Albemarle Corporation

Lithium supply bottlenecks: from mine to market

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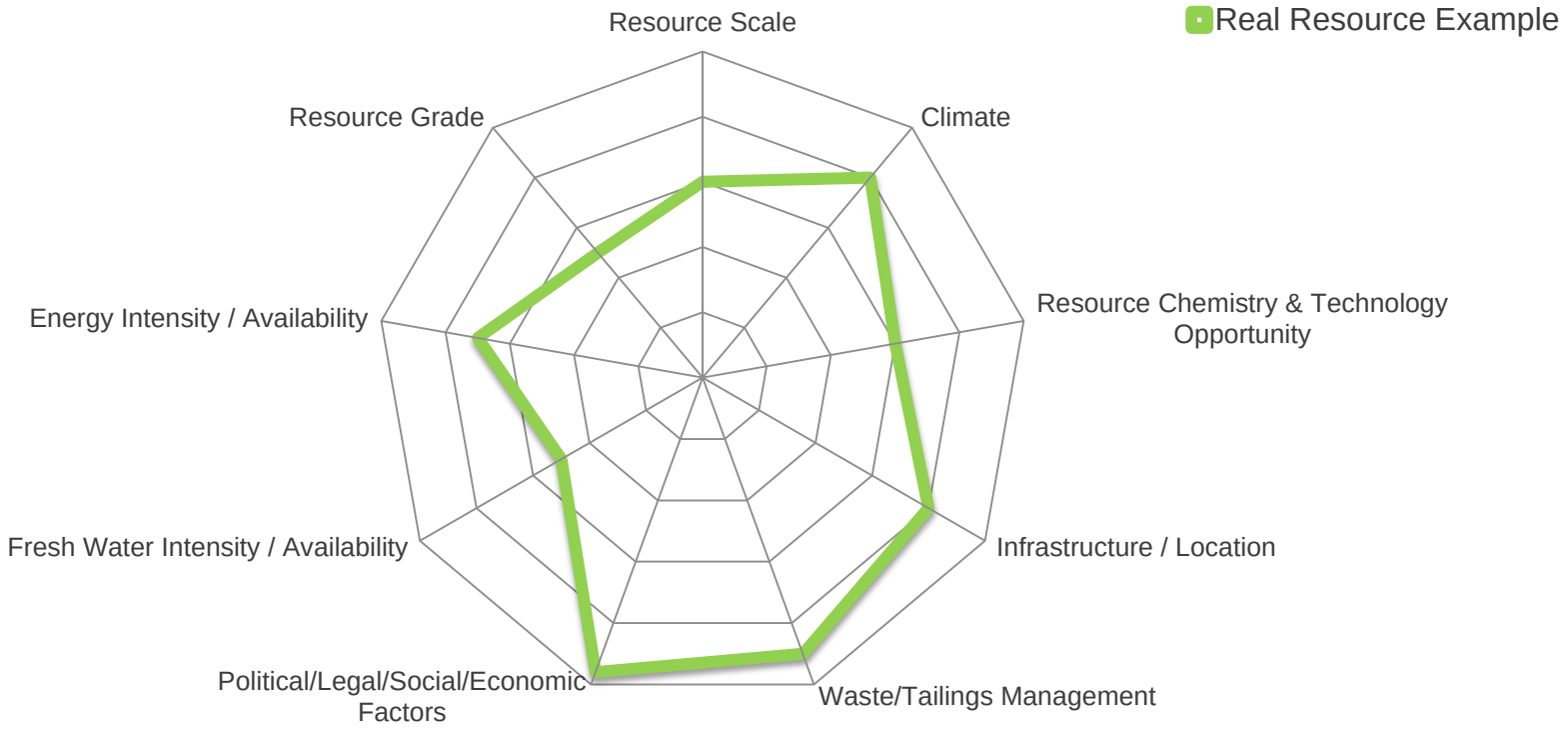
Why is it challenging to get new lithium supply to market?

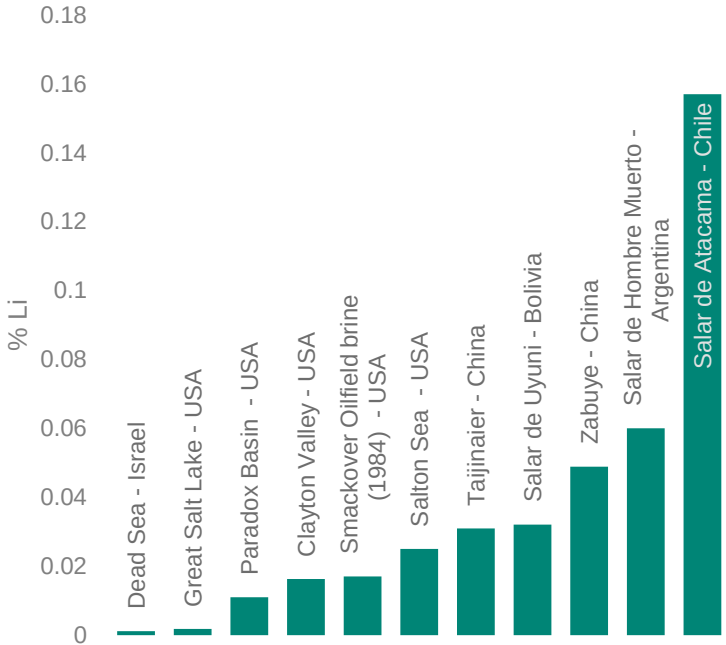
- Quality and consistency of resources vary widely and can determine success or failure of a new lithium project
- That resource variation drives the need for tailored chemical conversion capabilities for lithium materials
- New and un-tuned conversion processes result in chemical and physical characteristics (or ranges thereof) that have implications for battery failure modes
- Rapid evolution of battery technology is driving the need for different product forms of lithium chemistry

Each resource is unique – in many different respects



Complex considerations make it hard to evaluate ultimate success of a project

Brine resources have significant differences



	Salt Content (Weight %)[1]						
Resource	**Na**	**K**	**Li**	**Mg**	**Ca**	**Cl**	**SO_4**
Clayton Valley - USA	4.69	0.4	0.0163	0.019	0.045	7.26	0.34
Salar de Atacama - Chile	9.1	2.36	0.157	0.965	0.045	18.95	1.59
Salar de Hombre Muerto - Argentina	9.90-10.30	0.24-0.97	0.058-0.121	0.018-0.141	.019-.09	15.80-16.80	0.53-1.14
Salar de Uyuni - Bolivia	7.06	1.17	0.0321	0.65	0.0306	5	-
Great Salt Lake - USA	3.70-8.70	0.26-0.72	0.0018	.5-.97	.026-.036	7.00-15.60	0.94-2.00
Dead Sea - Israel	3.01	0.56	0.0012	3.09	1.29	16.1	0.061
Zabuye - China	7.29	1.66	0.0489	0.0026	0.0106	9.53	-
Taijinaier - China	5.63	0.44	0.031	2.02	0.02	13.42	3.41
Salton Sea - USA	5.00-7.00	1.30-2.40	.01-.04	0.07-0.57	22.6-39	14.20-20.9	42-50
Paradox Basin - USA	2.52	2.67	0.011	3.09	4.35	20.1	0.022
Smackover Oilfield brine (1984) - USA	6.7	0.28	0.017	0.35	3.45	17.17	0.04

Variations in concentrations and chemical profile drive need for customized extraction

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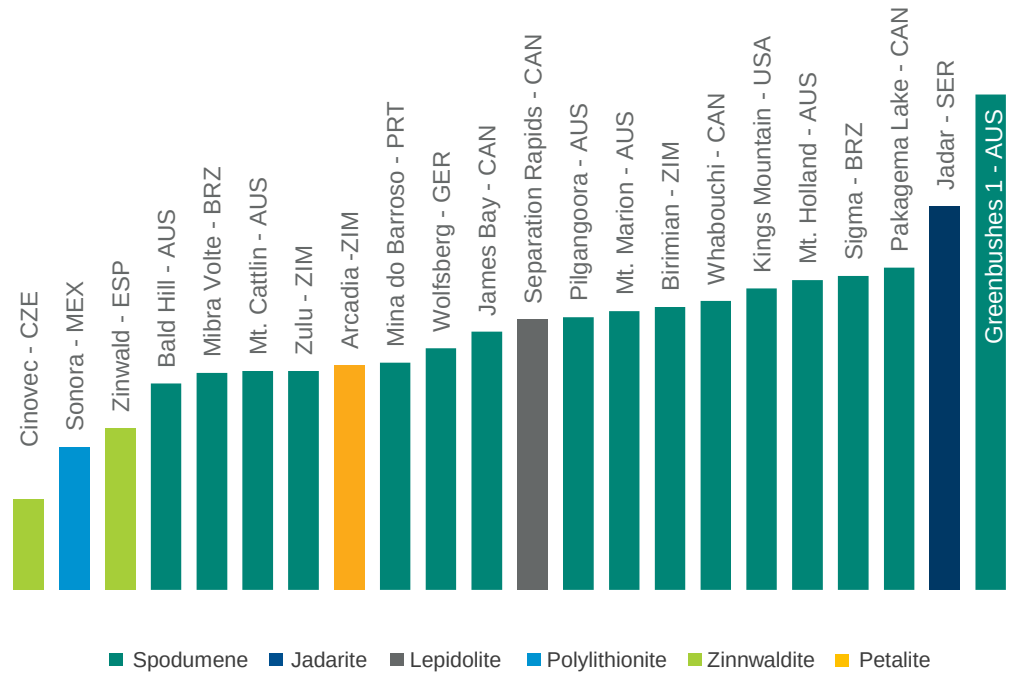
[1]Data from Garret 2004 – Handbook of Lithium and Natural Calcium Carbonate

Hard rock also varies in quality, grade and chemical profile



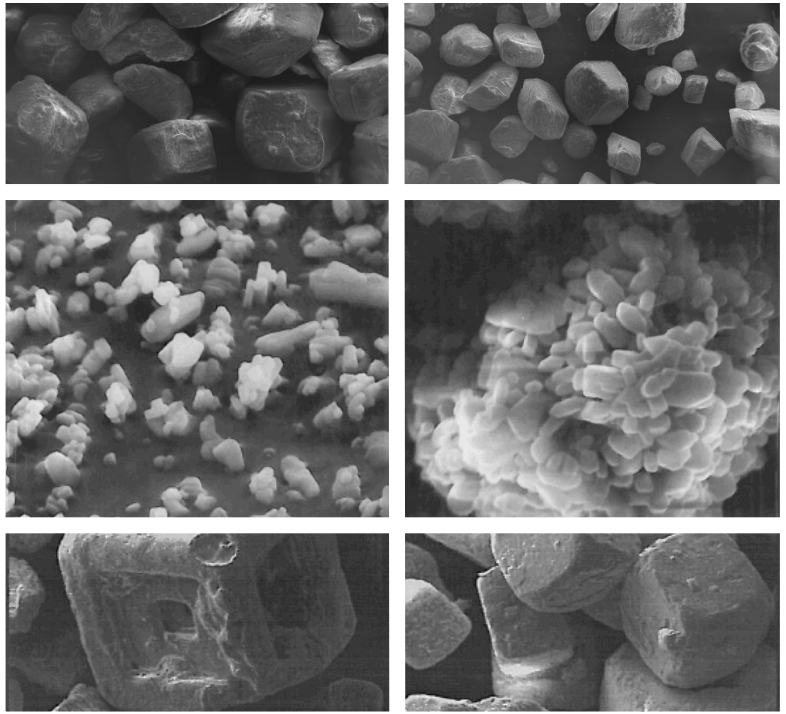
Mineral[1]	Formula	Average Li_2O%
Spodumene	$LiAlSi_2O_6$	2.9-7.7
Petalite	$LiAl(Si_4O_{10})$	3.0-4.7
Lepidolite	$K(Li,Al)_3(Si,Al)_4O_{10}(OH,F)2$	3.0-4.1
Amblygonite	$(Li,Na)Al(PO_4)(F,OH)$	
Montebrasite	$LiAl(PO_4)(OH,F)$	7.5-9.5
Zinnwaldite	$KLiFeAl(AlSi_3)O_{10}(OH,F)_2$	0.4-0.8
Eucryptite	$LiAlSiO_4$	4.5-6.5
Bikitaite	$LiAlSi_2O_6H_2O$	
Cookeite	$LiAl_4\ (AlSi_3O_{10})(OH)_8$	
Virgilite	$LiAlSi_2O_6$	
Jadarite	$LiNaSiB_3O_7OH$	1.75-2.0
Polylithionite	$KLi_2AlSi_4O_{10}(F,OH)_2$	

While extraction technologies are more standardized, hard rock cost and quality still vary widely

[1]Roskill Lithium: Global Industry, Markets, and Outlook, 2018

End-use quality standards demand well tuned conversion processes

- Morphology (form & structure) & Particle Size
  - Cathode structure
  - Processing Efficiency
- Impurities
  - Side reactions
  - Conductivity
  - SEI Layer Formation
  - Electrolyte integrity
  - Thermal Stability

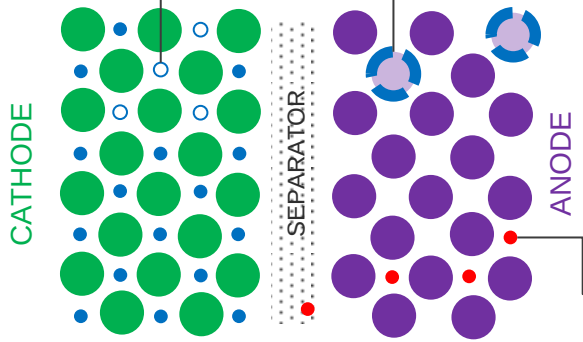


Resource variability and scarce process know-how can add years to process development timelines

Purity and consistency: a significant driver of battery performance

Impurities “deactivate” lattice positions in the metal oxide and DEGRADE CAPACITY

Material variation contributes to over/under charge and COMPROMISES SAFETY



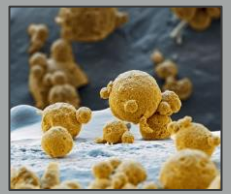
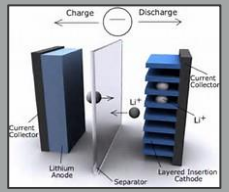
All degradation pathways combined reduce battery CYCLE LIFE

Impurities “clog” ion conduction channels, increase resistance & LIMIT POWER

Only a few producers today have demonstrated the ability to produce Battery Grade Lithium that enable safe, high-performance, long-life batteries

Bringing lithium products to xEV market is lengthy and complex

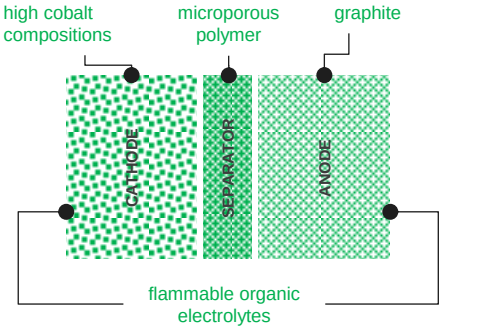
Raw Materials

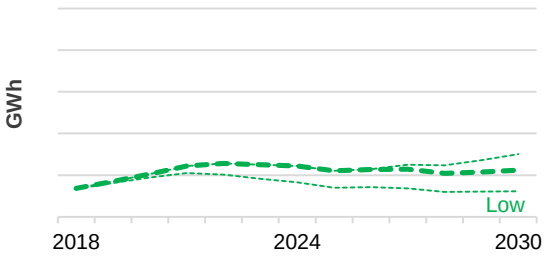
Performance Products	Battery Components	Battery Cells	Battery Packs	OEM's
				
Li Carbonate Li Hydroxide	Cathode, Anode, Electrolyte	Cylindrical, Pouch, Prismatic	xEV, PEV, ESS, CE	BEV, PHEV, HEV
• Specification varies by customer • New Supplier >/= 1 year for each cathode formulation	• Specifications vary by customer, application, and composition	• Spec's vary by OEM vehicle and Performance Required.	• Battery Cell and Pack Design vary by OEM and vehicle type	• Each OEM has a specific performance requirement and form factor they are designing

Qualification timing is 3-5 years for new cathode material to be qualified in a battery pack

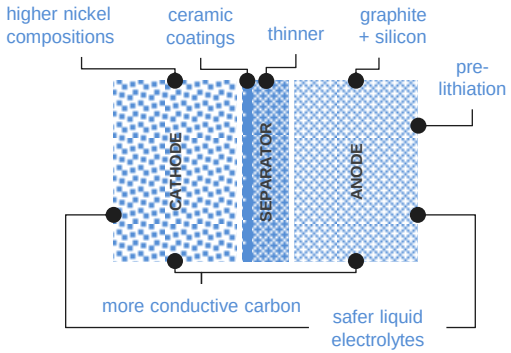
Cathode and battery material requirements are dynamic

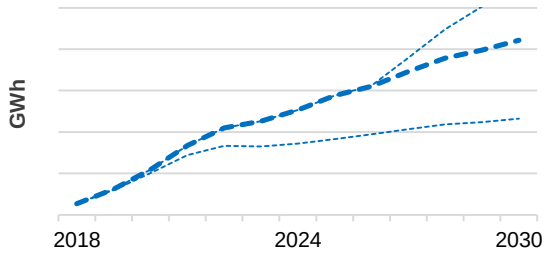
Current



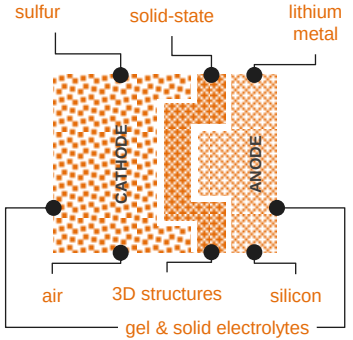


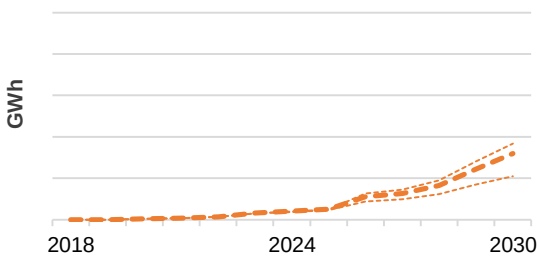
Advanced





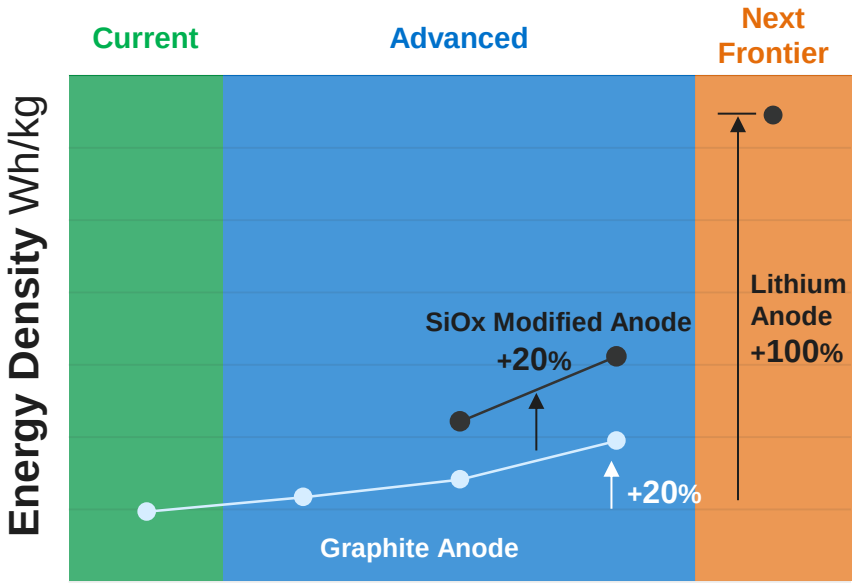
Next Frontier

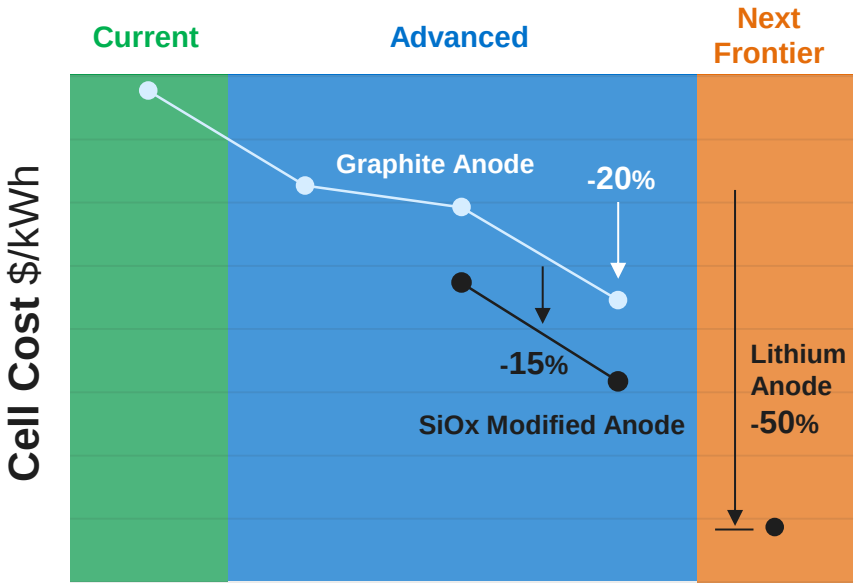




Breadth of lithium products and capabilities needed for a supplier to remain relevant to battery firms

Lithium plays a key role in battery technology evolution

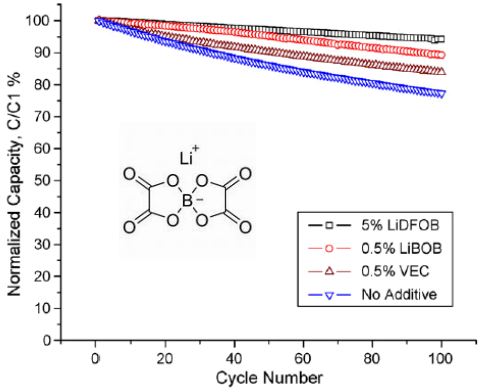




Material and cell advancements drive performance & cost improvements

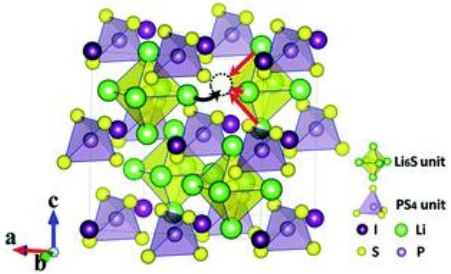
Examples of advanced lithium materials from Albemarle

Patented lithium-based materials to enable long cycle life



J. Power Sources, 2007,**174**, 852-855

Li_2S - key ingredient in next frontier solid separators



J. Mater. Chem. A, 2017,**5**, 21846-21857

Lithium metal foils for next frontier anodes

Leading cathode and battery producers are seeking suppliers with ability to partner on next gen technology

In summary, multiple factors make lithium a specialized business

- The lithium industry is still maturing from a technical and commercial perspective – does not behave like a commodity industry
- Obtaining capabilities to bring lithium from mine to market takes time
- Competitive cost advantage limited to only a few resources globally
- Significant capital being invested through the EV supply chain that drive need for high quality, consistent and secure supply
- The commercial structure of the market has moved to long-term relationships and commitments for the reasons listed above

Only a few suppliers today (largely the “majors”) can meet the significant growth in demand

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