occurs and the remaining 20 percent to the Salton Sea Restoration Fund, which will focus directly on community benefits and engagement (Legislative Analysis Office 2024; California Department of Tax and Fee Administration 2023). To promote additional facets of the value chain, Imperial County has imposed a $50 per metric ton severance tax break for Salton Sea lithium produced in the county (Wilson 2023).

Alongside the Salton Sea, other potential US DLE-producing regions include the Paradox Basin in Utah, Clayton Valley in Nevada, and—most notably—the Smackover Formation in southern Arkansas (though the latter's resources extend as far as Texas). Utah and Nevada seem to lag behind Arkansas in terms of DLE policy, regulatory, and commercial progress but have notable tax incentives for mining, including DLE. For example, Nevada imposes minimal taxes on the mining industry for production, with Albemarle's Nevada-based lithium mine reportedly paying less than 1 percent of the project's income in state taxes (Jackson 2024). Over time this low tax burden could rise because of the state's newly imposed gross revenue tax, which has already kicked in for gold and silver (California Department of Tax and Fee Administration 2023). While Utah has imposed a severance tax for minerals, additional legislation has been proposed that triples the severance tax, except for mines that leverage nonevaporitic processes (i.e., DLE) or agree to mitigate water use (Larsen 2024).

Like California's Salton Sea, southern Arkansas's Smackover region is a hot spot of DLE development. Despite no previously observed grants from the federal government to Arkansas projects, the DOE recently announced financing for two projects: Standard Lithium and Equinor's SWA Lithium, which received $225 million to expand its pilot to commercial scale production of carbonate from DLE, and TerraVolt's DLE facility, which is also likely to be located in southern Arkansas and received $225 million (although details remain limited, and the project is likely further behind that of SWA Lithium) (Department of Energy 2024). As of the time of writing, it remains unclear whether the Trump administration will honor these grants and issue the investments in these DLE projects.

No evidence of tax incentives for lithium production from the Arkansas government exists, but the state does have tax write-offs that range from R&D to machine procurement, both of which, in theory, could be applied to DLE sites in the Smackover (Arkansas Economic Development Council 2024). Moreover, Arkansas's DLE has garnered a unique level of bipartisan support, with local conservative politicians affirming a vision of the state as a "leader on the global stage for lithium production" (Arkansas Economic Development Council 2023). The state is currently devising a royalty scheme in anticipation of this potential lithium boom (Li 2024), and early reports indicate it could be similar to that of the Salton Sea, starting at $400 per metric ton, with a ceiling of $450 (Massey 2023).

Regulatory Framework

DLE projects in the US require federal and state permitting. On the federal side, any permitting developments are typically subject to the National Environmental Protection Act (NEPA), a process that may not apply if the project is not on federal lands, did not receive federal funding, or involves certain criteria for expedited permitting, such as being located on a brownfield site (e.g., existing geothermal brines, oil field brines, or already-tapped continental salt flats) (US Department of Energy; U.S. Fish and Wildlife Service). However, any DLE or hydrocarbon project needs to acquire water reinjection permits from the Environmental Protection Agency under the Clean Water Act: oil and gas are filed under Class II and mineral extraction under Class III (Environmental Protection Agency 2024). Some states, such as California and Nevada, may require a specialized permit for brine water discharge in addition to the federal permit (California State Water Resources Control Board; Nevada Division of Environmental Protection 2018).

At the state level, governments are finalizing regulatory processes to foster policy clarity. Several states have begun to include "brine" in existing regulatory processes for oil and gas extraction, a maneuver that could prove helpful to industry, especially as oil and gas engineers and firms are working on DLE projects. Arkansas, home to the lithium-rich Smackover Formation and multiple DLE sites, has led the way on this front: In 2020 the state's Oil & Gas Commission outlined procedural clarity for brine well drilling or injection (Justia 2020). Since 2018, Arkansas has granted the LANXESS DLE project ongoing approvals to scale its DLE pilot facility (Arkansas Oil & Gas Commission 2023).

Other states are developing analogous frameworks to include DLE into existing regulatory regimes. The Texas Senate has passed a bill that allows the Railroad Commission of Texas to include mineral-producing brines in its water regulations and authorizes the Texas Railroad Commission (TRC) to issue brine permits (Texas State Legislature 2023). But TRC has not yet issued rules specifying the intricacies of the process (Scott, Douglas, and McConigh 2023). The Louisiana Senate has proposed amending its permitting regulation to include brine in the section where subsurface commodities are noted (Louisiana State Legislature 2024). Utah's state legislature recently passed rules clarifying brine extraction and how it should be overseen by relevant subnational agencies (Utah State Legislature 2024). The Utah Department of Natural Resources Division of Oil, Gas, and Mining handles the permitting process for the state.

California is beholden to its own roster of subnational permitting processes, such as the California Environmental Quality Act (CEQA), which some view as analogous to NEPA in its length and complexity. To expedite permitting, the state government agreed in 2022 to fund a county-led programmatic environmental impact report for Lithium Valley development (Imperial County n.d.). Initial studies have been finalized by companies such as Controlled Thermal Resources and were approved by the Imperial County government in December 2023. One notable detail is that the CEQA process may have been further expedited through a loophole in the Warren-Alquist Act of 1974, which mandates that thermal generation projects under 50 MW do not need to be approved at the state CEC level and can be authorized by the local county agency (Holland and Knight 2020; California State Assembly 2023). Thus, Controlled Thermal Resources submitted an environmental review for geothermal plants of 49.9 MW capacity (County of Imperial 2022).

But some regions are beginning to take action against DLE operations, particularly in the Southwest, where ongoing drought has depleted groundwater resources and caused basin allocation levels supplied by the Colorado River Compact to reach record lows. In Utah the challenges facing the Great Salt Lake have heightened concern among policymakers about the potential impact that industry, including DLE, could have on this vital body of water. In 2024 Utah passed legislation, HB 453, that seeks to minimize water usage on the Great Salt Lake for mineral extraction (Utah State Senate 2024). The Colorado River Basin Salinity Control Act could likewise discourage the development of DLE projects, or at least those with notably high water intake (United States Department of Agriculture n.d.).

These challenges may not inhibit DLE projects regionwide and in some cases, water access and regulation could result in favorable conditions for DLE technologies that boast low water consumption. For example, Lilac Solutions is advancing its DLE project on the Great Salt Lake despite the aforementioned concerns. Lilac reports that its ceramic bead system is unique in that it can extract lithium from low-concentration brines and with little water demand (Peters 2024). While there is currently a lack of public information regarding the specifics of the technology, the firm has demonstrated resilience to existing barriers through technology development that could theoretically be applicable to other brines. On the other hand, on the heels of the Utah legislation, Anson Resources announced it would cancel its Paradox DLE project in the southeastern part of the state, citing new environmental and regulatory challenges (Winslow 2024). Another company, Compass Minerals, likewise abandoned its plans for DLE on the Great Salt Lakes (Vandenack 2023).

With respect to investment protection, there is no evidence of DLE-specific IP protections in the US. If subsidized by the federal government during the R&D process, US-backed DLE processes will need to contend with the DOE's recent determination of the Bayh-Dole Act. In essence, the ruling mandates firms to prove that their technology cannot result in domestic manufacturing before it can be brought to a foreign market, thus incentivizing domestic development (Peterson 2021).

Canada

Canada has levels of state and federal government support analogous to those of the US. Similar to the Salton Sea, Alberta's oil field DLE play has garnered outsize backing and is likely to emerge as the epicenter of Canada's lithium brine extraction, especially given the project's enormous potential long-term nameplate capacity of 150,000 metric tons LCE (E3 2024). While US and Canadian clean energy tax policies are comparable, Canada's public support for DLE may be more robust, especially given that it includes larger subsidies via tax credits for the extraction process.

Like the US, Canada is seeking to produce EVs and batteries. The country's 2023 federal budget, likely a response to the US IRA, created tax credits for the EV battery supply chain. Some forecasts have Canada reaching at least 60 GWh of cell production by 2030, concentrated in Ontario and Quebec (Department of Energy 2024). Further, Canada's legacy automobile integration with the US through the United States–Mexico–Canada Agreement (formerly North American Free Trade Agreement) has been advanced through IRA tax credits, which extend to Canadian minerals given Ottawa's longstanding free trade agreement with Washington.

Canadian lithium brine deposits are concentrated in the Western territories, particularly Alberta, Saskatchewan, and Manitoba (listed in order of activity). The regulatory outlook is not dissimilar from that of the US either: Federal permitting processes are coupled with state-level processes, many of which have developed permitting amendments to mirror conventional hydrocarbon production. Also, like the US, legacy hydrocarbon production will likely prove an asset in DLE development with transferable skills and correlating regulatory environments. In the long term, water risks could also emerge, notably in Alberta, where ongoing drought could impact the region's production.

Fiscal Analysis

Canada has multifaceted subsidies for critical mineral extraction as well as DLE-specific incentives. Subsidies for DLE projects span all facets of the project pipeline, from R&D to demonstration to extraction-adjacent infrastructure. Further, tax credits are offered at both the federal and state levels, which could help promote DLE production.

Driven largely by the US IRA and growing demand for green industrial policy, Canada's 2023 federal budget includes various new tax schemes designed to bolster critical mineral production, including DLE. In fact, the tax law specifically qualifies lithium brines as a mineral resource. While many of the budget's tax credits mirror those in the IRA, the Clean Technology Investment Tax Credit (ITC) could prove more valuable to DLE projects in that it extends a 30 percent write-off to either mineral extraction or processing activities (Government of Canada 2023), whereas the IRA extends a 10 percent production tax credit (PTC). The ITC also allows companies to write off upfront costs—which is especially useful for high-risk first projects—whereas the PTC rewards production only after the project has been activated. Additionally, the Canadian government has doubled the critical mineral exploration tax credit from 15 percent to 30 percent to encourage junior miners to expense exploration costs (the credit does not apply to mining majors) (Prospectors and Developers Association of Canada 2024). This is an important detail in the lithium and DLE space writ large, where many important players are not multinational mining or chemical producers but start-ups.

Beyond federal subsidies designed to scale demonstration projects, the Canadian critical minerals and new energy strategy contains measures that DLE developers can leverage for production. These include the Critical Minerals Infrastructure Fund (CMIF), which supports public infrastructure such as roads and transmission to potential mining sites (Government of Canada 2024). For energy costs, the 2023 federal budget provides a tax credit for carbon capture, utilization, and storage (CCUS) technology (Government of Canada 2023), which could reduce operational expenditure. For example, E3 will be powering its Alberta-based DLE facility with local natural gas and carbon capture (Alberta Energy Regulator 2024).

Canadian DLE projects, particularly E3, have also enjoyed ongoing access to R&D and demonstration funding. Natural Resources Canada, the nation's energy and resources ministry, has invested in early-stage R&D projects to advance DLE production in brines with low lithium concentration and streamline carbonate production from brine with a specific focus on oil field resources (Government of Canada 2023). In 2021 E3 received a C$1.8 million grant from Alberta Innovates, which helped scale a lab prototype DLE facility to its first deployment in the field (E3 2024). The following year the federal government's Strategic Innovation Fund announced up to C$27 million in funding to support various aspects of the project's development, including drilling, DLE technology, and downstream equipment for conversion to hydroxide (E3 2022). Most recently, E3 was awarded C$5 million from Alberta's Technology Innovation and Emissions Reduction fund to build its demonstration facility (E3 2024), further elevating the pathway to commercialization. E3 has also entered a joint agreement with US-based Pure Lithium to produce lithium-metal anodes in Alberta, a notable development for two potentially symbiotic next-generation technologies (The Globe and Mail 2024).

Saskatchewan and Alberta have their own tax incentives that can be utilized by DLE projects. In Saskatchewan, oil and gas tax breaks, including the Oil and Gas Processing Investment Incentive and the Saskatchewan Petroleum Innovation Incentive, have been amended to include lithium brine. The former offers a 15 percent tax credit on project costs up to $C75 million; the latter offers 25 percent on eligible R&D costs up to $C5 million (Collopy et al. 2023). The government has expanded its existing critical mineral exploration tax credit from 10 percent to 30 percent in addition to preexisting tax write-offs for R&D, manufacturing, processing, and other facets of the critical minerals supply chain and development process (Saskatchewan Government n.d.). Although Alberta rolled back its 30 percent ITC to "commercialize proprietary technology," there are analogous subsidies for the procurement of CCUS, again relevant to E3's project (Antonopoulos 2023).

Regulatory Framework

The Canadian Environmental Assessment Act (CEAA) of 2012 is the primary federal policy that oversees infrastructure and extraction projects. Similar to NEPA, the CEAA includes some exemptions, including for projects on private lands or small-scale operations with minimal environmental impact. Like in the US context, the CEAA is coupled with state-level regulatory processes. While the Canadian government has sought to streamline the permitting process through "substitution and equivalency"—where, in theory, certain facets can be determined by the federal or state body to reduce duplication and redundancies (Government of Canada 2023)—the efficacy of these mechanisms remains unclear. Recent studies indicate that permitting timelines for conventional mining are actually longer in Canada than in the US (Manalo 2024), though it should be cautioned that hardrock plays do not illustrate a direct correlation to subsurface fluid extraction and related procedures.

Despite these hurdles, state governments have created clarity for DLE producers through existing regulatory frameworks used in the oil and gas sector. In particular, Alberta's Mineral Resource Development Act, which came into effect in March 2023, added brine-based mineral production to the Alberta Energy Regulator's jurisdiction, which already included oil and gas (Alberta Government 2024; Alberta Energy Regulatory). Coinciding with the new legislation, the Alberta government released Directive 090: Brine-Hosted Mineral Resource Development (Alberta Energy Regulator 2023) and Brine-Hosted Mineral Resource Development Rules (Alberta Government 2023), which create instruments analogous to those of oil and gas extraction (Collop et al. 2023). The Saskatchewan government has also issued both a high-level framework to illustrate how lithium brine permits and leases can be acquired and multiple permits for lithium brine production (Saskatchewan Government n.d.; Saskatchewan Government 2024).

Canadian DLE operations will also need to grapple with existing water regulations, increasing water precarity, and any steps local governments take to address these issues. At the federal level, water permits are regulated through the CEAA, but provinces such as Alberta require Class II well permits for brine water injection (Alberta Energy Regulator 2023). Saskatchewan has its own variation of this (Saskatchewan Ministry of Energy and Resources 2023). However, both regions also have concerning levels of water stress. Pervasive drought in Saskatchewan has raised alarm over local oil and gas production (Bakx 2024), which could be extended to DLE. Water risk forecasts indicate that both Alberta and Saskatchewan will be areas burdened by groundwater stress in the coming years, and policymakers should prepare accordingly, especially in regions that already have high water demand industries, such as hydrocarbons and agriculture (World Resources Institute n.d.).

Chile

Chile is already an essential player in global lithium supply. In addition to holding the world's largest lithium reserves, the country is currently the world's second-largest producer and refiner of the battery metal (USGS 2024). Chile's lithium resources, located primarily in the Atacama Desert, a northern region that has emerged as the epicenter of the country's production, come from underground brine like in Argentina and Bolivia, though some of Chile's brine has higher concentration levels (Munk et al. 2016).

With demand rising fast and projected to continue to grow, existing challenges to Chilean production are highly relevant. Some of these challenges are linked to the environmental and social impacts of extracting lithium-rich brine from Chile's salt flats. Given that Chilean production takes place in the Atacama salt flat, one of the driest places in the word, hydrological balances are a concern (Hartley and Chong 2002; Herrera et al. 2018; Marazuela et al. 2019). Today, all of Chile's commercial lithium production is from brine evaporation ponds, which, as explained previously, demands large volumes of water. In this context the implementation of DLE technology in the Chilean salt flats has been touted by the government as "important for ensuring environmentally sustainable production" and a potential way to "increase current production" while reducing water use (Chile 2023).

Chile's National Lithium Strategy (NLS), published in 2023, included a push for DLE, which at least initially seemed to be a requirement for future lithium production (Chile 2023). After this prompted uncertainty, confusion, and criticism, the Chilean government clarified that, in the short term, DLE use was not a requirement but rather a complementary and desirable extraction technology (Guillou 2023; Bordoff et al. 2023; Atwood and Malinowski 2024). Any requirements about DLE in the medium- or long-term remain unclear. Although DLE technologies in Chile are still at an early stage of development, partly because of limited incentives compared with other geographies, they are clearly progressing. Several companies have announced the adoption of DLE on a commercial scale over the next decade, as explained below in the Public-Private Partnerships and Demonstration Projects sections (Codelco-SQM 2024; Albemarle 2023; Enami 2024; CTL 2024).

Fiscal Analysis

Chile has not leveraged significant fiscal support mechanisms to support DLE development. The country does not appear to have any tax credits or incentives targeting lithium production or DLE technologies in particular. In fact, over the last decade, the Chilean government has instead increased its fiscal income from lithium mining (CORFO 2024b; Jorrat 2022; Poveda 2024). While Chile does not currently have a DLE-specific initiative for research and development, it does have early-stage R&D mechanisms focused on lithium production, including DLE technologies.

One of these mechanisms is direct funding from Chile's central government. Chile's National Agency for Research and Development (ANID, by its initials in Spanish), the central government's leading agency on R&D, for example, is facilitating a federal investment of about $6 million USD via a competitive grant program called "Lithium and Salt Flat Research Rings" (ANID 2024). The program includes funding for research by universities and institutes on advanced production techniques (including DLE), as well as environmental and social aspects of lithium mining. The awardees were announced in July 2024, with 10 projects receiving funding, half of which include research projects related to DLE technologies (ANID 2024b).

Chile's economic development agency (CORFO) has also promoted R&D efforts specifically for lithium production and battery production initiatives (CORFO 2024). One example is a grant for the "development of new technological solutions for metallic lithium production in Chile," in which CORFO would provide up to $6 million USD for pilot projects where the participant had already committed at least 20 percent of the total cost (CORFO 2024). While not exclusively targeted at DLE R&D, these projects will likely be largely dedicated to DLE technologies given their emphasis on lithium production advancement.

As a second mechanism, the two companies currently producing lithium in Chile, SQM and Albemarle, must dedicate an annual amount to research and development centers. While none of that funding is required to go to DLE, it is reasonable to expect that some will be dedicated to the R&D of DLE technologies, especially since the government is pressuring both companies to improve yields per volume of brine water extracted. The committed amount is expected to increase annually and will account collectively for over $510 million USD by 2043 (ECLAC 2023). In the case of SQM, the annual contribution must increase from $10.7 million USD in 2018 to $18.9 million USD in 2030, when

SQM's current contract with CORFO expires. Albemarle's contribution must increase from $6 million USD in 2018 to $12.4 million USD in 2043, the end date of Albemarle's contract (ECLAC 2023). A report from the Natural Resource Governance Institute estimated that CORFO had already committed $198 million USD as of November 2023 (Poveda 2023).

These funds are administered by the Chilean government through CORFO, which has already concluded the bidding process for the creation of three research centers linked to lithium-related products: the Technological Center for a Circular Economy (CircularTec 2024), the Center for Electromobility Sustainable Acceleration (CASE 2024), and, most importantly, the Chilean Institute of Clean Technologies (ITL 2024). The latter, which will be developed and managed by the Agency for the Development of the Technological Institute as part of an agreement between CORFO and SQM, seeks to "promote solar energy, sustainable mining and advanced lithium materials and other minerals" by financing approximately $200 million USD through 2030. It will be located in the copper and lithium-rich region of Antofagasta (ASDIT 2024). In addition to these endeavors, Chile's NLS calls for the creation of the Technological Institute for Public Research on Lithium and Salt Flats (ITIP). Though little is known about the progress of ITIP, it may include R&D on DLE technologies given that one of its four preliminary research areas is "assessment and development of production technologies" (Chile 2024b).

Regulatory Framework

In April 2023 the administration of President Gabriel Boric published Chile's NLS, which seeks to expand the role of state of enterprises (SOEs) in lithium production (Chile 2023). Part of this strategy is fostering new lithium extraction technologies, including DLE, though this has received relatively little attention. The NLS appeared to mandate DLE technologies by suggesting that expanding lithium production would require new technologies to replace traditional brine evaporation (Chile 2023).[1] This raised concerns within the lithium industry about the early stage of DLE technologies, regulatory uncertainty, and the potential impact on investment (Guillou 2023; Bordoff et al. 2023). The Boric administration has since softened its approach, however, with Finance Minister Mario Marcel describing DLE as a "desirable variable" rather than a requirement and clarifying that the strategy was not as rigid as the text may have seemed (Atwood and Malinowski 2024).

The recent implementation of the NLS seems to confirm a softened stance on DLE. In March 2024 the Chilean government defined four categories of salt flat with varying requirements for SOE involvement. In the best-quality strategic salt flats, a majority stake of the SOE Codelco is expected. This could lead to less support for DLE if Codelco prioritizes production and revenue over technology development (Jobet et al. 2024). In other salt flats, recent announcements and tenders have not been transparent about expectations around DLE. For example, it is unclear what role DLE technologies will have in Codelco's $250 million investment in the Salar Blanco project (Codelco 2024).

On the other hand, increased state involvement in production activities through SOEs could be an opportunity to lead by example with best practices such as reducing water intensity through advanced technologies. After all, if Chile's public enterprises are not using DLE, how can the Chilean government reasonably expect to impose the use of DLE on other players (Jobet et al. 2024)? Several analysts argue that the Chilean government needs to define clear, nondiscriminatory, and precise regulations on DLE implementation while demanding attainable environmental standards and letting companies then pick the best technology to comply with them (Jobet et al. 2024).

While the Chilean government has certainly provided more clarity on the implementation of the NLS, some questions remain, particularly regarding the development of DLE technologies. For example, Chile still lacks regulations for DLE technologies and specifically for the reinjection of disposed brine back to the subsurface—something that has caused concern among stakeholders, from lithium producers to environmental organizations (Bnamericas 2023). Moreover, it is important to recall that the NLS was formulated by the president without legislative backing, akin to an executive order in the US, and so can easily be overturned by a different president in the future.

A relevant approach that the Chilean government has taken, which is not directly targeted to the implementation of DLE technologies but may influence it, is limiting the amount of brine companies can extract. These limits were established bilaterally with each of the two lithium-producing companies, SQM and Albermarle, at a commercial scale in Chile. In the case of SQM, they were part of the company's "Proyecto Salar Futuro" initiative, which plans for a maximum brine extraction of 822 liters per second (l/s) by 2028, in contrast to the 1,500 l/s granted in the 2018 contract modification, as well as halving the pumping of fresh water from 240 l/s to 120 l/s (SEIA 2022). In 2024 these plans were integrated into the bilateral agreement with SQM and Codelco, as detailed in the following section. SQM expects a post-2028 lithium carbonate production of over 280 metric tons per year without surpassing the 822 l/s brine extraction limit (Codelco-SQM 2024). For context, the company's lithium carbonate production was around 150 metric tons in 2023 (SQM 2024). A potential rise in lithium carbonate production with less brine extraction is therefore only possible by achieving better recovery rates from the extracted brine through the use of DLE or the combined use of technologies such as crystallization and forced evaporation (Codelco-SQM 2024). Codelco's chairman, Maximo Pacheco, stated in early June 2024 that while tests for DLE technologies by SQM had "promising results," DLE use may only take place "around 2033" and will still need to be complemented by current technologies (Atwood 2024).

The US company Albemarle pursued a different route. In May 2024 Albemarle and CORFO announced the end of an arbitration case between them at the International Court of Arbitration (CORFO 2024). That same day CORFO announced an agreement establishing an option for Albemarle to increase its maximum level of production to 240,000 metric tons of lithium metallic equivalent (CORFO 2024). This increase was conditional, however, on the use of "new more sustainable technologies," including DLE, as well as new environmental assessments and consultation with indigenous communities (CORFO, 2024). If Albemarle satisfied those conditions, it could potentially increase its production by around 12,000 metric tons per year. Thus, in both the SQM and Albemarle cases, the Chilean government has signaled implementing DLE technologies, though with different instruments, and neither in the short term nor with fiscal incentives.

No specific legal protections or provisions targeting DLE technologies or IP seem to exist at present in Chile. However, Chile's INAPI started a process of technological monitoring specifically focused on DLE technologies (INAPI 2024). As part of this initiative, INAPI published a report identifying patent requests for DLE in general as well as five technologies in particular: adsorption, ionic exchange, solvent extraction, membrane separation, and electrochemical separation (INAPI 2023). It found that since 2000 Chile has received 5.2 percent of these requests, the sixth most of any country. Of the total requests received by Chile, 156 were received between 2000 and August 2023, with a clear upward trend. The year 2022 had the highest number of patent requests with a total of 40.

Argentina

Argentina is currently the world's fourth-largest lithium producer and could emerge as an area of increased DLE activity because of the quality of its reserves. Specific government-backed lithium production and DLE technology efforts remain limited in Argentina despite lithium's growing importance to low-carbon technologies and the country's potential for producing this mineral. That said, lithium production, including the use of DLE technologies, has been in commercial operation since 1997 at the Fenix project in Catamarca province, and another project in the Salta province that also uses DLE technologies started operations in mid-2024. Regional lithium production has sparked concerns about water scarcity and environmental impacts, especially from nongovernmental organizations and indigenous groups, with significant protests occurring in the Salta province in 2023 (Vásquez 2020; Reventós and Favre 2023). The deployment of DLE technologies may reduce the water intensiveness of lithium production, but whether it will also mitigate opposition remains an open question.

Fiscal Analysis

At the federal level, two institutions stand out in terms of R&D: the National Scientific and Technical Research Council (CONICET) and the National Agency for the Promotion of Research, Technological Development and Innovation (Agencia I+D+i).

CONICET's importance lies in its role of providing direct financial support to researchers affiliated with universities or research centers across Argentina, as well as scholarships for PhD students and postdoctoral fellows (CONICET 2024). About 236 of the scholars and students supported by CONICET are conducting research related to lithium, with most focusing on batteries (Freytes et al. 2022). About 20 of the 236 focus on "production processes," which includes DLE technologies (Freytes et al. 2022). The fate of many of these research activities remains unclear because CONICET is undergoing a "restructuring process" after President Milei argued for its privatization or closure during his presidential campaign (Gulman 2024). Should CONICET's budget be significantly reduced or eliminated, the already limited R&D on lithium in Argentina will be further diminished.

The core mission of the Agencia I+D+i is to "promote scientific and technological research and innovation for the generation of knowledge and the improvement of production and service systems, through the financing of projects" (República Argentina 2024). This institution relies on funding from Argentina's treasury as well as loans from multilateral development banks. Between 2012 and 2021, it dedicated about $5.7 million USD to lithium-related research, of which the largest share (49%) went to battery-related topics and only 13 percent went to lithium production–related topics (Freytes et al. 2022). This sum over a period of nine years is equivalent to what Albemarle contributed in a single year (Freytes et al. 2022), showing that Argentina's public spending on lithium R&D is significantly smaller than that of Chile.

With respect to fiscal policy, Argentina does not seem to have lithium-specific fiscal incentives or tax credits at the federal level, no less ones that specifically promote DLE technologies. However, the federal Mining Investments Law does provide numerous fiscal incentives to mining producers in a bid to attract investment to this industry and boost mining in the country. Of these, the incentives that apply to lithium producers include a 3 percent production royalty, import duty exemption, VAT reimbursement, 30-year tax stability,[2] accelerated depreciation over three years, and income tax exemption on profits reinvested in registered companies (Argentina 1993). Of particular interest for DLE projects, which are by necessity early-stage, high-risk endeavors, is the 100 percent income tax deduction in prospecting, mineral and metallurgical tests, pilot plants, and similar feasibility efforts, which could help incentivize lithium production in the long term. Meanwhile, promises such as 30-year tax stability could limit policymakers' flexibility on future policy adjustments to further incentivize DLE adoption.

On top of federal tax policy, provincial governments impose fiscal obligations and provide incentives. At the provincial level, the northwestern province of Jujuy, home to two of the three lithium projects in operation in Argentina, stands out in terms of R&D. Since 2017, the Research and Development Center on Advanced Materials and Energy Storage of Jujuy (CIDMEJu)—a joint effort between the provincial government of Jujuy, the National University of Jujuy, and CONICET that employs about 30 staff members—has undertaken different projects in three main areas: lithium production, batteries, and recycling. The work on lithium extraction is mostly related to DLE technologies. CIDMEJu has also published at least eight reports on DLE-related topics (CIDMEJu 2024). The province of Jujuy has several fiscal policy incentives specifically for lithium production but none directly related to DLE (Rajzman et al. 2019).

Salta, the other lithium-producing province, also provides a series of fiscal credits for greenfield investments in a list of productive activities that includes mining (Provincia de Salta 2018). While this fiscal credit category technically includes lithium production, there are no specific incentives for producing this mineral or developing production technologies such as DLE.

Regulatory Framework

Argentina's mining regulatory framework is complex because of shared authority between the federal government and the 23 provincial governments, with the provinces playing a crucial role in defining concession conditions and regulations for lithium and water (López Steinmeitz et al. 2019). Lithium is classified as a "first-category mineral" in Argentina, like gold and silver, rather than a strategic mineral as in Chile and Bolivia. This allows private entities to obtain production rights through concessions (Freytes et al. 2022). The federal Secretariat of Mining under the Ministry of Economy oversees this framework, which includes the National Constitution, the Mining Code, and the Mining Investments Law. The National Constitution grants provinces original domain over natural resources, and the Mining Code allows them to issue mining concessions according to their own regulations (Freytes et al. 2022).

At the provincial level, Catamarca, Jujuy, and Salta are the key regions for Argentina's lithium projects, with each province managing its own mining procedural code, as well as exploration and production permits, royalties, and environmental compliance (Secretariat of Mining 2024). Although the federal government mandates Environmental Impact Assessment (EIA), provinces design and enforce these assessments and use the process to negotiate additional terms, such as local content and job creation, with mining companies (Freytes et al. 2022). The federal Mining Investments Law caps provincial royalties at 3 percent of the mineral's value despite the provinces' significant role in granting concessions and managing operations, highlighting a complex interplay between provincial control and federal revenue restrictions (Argentina 1993).

Scholars have argued that Argentina's lithium governance has created a "great heterogeneity" of administrative structures and procedures (e.g., for EIAs[3]) that are "increasing transaction costs for companies" (Freytes et al. 2022). For example, one procedure, the EIA, has in practice been used as a mechanism for provincial governments to negotiate with mining companies over aspects well beyond environmental issues, such as local content and job creation (Freytes et al. 2022). It is conceivable that it could also be used to incentivize companies toward greater use of DLE.

As of May 2024, there are no specific regulations for lithium production technologies in Argentina, and so there is no differentiation between evaporitic or DLE technologies. However, one factor that favorably positions some DLE technologies is water governance. In Argentina, brine, regardless of its dissolved mineral concentration, is considered water. As happens with mining, water concessions are granted by provincial governments, with different specific policies and priorities across provinces. The differences between lithium and water use governance in each province translates to an extremely complex framework that poses a "major obstacle for developing a performant public administration" and prevents "viable private investment projects" (López Steinmeitz et al. 2019).

A key element in the regulatory framework for DLE technologies, which is still to be defined in all three provinces, is brine use in DLE projects and its reinjection into salt flats. This is particularly notable in the case of Catamarca province for two reasons: It is home to the first commercial-scale DLE operation in Argentina, Arcadium's Fenix project, and its Supreme Court of Justice ordered the provincial government to undertake an "integral and cumulative environmental impacts assessment" in the Salar del Hombre Muerto and the Los Patos river, precisely where the Fenix project is located, and not to give any new permits to new projects or expansions in this area (Corte de Justicia de Catamarca 2024). These developments highlight the tensions surrounding the environmental impacts of lithium production on local communities and add uncertainty around the development of future projects in the Catamarca province, all of which could be an advantage to lithium producers using DLE technologies that claim lower water demand.

Bolivia

Bolivia, the northernmost country in the so-called lithium triangle, sits atop the world's largest lithium deposits, with 22 percent of the world's total lithium resources, but has no large proven reserves (USGS 2024).[4] As a result, Bolivia's lithium production is still very modest at about 600 metric tons of LCE in 2023. Despite two decades of effort to produce lithium industrially, little progress has been made (Von Vacano 2024). In the past, efforts to boost lithium production in Bolivia have faced challenges, such as relatively longer evaporation times, high levels of magnesium and other impurities in brine resources, and protests and social discord in the lithium-rich region (Sánchez et al. 2021; Jeon Woong An et al. 2021). The country's high altitude and limited infrastructure (including power and roads) have also inhibited development (Sánchez et al. 2021; Von Vacano 2024). Moreover, the governance of lithium production has been characterized by the exclusive control of the Bolivian state over the whole lithium supply chain through Yacimilentos de Litio Bolivianos (YLB), the lithium SOE, as detailed in the Regulatory Framework section below. Since 2021, however, YLB has begun partnering with companies from China and Russia, which could help Bolivian lithium production jump from a single pilot production plant in the Uyuni salt flat to industrial production.

Fiscal Analysis

Bolivia does not seem to have any specific funding programs, such as grants or fiscal incentives, for DLE technologies, but it does offer some R&D funding, though far less than in neighboring Chile and Argentina, as explained above. Given that in Bolivia the whole lithium value chain, including research, is a responsibility of SOE YLB, most research activity takes place under the YLB's umbrella and is thus publicly funded. This is the case for the Center for Research, Development and Pilot Projects (CIDYP, by its initials in Spanish, a research hub located in the community of La Palca in the Department of Potosí) and within it the Research Center on Science and Technology of Materials and Evaporitic Resources of Bolivia (CICYT-MAT-REB, by its initials in Spanish) (MHE 2022).

Regulatory Framework

In 2009, under Pres. Evo Morales, Bolivia amended its constitution to declare lithium a "strategic" resource. This placed lithium exploration, exploitation, and industrialization under the exclusive control of the state (Estado Plurinacional de Bolivia 2016). The 2010 National Strategy for the Industrialization of Evaporitic Resources set milestones for lithium production and the establishment of lithium-related research centers (ECLAC 2023). In 2017, Law 928 established YLB as the sole entity responsible for the entire lithium production chain, allowing private participation only in certain semi-industrial and waste-processing activities, and provided YLB maintains majority control (Estado Plurinacional de Bolivia 2017).

Despite this framework, private participation in Bolivia's lithium industry has been limited because of legal uncertainties. The absence of a lithium law enabling YLB to partner with private companies means that YLB has only been able to enter nonlegally binding agreements with private sector players. Former presidential adviser Diego von Vacano notes that for YLB to be able to form binding partnerships with private entities, constitutional amendments or new legislation will be required.

This limitation surely undermines DLE development since it is private entities that are developing DLE technologies. Although several lithium laws have been proposed, internal political conflicts and opposition from local communities make such legislation unlikely in the near term. Consequently, investors must be prepared to accept strict conditions imposed by YLB (von Vacano 2024).

Despite the constitutional and legal challenges to public-private partnerships, the Bolivian government is actively seeking new partnerships to ramp up lithium production. These are necessary because they provide financial support to upfront investments, technical capabilities including human resources, and technological expertise. Regarding the latter, private companies using DLE technologies are well suited to address three main challenges particular to Bolivia's brine deposits: high magnesium content, rainfall rates, and heavy reliance on water-intensive evaporation ponds, the latter of which can have detrimental impacts on the environment, leading to social opposition (von Vacano 2024). Because DLE technologies can contribute to reducing magnesium content and do not require constant sunshine, they could be especially beneficial to Bolivian brines.

In terms of environmental regulation, lithium production falls under the Environmental Law provisions for the mining sector (Estado Plurinacional de Bolivia 1992)—but that law contains no provisions on lithium production broadly or DLE technologies in particular. Mining operations in general require two environmental licenses: the Environmental Impact Declaration (DIA, by its initials in Spanish) and the Dispensation Certificate (CD, by its initials in Spanish), as well as an Environmental Impact Assessment Study and an Environmental Monitoring Report (ECLAC 2023).

China

China is the world's largest lithium refiner, third-largest lithium producer, and a powerhouse in lithium-ion battery production, with a forecasted production capacity of 3.6 TWh by 2030 (Marjolin 2023; USGS 2024). Over 70 percent of China's lithium reserves are found in brine, but the country's lithium brine production has been limited historically because of the high magnesium-to-lithium ratio in its brine reserves (Zheng 2023). The similar properties of magnesium and lithium make the separation and purification process a challenge and have posed a technical bottleneck for large-scale lithium development (Lin et al. 2021).

To overcome these technical limitations and satisfy surging lithium demand, China has been investing in DLE technology. While the central government set the overall policy guideline, provincial governments have done most of the heavy lifting, especially in Qinghai province, which is home to 50 percent of China's lithium reserves. In 2016, as part of its Thirteenth Five-Year Plan, Qinghai province set a goal of building a "trillion-yuan salt lake resource utilization industry cluster with significant national influence" (NDRC 2016). Most ongoing commercial-scale projects are concentrated in Qinghai, with new projects also emerging in Tibet.

Many DLE projects in China have been undertaken as public-private partnerships. While there is no national-level funding dedicated solely to DLE, relevant R&D efforts by research institutions and university labs receive support from general national and provincial research grants. At the provincial level, the Qinghai government has facilitated the launch of these projects by setting preferential tax rates and exempting administrative fees. Local commercial banks have also offered preferential lending rates to DLE projects.

Fiscal Analysis

Qinghai has channeled funding to DLE projects through both regular provincial-level R&D funding programs and targeted research schemes. Brine lithium extraction–related research themes are set by Qinghai's Science and Technology Department via programs such as the Provincial Science and Technology Major Projects ("Provincial S&T Major Projects," 省级科技重大专项). Under this major projects program, each province selects a handful of projects expected to drive regional innovation and economic growth by focusing on industries such as artificial intelligence or biotech. To date, three brine extraction–related projects have been announced in Qinghai (QHKJT 2024).

In addition, Qinghai has initiated several targeted research schemes focused on DLE. In 2023 the province launched its first bidding-based research initiative through the Lifting the List and Taking Command program, with 75 million yuan allocated to the production of anhydrous magnesium chloride from salt lake bittern (QHKJT 2023; Sina, 2021). This program opens bidding to public and private research entities and organizations from which those that can contribute the best solutions are selected (MOST 2021). Qinghai has also set up a research institute called the Qinghai Institute of Salt Lakes (ISL), which is a collaboration with the Chinese Academy of Sciences—China's highest consultancy for science and technology. According to the institute's 2022 annual accounting sheet, it had a total income of 132 million RMB ($18.5 million USD) for academic research that year (ISL 2022).

Outside Qinghai, university labs and research institutes have tapped into national-level research funding through programs such as the National Key R&D Program of China. For example, in 2022, research teams from Xi'an University of Architecture and Technology received funds to lead a project called Efficient Extraction and Eco-Friendly Processing Technology for Lithium-Magnesium Resources in Salt Lakes. The team used solid-phase ion binding technology to enrich lithium ions, with overall performance exceeding 20 times that of current adsorbents. A start-up called Gold-In, in which the Chinese mining company Tianqi Lithium holds a partial stake, spun out of this project (China Daily 2022). Another project called Enhancement of High-Efficiency Membrane, Transfer

Process and Development of Key Separation Membranes for Lithium Extraction in Salt Lake, led by a research group from Dalian University of Technology, has also been approved by the National Key R&D Program and is expected to be completed in 2025 (Jiang 2022).

Besides research grants, preferential tax rates have been set to facilitate lithium extraction in Qinghai province. The Implementation Plan for Resource Tax Items, Rates, and Preferential Policies in Qinghai Province outlines that lithium production be taxed at 6 percent, down from the 8 percent included in the original drafts of the plan published in June 2020 (GHRD 2020; The Paper 2020). However, there is some confusion about whether the tax should be based on the sale price of the brine or the final value of the lithium product. Reports show that integrated companies extracting and processing lithium sometimes sell brine internally at a much lower price than the market rate to avoid taxes (GHRD 2024). Lithium brine extraction projects that implement innovative technologies are eligible for reductions in certain administrative fees, though these reductions are minor compared with the overall project costs. For instance, royalties for certain exploration or mining projects are merely 100 yuan ($14 USD) per square kilometer per year.

Commercial banks in Qinghai also provide preferential lending to certain lithium companies. For example, to support Qinghai province's lithium industry development plan, the China Development Bank estimated financing needs from 2017 to 2020 and proposed a financing model and developmental finance measures (Qinghai Daily 2017). Numerous other local banks have also offered improved financing access to companies with lithium-related projects. In the first three quarters of 2016, ICBC lent around 1.2 billion RMB to support lithium projects in Qinghai (Qinghai News 2016).

Regulatory Framework

China's policy on the development of salt lakes is mainly driven locally. While the central government put forward Five-Year Plans and "Made in China 2025," which is a strategic initiative aimed to advance high-tech industries, Qinghai has elaborated these policies based on its own industrial and economic structure, which is partly based on its massive lithium reserves (SMM 2018).

Qinghai first raised the goal of "establishing a trillion-yuan salt lake resource utilization industry cluster with significant national influence" in its Thirteenth Five-Year Plan (2016–2021) (Minhe County Government 2016). This goal was then echoed in its Action Plan on "Made in China 2025" (Qinghai Provincial Government 2016), which focused on lithium purification given the high magnesium-to-lithium ratio in Qinghai's salt lakes. The more recent Fourteenth Five-Year Plan (2021–2025) likewise seeks to "diversify and refine the development of the magnesium-lithium industry." The word "lithium" is mentioned 26 times in the plan, compared with only five times in the plan from a decade ago.

After the trillion-industry plan was introduced in 2016, the Qinghai government issued its "Guiding Opinions on Promoting the Sustainable and Healthy Development of the Lithium Battery Industry in Qinghai Province" in 2018. This document sets out specific targets such as increasing lithium carbonate production to 170,000 metric tons per year by 2025. It also more explicitly articulates the goal to "build upon existing salt lake lithium extraction technologies, with a focus on researching and refining centrifugal extraction, box-type extraction, membrane adsorption, and other salt lake lithium extraction processes" (Golmud Industrial Park 2018).

In terms of permitting, registrations for newly established exploration and mining rights are processed by China's Ministry of Natural Resources and are categorized as a national-level administrative permit. The legal time limit for completing both permit reviews is 40 days. The registration for newly established exploration rights is fully digitalized, while the registration for newly established mining rights requires a visit to the service site (National Government Service Platform 2024a; National Government Service Platform 2024b).

The region has also advanced a robust regulatory monitoring system for DLE-related patents and IP. The Qinghai Institute of Salt Lakes Chinese Academy of Sciences has built a team of over 20 IP specialists who handle patent applications, ensure compliance, manage legal protections, and oversee commercialization, providing robust and strategic IP management. Moreover, in 2023 the institute launched an aggregated property service platform for enterprises and research organizations to track all globally certified salt lake–related patents (Saltlake Patent 2024).

Besides domestic R&D, several Chinese companies have collaborated with research institutions overseas on tech transfer, adapting similar technologies for DLE applications. For example, in 2010 Qinghai Salt Lake Potash, which operates a DLE project in Qarhan Salt Lake, had its joint venture company Lanke Lithium import adsorbent technology from Russia (Southern Weekly 2021). Similarly, China Minmetals Corporation has entrusted multiple parties to develop various process technology routes for lithium resource extraction, including through collaboration with research groups from Freiberg University of Mining and Technology in Germany (Huang 2019).

Europe

Europe, including both the EU and the UK, is responding to the US IRA and Chinese green industrial policy by seeking near-total self-sufficiency in the domestic EV battery industry through the goal of producing 90 percent of its domestic battery demand, expected to be around 550 GWh (1 TWh of capacity is expected to be online by 2030, massively surpassing these goals) (Marjolin 2023). Demand for lithium products is emerging in several battery hubs in mainland Europe, concentrated in the Nordic countries, France, Germany, and several Eastern European countries. However, mining and onshore hydrocarbon production are relatively uncommon on the continent given environmental protection laws and interrelated community opposition. Europe is currently home to only one small-scale lithium project, which is in Portugal, with other hardrock plays in the planning stage in Germany, Serbia, and Sweden, among other countries (Sadden 2023).

Europe has the potential to unlock geothermal DLE, much like in the California Salton Sea. For the European market, geothermal DLE represents a unique opportunity to produce the lowest-emissions lithium given that the projects will be powered by on-site, zero-carbon geothermal power plants. Similarly, as the EU has continued to embrace biodiversity as its next pillar of environmental legislation, laws that protect domestic land use are likely to dissuade goals of expanding hardrock mining operations. Lastly, several hardrock plays in Europe—Portugal and Serbia, specifically—have faced ongoing backlash from civil society (Demony 2023; Vasovic 2024). Given DLE's potential to be less invasive on local biodiversity, it could offer a production pathway that satisfies many of the civil society concerns.

Thus far, Europe's progress in advancing DLE facilities is not far behind the US and Canada. The two primary geothermal DLE plays in Europe are Vulcan Energy's facility in Ortenau, Germany, and Cornish Lithium's project in Cornwall, UK. Several other projects are at an earlier stage of investigation across the so-called "Lithium Valley" spanning the France-Germany border in the Upper Rhine. Other firms exploring in this region include Equinor-backed Lithium de France and Alsace Geothermie Lithium, a project backed by French mineral giant Eramet and Electricite de Strasbourg (Sadden 2023).

Fiscal Policy

The EU has extended substantial grants to geothermal DLE R&D projects. In 2019 the EU's EIT RawMaterials began funding the EuGeLi program focused on geothermal lithium extraction, contributing nearly 85 percent of the EUR 3.9 million budget (EIT RawMaterials 2023). The program's aim was to develop technology capable of filtering lithium brine from high-temperature deposits in the Lithium Valley at the French-German border. The project connected 10 stakeholders, including regional universities and relevant corporations such as Erament, Electricite de Strasbourg, and BASF (EIT RawMaterials n.d.). More recently, EIT RawMaterials provided EUR 1.7 million to the BrineRIS project for continued research on extracting minerals from geothermal brines (EIT RawMaterials 2024) (EIT RawMaterials 2022).

While not specific to DLE, Brussels has financed several projects focused broadly on new mineral extraction processes. The European Research Council under EU Horizon issued funding for the development of solvent extraction technology with KU Leuven (KU Leuven 2020), though the exact funding amount remains unclear. The EU's CORDIS program has funded relevant projects in mineral extraction, such as the EUR 6.7-million LiCORNE project to advance new lithium processing and recovery techniques, and the EUR 12.7-million SEA4VALUE program to recover minerals from seawater (EU CORDIS 2020; EU CORDIS 2020).

Similar R&D programs have been enacted at the member-state level, several of which are now underway. In 2022, France's primary R&D branch, the Agence Researche de la Nation (ANR), extended EUR 748,189 to Lithium de France and Sorbonne University for the GLITER geothermal lithium study project (Agence National del la Recherche n.d.). The German government authorized a EUR 2.7-million grant in 2022 to support geothermal brine research in the Upper Rhine (ENBW 2020) and the following year an intergovernmental effort to coordinate geothermal brine strategy for Germany (Steinbach et al. 2023). In the UK the Department for Business and Trade's Automotive Transformation Fund awarded Geothermal Engineering Limited GBP 1.8 million in grant funding for a DLE geothermal pilot facility (UK Department for Business and Trade 2023; Cariaga 2023; Bentham 2023).

Unlike the US and Canada, Europe does not offer tax credits for mineral extraction and processing, but there are notable examples of government financing across the European energy transition. The European Investment Bank (EIB), for instance, has extended a EUR 500-million loan to Vulcan Energy for its geothermal lithium brine project (European Investment Bank 2024). The EIB is a notable force for low-interest rate project financing broadly, committing EUR 45 billion in 2023 to the Green Deal Industrial Plan (EIB 2023). In addition to funding from Brussels, the Upper Rhine geothermal project received a $AUS 200 million nonbinding letter of support from the Australian Export Finance Agency (although the project is based in Germany, Vulcan Energy is domiciled in Australia) (MT 2023). In the UK, the UK Infrastructure Bank has announced a first-round equity investment of GBP 24 million to develop a demonstration-scale facility with the potential of GBP 168 million in total long-term funding (UK Investment Bank 2023).

Regulatory Framework

Given the many impacts of mining, as well as its capital intensity, more European domestic regulations have the potential to slow down DLE development. That said, there are several EU-level regulations that can support DLE technology and project development. As an overarching strategy for sustainable growth, the European Green Deal promotes innovation in green technologies (European Commission 2019), and it is complemented by several other regulatory mechanisms that can support DLE. Most of these regulatory mechanisms offer only broad support, however, and still need national member state action to be implemented and truly help advance DLE development.

Within the EU regulations, the Critical Raw Materials Act (CRMA) most directly impacts DLE by designating lithium a critical raw material essential for renewable energy and electric vehicle industries. The CRMA aims to secure a sustainable supply of this material within the EU by setting targets for domestic sourcing, recycling, and refining, which encourages local lithium extraction projects and reduces dependence on non-EU sources.

The CRMA also offers specific incentives for so-called "strategic projects," such as streamlined permitting procedures and support in accessing finance. These incentives are designed to reduce administrative burdens and accelerate the development timeline of critical raw materials projects. For DLE technologies, with their significant upfront costs and regulatory hurdles, these provisions can help expedite support measures. Additionally, the CRMA's emphasis on technological progress and resource efficiency encourages the adoption of more sustainable and efficient extraction methods, such as DLE, which can contribute to the EU's broader goals of environmental sustainability and economic resilience (Official Journal of the European Union 2024).

The requirements to become a "strategic project" under the CRMA can be daunting, however. A cumulatively applicable list within the CRMA notes that projects need to become technically feasible within a reasonable timeframe, and their expected production volume must be measured with a sufficient level of confidence. While DLE technology is developing fast in this direction, it has not reached a point where scaled-up output levels are certain (Official Journal of the European Union 2024).

Once recognized as a strategic project, DLE projects can benefit from enhanced EU support. The CRMA foresees the establishment of a board with subgroups on financing, public acceptance, exploration, and monitoring (to name a few) that will help navigate complex processes. It also aims to improve the permitting process for strategic projects, even though any such changes would still need to be approved by national member states, which can also veto the strategic designation of a project on their territory. That said, once recognized as strategic, those projects would benefit from priority status at the national level to ensure rapid administrative handling in all judicial and dispute resolution procedures. The CRMA sets specific permit-granting deadlines such as 27 months for projects involving extraction. It also foresees discussions with standing subgroups about additional financing, including through the European Investment Bank Group and other relevant EU funding and financing programs (Official Journal of the European Union 2024).

There are at least three other EU regulatory instruments that can support DLE. The first is the EU Battery Regulation, which establishes strict requirements for the sustainability, safety, and life cycle management of batteries, including the sourcing of materials such as lithium. Provisions on minimizing environmental impact and ethical sourcing could benefit DLE projects (European

Parliament and Council 2023). The second is the EU Water Framework Directive, which mandates the sustainable use and protection of water resources. This is particularly pertinent for DLE as a production process that typically involves significant water use and management (European Parliament and Council 2000). The directive benefits technologies with lower water consumption footprints over those that are more water intensive. The third is the EU's research and innovation policies, such as Horizon Europe, which offer funding opportunities for developing and scaling DLE technologies, even if no DLE projects have been funded to date (Batteries European Partnership Association 2024).

Policy Trends and Recommendations

As global long-term demand for lithium continues to surge, DLE technologies offer a pathway to increase supply in the medium and especially the long term while potentially reducing environmental impacts compared with traditional extraction methods. Currently at the cusp of commercialization, they can potentially unlock significant unconventional lithium brine production in markets such as the US, China, and Argentina by the end of this decade, helping ease pressure from anticipated lithium demand growth. Additional and notable production is likely to come online over the next couple of years in Canada and Europe and more slowly in other Latin American countries such as Bolivia and Chile.

This report offers the following key insights into the policy ecosystems surrounding DLE development:

1. R&D policies have been effective for developing site-specific projects, particularly in California (US), Alberta (Canada), Qinghai (China), and Saxony (Germany). R&D and early pilot incentives are especially crucial for geothermal brines, which historically face technological challenges to commercialization.
2. Regulatory policy uncertainty is a major obstacle to DLE development. To address this issue, some provinces or states in Canada and the US have harmonized DLE regulatory policy with oil and gas drilling, and some Chinese provinces have established notably quick permitting timelines. In Chile and Argentina, questions around water reinjection practices could complicate DLE's outlook.
3. Numerous DLE projects have reached the pilot stage, with a couple moving toward large, commercial demonstration scale. But others may face challenges from downward pressure on lithium prices and uncertainty over project financing costs for first-of-a-kind developments.
4. While DLE could prove an impactful new driver of global lithium production, further research is needed regarding its impact on freshwater resources and positioning on the cost curve.

If policymakers wish to support the continued development and deployment of DLE technologies, they could consider the following policy recommendations:

1. Award R&D stage grants to new filtration technologies that specifically focus on balancing the lowest freshwater and carbon or energy intensity levels for DLE production. Governments may consider creating a prize-based system that awards winners based on lowest potential water or energy impact.

2. Explore whether conventional regulatory structures observed in the oil and gas industry would benefit emerging DLE projects. This is especially notable given the emerging synergy between industries. Policymakers in hydrocarbon-producing regions may consider exploring DLE permitting processes and regulations in terms of those applied to the traditional energy sector.
3. Target grants or loans to help firms scale their pilot facility into a phase 1 DLE deployment. This process is a significant leap that requires steep capital expenditures, which may prove difficult for start-ups amid price volatility and despite political directives to diversify supply.
4. In the US market, create and implement supply- and demand-side tax credits that prioritize the inclusion of DLE to help stimulate demand, especially amid downward price signals. In other markets, experiment with double counting—claiming the same expense or incentive twice—toward meeting regulatory requirements. The US could also explore the double counting of DLE to help it more easily qualify for local content requirements.
5. Consider mechanisms to help derisk investment by stimulating off-taker appetite, an important pathway to accessing project finance amid challenging market conditions.

Appendix: DLE Demonstration Projects

The United States

Several demonstration projects are emerging in Arkansas, Utah, and California—the three main DLE states in the US. In general, most US projects under study here are around the pilot stage, with several likely to proceed to commercial-scale demonstration before the end of the decade if proposed start dates are realized. For example, oil field servicing giant SLB announced the successful pilot of EnergySource Minerals' DLE technology in Nevada with plans for commercial production of 10,000 metric tons LCE starting in 2027 (Scheyder 2024). Most notably, US Magnesium and International Battery Metals has begun commercial production of its 5,000 ton LCE project in Utah (Scheyder 2024).

In Arkansas, Standard Lithium's LANXESS project has announced the successful development of a commercial-scale DLE facility, likely the first in the area to be near production (Standard Lithium 2024). While Mobil Lithium and Albemarle have DLE projects reportedly at varying pilot stages, they are likely further behind Standard Lithium's LANXESS project despite similar production goals (Scheyder 2024; McNeill 2024).

In California's Salton Sea, Controlled Thermal Resources has broken ground on what will be a commercial-scale demonstration project, with a goal of producing 25,000 metric tons of LCE (Cariaga 2024). EnergySource Materials and ILiAD's geothermal DLE project has been piloting for years, but it remains unclear when it will scale to demonstration stage (Benchmark Mineral Intelligence 2024). Berkshire Hathaway Energy has also been piloting its technology but struggling to scale to demonstration phase, despite the recent news that it will collaborate with TerraLithium, a subsidiary of Occidental Petroleum (Suzuki 2024).

In sum, all three DLE brines in the US—geothermal, oil field, and continental—are reaching commercial tipping points after years of testing DLE's potential capacity. The geothermal DLE plays are distinct technologically, and bridging their pathway to commercial production could require additional support mechanisms. As discussed in the fiscal policy section of this report, some of the nongeothermal DLE projects progressed toward commercial production without direct federal or subnational financing measures until the two grants from the DOE were authorized in 2024.

But overall the advancement of DLE projects in Arkansas, Nevada, and Utah is indicative of the US domestic industry's ability to innovate and drive new technologies to market, despite cumbersome market dynamics and, at best, modest fiscal support. Going forward, all three DLE plays and brine types will be important signposts in the uphill struggle of the US to reshore its once-depleted mineral production.

Canada

Canada's primary DLE project—E3's oil field brine project near Leduc, Alberta—is moving forward to the demonstration phase. E3's project will purify, concentrate, and produce battery-grade lithium carbonate as a final product (E3 2024). Its success illustrates the importance of various support measures from the federal government and local incentives from Alberta. The project could theoretically reach annual production levels of 150,000 metric tons LCE, which is nearly equivalent to the production levels of SQM in Chile's Salar de Atacama, the second-largest lithium operation globally (E3 2024; Silva 2024). Aside from the E3 project, several other DLE projects are in development in Alberta and Saskatchewan. These remain further off from demonstration phase.

Chile

Lithium producers in Chile have made limited progress on DLE demonstration or pilot projects. Both current producers, Albemarle and SQM, have committed to investing in research but have not publicly announced any concrete demonstration projects. Meanwhile, Enami has launched a tender for new lithium production technologies, and the British-based company CleanTech Lithium (CTL) has a DLE demonstration project in the Maricunga salt flat (CTL 2024).

That said, Albemarle and SQM report some progress on DLE demonstration projects. After more than a decade of research on DLE, Albemarle announced a DLE pilot project in Chile "which may enhance long-term sustainability" of their operations (Albemarle 2024). As for SQM, similarly to Albemarle, it claims that its "Salar Futuro Project" included pilot-scale development of four DLE technologies (SQM 2024). The company also reported $33 million of investment in R&D for lithium production, without disclosing how much of that amount is dedicated to DLE technologies (SQM 2024).

The SOE Enami launched a tender process in February 2024 to test lithium extraction technologies, arguing that it is "crucial to know processes with the least possible environmental impact" (Enami 2024). After that process ended in April, Enami received proposals from 30 firms, including Eramet, Rio Tinto, and Sunresin New Materials. Enami also announced that it may partner with one or more of the companies participating in the process on future lithium production projects (Enami 2024). As of December 2024, no contracts have been awarded.

CTL has a DLE pilot project with its China-based technological partner Sunresin, as well as two production plants that have the goal of producing around 40,000 metric tons of LCE by 2027 (CTL 2023). The DLE pilot project, based in Copiapó in the Atacama Region, was inaugurated in late May 2024 and, when operational, will be able to produce 1 metric ton of LCE monthly (CTL 2024). It is fed by pipeline from Laguna Verde in the Maricunga salt flat with brine of 196 milligrams per liter (mg/L) lithium concentration (Bentham 2024). The plant concentrates the brine by a factor of 3.6 to 710 mg/L, with an adsorption recovery rate of 94 percent (Bentham 2024). Then through reverse osmosis, the eluate is further concentrated to 2,194 mg/L before being shipped to North America (Bentham 2024).

Argentina

As mentioned previously, no public institution in Argentina is pursuing demonstration and pilot projects for DLE technologies, though research and development efforts for DLE technologies exist at both the federal and provincial levels, including by CONICET and CIDMEJu. In the private sector, Arcadium's Fenix project, located in the Salar del Hombre Muerto in Catamarca province, has been operational since 1997 using a combination of adsorption and evaporation technologies and is slated to be expanded. Since the project currently uses both brine and fresh water for its "Selective Adsorption process," after which the processed brine goes to an evaporative step to achieve further lithium concentration, the company aims for increased use of DLE technologies (Kosinsky and Cutler 2023). The Fenix expansion project has been facing obstacles, including a decision by the Catamarca Court of Justice that mandates a cumulative and integral EIA of lithium production and bans Catamarca's government from issuing new permits for lithium mining until the said assessment is completed (Corte de Justicia de Catamarca 2024; Sigal 2024).

In July 2024 a joint venture between the French company Eramet and the leading Chinese iron producer Tsingshan formally inaugurated the second commercial project using DLE technologies in Argentina. After five years of operating a pilot plant, the Centenario-Ratones project started commercial operations and will produce 24,000 metric tons of LCE per year when operating at full capacity (Eramet 2024b).

In addition, there are at least 15 other projects in Argentina that plan to use DLE in different phases of development (Secretariat of Mining 2024). Interestingly, as of June 2024, there is a DLE pilot project in operation owned by the oil and gas company Tecpetrol. The Olacapato plant, located in Salta province not far from the Tolillar project, was commissioned in 2022 and has a capacity of 25 metric tons of LCE per year with a 90 percent recovery rate (Tecpetrol 2024).

Bolivia

There are currently two DLE pilot projects in Bolivia, which are part of two separate agreements signed between December 2023 and January 2024. A first agreement was between YLB and Uranium One Group, a subsidiary of Russian SOE Rosatom, which does not have extensive experience with DLE. A second agreement was between YLB and the CATL-led consortium CBC, which is composed of three companies: Contemporary Amperex Technology Co., Limited (CATL), Guangdong Brunp Recycling Technology Co., Ltd. (a subsidiary of CATL), and CMOC Group Limited. The agreement has "the objective of carrying out tasks towards the development of two industrial complexes with an estimated investment of $1 billion USD" (Ramos 2023).

YLB's plans are to "test the DLE technology offered by the Chinese and Russian companies in order to guarantee positive results" and later install lithium carbonate industrial complexes (YLB 2024). Experts highlight that both DLE pilot plants are to be installed in the Uyuni salt flat with the chosen companies fully responsible for the investment and risk (von Vacano 2024b). YLB's president declared that these pilot projects, which YLB expects to last for about two years, will provide the company with detailed information on water use and environmental impacts. Some observers view the processes behind the two demonstration projects as opaque and nontransparent (Los Tiempos 2023).

China

In 2019 Qinghai launched two Provincial Science and Technology Major projects. One, called the Research of Key Technologies for Building a Lithium Industry Chain from Salt Lake Resources, was undertaken by three private companies and the Qinghai Institute of Salt Lakes Chinese Academy of Sciences (ISL) (QPPG 2019). It develops an efficient and eco-friendly process for extracting lithium chloride from the salt lakes and studies the impact of impurities on the electrolysis of salt lake lithium chloride (MOST 2019). In December 2023 the project successfully established production lines for 10,000 metric tons of lithium chloride and 1,000 metric tons of lithium metal using molten salt electrolysis (QHKJT 2023).

A second project, called the Research and Demonstration of High Quality Lithium Carbonate Production Processing Deep Brine, is led by a research group within ISL, with total funding of 28 million RMB (roughly $4 million USD). This project built two 10,000-metric-ton, battery-grade lithium carbonate demonstration production lines at Tsarhan and Yiriping Salt Lake (ISL 2023). Both these projects are now in demo-commercial scale production.

Europe

While Europe has few DLE projects, those that exist are generally at a slightly earlier stage of maturity as their American and Chinese counterparts. In the UK, Cornish Lithium's project is still at pilot stage, while in Germany, a pilot facility is successfully producing chloride and working toward building hydroxide conversion (Cornish Lithium n.d.; Alkousaa 2024). In France, Eramet is developing its own pilot projects in the Alsace region, but little information about the project's viability is available (Eramet 2023). All these projects garnered early-stage R&D investment from their respective government, and those in the UK and Germany received state financing at a later stage. In sum, Europe's geothermal DLE potential has not been actualized to the same extent as other DLE regions, and the projects that have been developed will need to contend with lagging direct subsidies and lower-cost products from abroad. However, the sustainable nature of these projects—that they are zero carbon and have a negligible impact on land—could open market opportunities if European policymakers continue to push for greater levels of sustainability in energy transition supply chains.

Notes

1. Another area of uncertainty, which seems to have been cleared up, related to differences between the Spanish and English versions of the texts, with the latter version being more emphatic regarding the mandate aspect.

2. Tax stability means that investments under this law "may not see their total tax burden increased...at the national, provincial and municipal levels," as defined in Article 6 of the cited Mining Activity Law.

3. The EIA is a federal legal requirement that, in principle, serves as a minimum regulatory floor. However, while mandated by the Federation in the Mining Code, the EIA has to be submitted to the provincial authority (Argentina 1886). The EIA standards and requirements are designed by the provincial government, which, if compliant, is also responsible for providing an environmental impact statement valid for two years, allowing companies to carry out their activities (Argentina 1886).

4. According to the USGS, reserves are the part of an identified resource that meets specified minimum physical and chemical criteria related to current mining and production practices and could be economically extracted or produced at the time of determination. The term "reserves" includes only recoverable materials. For more detail, see appendix C of the USGS Mineral Commodities Summary from January 2024.

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