Note: The following is a redacted version of the original report published 27 April 2023 [35 pgs].

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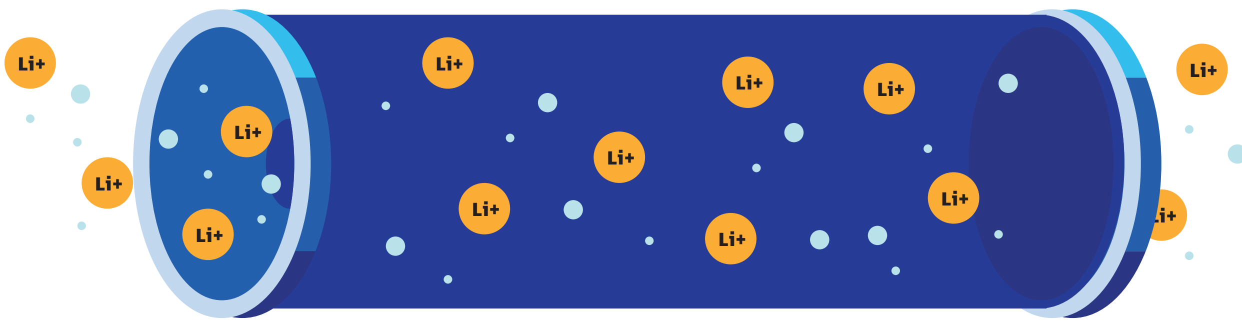

Global Metals & Mining

Direct Lithium Extraction: A potential game changing technology

The implementation of Direct Lithium Extraction (DLE) technologies has the potential to significantly increase the supply of lithium from brine projects (much like shale did for oil), nearly **doubling lithium production** on higher recoveries and improving project returns, though with the added bonus of offering ESG/sustainability benefits, while also **widening rather than steepening the lithium cost curve**. We explore the progress, economics, and implications of DLE being implemented at scale, with increasing relevance in the context of Chile's recent National Lithium Policy.

- **Potential game changing technology:** A number of proven DLE technologies are emerging and being tested at scale, with a handful of projects already in commercial construction. While there may still be challenges around scalability and water consumption/ brine reinjection, with the ongoing efforts, DLE could be implemented between 2025-2030 in both Chile and Argentina, in our view (compared with market skepticism on development by 2030). We estimate on scenarios/ benchmarking the capital intensity range of DLE is comparable with a traditional pond project, where risk of a higher upfront capital intensity is potentially offset by lower unit costs. We see NPV breakeven for a DLE project (80%+ recovery) vs. a traditional pond (~50%) at opex of <US $5,700/t (on GSe lithium prices), and look to our upcoming trip to Argentina to affirm our analysis.
- **Cost curve & supply/demand impacts:** Our analysis suggests that DLE will widen, rather than steepen, the lithium brine cost curve with an average project likely sitting in the second or third cost quartile. With resulting additional lithium supply we also see risk that **DLE implementation could extend the size and duration of lithium market surpluses/reduce deficits** vs. our base case SD balance (without a pull forward of demand with new supply), where ~20-40% of LatAm brine projects implementing DLE (recovery from ~50% to ~80%) could add ~70-140ktpa LCE from 2028+, increasing GSe global raw supply by c.8%.

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The Benefits & Economics: How DLE compares to traditional brine ponds

Direct Lithium Extraction (DLE) has the potential to significantly impact the lithium industry, with implementation on the extraction of lithium brines potentially revolutionary to production/capacity, timing, and environmental impacts/permitting.

Much like shale did for oil, DLE has the potential to significantly increase the supply of lithium from brine projects, nearly doubling lithium production/yield (taking recoveries from 40-60% to 70-90%+) and improving project returns, though with the added bonus of offering sustainability benefits and ESG credentials for its implementors (land usage from lack of ponds declines >20x, water usage and metrics improve on potential brine reinjection), while also widening (rather than steepening) the lithium cost curve.

A number of proven DLE technologies are emerging and being tested at scale, with a handful of projects already in commercial scale construction (some China projects in production). Though the application of technologies used in DLE processes may be fairly new to the lithium industry, many are already utilised across other commodities.

While there may still be key challenges around scalability, water consumption, and brine reinjection, with the ongoing efforts, DLE could be implemented between 2025-2030 in both Chile and Argentina, in our view, both as greenfield projects and brownfield expansions, or to enhance recoveries of existing pond operations. Chile's recent National Lithium Policy (NLP) also pushes for new lithium projects to implement DLE for water/environmental concerns, further supporting an accelerating implementation of DLE technologies. This compares with market skepticism around commercial development of DLE by the end of the decade (from discussions with investors).

We set out a summary of the processes for traditional brine ponds and key DLE technologies below, with a more detailed comparison of the variations in a later section.

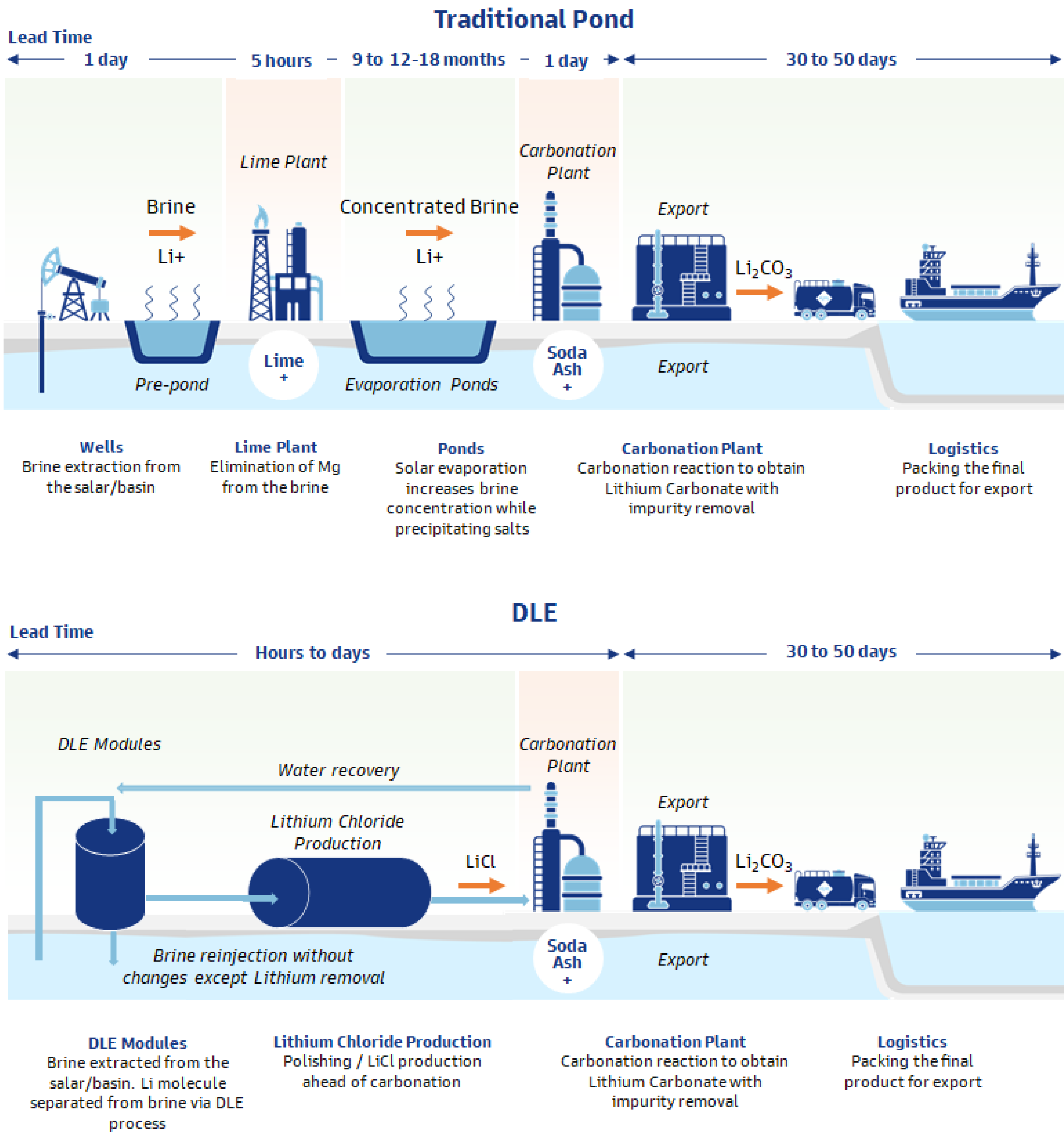
Exhibit 1: Comparison of lithium extraction methods

Lithium extraction methods	Hard Rock	Brine	
	Mining	**Evaporation**	**DLE**
Production times (extraction to production)	Weeks to months	Months to years	Hours to days
Lithium recovery rates	~60-80% (processing)	~40-60%	~70-90%+
Costs	Medium-High	Low	Low-Medium
Capex	Varied on grade/ chemical conversion	~US$23-34,000/tpa LCE	~US$26-34,000/tpa LCE
Opex		~US$3,300-4,900/t LCE	~US$2,800-3,600/t LCE
Lithium product	Spodumene (~5-6% Li_2O)	Lithium Carbonate (Li_2CO3) / Lithium Chloride (LiCl)	Lithium Carbonate (Li_2CO3) / Lithium Chloride (LiCl)
Process	Heating, cooling, crushing, and roasting	Staged atmospheric evaporation, plant processing	Adsorption (Ad), Ion Exchange (IX), Solvent Extraction (SX), Membrane
Further processing requirements	Yes	No (subject to end use)	No (subject to end use)
Land area requirement	High	High	Low
Weather dependance	Yes	Yes	No
Water consumption	High	Medium-High	Low-Medium (subject to reinjection availability)
Energy Consumption	High	Low (free solar evaporation)	Medium
Emissions	High	Low	Low

Generalised; IX often already utilised in sorption and pond processes for impurity removal; Brine capital intensity and opex based on GSe modeled scenarios outlined below.

Source: Company data, Data compiled by Goldman Sachs Global Investment Research

Exhibit 2: Traditional process of Brine Extraction vs. DLE, and timing of each stage



Indicative timings; pond based on Olaroz flowsheet

Source: Company data, Goldman Sachs Global Investment Research

DLE implementors and technology developers

Several lithium projects are utilising or in the process of selecting technologies for DLE implementation, while a number of large global OEMs and miners (who may also be interested in by product application for extraction of other elements, such as potassium) have backed or have stakes in some technology developers. We outline in the table below 27 global lithium projects that are using or plan to implement DLE, along with a further nine advancing third-party technology developers.

Company	Project	Country	DLE Project stage	DLE technology provider	Lithium extraction technology	Tech Origin	Geothermal	Resource (Mt LCE)	Start date	Capacity (ktpa LCE)
Lithium project developers/operators										
Eramet/Tsingshan	**Centenario-Ratones**	Argentina	Construction	Proprietary	Sorption	-	-	10	2024	~24+50 (P1+P2)
Livent	**Fenix (Hombre Muerto)**	Argentina	Production	Proprietary	Sorption	USA	-	12	1998	~80 (3 expansions)
RIO	**Rincon**	Argentina	Pilot	Proprietary	Sorption	-	-	12	2024	30
Lake Resources	**Kachi Project**	Argentina	Pilot	Lilac Solutions	IX	USA	-	4	2024	25
Allkem	**Olaroz enhanced recoveries**	Argentina	Study	TBD (in testing phase)	TBD	TBD	-	-	-	-
Tibet Summit Resources	**Angeles**	Argentina	Construction	SunResin	Sorption	China	-	2	2024	25 (P1)
Eon Minerals	**Amanecer**	Argentina	Pilot	Proprietary	Sorption	Argentina	-	-	-	-
Albemarle	**Atacama**	Chile	Pilot	Proprietary LiET / Third party testing	TBD	TBD	-	11	2023	-
SQM	**Atacama**	Chile	Pilot	Proprietary / Third party testing	TBD	TBD	-	68	2024	220-250
CleanTech Lithium	**Laguna Verde**	Chile	Pilot	SunResin	Sorption	China	-	2	2026	20
CleanTech Lithium	**Fransisco Basin**	Chile	Pilot	TBD (in testing phase)	TBD	TBD	-	1	-	-
Lanke Lithium	**Yiliping Lake**	China	Production	SunResin	Sorption	China	-	-	2017	20
Zangge lithium	**Chalkhan Lake**	China	Production	SunResin	Sorption	China	-	-	2018	20
Jintai Lithium	**Mahai Lake**	China	Production	SunResin	Sorption	China	-	-	2019	7
Tibet National	**Qinghai**	China	Commissioning	SunResin	Sorption	China	-	-	-	-
Yiwei Lithium	**Qinghai Salt Lake**	China	Construction	SunResin	Sorption	China	-	-	-	-
Anson Resources	**Paradox Lithium**	USA	Pilot/DFS	SunResin	Sorption	China	-	-	-	-
Compass Minerals	**Great Salt Lake**	USA	Pilot	Energy Source Minerals (ILiAD)	Sorption	USA	-	2	2025	35
Berkshire Hathaway	**Salton Sea**	USA	Pilot	Proprietary	Sorption	USA	Yes	-	-	90
Energy Source Minerals	**Salton Sea (Project ATLIS)**	USA	Pilot	Proprietary (ILiAD)	Sorption	USA	Yes	-	2024	20
Controlled Thermal Resources	**Salton Sea**	USA	Pilot	Lilac Solutions	IX	USA	Yes	-	-	25
Controlled Thermal Resources	**Hell's Kitchen**	USA	Offsite Pilot	Lilac Solutions	IX	USA	Yes	3	2024	25
Standard Lithium	**Smackover (Lanxess Project)**	USA	Demonstration	Proprietary (LiSTR)	IX	USA	-	3	-	22
American Battery Materials	**Lisbon Lithium Project**	USA	Pilot	TBD (in testing phase)	TBD	USA	-	-	-	-
E3 Metals Corp	**Clearwater**	Canada	Pilot	Proprietary	IX	Canada	-	7	2025	20
LithiumBank	**Boardwalk**	Canada	Pre-PEA	Conductive Energy	IX	Canada	-	6	-	-
Vulcan Energy	**Upper Rhine Valley**	Germany	Pilot	Proprietary (VULSORB)	Sorption	Germany	Yes	16	2024	48
Technology developers										
Summit Nanotech	-	-	Pilot/Demo	Proprietary (denaLi)	Sorption	Canada	-	-	-	-
SunResin	-	-	Commercial (growing scale)	Proprietary	Sorption	China	-	-	-	-
International Battery Metals (IBAT)	-	-	Demo/Commercial	Proprietary	Sorption	USA	-	-	-	-
Koch Technology Solutions	-	-	Lab/Pilot	Proprietary (Li-Pro)	Sorption	USA	-	-	-	-
Lilac Solutions	-	-	Demo/Commercial	Proprietary	IX	USA	-	-	-	-
Conductive Energy	-	-	Pilot/Demo	Proprietary	IX	Canada	-	-	-	-
EnergyX	-	-	-	Proprietary (LiTAS)	Membrane	USA	-	-	-	-
Geo40	-	-	Lab	Proprietary (GeoSieve)	Membrane	NZ	Yes	-	-	-
Solvay	-	-	Pilot	Proprietary (CYANEX 936P)	SX	Belgium	-	-	-	-

List not exhaustive; Technology developers listed separately where not developing own resource; Geothermal category for project/tech that is specifically geothermal - technologies may be applicable across resource types; Quoted resource/start date may apply to whole project rather than planned expansion.

Source: Company data, Data compiled by Goldman Sachs Global Investment Research

Scenario economics and real world asset benchmarking

While we believe there is increasing awareness of the technological implications of DLE around increased recoveries/production and accelerated ramp-up of projects, the economics of its implementation, along with the implementation of the various technologies in other mineral commodity extraction, remain underappreciated, in our view.

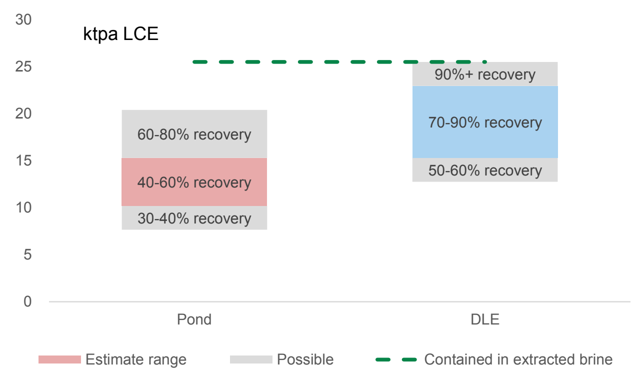
In this context, we provide a desktop indicative analysis of the possible economics of a DLE project vs. a traditional brine pond under a range of scenarios, informed by existing projects and our sense checks with industry participants, along with a comparison to announced projects.

These scenarios assume a hypothetical brine resource is extracted at the same grade and volume at ~25ktpa contained LCE over a 20-yr production life to produce and sell the same quality of lithium carbonate product, both as a DLE (which ramps up 18mths faster vs. traditional ponds though with higher nominal capex/opex) and a traditional evaporation pond project.

We expect a DLE project achieves recoveries of ~70-90% producing ~18-23ktpa LCE (though model a wider 50-100% range covering up and downside risk), while a traditional brine pond achieves recoveries of ~40-60% producing ~10-15ktpa LCE (again modeling a wider 30-80% range to capture upside risk of improving recoveries of newer pond projects). We expect plant and processing infrastructure drive a higher upfront capex for a DLE project, which more than offsets the lack of traditional pond infrastructure.

Exhibit 4: DLE can increase lithium recoveries to 70-90%, from 40-60% for traditional ponds

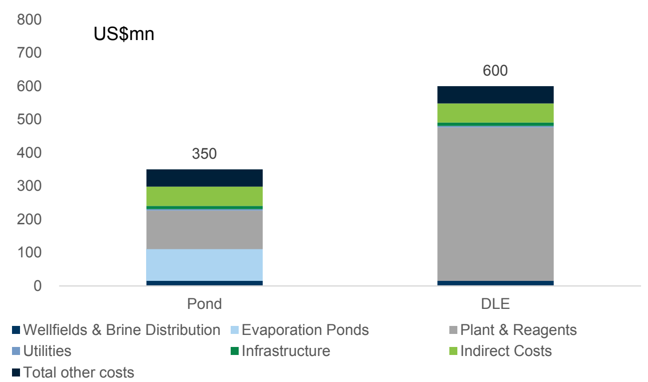
Annual lithium carbonate production (ktpa LCE) on modeled scenario lithium recoveries



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 5: Plant and processing infrastructure are likely the bulk of higher DLE capex

Pond vs. DLE project indicative capex split for mid-point of scenario modeling (US$mn)



SdV Stage 1 & 2 technical study (2022) split for pond capex, apportioned to mid-point of capex scenario estimates; DLE plant capex taken as balancing item of capital items (as no pond capex) for illustrative purposes.

Source: Company data, Goldman Sachs Global Investment Research

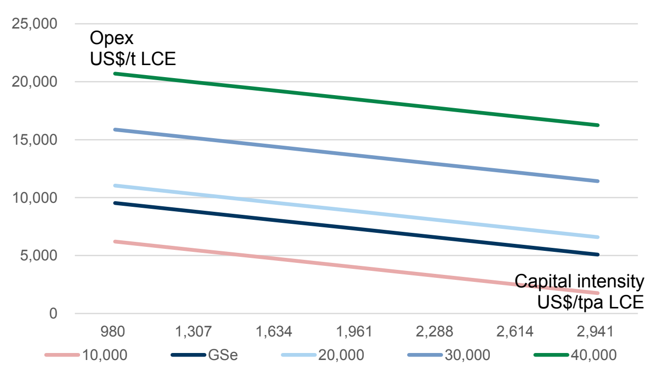
Though there remains a range of outcomes subject to capital and opex requirements of a DLE project, ultimately the improvement in the achieved lithium recovery and resulting increase in annual production is the key driver of economic outcomes, in our view, supporting the implementation of DLE over traditional brine ponds. Therefore our scenarios predominantly test input assumptions (capex/opex/price etc) against achieved recovery.

The charts below outline the required lithium price of a mid-range DLE project (80% recovery/~20ktpa LCE) vs. pond the recovery range (40-60%/~10-15ktpa LCE). We see **NPV breakeven for a DLE project with a mid-point 80% recovery vs. a traditional pond with a bottom end 40% recovery on our mid case capex estimates (capital intensity ~US$30,000/tpa LCE), and GSe lithium pricing, requiring an opex unit cost of <US$7,500/t**. When compared with a **pond at the top end of the recovery range at 60%, this opex unit cost requirement for break even would fall to <US$4,000/t** (though we expect most pond-only projects are unlikely to consistently achieve overall lithium recoveries as high as 60%). **Compared to a mid-point 50% recovery pond, the breakeven opex unit cost would be <US$5,700/t.**

We note these economic outcomes only reflect the 18 month faster production ramp up, and don't consider any possible benefits from product grade variation, or lower land usage and water loss that may accelerate environmental permitting and hence the project timeline of new projects (also benefiting NPV). The application of the technology for selective removal of by-products (such as potassium) into their own saleable products may also improve the economics of DLE projects.

Exhibit 6: DLE project (80% recovery) NPV breakeven vs. pond project (40% recovery) at varying lithium prices

Opex unit cost (US$/t LCE; FOB, pre-royalty) vs. capital intensity (US$/tpa LCE)

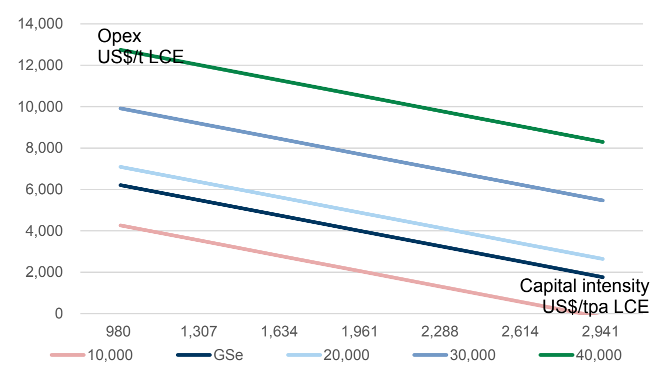


DLE capex range US$300-900mn in US$100mn increments for resulting capital intensity on an 80% recovery DLE project (~20ktpa LCE) vs. a pond project at 40% recovery (~10ktpa LCE).

Source: Goldman Sachs Global Investment Research

Exhibit 7: DLE project (80% recovery) NPV breakeven vs. pond project (60% recovery) at varying lithium prices

Opex unit cost (US$/t LCE; FOB, pre-royalty) vs. capital intensity (US$/tpa LCE)

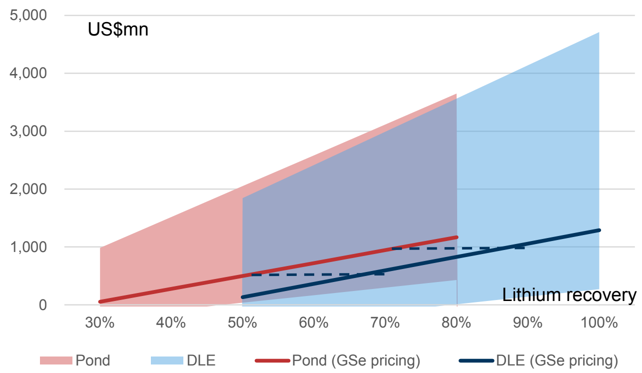


DLE capex range US$300-900mn in US$100mn increments for resulting capital intensity on an 80% recovery DLE project (~20ktpa LCE) vs. a pond project at 60% recovery (~15ktpa LCE).

Source: Goldman Sachs Global Investment Research

At our mid-case scenarios outlined above, and on GSe lithium prices, we model a **NPV range for a DLE project of ~US$0.6-1.1bn on a 70-90% recovery range for an IRR of c. 20-30%, while a traditional brine pond has a NPV of US$0.3-0.7bn on a 40-60% recovery range for an IRR of c. 20-25%**. Put another way, a DLE project with bottom end recovery (70%) achieves a higher NPV than a mid-upper end recovery (50-60%) pond project.

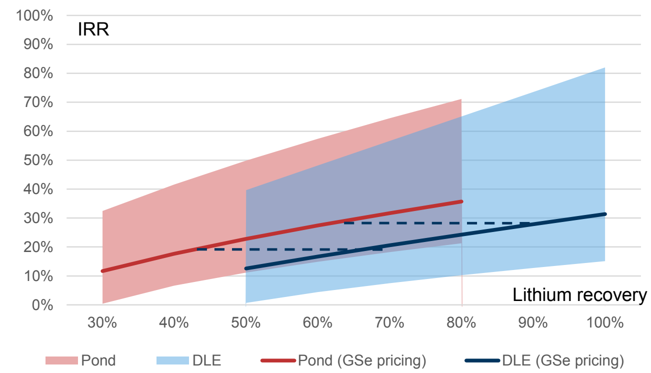
Exhibit 8: Pond vs. DLE project NPV on production recovery at price scenarios
NPV (US$mn) vs. production recovery (%)



Pricing scenarios US$10,000-40,000/t carbonate, with GSe pricing scenario shown as line. Dotted lines equate base DLE recovery range at 70-90% to pond scenarios.

Source: Company data, Goldman Sachs Global Investment Research

Exhibit 9: Pond vs. DLE project IRR on production recovery at price scenarios
IRR (%) vs. production recovery (%)



Pricing scenarios US$10,000-40,000/t carbonate, with GSe pricing scenario shown as line. Dotted lines equate base DLE recovery range at 70-90% to pond scenarios.

Source: Company data, Goldman Sachs Global Investment Research

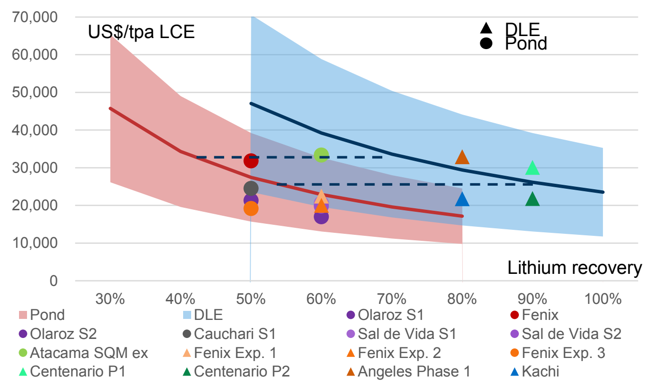
As outlined in the charts below, we estimate **the capital intensity range of DLE is comparable with a traditional pond project after adjusting for higher recoveries**, with **a capital intensity range of DLE at ~US$26-34,000/tpa LCE at a 70-90% recovery rate** on upfront capex of US$600mn (mid-point of US$300-900mn estimate range), and a **traditional pond range of ~US$23-34,000/tpa LCE at a lower 40-60% recovery range** on upfront capex of US$350mn (US$200-500mn estimated range). DLE at commercial production levels may also be more incrementally/rapidly scalable without the need for new brine ponds.

However, **we expect the risk of a higher upfront capital intensity of DLE vs. evaporation ponds is offset by lower unit costs resulting from higher production on improved lithium recovery**. We estimate an **opex unit cost (FOB, pre-royalty) range of DLE at ~US$2,800-3,600/t LCE at an 70-90% recovery rate** on annual opex of US$65mn (mid-point of US$35-95mn estimate range), compared with a **traditional pond range of ~US$3,300-4,900/t at a lower 40-60% recovery range** on opex of US$50mn (US$20-80mn estimated range for ponds at this scale). These ranges will likely be subject to the grade of the resource and the availability & cost of reagents, though we note the possibility of more unique regagents/eluents being used in DLE may also reduce opex variability (less used by other markets/accessibility to site of acids vs. soda ash), while we note traditional pond unit costs may reduce more at scale (though with increased permitting challenges for the ponds/land required). We further highlight that, like with most new technologies, the capex and opex intensity may improve as DLE technology and implementation advances beyond the first wave of implementation.

As a sense check of our hypothetical resource modeling, in the range charts below we also benchmark a selection of existing real world green and brownfield lithium brine projects on both capital & opex intensity. In this context we highlight that Eramet's Centenario-Ratones project is a commercial scale DLE (sorbent) project with Phase 1 already in construction (~24ktpa LCE commissioning targeted 1Q24 and full ramp up mid-2025) following on site pilot testing since 2019, with FID on a Phase 2 targeted by year-end 2023 (additional ~50ktpa LCE). Livent's Fenix Expansions 1 & 2 are both utilising their DLE technology, while Expansion 3 uses convential brine ponds to utilise the already existing pond infrastructure from earlier stages to achieve a lower capital intensity on spent capital (rather than implying their DLE technology has been less effective than planned).

Exhibit 10: Pond vs. DLE project capital intensity vs. production recovery at varied capex scenarios

Capital intensity (US$/tpa LCE capacity; FOB, pre-royalty) vs. production recovery (%)

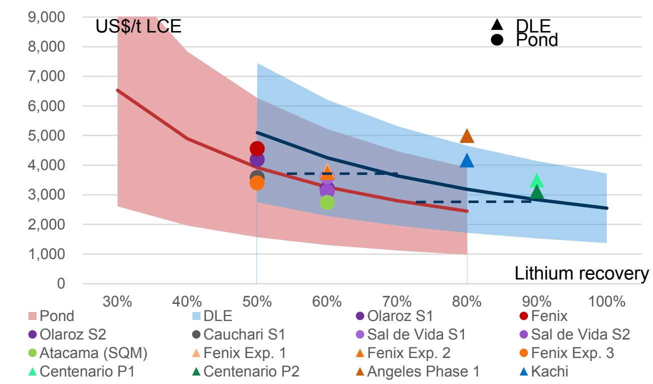


Capex/opex ranges on GSe modeled outcomes as described above (with shorter DLE build time/ramp up), and assumes an Argentinian fiscal regime on a constant FX rate; Capex excludes VAT as may be partially reimbursed, consistent with company estimates; Recoveries rounded to nearest 10% and are resource recovery (project technical studies may quote plant recovery); Centenario Phase 1 (~24ktpa) based on Eramet Mar-23 release and includes supporting infrastructure not replicated in Phase 2 (~50ktpa) or other included comparable brownfield projects, Phase 2 GSe on recent industry inflation; Fenix expansions (1: 20ktpa; 2: 30ktpa; 3: up to 30ktpa) based on Livent Feb-23 presentation (mid-point where ranges given), with Exp. 3 capex/recovery a GSe on repurposed pond infrastructure; Angeles (SunResin tech) estimated on PLASA parent co, Tibet Summit's funding partner, Honbridge Holdings' reported (Apr-23) capex of ~US$700mn combined with ~US$100mn spend on Phase 1 (~25ktpa) DLE equipment from SunResin, with recovery taken at mid-range of our DLE estimates of 80% (though early work has been reported at >90%); Olaroz S1 (17.5ktpa) reported 2014 completion capex (intensity of ~US$13,000/tpa) inflated to comparable real $; Fenix initial project recovery/capex estimated and inflated to comparable real $; Cauchari-Olaroz capital intensity Stage 1 (~40ktpa) as of Mar-23, with planning for Stage 2 expansion (at least 20ktpa) continuing to progress to align with completion of Stage 1; Atacama (SQM) feeding Antofagasta Carmen 2024 plant capacity extension on Mar-23 capex (30ktpa); SQM/ALB DLE projects not shown pending cost updates; Olaroz Stage 2 (25ktpa) and Sal de Vida Stage 1 & 2 (15ktpa & 30ktpa) costs based on Allkem 2022 technical reports; Kachi (Lilac tech) estimates based on Lake's 2021 FS at (25ktpa), though updated DFS due mid-2023 (~50ktpa) following pilot/demo completion. Dotted lines equate base DLE recovery range at 70-90% to pond scenarios.

Source: Company data, Goldman Sachs Global Investment Research

Exhibit 11: Pond vs. DLE project unit cost vs. production recovery at varied opex scenarios

Opex unit cost (US$/t LCE; FOB, pre-royalty) vs. production recovery (%)



Production/recovery numbers as per previous Exhibit notes unless noted; SQM shown on 2022 costs and estimated recovery; Angeles quoted costs from partner may not be like for like; Centenario Phase 2 unit costs esimtated on assumption ~40% Phase 1 costs are fixed, which increase 1.5x on Phase 2, while variable costs increase proportionally to volume; Growth projects are life of mine (LOM) real unit costs, while operating assets are 2022 reported unit costs; Fenix taken at Woodmac unit cost estimate for 2022, and first year of full production for expansions; Cauchari-Olaroz operating costs on Oct-20 DFS. Dotted lines equate base DLE recovery range at 70-90% to pond scenarios.

Source: Company data, Goldman Sachs Global Investment Research

The Supply/Demand Implications: New DLE supply from 2025+

Much like shale did for oil, Direct Lithium Extraction (DLE) has the potential to significantly increase the supply of lithium from brine projects - although unlike shale, which typically sits toward the top of the oil cost curve, the cost analysis set out above suggests that **DLE will widen, rather than steepen, the lithium brine cost curve with an average project likely sitting in the second or third cost quartile.**

DLE in contrast to shale also offers lower perceived environmental risk and significant environmental benefits vs. traditional brine ponds, nearly doubling lithium production/yield (taking recoveries from 40-60% to 70-90%+) and improving project returns, offering sustainability benefits and ESG credentials for its implementors (land usage from lack of ponds declines >20x, water usage and metrics improve on potential brine reinjection), while also widening (rather than steepening) the lithium cost curve. These benefits may also support improved timelines for community and permitting approval, while enhanced production on higher recoveries could also improve/bring forward government take from projects.

While the impact of DLE on market dynamics will be linked to the pace and scale at which it is adopted, as we highlight (Exhibit 3), there are a significant number of resources business and technology providers that have been incentivised to find technological improvements to lithium resource extraction as a result of record lithium prices that are well above the marginal cost of existing and proposed lithium supply (and thus more than offset the upfront R&D costs). Policy changes, such as Chile's recent NLP, may further support an accelerating implementation of DLE technologies.

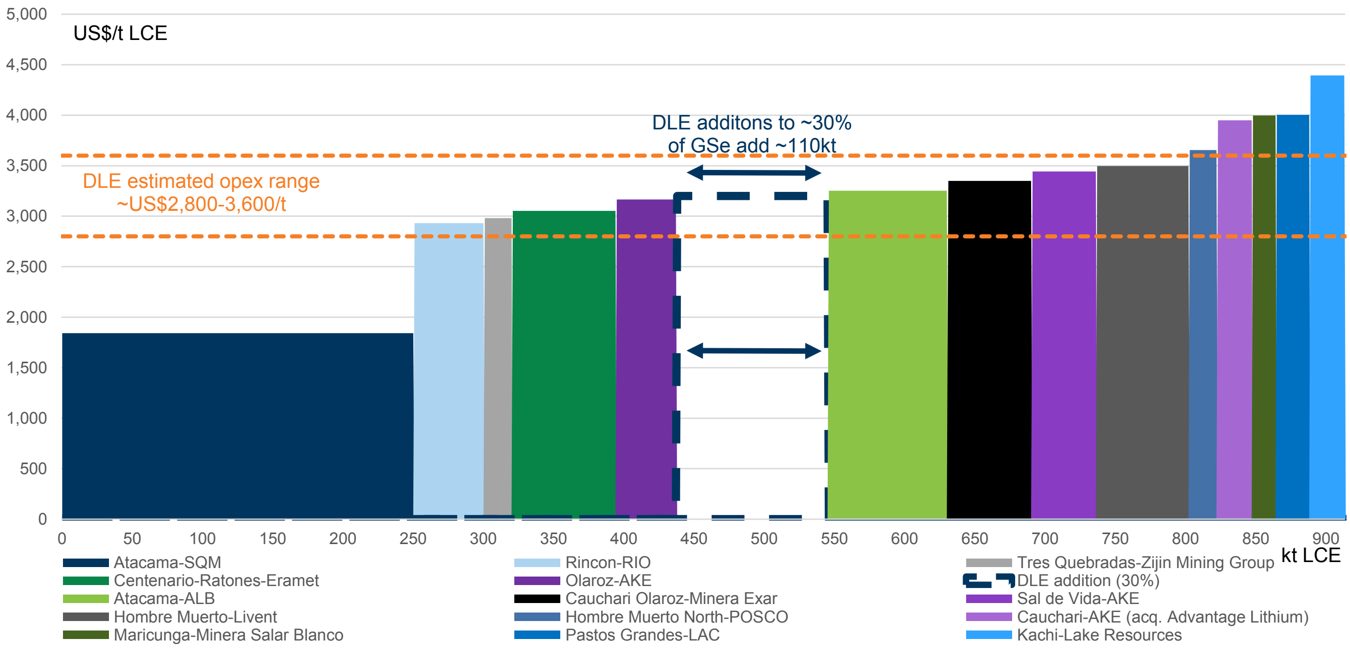
DLE offers a potential game changing technology for lithium supply, and while there may still be key challenges around scalability and water consumption, with the ongoing efforts, DLE could be implemented between 2025-2030 in both Chile and Argentina, in our view. This compares with market skepticism (based on discussions with investors) around commercial development of DLE technology by the end of the decade.

Following on from the project economic analysis above, **we set out below an indicative impact to both the LatAm lithium brine cost curve vs. industry estimates, and lithium market supply/demand dynamics vs. the GSe base case**. While implementation at this scale may be unlikely on a five-year view, and is not included in our supply/demand base case, the analysis gives an indicative guide as to the potential cost curve and supply/demand impacts of the implementation of DLE.

Cost curve

Our cost analysis above suggests that DLE will widen, rather than steepen, the LatAm lithium brine cost curve with an average project likely sitting in the second/third cost quartile, with an estimated opex range of US$2,800-3,600/t. The chart below sets out the potential DLE impact to a five-year forward (2028) LatAm lithium brine industry cost curve (Woodmac), under an indicative only scenario if ~30% of LatAm lithium brine projects (GSe) implemented DLE in some form and took average extracted brine lithium recoveries from ~50% to 80% (mid-point DLE scenario recovery range), with an ~18 month timing benefit on faster ramp up than traditional ponds. We highlight this level of accelerated ramp up of DLE-linked projects in five years is unlikely, in our view, with the curve only illustrating the potential cost curve impact from DLE implementation.

Exhibit 12: We estimate that DLE implementation will widen, rather than steepen, the lithium brine cost curve
2028 LatAm lithium brine cost curve with impact of DLE additions (US$/t LCE FOB; pre-royalty)

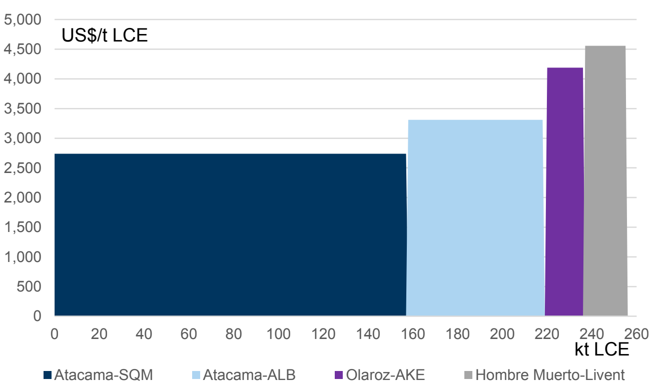


All volume and costs estimates are Woodmac (may differ vs. GSe supply forecasts) and don't include small scale projects proposed or already in production, Centenario Phase 2 added at WM Phase 1 costs; DLE indicative ranges on GSe. Indicative scenario if 30% of LatAm projects (GSe) implemented DLE in some form and took recoveries from an average 50% extracted brine lithium recovery to 80% recovery (mid-point DLE scenario recovery range), with an ~18 month timing benefit on faster ramp up than traditional ponds.

Source: Woodmac, Goldman Sachs Global Investment Research

The charts beneath show the 2022 and industry 2028 cost curves.

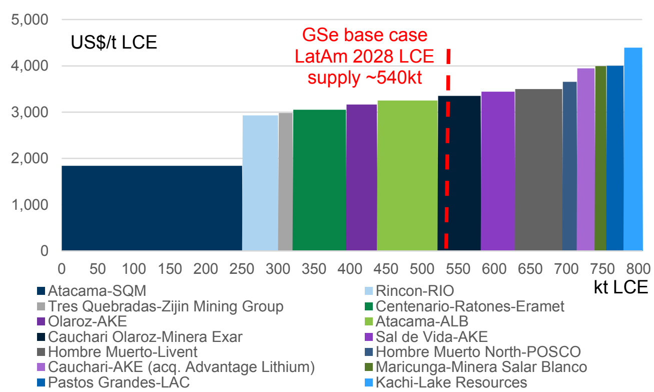
Exhibit 13: While only a handful of projects produced in 2022...
2022 LatAm lithium brine cost curve (US$/t LCE FOB; pre-royalty)



Indicative; Combination of reported 2022 volumes and costs (approximated from accounts where not specified)

Source: Company data, Goldman Sachs Global Investment Research

Exhibit 14: ...several projects of scale will be in production by 2028
2028 LatAm lithium brine cost curve (US$/t LCE FOB; pre-royalty)



All volume and costs estimates are Woodmac (may differ vs. GSe supply forecasts) and don't include small scale projects proposed or already in production, Centenario Phase 2 added at WM Phase 1 costs

Source: Woodmac, Data compiled by Goldman Sachs Global Investment Research

Supply/demand

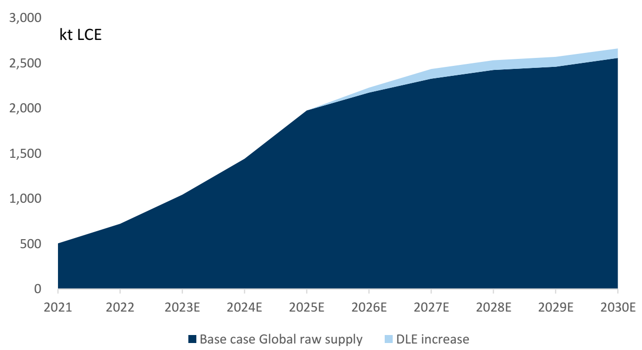
Globally brine makes up nearly two thirds of lithium resources, though only c.40% of production (2022), where production from the Lithium Triangle (Bolivia, Chile, Argentina) has lagged that from spodumene sources like Australia. While our base case lithium supply forecast has this share of production continuing to decline, the implementation of DLE may increase brine's share of output, where new brine projects or those with expansions planned are likely able to implement components of DLE technology, which could also bring project ramp ups forward ~18 months. Policy changes, such as Chile's recent National Lithium Policy (NLP), may further support an accelerating implementation of DLE technologies.

The DLE impact to supply/demand, simplistically, if ~20-40% of our base case LatAm brine projects implemented DLE in some form, increasing their recoveries from ~50% to ~80% (mid-points of above project economic analysis) and accelerating supply by ~18 months, this could add ~70-140ktpa of LCE from 2028+ (GSe LatAm brine supply ~540kt; Woodmac ~800kt), which on GSe supply numbers would increase LatAm brine supply c.35% (average 2026-2030E) and our global raw supply by c.8%.

These impacts are in addition to Eramet's Centenario Phase 1 (ramped up by 2025), and Livent's proposed expansions at Fenix, where we note this excludes the impact of newly economic projects that work with DLE, any DLE supply linked to brine projects in China, or DLE implementation on European/North American geothermal brines, where all may increase the lithium supply impact of DLE.

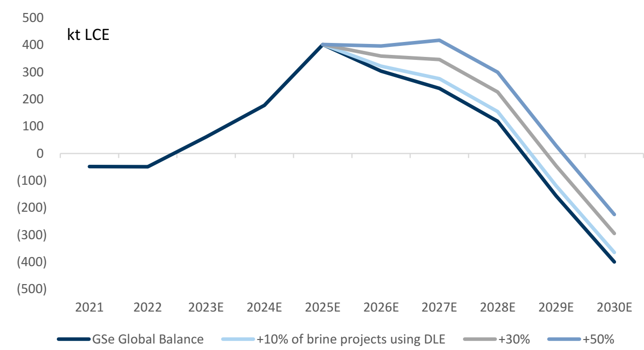
Put another way, **DLE implementation could extend the size and duration of lithium market surpluses/reduce deficits vs. our base case** (without a pull forward of demand with new supply).

Exhibit 15: GSe base case Global raw lithium supply with the addition of 30% of LatAm brine projects adopting DLE
Global lithium raw supply (kt LCE)



Source: Goldman Sachs Global Investment Research

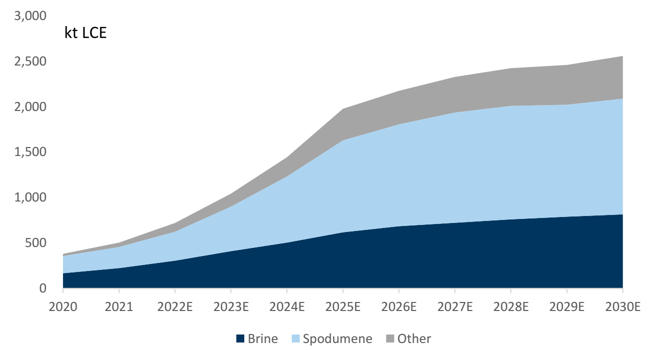
Exhibit 16: Global lithium balance under DLE scenarios
Global lithium supply surplus/(deficit) (kt LCE)



SD balance reflects recently updated demand estimates

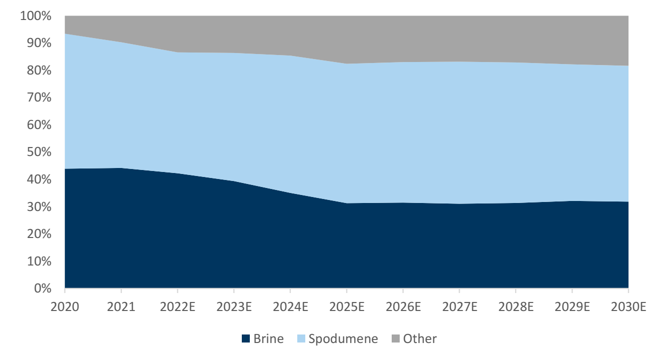
Source: Goldman Sachs Global Investment Research

Exhibit 17: Brine makes up only c.40% of global lithium supply (2022) though nearly two thirds of global lithium resources...
Global lithium supply composition (kt LCE)



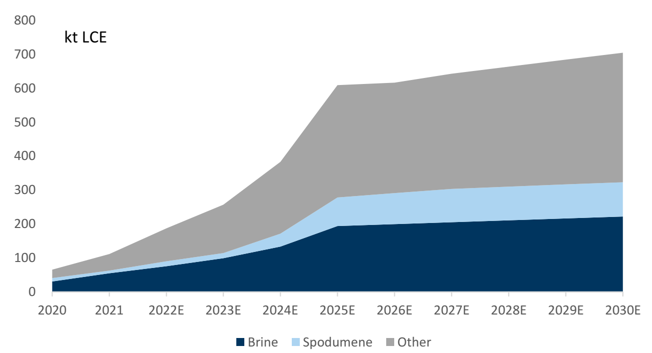
Source: Goldman Sachs Global Investment Research

Exhibit 18: ...where implementation of DLE may increase brine's share of output
Global lithium supply composition (%)



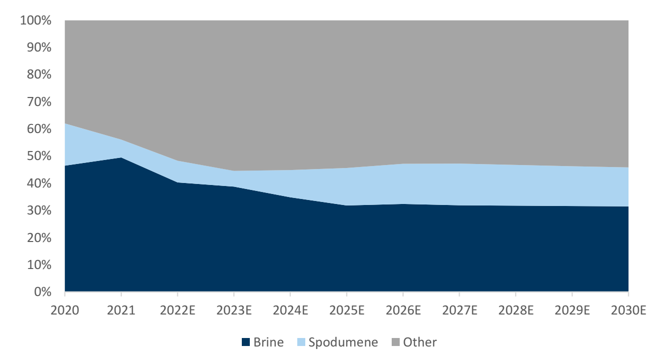
Source: Goldman Sachs Global Investment Research

Exhibit 19: With brine a significant portion of China supply...
China lithium supply composition (kt LCE)



Source: Goldman Sachs Global Investment Research

Exhibit 20: ...supprting development/implementation of SunResin and other DLE technologies
China lithium supply composition (%)



Source: Goldman Sachs Global Investment Research

Chile's National Lithium Policy

Chile's recently announced National Lithium Policy (NLP) outlines the plans for the future implementation of lithium exploration and exploitation policies that are intended to bring Chile back to the forefront of global lithium production, with the new policy being the result of a consultation process with a wide variety of stakeholders nationally and internationally (including project operators/developers). It has also taken into consideration the objectives of the Chilean State, including its role to participate in the efficient and rapid development of the lithium industry, where the government has outlined Codelco as the vehicle for project partnerships.

As recently commented by Lithium Power International, in their view the new policy does not constitute a nationalisation of the lithium industry in Chile, rather its objective, as clarified by the Mining Minister, is to set the conditions and parameters for the country to have a more active involvement and higher financial returns in a strategic industry, particularly where those lithium resources are located on concessions already owned by the Chilean State on the Atacama Salar (Chilean output is currently restricted to SQM and Albemarle from Atacama, with their contracts expiring in 2030 and 2043 respectively). Essentially the policy sets to move toward a more public-private model, with the government expecting to start conversations with operators this half and hosting talks with local and Indigenous communities in the Atacama salt flat early on in the process.

The NLP also seeks to accelerate the development of new projects in the country, with a push for new projects to implement DLE for water/environmental concerns (SQM has already committed to cutting its brine extraction in half over the course of a decade via its DLE implementation and expansions), further supporting an accelerating implementation of DLE technologies.

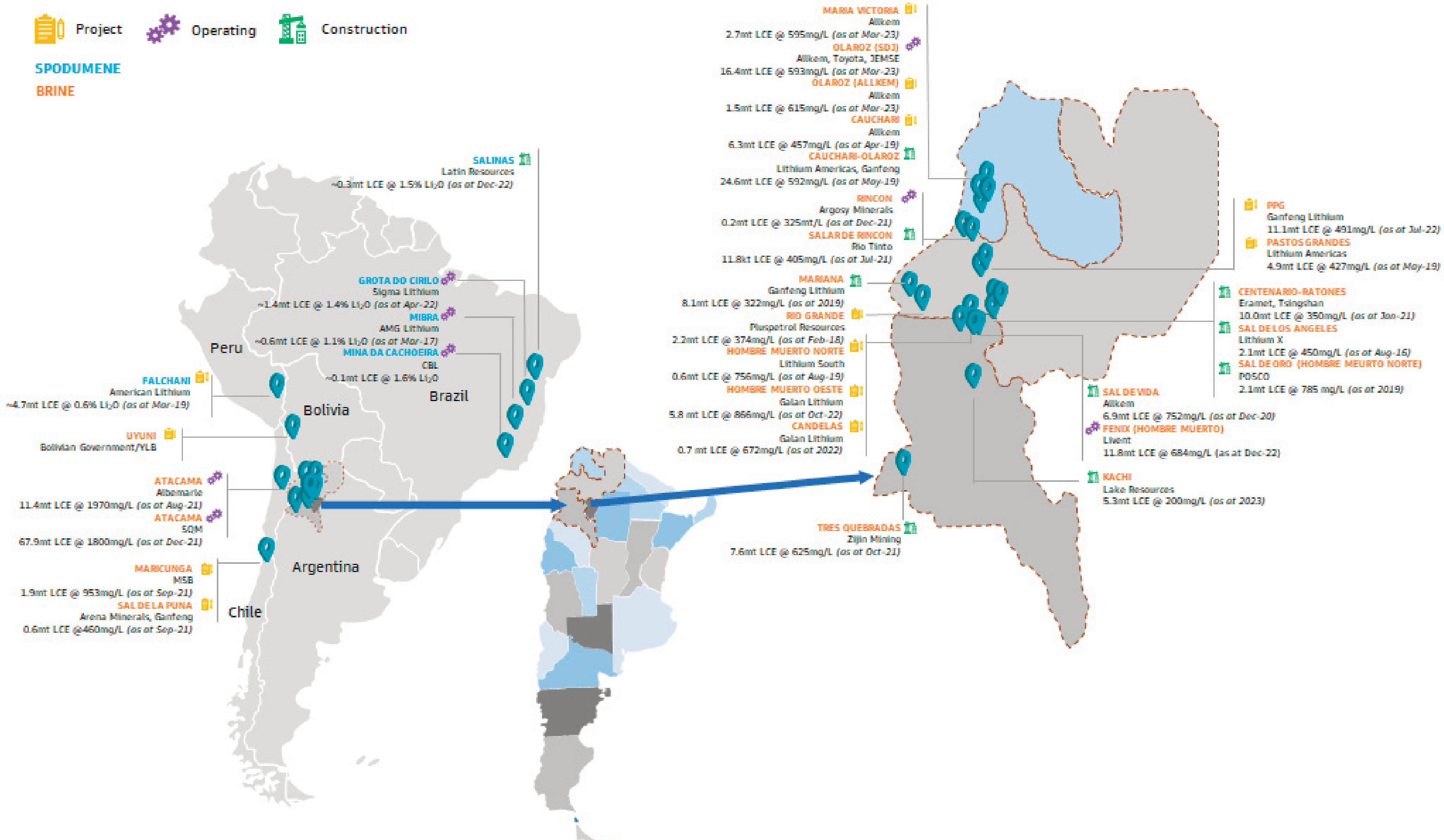
evaporator would remove water and the fertilizer potassium chloride, yielding a concentrated lithium brine. The DLE plant would use water from the mechanical evaporator to strip lithium from the concentrated brine, and the spent brine would be reinjected. SQM doesn't expect to submit an environmental assessment of its project to Chilean regulators until the second half of 2024.

- **Other early stage LatAm brine projects** that are either in ramp up or with growing resources bases (i.e. Salar de Rincon (Argosy), Hombre Muerto West (Galan), etc) may also stand to benefit from the possible implementation of a successful technology, with enough third party providers emerging to avoid the need for lengthy development processes with quicker implementation.
- **DLE projects in China:** A number of China projects already utilise DLE in some form (where SunResin technology is being implemented across Qinghai and Tibet projects).
- **Geothermal projects in Europe and North America** are also looking to implement DLE (Upper Rhine Valley (Vulcan Energy), Clearwater (E3 Metals), Salton Sea (various), amongst others), though with generally lower lithium concentrations and the possibility of geothermal power offering different project economics to those described above.

- **Technology developers:** Third party technology providers that are increasingly advanced and moving to demo and potentially commercial scale projects over the coming years (particularly those that have successfully tested multiple brine sources) will likely also be well positioned (including Summit Nanotech, Lilac, IBAT, SunResin, and others (Exhibit 3)) potentially unlocking future technology licensing revenue streams, or the ability to acquire and develop their own resource. The environmental push to reinject brine and use DLE may also create a push for more advanced geophysical models, which could also support the work pipeline of services companies.

LatAm lithium resources

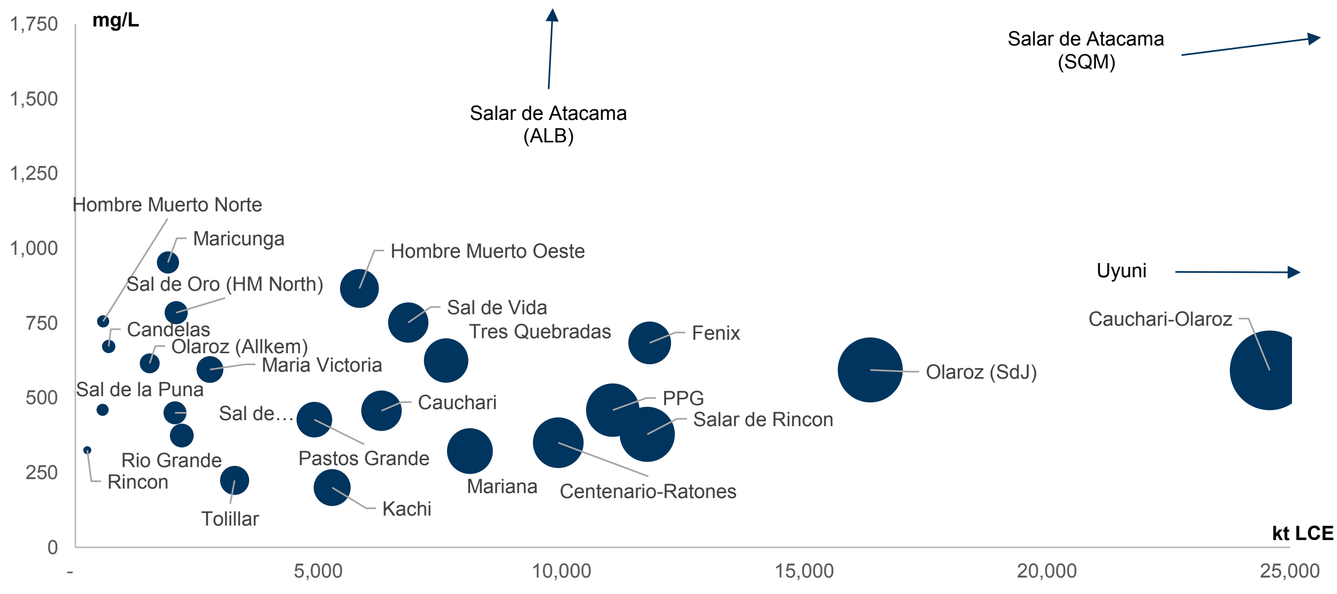
Exhibit 21: LatAm lithium projects



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 22: LatAm lithium brine resources

Lithium concentration (mg/L) vs. contained LCE (kt); bubble size of contained lithium resource

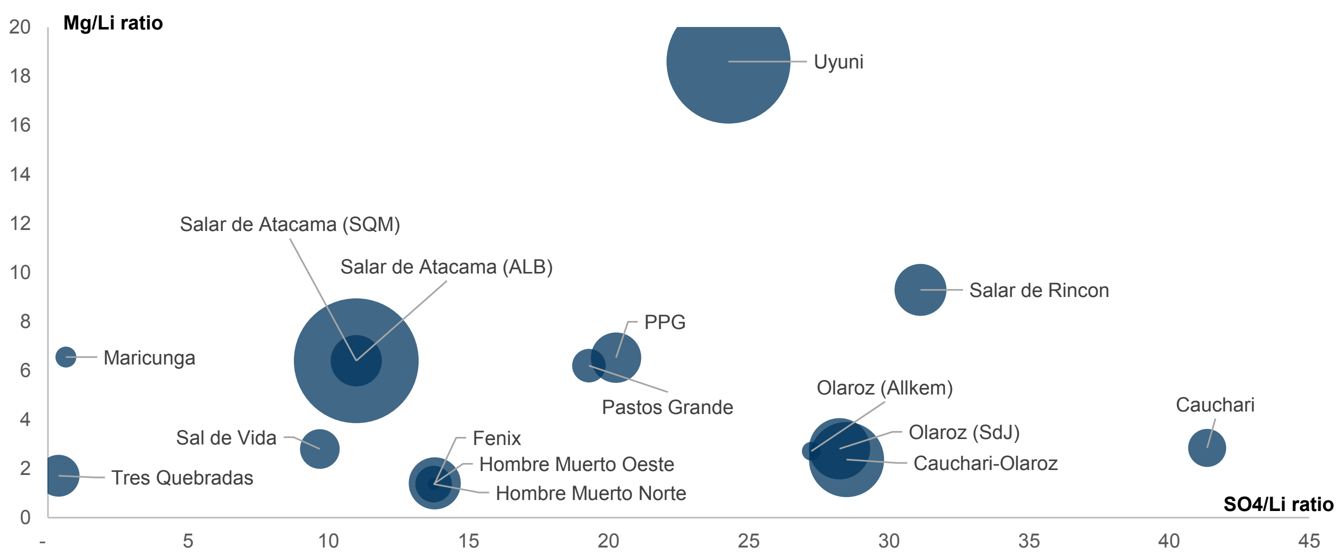


Source: Company data, Data compiled by Goldman Sachs Global Investment Research

As impurity ratios will impact the ultimate recovery of projects, including in DLE implementation, we outline the impurity ratios of key projects vs. lithium concentration and resource size in the chart below, where typically in a traditional brine pond high impurities are more expensive to process.

Exhibit 23: LatAm lithium brine impurity ratios

Magnesium ratio (Mg/Li) vs. SO4 ratio (SO4/Li); bubble size of contained lithium resource



Missing pieces of impurity data have been approximated where possible on neighbouring projects sharing a salar

Source: Company data, Data compiled by Goldman Sachs Global Investment Research

The Technology: DLE vs. traditional brine evaporation

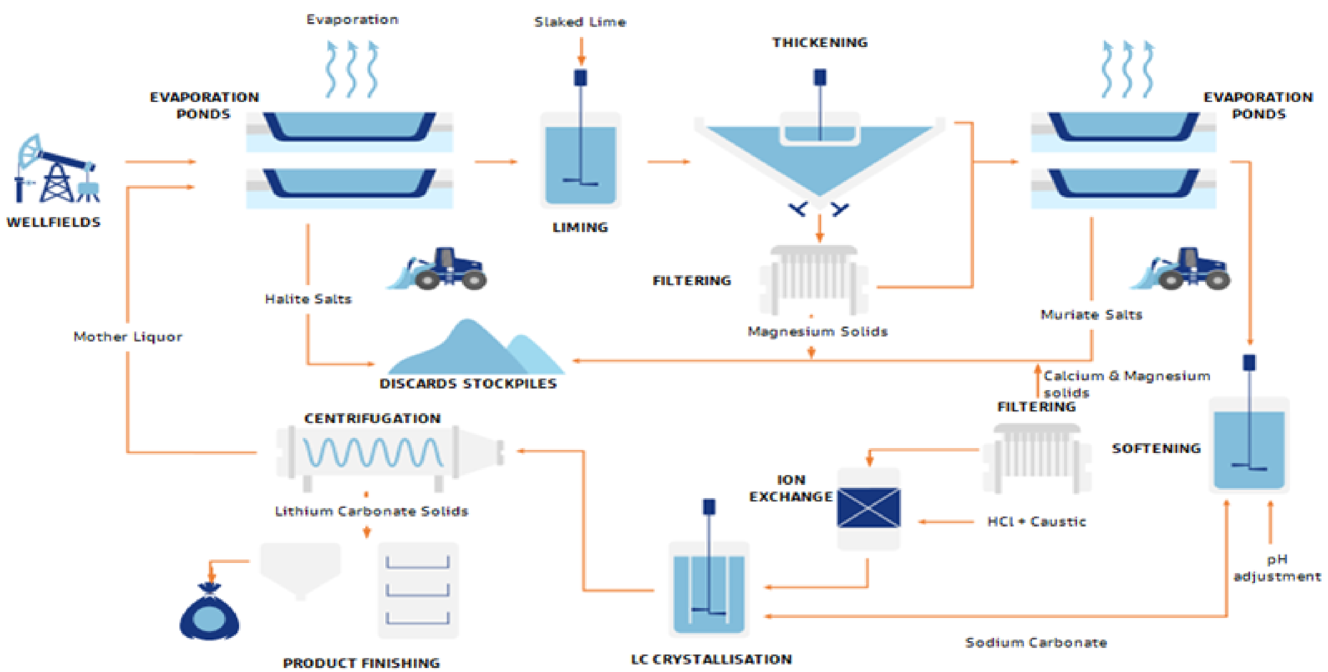
Traditional brine pond lithium extraction

With the lithium brine pumped to surface, it is distributed to evaporation ponds where the brine remains for 9 to 12-18 months (depending on the project/weather conditions) until most of the liquid water content has been removed through solar evaporation. Salar brines are very concentrated and contain a range of other salts. Facilities usually operate several large evaporation ponds of various ages and may extract other metals (e.g. potassium) from younger ponds while waiting for the lithium content to reach a concentration optimal for further processing. In some cases, reverse osmosis is used to concentrate the lithium brine to speed up the evaporation process. Once the brine in an evaporation pond has reached an ideal lithium concentration, the brine is pumped to a lithium recovery facility for extraction using a series of treatments and processing.

Pros: (i) Conventional/established technology potentially offers lower risk deployment, (ii) Lower energy consumption (free solar evaporation can raise lithium concentration in brine from ~0.2% to ~6%), (iii) smaller variety of chemicals used in reagents.

Cons: (i) Environmental concerns (diversion of sometimes limited water can impact on the surrounding area and communities, waste build up from impurities at each pond/ plant stage can't be reinjected), (ii) Slow time to market (likely longer build time and lengthy evaporation process), (iii) Only relevant in certain regions of the world, where deposits and right weather conditions exist, (iv) As lithium has a very low concentration in brine, a larger volume is often required to achieve high production values.

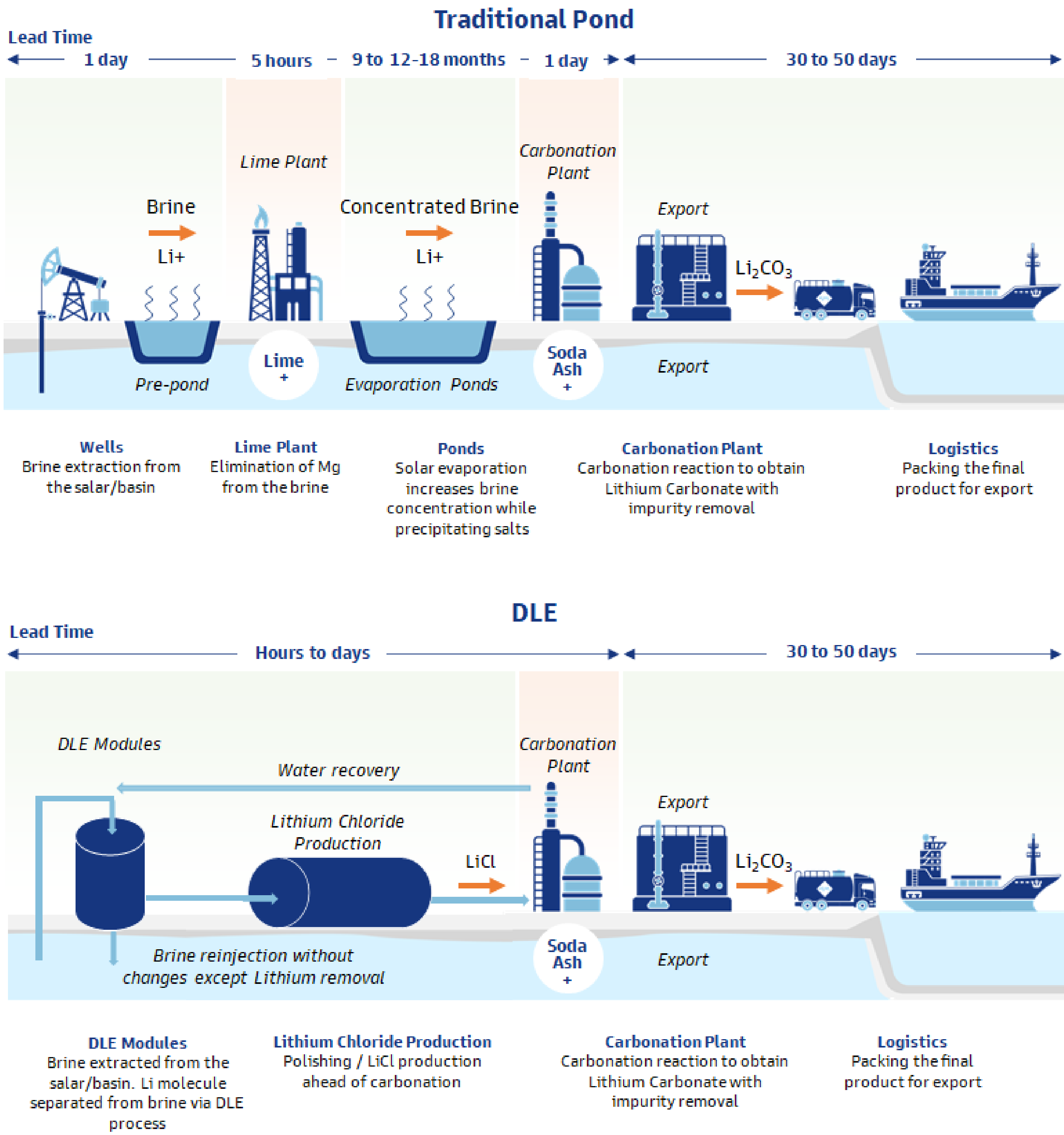
Exhibit 24: Traditional brine pond flowsheet



Indicative pond process flowsheet based on Sal de Vida flowsheet

Source: Company data, Goldman Sachs Global Investment Research

Exhibit 25: Traditional process of Brine Extraction vs. DLE, and timing of each stage



Indicative timings; pond based on Olaroz flowsheet

Source: Company data, Goldman Sachs Global Investment Research

Direct Lithium Extraction (DLE) technologies

DLE technologies precipitate lithium out of brine using filters, membranes, ceramic beads, or other equipment, which is often housed in a small warehouse, significantly shrinking the environmental footprint of evaporation ponds used to produce commercial quantities of lithium traditionally. In a DLE operation, brine is pumped to a processing unit where an adsorption, resin or membrane material is used to extract only the lithium from the brine, while spent brine can be reinjected into the basin aquifers. The more rapid production time frame and possible brine reinjection into the aquifer is a key environmental differentiator between the DLE process and traditional lithium process that uses evaporation ponds.

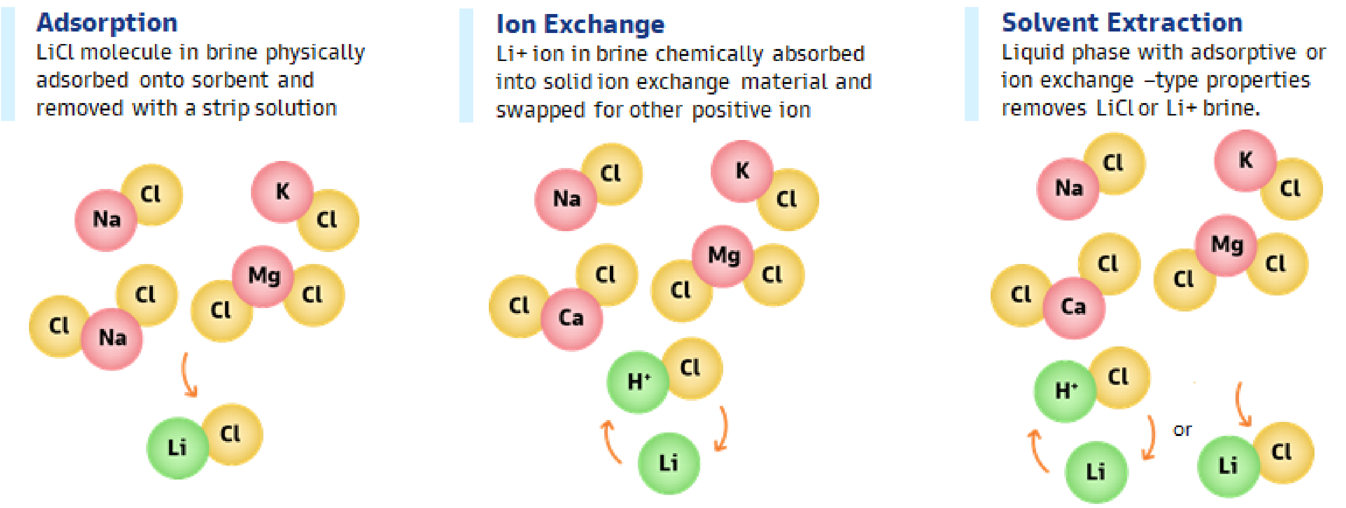
Though the application of technologies used in emerging DLE processes may be fairly new to the lithium industry, adsorption (AD), ion exchange (IX), and solvent extraction (SX) technologies are already utilised across other commodities at commercial scale (and we note IX is already utilised in some conventional lithium brine processing to manage impurities). Other DLE technologies in early stage development, including membranes and precipitants, may also offer potential DLE solutions.

While the impact of DLE on market dynamics will be linked to the pace and scale at which it is adopted, as we highlight (Exhibit 3), there are a significant number of resources business and technology providers that have been incentivised to find technological improvements to lithium resource extraction as a result of record lithium prices that are well above the marginal cost of existing and proposed lithium supply (and thus more than offset the upfront R&D costs). Policy changes, such as Chile's recent NLP, may further support an accelerating implementation of DLE technologies.

While each salar/brine resource is different (varying concentrations of lithium and other elements/impurity ratios), and variations between salars mean there is unlikely a one size fits all solution, we would expect a degree of transferability of successful DLE technologies between resources (though likely requiring optimisation/subject to impurity ratios), with differing applications and end products (lithium carbonate or chloride) depending on the project/available finishing capacity/end market optimisation.

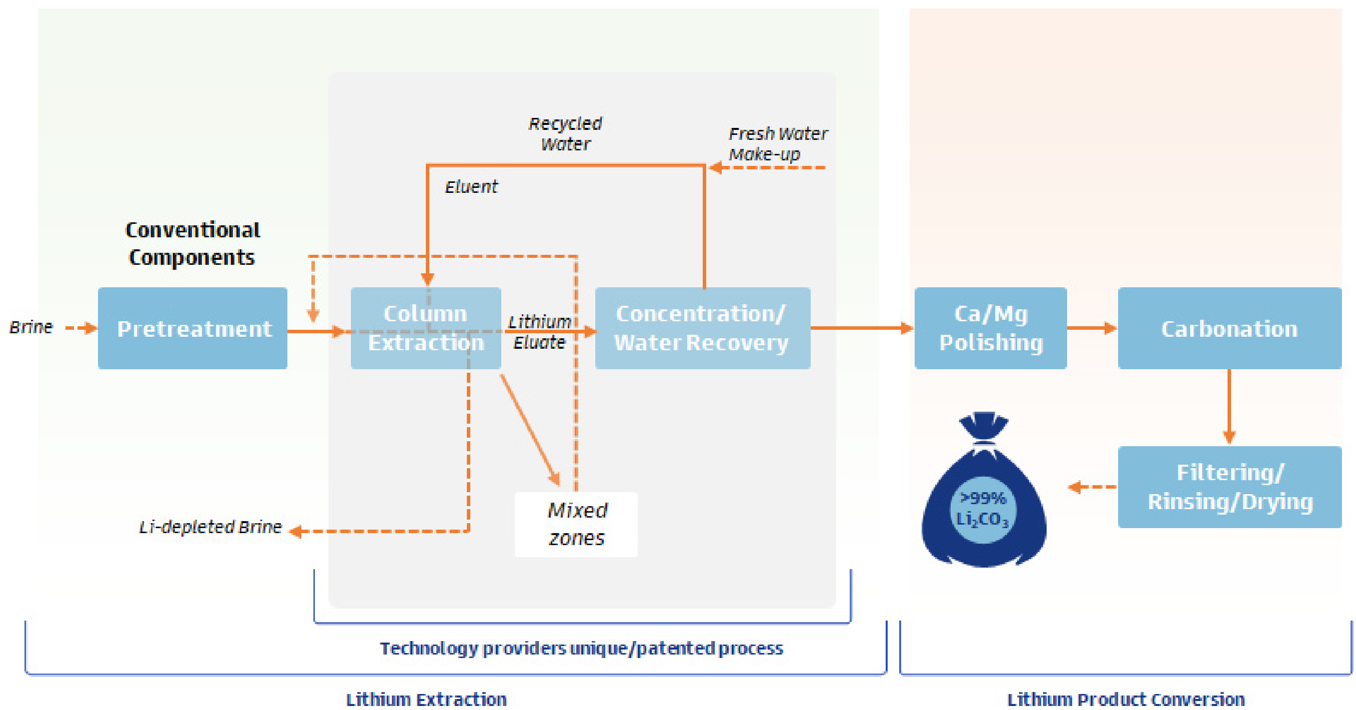
DLE offers a potential game changing technology for lithium supply, and while there may still be key challenges around scalability and water consumption (though modular designs and water recycling may assist with these issues, though could require energy intensive mechanical evaporation), and brine reinjection may be slightly dilutive to the resource (though proponents don't expect material impacts over proposed project lives), with the ongoing efforts, DLE could be implemented between 2025-2030 in both Chile and Argentina, in our view. DLE projects could also be implemented both as greenfield projects and brownfield expansions, or to enhance recoveries of existing pond operations. This compares with market skepticism around commercial development of DLE technology by the end of the decade.

Exhibit 26: Technical details of the 3 different types of DLE processes



Source: Data compiled by Goldman Sachs Global Investment Research

Exhibit 27: Example of DLE flow sheet



Process shown for sorption

Source: Compiled by Goldman Sachs Global Investment Research

Adsorption

Adsorption is increasingly the most developed DLE technology globally, with the majority of DLE projects utilising it to some degree (Exhibit 3).

Adsorption-separation resins are typically synthetic round-shaped beads with designed physical characteristics (i.e. pore size/structure, surface area, porosity) and chemical structure (e.g. functional groups) to capture desired / remove undesired molecules in **aqueous** solutions to enable **purification, extraction, separation, concentration and decolorization**. The material is already experiencing widespread adoption across a broad range of industries, including water management, pharmaceuticals, food processing and hydrometallugry.

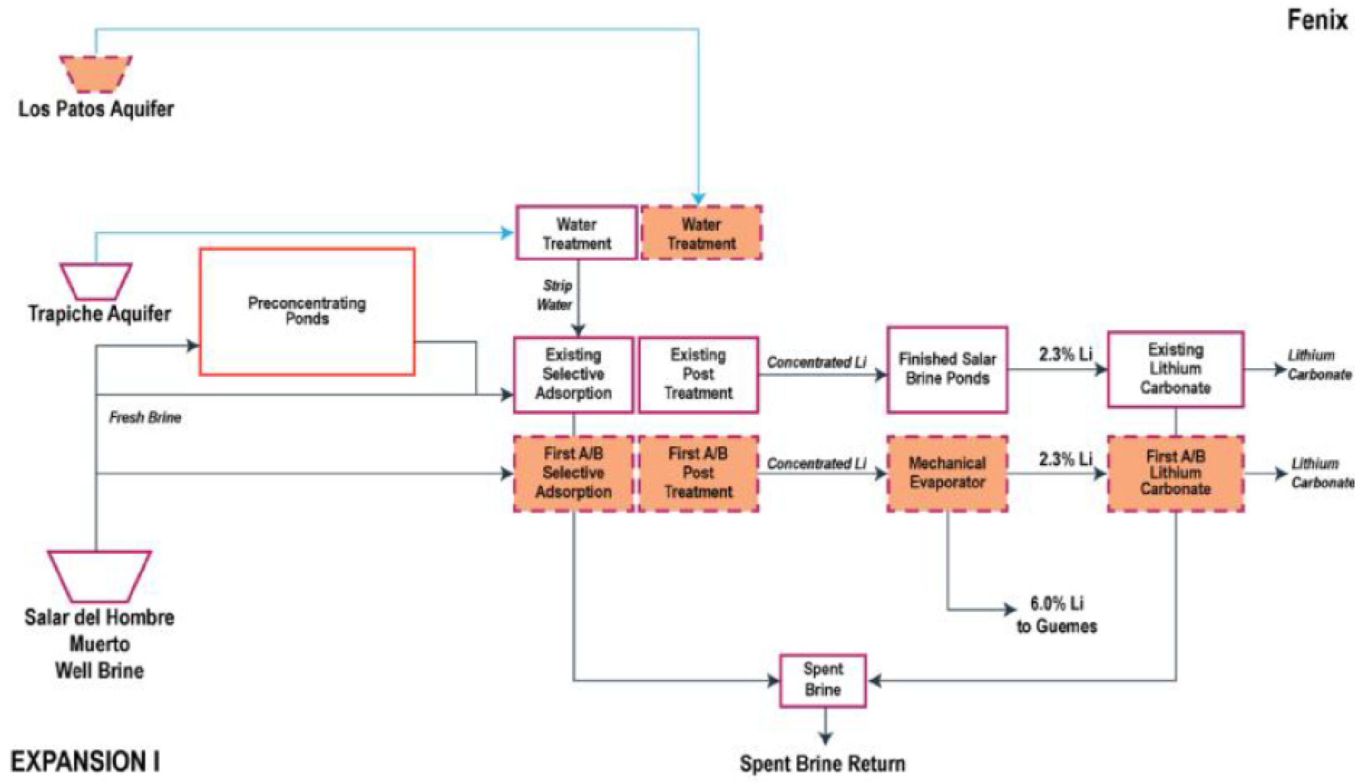
In adsorption's use in DLE, lithium chloride (LiCl) molecules from the brine infiltrate within the atomic layers of an adsorbent. Once LiCl fills the interstitial layers of the adsorbent, it is removed with a strip solution, typically warm-hot water. After the sorbent is loaded with the LiCl, it's washed with a diluted lithium chloride stream to remove unwanted ions, and then washed a second time to unload the lithium chloride. Some sorbents developed can recover >90% of the lithium present, with this method not requiring an acid wash or other chemicals, adding to its environmental credentials.

Other variations may include a recently tested lithium aluminum layered double hydroxide chloride sorbent (LDH), which is still being tested (though researchers consider them promising).

Pros: (i) Does not require reagents like ion exchange or solvent extraction, instead water is used to recover the lithium chloride, with soda ash to convert to carbonate (which is more readily available and easier to get to site vs. some acids for IX), (ii) Less impacted by brine composition, or by weather conditions, with lower waste generation, (iii) potentially >90% lithium extraction efficiency, (iv) Typically produces high quality lithium chloride/carbonate, and can be suitable for low lithium concentration brines.

Cons: (i) Usually requires temperatures >40 C, (ii) Lower eluate LiCl concentration than IX, and may require further steps to purify product and recycle water, (iii) Some implementation may find it difficult to prevent contamination with the brine, compromised by lower lithium uptake and carry-over of more impurities into the product, (iv) The adsorption equipment can be expensive (potentially high upfront costs) and complicated, with the cost of the adsorbent potentially higher if increasingly tailored.

Exhibit 28: Livent's DLE implementation at Fenix supports both enhanced recoveries of ponds and DLE-based expansions
Project Fenix facility first expansion process flow diagram



Expansion 1 of 3 shown

Source: Company reports

Ion Exchange (IX)

Ion exchange systems separate ionic contaminants from solution through a physico chemical process where undesirable ions are replaced by other ions of the same electrical charge. Essentially, the ion-exchange material acts as a sieve with an adjusted porosity that only allows lithium (and hydrogen) ions to pass through, where the ion-sieve can then be washed with an acidic solution promoting the replacement of lithium ions with hydrogen ions. Lithium recovery by ion exchange can change with a simple adjustment in pH, temperature, or stream composition (though the same goes for other lithium extraction methods), but researchers also believe this method can recover ~90% of the lithium present.

Pros: (i) Simple process, (ii) High selectivity for lithium and reduced risk of impurity contamination in the product stream, (iii) High capacity and therefore high concentration of Li in the strip solution, and can be suitable for low lithium concentration brines, (iv) Low energy/water consumption and unaffected by weather conditions, (v) continuous operation potential.

Cons: (i) Potentially high upfront costs, and may require further steps to purify product, (ii) High opex resulting from large amounts of base and acid inputs, and risk around acid supply to site, (iii) Some IX material have the potential to degrade in acidic conditions.

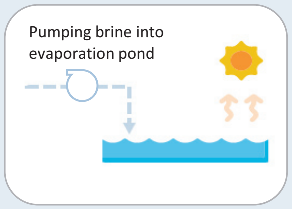
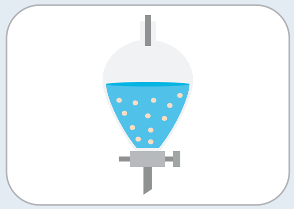
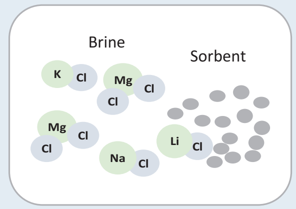
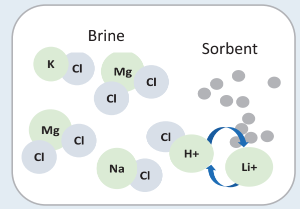
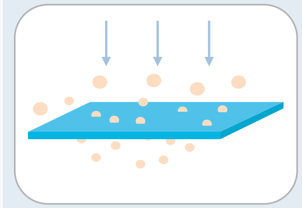
Solvent Extraction (SX)

Solvent-extraction uses an organic solution (containing solvent and extractant) to extract lithium from brines either chemically or physically and transforming it into LiCl (or ions). The organic solution typically comprises of kerosene (or similar material) and an extractant, which show very high selectivity toward lithium over sodium and magnesium ions under optimized conditions. Solvent extraction can theoretically achieve any concentration factor up to the saturation limit, where there is also the potential to use solvent extraction as a post-DLE step to polish the product stream and produce concentrated lithium solutions with high battery-quality purity. The process is also versatile and can potentially be adapted to produce high-purity lithium hydroxide, rather than lithium carbonate through precipitation with soda ash, with the technological process also being explored in battery recycling.

Pros: (i) High concentration of lithium can be produced from the brine with a high recovery rate, and is also unaffected by weather conditions, (ii) Low opex costs, (iii) Lithium solvent extraction is essentially a stand-alone process, whereas the other two DLE processes typically require an additional concentration step, either through smaller solar evaporation ponds, forced (artificial) evaporation, before the purified solution can be converted to the final product.

Cons: (i) Potentially less applicable with higher impurity ratios (lower concentrations of Ca and Mg usually required which may require pre-treatment of brine), (ii) Organic solvents are environmentally challenging, and are potentially more difficult to get to site, (iii) Fire risk with high temperature brines, (iv) Expensive relative to other technologies, potentially larger capex for the first fill and can cause costly equipment corrosion, (v) The residual brine that remains after lithium extraction may require post-treatment to remove the leached solvent before it can safely be sent for disposal.

Exhibit 29: Variations between salars mean there is unlikely a one size fits all solution (though solutions may still offer some transferability)
Comparison of different lithium brine extraction methods

Method	Precipitation/Evaporation	Solvent extraction	Adsorption	Ion-exchange	Membrane separation
How does it work	The salt-rich water from the underground brine deposit is pumped to the surface and direct into evaporation ponds. The precipitation process takes months/years to remove the water content through evaporation, yielding a high lithium concentration	The lithium is selectively extracted from brine into the organic phase of the solvent during the extraction process	The lithium chloride in brine is selectively captured by sorbent	The lithium ion in brine water is selectively captured by ion-exchange sorbents and replace with like-charged ions	Use lithium-selective membrane to separate Li/Mg ions, induced by external driving forces such as pressure (nanofiltration), electric field (selective electrodialysis) or thermal gradient
Schematic illustration					
Advantages	Simple process Low operating cost	Efficient Low operating cost Non-weather dependent High recovery rate	Simple process Efficient Unaffected by weather conditions Suitable for low lithium concentration High recovery rate	Simple process Efficient Unaffected by weather conditions Suitable for low lithium concentration High recovery rate	Efficient Environmental friendly
Disadvantages	Time consuming Weather-dependent Requires additional processing steps Environmental impact	Corrosion to equipment Environmental impact	High upfront cost Requires additional processing steps	High upfront cost Requires additional processing steps	Limit to brine with low Na/K content Water-intensive process High upfront and operating cost

Source: Company data, Goldman Sachs Global Investment Research

Disclosure Appendix

Reg AC

We, Hugo Nicolaci, Paul Young, Trina Chen, Joy Zhang, Yan Lin, Elise Bailey, Roy Shi and Nick Zheng, CFA, hereby certify that all of the views expressed in this report accurately reflect our personal views about the subject company or companies and its or their securities. We also certify that no part of our compensation was, is or will be, directly or indirectly, related to the specific recommendations or views expressed in this report.

We, Nicholas Snowdon and Aditi Rai, hereby certify that all of the views expressed in this report accurately reflect our personal views, which have not been influenced by considerations of the firm's business or client relationships.

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Growth is based on a stock's forward-looking sales growth, EBITDA growth and EPS growth (for financial stocks, only EPS and sales growth), with a higher percentile indicating a higher growth company. **Financial Returns** is based on a stock's forward-looking ROE, ROCE and CROCI (for financial stocks, only ROE), with a higher percentile indicating a company with higher financial returns. **Multiple** is based on a stock's forward-looking P/E, P/B, price/dividend (P/D), EV/EBITDA, EV/FCF and EV/Debt Adjusted Cash Flow (DACF) (for financial stocks, only P/E, P/B and P/D), with a higher percentile indicating a stock trading at a higher multiple. The **Integrated** percentile is calculated as the average of the Growth percentile, Financial Returns percentile and (100% - Multiple percentile).

Financial Returns and Multiple use the Goldman Sachs analyst forecasts at the fiscal year-end at least three quarters in the future. Growth uses inputs for the fiscal year at least seven quarters in the future compared with the year at least three quarters in the future (on a per-share basis for all metrics).

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