November 16, 2021 | 13:39 ET | 16:03 ET~

Battery Materials

Anode Material Deep Dive: Cut Through the Noise; Graphite to Remain Dominant

Bottom Line:

In this EV transition decade, the unwavering need for conventional graphite-based anodes is underappreciated. The perception that replacement technologies are around the corner, and wholly and immediately disruptive is a disconnect from reality. Major EV OEMs are looking to secure supply of proven materials and reduce reliance on Chinese-dominant supply, while also lowering battery production costs. Within a resulting strong demand backdrop for graphite anode material this decade, we see a unique opportunity for lower-cost, natural-based graphite anode material (CSPG), vs. synthetic graphite alternatives. New graphite-anode projects are going to be needed beyond the large Asian incumbent capacity growth plans (mostly synthetic-based), and new entrants able to break into Western auto OEM supply chains will be favorably positioned. However, anode material production is complex, particularly considering the importance of battery safety and performance. In this environment, we see a supportive backdrop for CSPG pricing this decade.

Key Points

We expect graphite-based anode material to remain dominant in EVs this decade underpinning robust demand growth (2.4Mt by 2030E; 23% CAGR off 2020-levels). We assume graphite holds underlying composition mix within total lithium-ion battery anode material of 96%/90% in 2025/30E (vs. ~98% now).

Next-gen battery commercialization at scale (with lithium metal or silicon anodes) not expected until back half of the decade at the earliest, and that is only if remaining R&D hurdles can be overcome. Next-gen EV battery prototypes potentially ready in the coming years at the earliest, followed by multi-year auto qualification and testing periods including assessing commercial viability (i.e., will production be cost competitive with conventional li-ion batteries by then at massive scale?).

See an opportunity for lower-cost natural graphite-based anode material (CSPG) to gain incremental mix share within blends with synthetic graphite alternatives as downstream OEMs look to lower battery production costs (e.g., Tesla is increasing natural mix). We model 50/50 natural and synthetic blends within anode material across the decade (vs. ~40/60 natural/synthetic blends in 2020).

We expect a supportive backdrop for CSPG pricing upside. While anode material price discovery is very opaque, we feel comfortable modeling CSPG ASPs of US$7-8k/t across the decade, above current average industry opex costs of US$3.5-6k/t. Current synthetic-anode material ASPs are over US$10k/t.

Opportunity for new entrant anode material suppliers to penetrate highly concentrated and Chinese-dominant supply chains given downstream desire to localize supply to lower carbon footprints and reduce geopolitical risk.

Anode material production is complex adding to overall greenfield development risk. Multi-year anode material qualification processes with the downstream are also a key hurdle for new entrants.

Concurrent with this report we launch coverage of **NEXT** at Outperform and **NMG** at Market Perform.

For disclosure statements, including the Analyst Certification, please refer to page(s) 26 to 29.

Battery Materials

Robin Fiedler, CFA Analyst
robin.fiedler@bmo.com (647) 242-3191
Legal Entity: BMO Nesbitt Burns Inc.

What's Inside

- Deep dive on the graphite-based anode material market coinciding with launch of NextSource (NEXT) at Outperform and Nouveau Monde (NMG) at Market Perform
- Insights from conversations with various natural and synthetic graphite companies, graphite-anode consultants, downstream battery/auto OEMS, and from visiting a natural graphite deposit and anode material plant
- Comprehensive graphite-based anode material supply and demand model out to 2030
- Detailed overview of graphite-anode material pricing, opex costs, project capital intensities, and overall competitive landscape
- N.American/European LIB Plant and Anode Material Supply Maps
- In-depth analysis on downstream qualification/testing timelines of conventional battery raw materials and next-gen battery products
- Assessment of next-gen battery development path including technological hurdles, start-ups and incumbent strategies, commercial potential, etc.

Industry Research

Glossary

Table of Contents

Glossary

Figure 1: Glossary and Key Terms

Term	Definition
Amorphous Graphite	Lower-grade natural/mined graphite largely limited to lower-value industrial applications
Anode	Positive-sided electrode within a battery cell that houses electrons in a charged state
Coated-Spherical-Purified-Graphite (CSPG)	Natural graphite-based anode material finished product sold into battery end-markets
Graphite Concentrate	Processed graphite ore material sold into industrial applications (eg. electrodes, refractories, etc.) or used as feedstock for natural graphite-based anode material processing
Lithium-ion Battery (LIB)	Rechargeable battery commonly used for portable electronics or electric vehicles
Natural Flake Graphite	Mined graphite material varying by size and grade
Next-Gen Batteries	Batteries innovating upon conventional LIB structure typically with silicon or lithium metal anodes
Spherical-Purified-Graphite (SPG)	Mid-level natural graphite-based anode material that still requires coating prior to CSPG status
Solid State Battery (SSB)	Type of next-gen battery with a solid electrolyte and typically either a silicon or lithium metal anode
Synthetic Graphite	Artificial graphite manufactured by the process of graphitization using hydrocarbon raw materials
Synthetic Graphite Anode Material	High-cost anode material typically with high grade and high consistency enabling long cycle life

Source: Industry Reports, BMO Capital Markets

Anode Material Deep Dive: Cut Through the Noise; Graphite to Remain Dominant

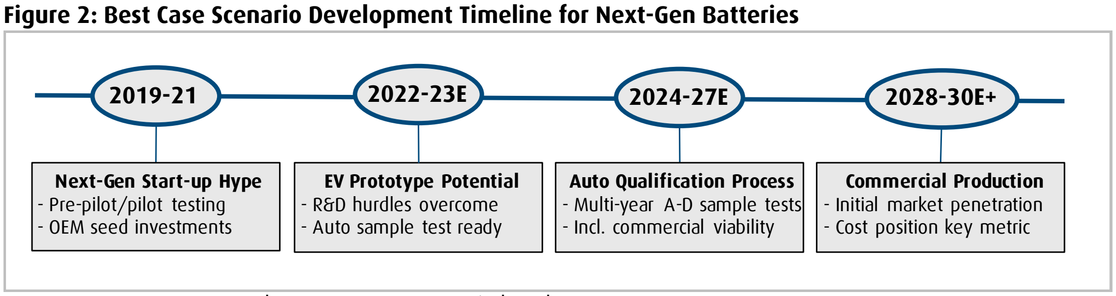
Bottom Line: In this EV transition decade, the unwavering need for conventional graphite-based anodes is underappreciated. The perception that replacement technologies are around the corner, and wholly and immediately disruptive is a disconnect from reality. Major EV OEMs are looking to secure supply of proven materials and reduce reliance on Chinese-dominant supply, while also lowering battery production costs. Within a resulting strong demand backdrop for graphite anode material this decade, we see a unique opportunity for lower-cost, natural-based graphite anode material (CSPG), vs. synthetic graphite alternatives. New graphite-anode projects are going to be needed beyond the large Asian incumbent capacity growth plans (mostly synthetic-based) and new entrants able to break into Western auto OEM supply chains will be favorably positioned. However, anode material production is complex, particularly considering the importance of battery safety and performance. In this environment, we see a supportive backdrop for CSPG pricing this decade.

Model graphite anode material at 96/90% mix in LIB anodes in 2025/30E

We expect graphite to continue to be the underlying raw material of choice for LIB anode material across this decade, holding an underlying composition mix of 96% in 2025E and 90% in 2030E (vs. ~98% in 2020). As an anode material, graphite has proven to be stable, it's widely used and already ingrained in battery manufacturing processes, and it provides battery energy density (i.e., vehicle range) that is largely "good enough" for consumer driving habits.

We see next-gen battery commercialization at scale (w/ lithium metal or silicon anodes) by the latter-half of the decade, at the earliest. The qualification timeline for new battery materials/technologies for use in EVs can take upwards of five years, and this is after technological hurdles are overcome at the R&D phases and proven beyond lab levels (this is still under way for high-silicon/lithium-metal anodes and SSBs).

Figure 2: Best Case Scenario Development Timeline for Next-Gen Batteries



Source: Company Reports, Industry Reports, BMO Capital Markets

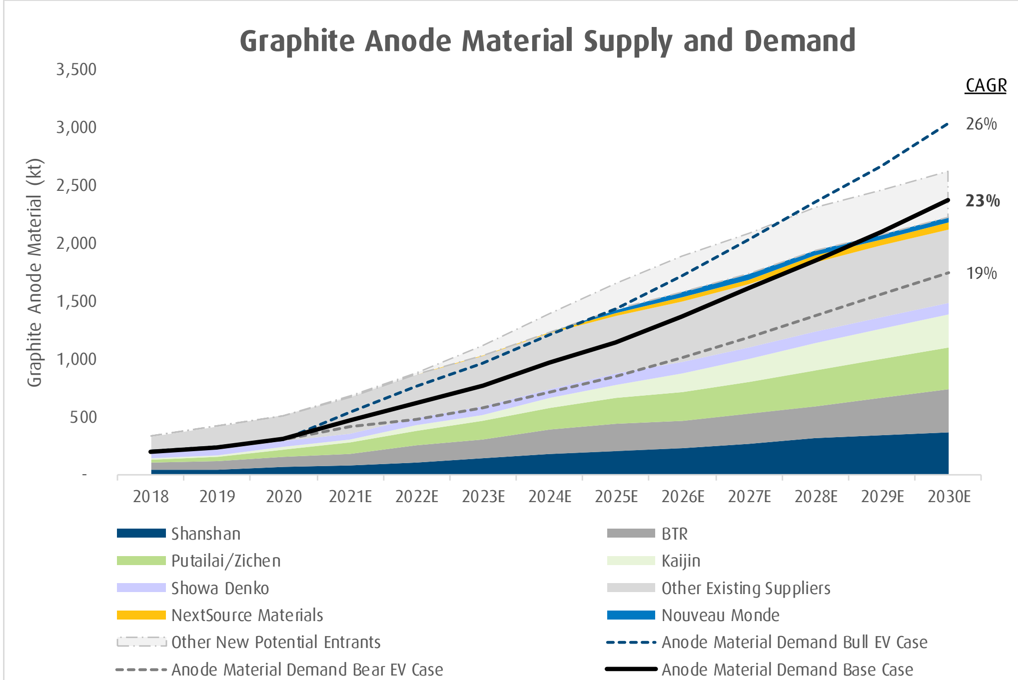
New Graphite-Based Anode Material Projects Needed in Bull and Base Case Demand Scenarios

Graphite anode material demand CAGR of ~23% this decade

We believe there will be a necessity for incremental graphite-based anode material supply from alternative projects to the largely dominant Chinese/Japanese incumbents in order to fulfill mid-term downstream demand expectations and for better global supply chain diversity overall.

- We model graphite-based anode material demand of ~475kt/1,150kt/2,400kt in 2021/25/30E as a base case, implying ~23% demand CAGR off 2020 levels.
- We model graphite-based anode material capacity of ~715kt/1,700kt/2,725kt in 2021/25/30E as a base case, implying ~18% CAGR off 2020 levels.

Figure 3: Incremental Anode Material Production Required in Bull and Base Demand Scenarios



Note: assumes graphite market share in battery anode material is ~96% in 2025E and ~90% in 2030E (vs. 98% in 2020A).
Source: BMO, Company Reports, Industry Reports

Expect Mix Shift in Favor of Natural Material in Graphite Anodes

Expect 50/50 blends of natural/synthetic graphite anode material over mid-term

We expect lower-cost natural graphite-based anode material (CSPG) to gain incremental mix share within anode material blends with synthetic graphite anode material alternatives as downstream OEMs look to lower battery production costs. Graphite-anode material can be made from either natural graphite material (using mined graphite) or synthetic graphite. Each option has different characteristics and are often blended together to balance performance and costs. The quality and consistency have historically been superior with synthetic anode material, but production costs are ~30-50% higher. Natural graphite anode material (CSPG) production quality has also improved in recent years with technological advancements such that increasing its mix within blends to lower costs is increasingly possible without compromising battery performance. We model 50/50 natural and synthetic blends within anode material across the decade (vs. ~40/60 natural/synthetic blends in 2020).

Push for More Localized Battery Supply Chains Creates Opportunity for Ex. Asia Anode Material Production

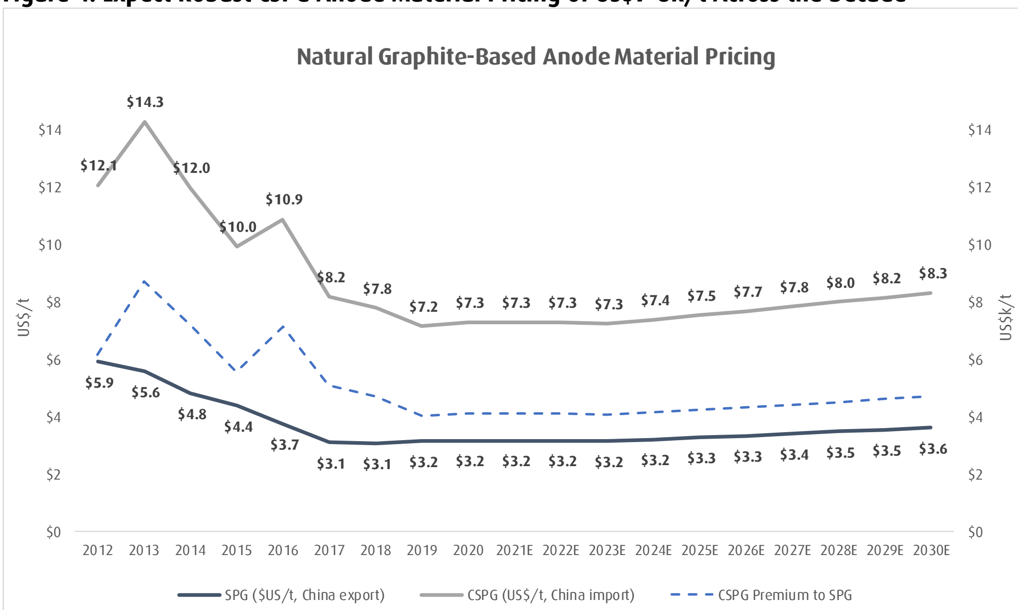
We see an opportunity for ex. Asian anode material production given the significant anode material demand stemming from battery cell manufacturing growth in N.America and Europe this decade. We recognize the challenges for new anode material entrants to penetrate a well-ingrained supply chain currently dominated by a handful of incumbents geographically positioned to supply market-leading Asian battery manufacturers. However, we believe new anode material suppliers could find a foothold within a more geographically diverse supply chain structure, particularly given the increased mindfulness of the environmental footprint (and geopolitics) of Western EV/battery OEMs as well as the logistical benefits.

Expect CSPG Pricing to Remain Firm With Upside Potential by Mid-Decade

Model CSPG pricing of US$7-8k/t across the decade

We expect a supportive backdrop for CSPG pricing upside. While industry anode material price discovery is very opaque, we feel comfortable modeling CSPG ASPs of US$7-8k/t across the decade (vs. US$6-7.5k/t currently), above current average industry opex costs of US$3.5-6k/t.

Figure 4: Expect Robust CSPG Anode Material Pricing of US$7-8k/t Across the Decade



Source: Fastmarkets, BMO Capital Markets

Anode Material Production Process Complexities Not to Be Overlooked

The GM-LG Chevy Bolt recall was partly due to issues with the anode material

Anode material requires significant value-added processing across various non-trivial/technical steps in order to meet sufficient spec/quality/performance demanded by auto/battery OEMs. This increases process risk for new entrants but also creates higher barriers to entry if process know-how and proven process ability can be achieved. Graphite-based anode material production is dominated by Asian incumbents with refined process know-how; end-to-end EV-battery anode material manufacturing has yet to be replicated at commercial scale outside of Asia.

Anode Material Qualification Processes a Key Hurdle for New Entrants

Prospective new sources of anode material (particularly if used in EV batteries) must undergo extensive product qualification and testing with cell manufacturers that can take up to two years (if production tweaks need to be made), or at best roughly 12 to 18-months. Downstream qualification/testing at the vehicle level is an incremental 9 to 12 months.

Figure 5: Average Anode Material Testing and Qualification Timelines for New Entrants Take Roughly Two Years (and Potentially More)

Stage	Quantity (kg)	Timeline (months) 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24	Notes
Battery cell level testing:			
Material specification	10 to 50		• Eg. anode material purity requirements
Anode performance	100 to 500		• Eg. specific capacity requirements of anode material
Cell performance	1000 to 5000		• Eg. energy density, longevity, safety, etc.
Manufacturing consistency	1000 to 5000		• Meet spec over multiple material batches
Vehicle testing	1000 to 5000		• Meet performance and safety requirements

Source: Industry Reports, Company Reports, Battery Materials Review, BMO Capital Markets

Graphite Anode Material Supply and Demand Model

Figure 6: Base Case Graphite Anode Material Supply and Demand Model

Graphite Anode Material (kt)				2018	2019	2020	2021E	2022E	2023E	2024E	2025E	2026E	2027E	2028E	2029E	2030E
Key EV Assumptions:																
EV Market Penetration Rate (BEV/PHEV of total car sales)				**2.1%**	**2.5%**	**4.1%**	**7.0%**	**9.0%**	**11.0%**	**13.0%**	**15.0%**	**17.5%**	**20.2%**	**23.0%**	**25.5%**	**28.0%**
EV Car Sales (millions)				**2.0**	**2.2**	**3.2**	**5.9**	**8.1**	**10.1**	**12.2**	**14.2**	**16.7**	**19.5**	**22.4**	**25.2**	**28.0**
BEV (Battery Electric Vehicle)				*1.4*	*1.7*	*2.2*	*4.4*	*6.0*	*7.6*	*9.8*	*11.4*	*13.4*	*15.6*	*18.0*	*20.1*	*22.4*
PHEV (Plug-in Hybrid Vehicle)				*0.6*	*0.6*	*0.9*	*1.5*	*2.0*	*2.5*	*2.4*	*2.8*	*3.3*	*3.9*	*4.5*	*5.0*	*5.6*
BEV Avg. Battery Pack Size (kWh)				45.0	49.0	50.0	51.0	53.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0	70.0
PHEV Avg. Battery Pack Size (kWh)				12.0	12.4	12.8	13.2	13.6	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5
E-Bus Sales (millions)				0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.30
E-Bus Avg. Battery Pack Size (kWh)				150	200	300	300	300	300	300	300	300	300	300	300	300
E-Bike Sales (millions)				2.4	3.4	3.8	5.2	7.1	8.7	10.3	12.1	14.1	16.4	19.2	22.4	26.4
E-Bike Avg. Battery Pack Size (kWh)				4.0	4.0	5.0	5.5	6.0	6.0	6.5	7.0	7.0	7.5	7.5	7.5	7.5
Battery Grade Graphite Anode Material Content (kg/kWh)				**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**
Graphite-Based Anode Market Share				**99%**	**98%**	**98%**	**98%**	**98%**	**97%**	**97%**	**96%**	**96%**	**94%**	**92%**	**91%**	**90%**
Natural Graphite Anode Mix				*38%*	*40%*	*40%*	*45%*	*45%*	*45%*	*48%*	*50%*	*50%*	*50%*	*50%*	*50%*	*50%*
Synthetic Graphite Anode Mix				*63%*	*60%*	*60%*	*55%*	*55%*	*55%*	*53%*	*50%*	*50%*	*50%*	*50%*	*50%*	*50%*
Anode Material Demand (kt):																
Batteries																
EVs				31	42	58	130	183	241	331	418	507	602	696	792	895
E-Buses				12	13	21	25	27	29	32	36	39	41	43	45	48
E-Bikes				4	6	9	15	22	27	37	49	57	70	80	92	106
Mobile Devices				15	17	15	15	15	15	16	16	16	16	16	16	17
Grid Storage				2	2	2	3	3	4	4	5	5	6	7	8	9
Non Lithium-ion Batteries (incl. Fuel Cell)				15	15	16	16	16	16	17	20	25	31	36	42	48
Natural Graphite Anode Material				**78**	**95**	**120**	**204**	**267**	**332**	**436**	**543**	**649**	**765**	**878**	**995**	**1122**
Batteries (SG)																
EVs				51	63	86	159	224	294	365	418	507	602	696	792	895
E-Buses				19	19	32	31	33	35	36	36	39	41	43	45	48
E-Bikes				11	16	22	33	50	60	78	98	114	140	159	183	212
Mobile Devices				25	27	25	25	26	26	26	26	27	27	27	27	28
Grid Storage				2	4	4	4	5	6	7	8	10	11	13	16	19
Non Lithium-ion Batteries (incl. Fuel Cell)				15	15	16	16	16	16	17	20	25	31	36	42	48
Synthetic Graphite Anode Material				**124**	**145**	**185**	**269**	**353**	**437**	**529**	**606**	**721**	**851**	**974**	**1105**	**1249**
Total Graphite Anode Material Demand				**202**	**239**	**305**	**473**	**620**	**769**	**965**	**1149**	**1370**	**1616**	**1852**	**2100**	**2371**
Demand Growth y/y					*18%*	*28%*	*55%*	*31%*	*24%*	*25%*	*19%*	*19%*	*18%*	*15%*	*13%*	*13%*
Anode Material Production (kt):																
Shanshan	**Tier 1**	***China***	***Synthetic/Natural***	**45**	**45**	**65**	**85**	**110**	**140**	**185**	**210**	**235**	**270**	**310**	**335**	**360**
BTR	**Tier 1**	***China***	***Synthetic/Natural***	**60**	**75**	**85**	**100**	**145**	**165**	**210**	**235**	**235**	**260**	**285**	**335**	**385**
Putailai/Zichen	**Tier 1**	***China***	***Synthetic***	**30**	**30**	**65**	**90**	**125**	**160**	**185**	**215**	**240**	**265**	**305**	**330**	**355**
Kaijin	**Tier 1**	***China***	***Synthetic/Natural***	**9**	**20**	**25**	**30**	**50**	**55**	**85**	**120**	**165**	**200**	**240**	**265**	**290**
Showa Denko	**Tier 1**	***Japan***	***Synthetic/Natural***	**45**	**50**	**50**	**50**	**60**	**70**	**80**	**90**	**100**	**100**	**100**	**100**	**100**
Posco	**Tier 1**	***S.Korea***	***Natural***	**15**	**20**	**29**	**40**	**40**	**50**	**50**	**60**	**60**	**65**	**75**	**85**	**100**
Other				**145**	**197**	**225**	**322**	**397**	**506**	**622**	**778**	**915**	**990**	**1074**	**1099**	**1134**
Baichuan High Tech Minerals		*China*	*Synthetic*						5	5	5	5	5	5	5	5
Cosmo		*S.Korea*	*Synthetic*		5	8	10	10	10	10	10	10	10	10	10	10
Ecograf		*Australia*	*Natural*							5	10	15	20	20	20	20
EcoPro		*S.Korea*	*Synthetic*	20	30	35	50	50	50	50	60	65	70	75	75	75
Elkem/Vianode		*Norway*	*Synthetic*						5	10	15	25	50	60	60	60
Jiangxi Zhengtuo New Energy Technology (ZETO)	Tier 2	*China*	*Synthetic/Natural*	8	15	20	30	30	40	45	45	45	45	45	45	45
JFE Chemical		*Japan*	*MCMB/Natural*	5	5	5	5	5	5	5	5	5	5	5	5	5
L&F Chemical		*S.Korea*	*Synthetic*	20	30	35	50	50	50	50	50	50	50	50	50	50
Mitsubshi Chemical	Tier 1	*China/Japan*	*Natural*	12	12	12	12	20	25	35	35	35	35	35	35	35
MRC/Skaland		*Norway*	*Natural*							5	15	25	25	25	25	25
Mulan New Material Tech		*China*	*Synthetic*				4	8	8	16	24	30	30	30	30	30
NextSource Materials		*TBD*	*Natural*						4	11	28	42	42	56	56	56
Nippon Carbon	Tier 1	*Japan*	*Natural*	3	3	3	3	6	6	6	6	6	6	6	6	6
Novonix		*U.S.*	*Synthetic*				1	2	5	10	40	40	40	40	40	40
Nouveau Monde		*Canada*	*Natural*							1	24	42	47	47	47	47
Pyrotek		*U.S.*	*Synthetic/Natural*	4	4	4	4	10	20	20	20	20	30	40	40	40
Shangtai Technology	Tier 2	*China*	*Synthetic/Natural*		10	15	40	60	70	70	70	70	70	70	70	70
Shanxi Huashun New Energy Tech		*China*	*Synthetic*						10	25	40	60	60	60	60	60
SGL Carbon		*Germany*	*Synthetic*	18	18	18	18	18	18	18	18	18	18	18	18	18
Sinuo	Tier 2	*China*	*Synthetic*	10	20	25	25	30	40	50	58	58	58	58	58	58
Shenzhen Xiangfenghua (XFH)	Tier 2	*China*	*Synthetic/Natural*	20	20	20	30	30	30	40	40	50	50	60	60	60
Shinzoom	Tier 2	*China*	*Synthetic/Natural*	15	15	15	30	40	50	50	50	50	60	75	85	100
Sunward Intelligent		*China*	*Synthetic*					3	10	20	30	50	60	75	85	100
Syrah Resources		*U.S.*	*Natural*						5	10	10	10	10	10	10	10
Talga Group		*Sweden*	*Natural*						5	10	15	19	19	19	19	19
Yicheng New Energy		*China*	*Synthetic*					5	10	15	20	30	30	30	30	30
Other		*China*	*Synthetic*	10	10	10	10	20	25	30	35	40	45	50	55	60
Total Natural Supply						*200*	*250*	*325*	*350*	*425*	*550*	*650*	*800*	*900*	*1050*	*1200*
Total Synthetic Supply						*300*	*400*	*602*	*796*	*992*	*1158*	*1300*	*1350*	*1489*	*1499*	*1524*
Total Supply Capability				**349**	**437**	**544**	**717**	**927**	**1146**	**1417**	**1708**	**1950**	**2150**	**2389**	**2549**	**2724**
Supply Growth y/y					*25%*	*24%*	*32%*	*29%*	*24%*	*24%*	*21%*	*14%*	*10%*	*11%*	*7%*	*7%*
Est. Manufacturing Scrap Loss (~5%)				(17)	(22)	(27)	(36)	(46)	(57)	(71)	(85)	(98)	(108)	(119)	(127)	(136)
Total Estimated Production				**331**	**415**	**516**	**681**	**881**	**1088**	**1346**	**1623**	**1853**	**2043**	**2270**	**2422**	**2588**
Surplus / (Deficit)				**129**	**176**	**211**	**208**	**260**	**319**	**381**	**474**	**482**	**426**	**418**	**322**	**217**
Capacity Utilization				*58%*	*55%*	*56%*	*66%*	*67%*	*67%*	*68%*	*67%*	*70%*	*75%*	*78%*	*82%*	*87%*

Source: Company Reports, Industry Reports, BMO Capital Markets

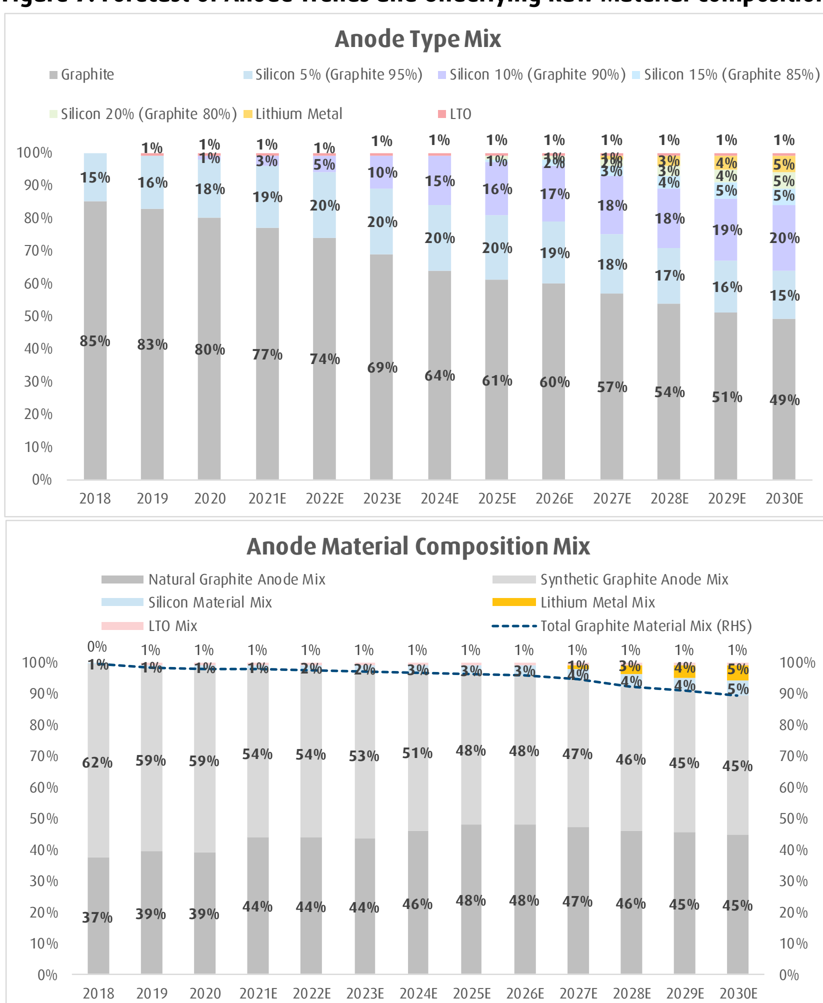
Expect Graphite Anodes to Remain Dominant Amid Practical Assessment of Next-Gen Battery Development Pathways

We expect graphite to continue to be the underlying raw material of choice for EV battery anode material across this decade, holding an underlying composition mix of 96% in 2025E and 90% in 2030E (vs. ~98% in 2020). As an anode material, graphite has proven to be stable, it's predominantly used and ingrained in manufacturing processes, and it provides battery energy density (i.e., vehicle range) that is largely "good enough" for consumer driving habits. However, next-gen batteries offer other potential anode material substitutes (i.e., silicon and lithium metal) that would generate much higher energy density lower volume/weight requirement; along with other potential benefits like improved battery safety. At this stage, both substitute anode materials still have R&D hurdles with reaching commercialization. If next-gen battery start-ups can develop prototypes for EVs in the coming years as planned, follow-on auto qualification processes will still take up to five years. The manufacturability and cost competitiveness (vs. LIBs at massive scale by this time) must also be viable to warrant large-scale production, which would take a couple years to scale-up. We see next-gen battery commercialization at scale by the latter half of the decade, at the earliest.

- **We see greater uptick of silicon blending with graphite (with growing silicon composition therein),** but we see this largely capped at 10% silicon/90% graphite blends (and 15-20% silicon at most) vs. some batteries using ~5% silicon today. Adding silicon to graphite anode material increases energy density, but there is a limit before battery safety/life is compromised.

- **We model low-single-digit penetration of lithium metal anodes by the end of the decade.**

Figure 7: Forecast of Anode Trends and Underlying Raw Material Compositions Over Time



Source: Industry Reports, Company Reports, BMO Capital Markets

Figure 8: Pros and Cons of Main Anode Material Options

Anode Material	Specific Capacity (mAh/g)	% Volume Increase (Swelling)	Benefits	Challenges (current)
Commercialized				
Lithium Titanium Oxide (LTO)	175	n/a	Very safe = no lithium plating	Lowest energy density
Graphite	375	10%	Stable; widely used	Limited energy density
Next-Gen				
Pure Silicon	3,600	300%	High energy density, lightweight, ample supply	Extreme volume changes impacting safety/longevity
Lithium Metal	3,860	None	Very high energy density, lightweight	Unstable, slow charge, supply chain challenges

Source: Nitta et al., 2015, BMO Capital Markets

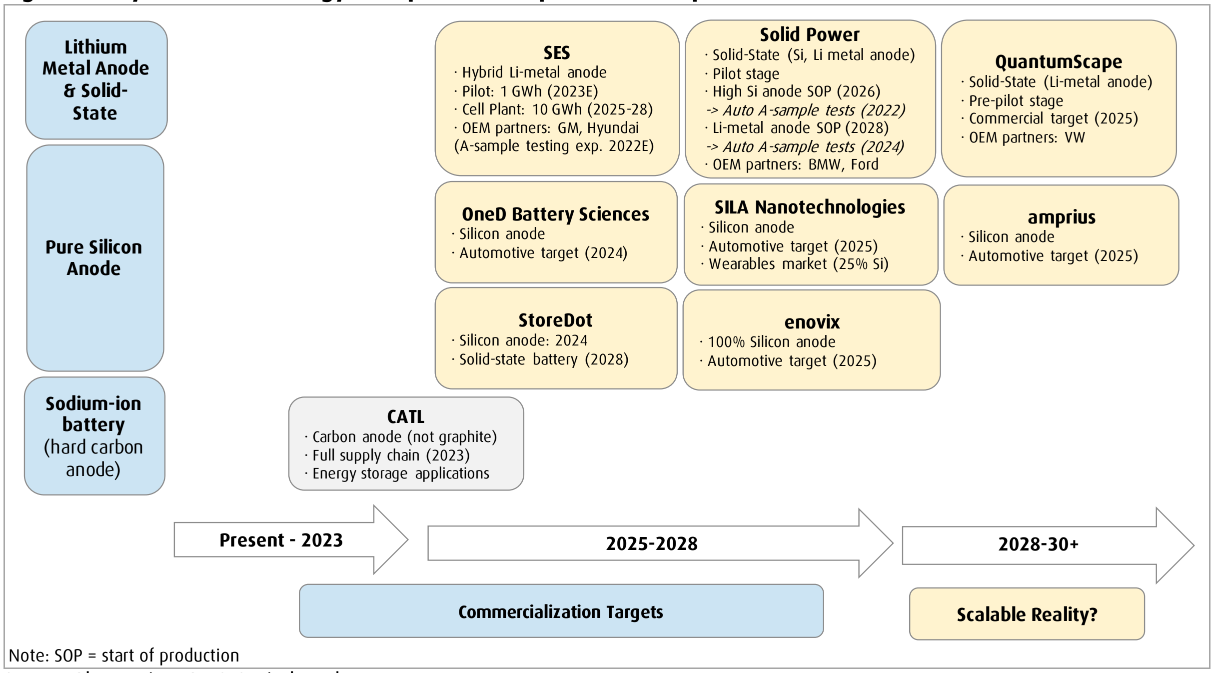
Where are major auto OEMs in all of this? Western auto OEMs have recognized that they are unlikely to compete with Asian incumbents on traditional LIB manufacturing anytime soon, if ever. As a result, major Western EV OEMs either buy third-party batteries or have formed production joint ventures with S.Korean/Japanase battery OEMs. That said, select auto OEMs (e.g. GM, Ford, BMW, VW) have made small seed investments in start-up companies (i.e., Solid Power, QuantumScape, SES, etc.) developing next-generation batteries as an attempt to ensure first-mover status on that frontier. These investments provide optionality and upside potential if the technology is proven, but are not core mid-term battery strategies in our view. These investments amount to only a few hundred million dollars, a tiny sum within massive $30 billion plus EV investments per company over the mid-term. S.Korean battery OEM SK Innovation recently invested $30 million into Solid Power as part of a joint development agreement to develop solid-state batteries (with a target of high-silicon/graphite blended anodes by 2025, and lithium metal anode by 2030), as well as to assess the manufacturability of SSBs with existing LIB equipment (a key hurdle in our view).

The qualification and testing timeline for new battery materials/technologies for use in EVs can take upwards of five years, and this is after technological hurdles are overcome at the battery cell R&D phase and proven beyond lab levels (this is still under way for high-silicon/lithium-metal anodes and SSBs). We understand some of the individual steps below can be done in parallel, but typically the total timeline from post-R&D cells to driver-ready EV production is roughly three to five years. First, the battery cell manufacturer tests the new raw material supply (discussed in detail elsewhere in this report), which takes at best 12 months. Next, the battery maker certifies the manufacturing facilities and suppliers of the raw material supplier, which takes about six months. If an auto OEM likes the theoretical performance of the new battery cells with the underlying raw materials based on the cell manufacturer's tests, the auto OEM then initiates its own testing and cycling at the auto level over a three-to-four-year period. This includes the standard A-sample to D-sample testing/qualification timeline. If the auto OEM is satisfied after A-D sample testing, the full production facilities and supply chains of the battery cell maker and raw material supplier are vetted to determine commercial manufacturing scalability, which takes about six months. If successful, the battery with the new material is now qualified to be installed in a production car. The resulting scale-up of commercial auto production with the new battery material will also take another year or two.

Overview of auto OEM battery cell testing process:

- A-sample testing (1-2 years): validate the battery cell concept and probe multiple designs and material combinations to test performance against customer requirements.
- B-sample testing (1-2 years): validate the battery pack design to include battery module and pack testing to ensure performance meets customer spec.
- C-sample testing (6-months): validate battery cell production process based on B-sample design for vehicle integration at the auto prototype level.
- D-sample testing (1-year): validate vehicle performance using battery cell to ensure performance and safety requirements are met ahead of full commercial production if cleared.

Figure 9: Key Anode Technology Disruptors and Expected Development Timelines



Source: Rho Motion, BMO Capital Markets

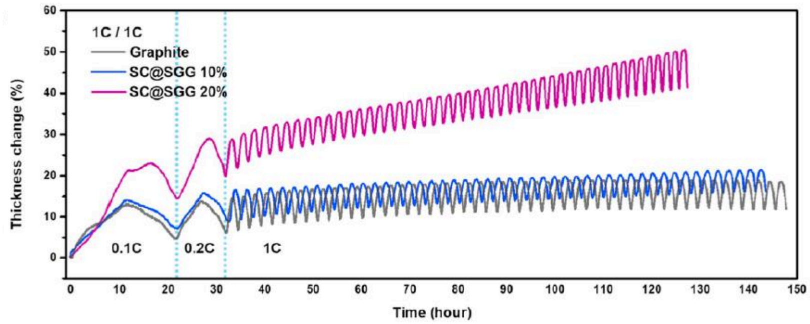
Quick overview of key considerations and limitations for next-gen anode material technologies:

- Refer to previous BMO research for a deeper dive report on anode materials.
- **Pure silicon-based anodes**: silicon material enables much higher energy density potential and, therefore, EV range as the specific capacity of silicon is ~10x higher than graphite. However, silicon tends to swell up more than ~300% during charging and discharging (vs. graphite of sub-10%), leading to material pulverization and irreversible capacity loss. In other words, the battery ages prematurely (i.e., it only lasts around 100 cycles), notwithstanding the impractical design requirements of a cell material expanding 300%. The processes involved in producing a more efficient silicon anode design that keeps the swelling in check are not cost competitive and/or are impractical, and the increased surface area causes other problems in the cell that disrupts the overall performance of the battery.
- **Silicon composite anodes (i.e., silicon-graphite blends):** blending graphite material with small amounts of silicon (~5%) has proven to be commercially viable and has enabled positive energy density improvements within the battery (i.e., 5-10% silicon can boost energy density by ~10-20%). However, a greater mix of silicon generates diminishing marginal improvements to energy density and at increasingly lower stability creating a losing trade-off much beyond this mix level, at least at this stage. We do not expect the composition of silicon to reach much higher than 10% of the anode (i.e., with 90% graphite blends) this decade as amounts well past this level likely requires a new (solid) electrolyte material, requiring several years of further development and testing at best. We model low-single-digit penetration of 15-20% silicon blends later this decade assuming technological breakthroughs allow for it, but really under the current structure ~10% silicon is the maximum allowable mix before material swelling occurs.

Silicon blends likely capped at ~10% (90% graphite) in anode material

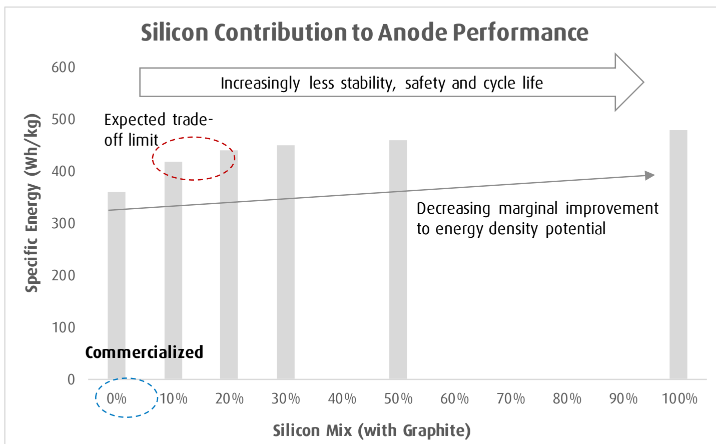
Natural graphite helps to reduce silicon swelling in anode blends somewhat

Figure 10: Anode Material Is Prone to Severe Swelling With Silicon Blends Above 10% Currently



Reprinted with permissions from He *et al.* (2021). *Considering Critical Factors of Silicon/Graphite Anode Material for Practical High-Energy Lithium Battery Applications.* American Chemical Society; 35(2):944-964.

Figure 11: Expect Silicon Blending in Anode Material to Be Largely Capped at 10% Over the Mid-Term



Source: UC San Diego, Industry Reports, BMO Capital Markets

- **Lithium metal anodes:** the option with the highest energy density potential (with ~12x the theoretical capacity of graphite anodes), with faster charging capability and improved safety given the potential need to replace the conventional liquid electrolyte (key ignition to battery fires) with a solid electrolyte material, i.e., solid-state batteries. However, there remain many technological barriers to commercialization at this stage. The key issue with lithium metal anodes and solid-state batteries currently is the excessive levels of lithium dendrite/spike formation within the cell that pierces the separator and causes short circuits and potentially thermal runaway (fire), compromising battery longevity/safety. Most solid-state battery start-ups expect to work out the various R&D stages/kinks in the next few years, to then be ready for multi-year downstream vehicle tests ahead of commercialization. **This timeline translates to market penetration closer to the back half of the decade at the earliest, in our view. Again, that is if significant technological hurdles can be overcome at commercial scale and also prove to be cost competitive** (i.e., essentially must be manufacturable within existing LIB plant frameworks). We understand SSB pre-pilot/pilot level testing to date has been proven to work due to the material uniformity within a *small* cell prototype, or the batteries were tested at low charge rates (i.e., not practical for EV use) with fast charging capability likely requiring very specialized and expensive equipment. In addition, production of solid-state cells with lithium metal may require a dry-air environment (as lithium metal is highly reactive with water vapor in the air), which is expensive and not likely compatible with lithium-ion battery Gigafactory designs. We also note that the lithium anodes require high-quality lithium metal foils, which are not widely available currently. A leading lithium metal supplier (Ganfeng) recently stated that it does not expect lithium metal adoption as an anode material until 2028 at the earliest. **If lithium metal anodes prove to be commercially viable, we believe the potentially higher battery manufacturing costs would**

lend to luxury EV markets and/or more demanding end-markets such as electric aviation, vs. mass-market EVs.

- Hybrid lithium-metal battery developer SES recently unveiled a demo of an automotive-size battery cell (100 Ah) and announced plans to build a 1 GWh facility by 2023. SES is working towards a hybrid lithium-metal battery (replacing graphite-based anode) with a proprietary liquid electrolyte. SES previously worked on solid-state batteries but ultimately deemed the technology practically infeasible. At this stage, further key cell testing is required (incl. lifecycle tests, safety tests, high-low temperature tests, etc.) for the auto-sized prototype battery ahead of planned auto A-sample testing expected by 2022-end (with GM and Hyundai). If successful, SES plans to be in commercial production by 2025.

New Graphite-Based Anode Material Projects Required in Bull and Base Case Demand Scenarios

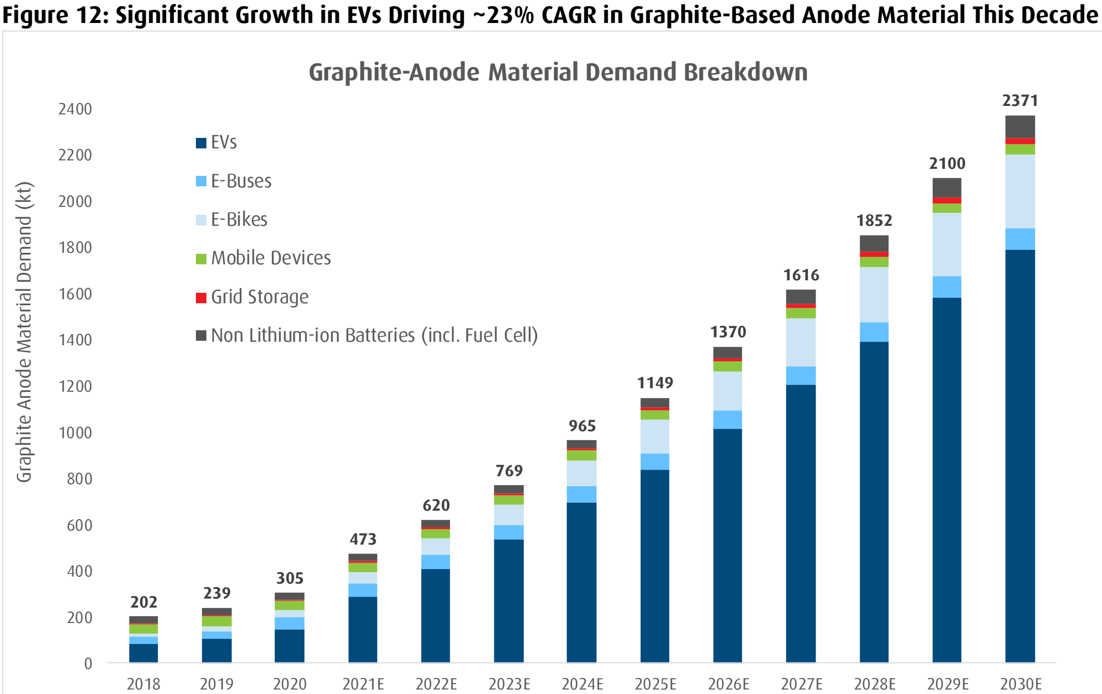
We believe there will be a necessity for incremental graphite-based anode material supply from alternative projects to the largely dominant Chinese/Japanese incumbents in order to fulfill mid-term downstream demand expectations and for better global supply chain diversity overall. Our base case anode material supply and demand estimates suggest a tightening market across the decade, and this is based on the assumptions/factors that: 1) graphite-based anode material market share gradually holds to ~90% by 2030E from ~98%; 2) many new prospective entrants for graphite-based anode material supply are currently unfunded and require multi-year downstream qualification (on top of potential delays and/or development and product quality risks); and 3) the big-four Chinese anode material producers have already telegraphed massive capacity growth expectations this decade.

We model graphite-based anode material demand of ~470kt/1,150kt/2,400kt in 2021/25/30E as a base case, implying ~23% demand CAGR off 2020 levels. The majority of expected anode material demand is underpinned by lithium-ion battery-related demand (graphite-based anodes are used in lead-acid/alkaline batteries as well) and largely from electric vehicle growth. We also assume that battery anode material requires 1.2kg of battery-grade graphite anode material per kWh.

EV batteries typically require ~50-65kg of graphite anode material (~1.2kg/kWh)...

...the largest active material weight across all battery tech

Figure 12: Significant Growth in EVs Driving ~23% CAGR in Graphite-Based Anode Material This Decade

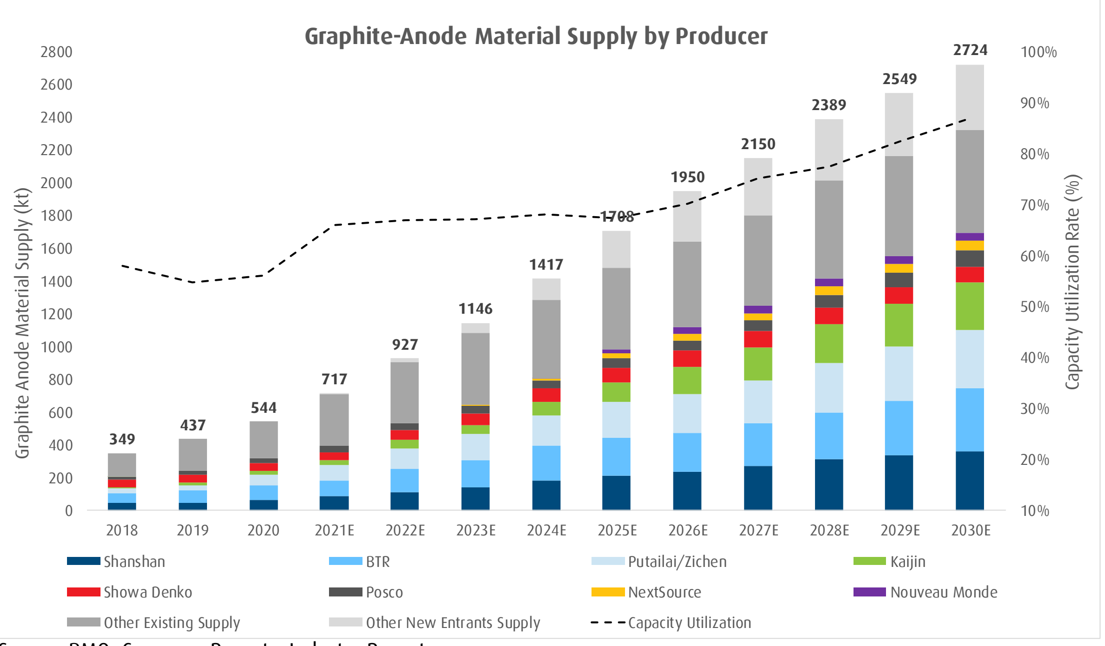


Source: BMO, Company Reports, Industry Reports

Chinese big-four anode producers expected to hold ~50% of mid-term supply

We model graphite-based anode material capacity of ~715kt/1,700kt/2,725kt in 2021/25/30E as a base case, implying ~18% CAGR off 2020 levels. This is underpinned by massive expansion plans from the major incumbents from China (i.e., BTR, Shanshan, Zichen and Kaijin), Japan (i.e., Showa Denko, Mitsubishi Chemical, etc.) and S.Korea (i.e., POSCO, EcoPro, L&F Chemical, etc.), expected to maintain majority market share across the decade. This includes the big-four tier 1 Chinese producers all recently announcing plans to add an incremental 200kt of anode material capacity each in Sichuan (we assume beginning mid-decade) on top of the large plans already under way. We believe the supply picture is somewhat de-risked considering the size and recency of incumbent announcements. In addition, roughly 75% of planned new anode capacity growth is synthetic-based material (vs. mined/natural graphite), which is higher cost. As a result, **we see a plausible pathway that would necessitate various new (ex. Asia) anode material entrants/projects to come to market, particularly natural graphite-based anode material projects targeting the European and N.American battery manufacturing plants looking for supply chain diversity.**

Figure 13: Graphite-Anode Material Supply Controlled by Select Chinese/Japanese Incumbents



Source: BMO, Company Reports, Industry Reports

Expect Mix Shift in Favor of Natural Material in Graphite Anodes

Anode material is typically blended to balance performance and costs:

We believe lower-cost anode material derived from natural-based graphite feedstock will gain share within graphite-anode blends with synthetic material this decade, particularly from Western EV OEM supply chains. Graphite-anode material can be made from either natural graphite material (using mined graphite) and synthetic graphite. Each option has different characteristics and are often blended together to balance performance and costs. The quality and consistency have historically been superior with synthetic anode material, but production costs are ~30-50% higher. Natural graphite anode material (CSPG) production quality has also improved in recent years with technological advancements such that increasing its mix within blends to lower costs is increasingly possible without compromising battery performance.

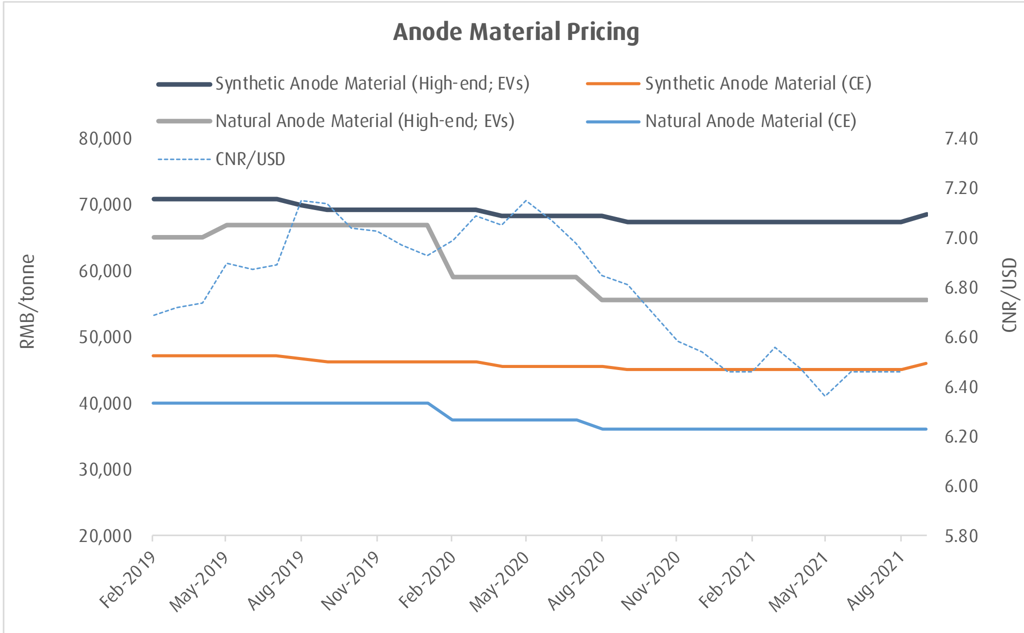
Synthetic graphite provides better battery life (and historically is more readily available)...

We expect the availability of CSPG supply will be the key limiting factor to a higher mix shift, not demand. This is partially a function of limited high-grade domestic Chinese natural graphite production growth availability for CSPG feedstock (China has increased flake graphite imports in recent years) and is also prioritizing synthetic graphite anode production. This is further exacerbated by the broadly unfunded status of ex. Asia new entrants currently and non-trivial anode material process development paths to meet stringent downstream quality/safety standards.

...while natural graphite lowers battery production costs and has good low-temp performance

We model 50/50 natural and synthetic blends within anode material across the decade (vs. ~40/60 natural/synthetic blends in 2020) and expect new entrant CSPG suppliers who can successfully bring online new production and break into Western auto OEM supply chains as best positioned to benefit.

Figure 14: Lower-Priced CSPG Anode Material vs. Synthetic Expected to Be a Key Factor for Mix Gains of Natural Graphite Within Anode Material Blends This Decade



Source: ICCSINO, FactSet, BMO Capital Markets

We believe auto/battery OEMs have an incentive to shift to a greater relative mix of natural graphite-based anode material (if it's available and meets quality thresholds) for the following key reasons:

- *Significantly lower cost* - synthetic anode material prices trade ~30-50% higher than CSPG prices due to the inherently higher production costs. This has been further exacerbated with a recent tightness of Chinese graphitization capacity coupled with electrical power constraints in China. Note that anode material makes up ~10-15% of battery raw material costs.

- *Lower carbon footprint* - synthetic anode material is derived from a very energy-intensive process by "graphitizing" raw materials from the hydrocarbon industry (e.g. petroleum needle coke, etc.), with the power consumption during graphitization ~13-14 MWh per tonne.

- *Lower Chinese concentration risk* – while this likely only pertains to N.American/European EV OEMs, we note that Chinese companies dominate synthetic anode material production whereby Japanese and S.Korean anode suppliers typically favor natural graphite anode material (and thus are more prominent in S.Korean/Japanese batteries, the main partners for U.S./Euro auto OEMs).

- *Better compatibility with select additives to boost battery energy density* - natural graphite helps to reduce the swelling of silicon to allow marginal increases of silicon additives to anode material mix.

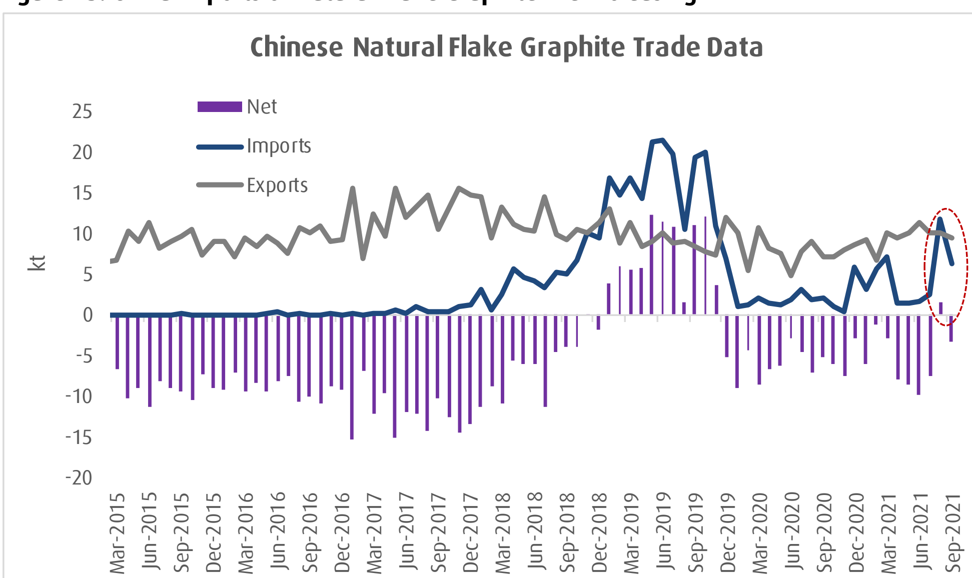
Tesla is increasing mix of natural graphite in its anode material to lower costs

An industry shift to natural over synthetic anode material is already under way – *a Tesla case study.* We understand Tesla/Panasonic batteries utilize ~50/50 blends of synthetic/natural anode material currently (vs. 60/40 previously) with low-to-mid-single-digits of silicon additives. Tesla's in-development 4680 battery cell form factor is expected to have a graphite-based anode material split of 40-45/55-60% synthetic/natural with 5-10% silicon. However, we understand the Tesla batteries derived from CATL are 100% synthetic (owing to China's synthetic anode material production dominance and availability, and lack of Chinese IP with anode material blending). **Tesla management had some interesting comments when asked about the company's anode material strategy on the Q3/21 earnings call:**

- *"...there's less of a focus on rapidly changing [anode material] one way or the other because they're generally stable commodities"*
- *"the primary focus on the anode side that we have is just ensuring that we are able to continue to reduce the cost of the anode without impeding on the long-term cyclability of the product"*
- **BMO's view**: it does not seem that Tesla is planning to overhaul anode material technology anytime soon in favor of next-gen components, and in fact the comment about continuing to lower anode material costs without impeding long-term cyclability is indicative of an increasing shift to use more natural graphite anode blends (lower cost, worse cyclability) relative to synthetic graphite anode material (higher cost, better cyclability). Tesla's battery strategy also includes increasing the energy density of the anode by adding more silicon (whereby natural anode material can help to reduce silicon's swelling issues).

We expect incremental CSPG supply to be disproportionately dependent on ex. China natural flake graphite projects (many of which remain unfunded) owing to limited high-quality Chinese natural-flake expansion opportunities, with over 75% of China's anode material supply growth expected from synthetic graphite. China has been the dominant supplier of graphite for decades, both natural and synthetic, with higher-quality domestic natural flake production largely already in circulation (averaging 90-94% purity), limiting growth potential going forward particularly for feedstock for anode material. Related to this is the fact that current graphite production in China has a large mix of lower-quality amorphous graphite (~40/60% amorphous/flake) not suitable for anode material processing. As a result, **Chinese imports of natural flake graphite have significantly increased in recent years, potentially marking a shift whereby China may become a sustained net importer of flake graphite.** This dynamic would also help to level the playing field for vertically integrated ex. China CSPG suppliers from a cost perspective (graphite feedstock and freight are large cost components), crucial for new entrants to be competitive.

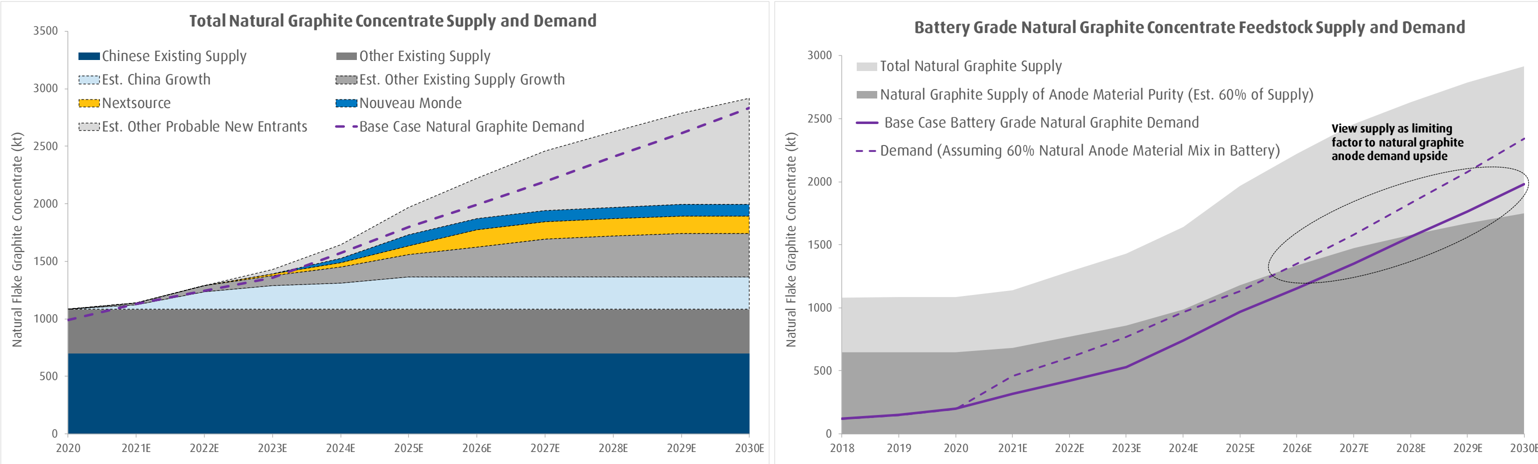
Figure 15: China Imports of Natural Flake Graphite Are Increasing



Source: CEIC

We view the supply of battery-grade natural graphite supply as a limiting factor to increased use/demand as an anode material. The majority of graphite deposits have average flake distributions whereby ~30-75% of the mix is cost efficient for anode material processing (i.e., small-medium flakes), with select projects having a portion (or all, if amorphous) of the grade distribution unacceptable or too costly for anode material processing. Even conservatively assuming 60% of global natural flake graphite supply is amenable to anode material processing, the supply and demand outlook appears tight for natural graphite demand in graphite anode material at 50% (vs. synthetic) this decade.

Figure 16: Expect Market Further Tightness for Natural Graphite Suitable for Anode Material This Decade

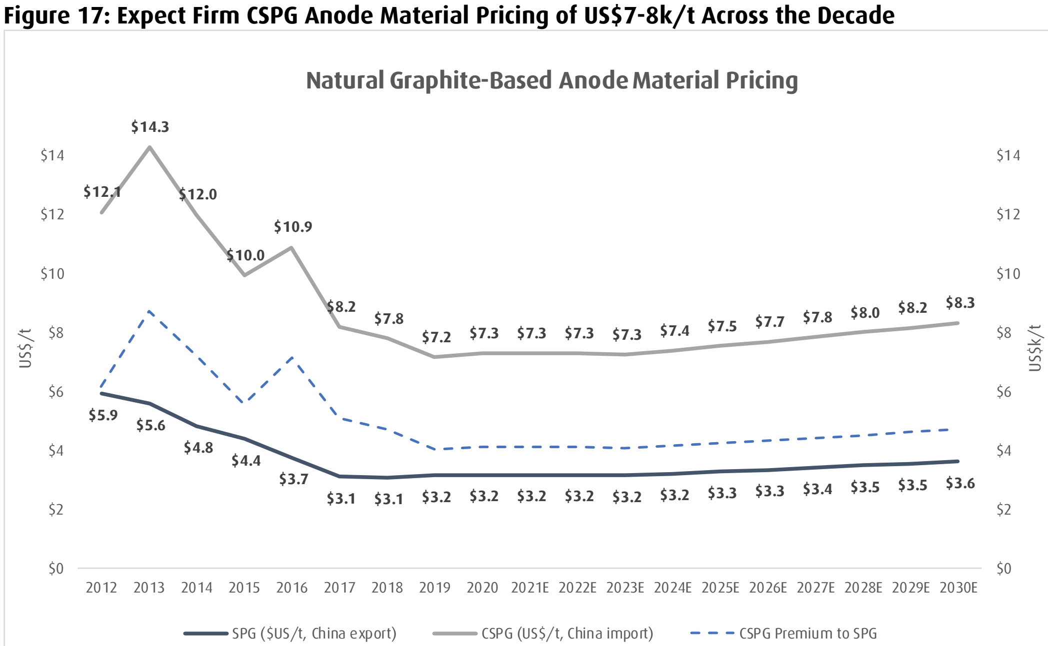


Source: Company Reports, Industry Reports, BMO Capital Markets

Expect CSPG Pricing to Remain Firm With Upside Potential by Mid-Decade

We expect a supportive backdrop for CSPG pricing upside. While industry anode material price discovery is very opaque, we feel comfortable modeling CSPG ASPs of US$7-8k/t across the decade (vs. US$6-7.5k/t currently), above current average industry opex costs of US$3.5-6k/t. We believe this is a function of continued demand growth for anode material in general (~23% CAGR to 2030E), but also particularly for CSPG material specifically given the inherent cost savings relative to synthetic graphite alternatives. We also expect potential downside risk to natural-based anode material supply given the broad unfunded status of various natural graphite new entrants and non-trivial nature with SPG/CSPG processing (for new entrants planning to be downstream vertically integrated). In addition, we expect potential industry cost curve pressure associated with incremental natural anode material production in China due to a growing reliance on feedstock from ex. China markets with elevated feedstock freight costs (i.e., to send graphite concentrate feedstock from mine to anode material plants) and/or from third-party feedstock at market prices.

Figure 17: Expect Firm CSPG Anode Material Pricing of US$7-8k/t Across the Decade



Source: Fastmarkets, BMO Capital Markets

We understand CSPG cash costs are on average ~US$3.5-6k/t (almost half the cost of synthetic anode material production) but could experience potential upside pressure going forward. This may occur as most incremental natural graphite projects needed are outside of China causing graphite feedstock cost inflation from greater feedstock freight (mine to plant) and/or via increased third-party purchases, and also from increased environmental scrutiny and associated costs. The wide CSPG cash cost range is largely a function of the level of vertical integration of the entire process. Anode material production is fairly bifurcated with graphite concentrate mining, processing and purification (to SPG product), and coating (to CSPG product) often done by different companies due to varying specialties (requiring additional margin buffers along the way). There is also the final freight cost of shipping anode material to cell manufacturing plants, which can be meaningful if not intended for localized battery cell manufacturing, i.e., from China to Europe/N.America (US$500-1,000/t).

- *Feedstock costs (~US$700-1,300/t).* Graphite concentrate cost curves range from US$300/t (China) to US$800/t. Due to average anode material process yields (of ~50%), on average two tonnes of graphite concentrate feedstock is needed per tonne of anode material end-product. Feedstock costs could be even higher if the material is purchased from a third-party graphite producer, which will likely increasingly be the case for Chinese SPG/CSPG processors in order to meaningfully expand capacity.

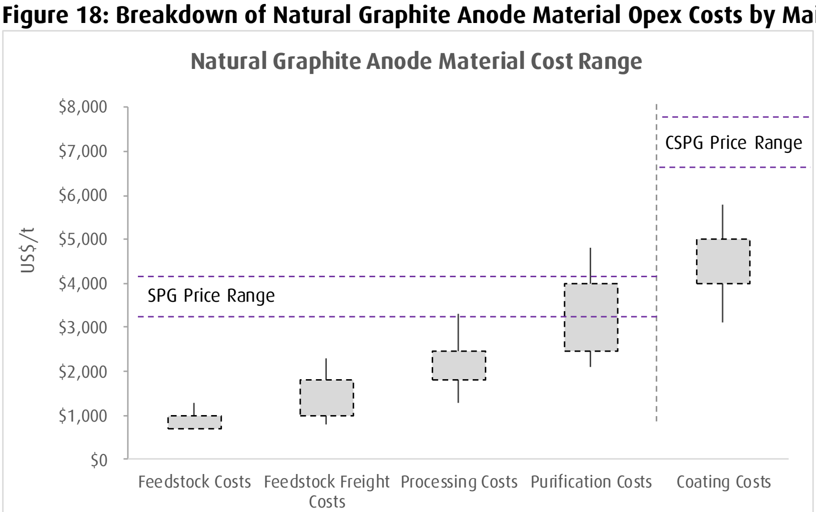
- *Feedstock freight costs (~US$100-1,500/t).* These are the costs associated with shipping graphite concentrate feedstock to the anode material plant, often in a different location. With a large portion of incremental natural graphite projects based in Africa/Australia/Canada and coinciding anode plants in Asia, U.S. or Europe, average feedstock freight costs could trend towards the upper end of this range. Graphite mines typically produce a basket of sizes/specs, with only a portion amenable to anode material processing. As a result, graphite concentrate is separated at the mine and shipped to different end customers directly or for anode material processing, minimizing scale benefits for shipment.

- *Processing costs (~US$500-1,000/t).* This involves the micronization and spheronization processing steps, with costs largely a function of process yields (i.e., ratio of concentrate feedstock required per end-product) and dependent on graphite feedstock quality and process know-how.

- *Purification costs (~US$800-1,500/t).* The purification costs are dependent on the type of process used, with conventional hydrofluoric/alkali acid processes in China at the low end (particularly if environmental procedures are not followed, but we understand are beginning to be more enforced) while high temperature thermal purification methods are higher cost (by ~50-100% within China) with energy costs a key variable (~30% of thermal purification costs).

- *Coating (~US$1,000-1,200/t).* Higher-value coating typically takes place in Japan and S.Korea, though increasingly in China by licensing Japanese IP.

Figure 18: Breakdown of Natural Graphite Anode Material Opex Costs by Main Components



Source: Company Reports, Industry Reports, BMO Capital Markets

Push for More Localized Battery Supply Chains Creates Opportunity for Ex-Asia Anode Material Production

We see an opportunity for ex-Asia anode material production given the significant anode material demand stemming from battery cell manufacturing growth in N.America and Europe this decade. We recognize the challenges for new anode material entrants to penetrate a well-ingrained supply chain currently dominated by a handful of incumbents geographically positioned to supply market-leading Asian battery manufacturers. However, we believe new anode material suppliers could find a foothold within a more geographically diverse supply chain structure, particularly given the increased mindfulness of the environmental footprint (and geopolitics) of Western EV/battery OEMs as well as the logistical benefits.

Key factors incentivizing localized anode material supply:

- **Supply chain diversification.** N.American and European auto/battery OEMs are increasingly looking to limit raw material concentration risk across the entire supply chain inclusive of predominantly Chinese anode material supply. China currently represents ~85% of lithium-ion battery anode material production globally, followed by Japan (~10%) and S.Korea (~5%).

Figure 19: Handful of Tier 1 Anode Material Incumbents Dominate the EV/Battery Supply Chain Currently

Anode Producer	Primary Location	Market Share Estimate			Downstream Battery OEM Customer
		2020E	2025E	2030E	
BTR Energy	China	16%	14%	14%	Panasonic/Tesla, LG Chem, Samsung, BYD and Sony
Shanshan	China	12%	12%	13%	LG Chem, CATL, BYD, Sony, Lishen, BAK
Putalai / Zichen	China	12%	13%	13%	Panasonic, CATL
Kaijin	China	5%	7%	11%	CATL
Shangtai Tech	China	3%	4%	3%	CATL
Mitsubishi Chemical	Japan	2%	2%	1%	Panasonic, Samsung
Showa Denko	Japan	9%	5%	4%	Panasonic/Tesla, Samsung, LG Chem
Posco	S.Korea	5%	4%	4%	LG Chem, Ultium, SK Innovation
Total		**63%**	**61%**	**62%**	

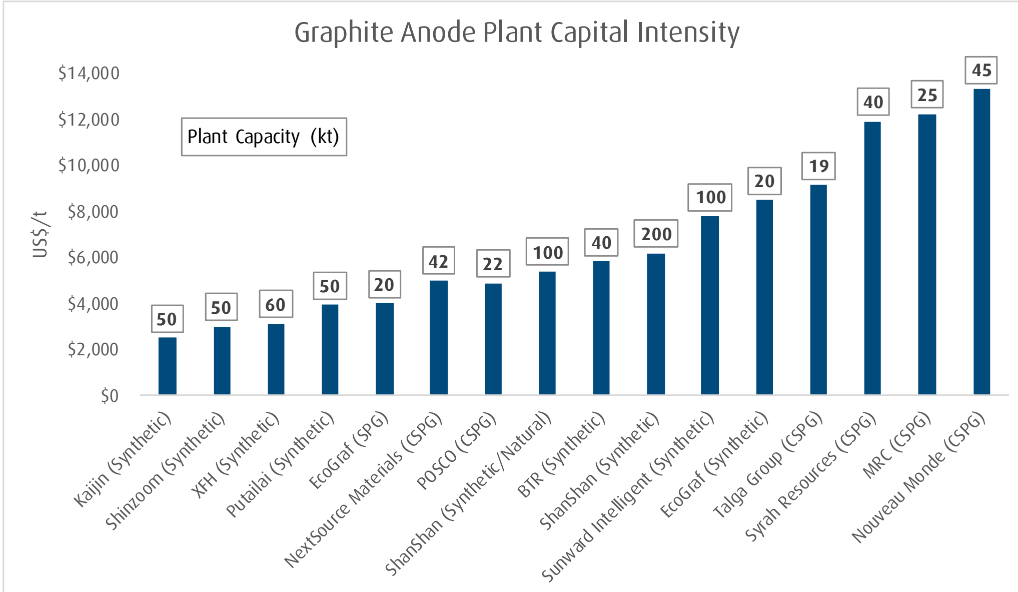
Source: BMO, Company Reports, Industry Reports

- **Faster shipment and reduced shipping costs.** Normalized anode material shipments from China to N.America take one to two months and cost ~US$500-1,000/t (~10-15% of natural graphite-based anode production costs and ~5-10% of synthetic-based anode production costs). However, in the current environment of tight markets for battery materials coupled with global freight constraints, we understand delivery times are closer to three months and cost upwards of US$1,500/t. This compares to normalized timelines of days or a week for delivery within N.America at sub-US$100/t and three to five weeks for European delivery at a cost of US$200-500/t.
- **Lower environmental footprint demands of EV/battery OEMs.** While life-cycle assessments may not materially drive EV/battery supply chain decisions in the next few years, we believe that they likely will in the latter half of this decade as more environmentally friendly supply alternatives come to fruition, and as regulation (and EV customers) begins demanding it. This would be significant for the graphite-based anode material market considering energy intensity of both natural and synthetic production and given the level of wastewater contamination from cheaper Chinese acid-based CSPG purification methods.
    - *Chinese anode material suppliers are already beginning to respond as the Chinese big four anode producers (BTR, Shanshan, Kaijin, Zichen) have all planned large 200kt anode material expansions in Sichuan/China to utilize the regions hydropower.*

Anode plant capital intensities ~2-3x lower in Asia

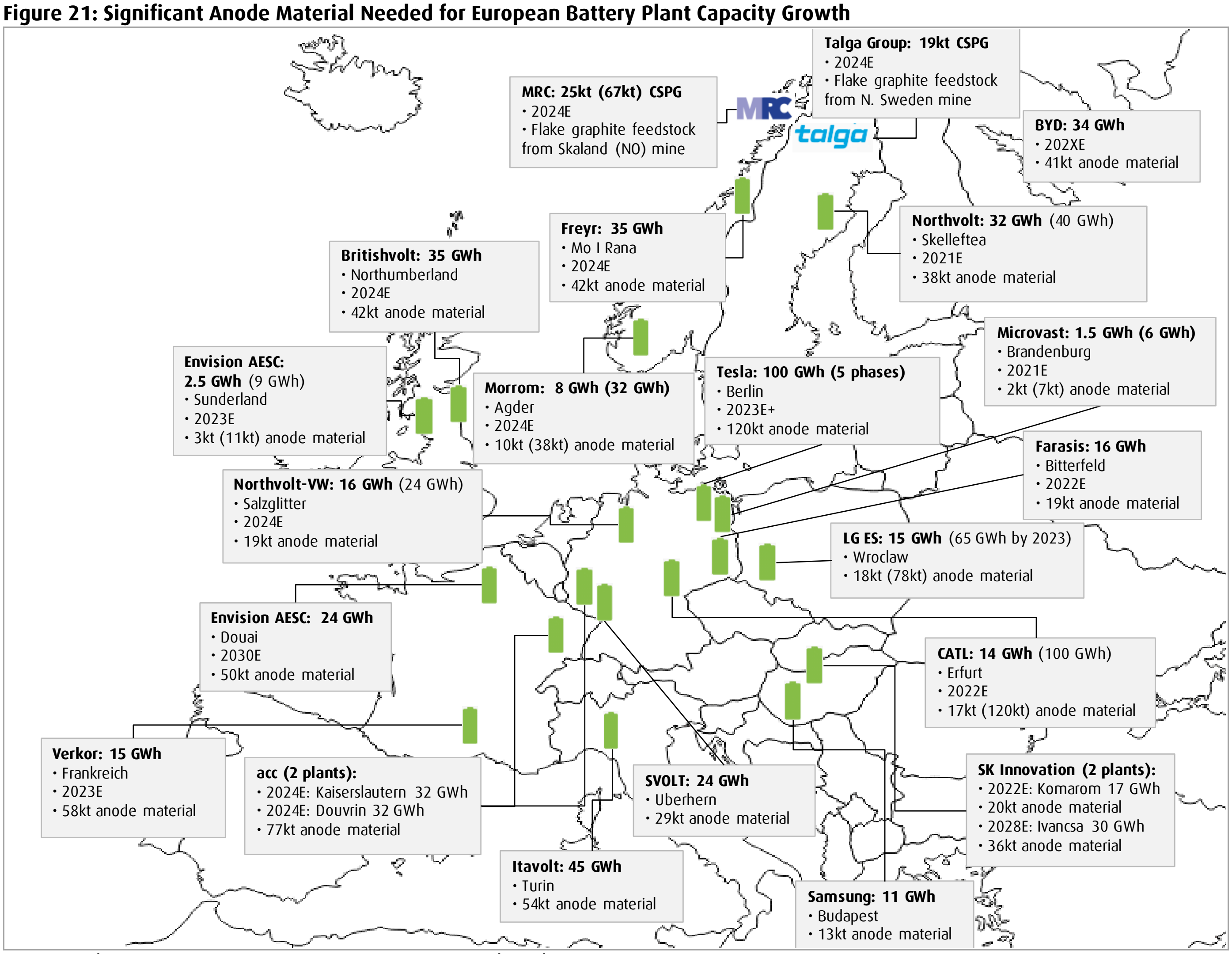
The disincentive to localized N.American/European anode material production is with upfront capex costs. Capital intensity levels of Asian graphite anode material plants range between ~US$3-8k/t vs. select N.American and European plants with expected capex costs of ~US$9-13k/t. This is a function of cheaper labor and lower equipment costs with acid purification methods (used in China) in SPG/CSPG processing.

Figure 20: Wide Range of Industry Graphite-Anode Plant Capital Intensities



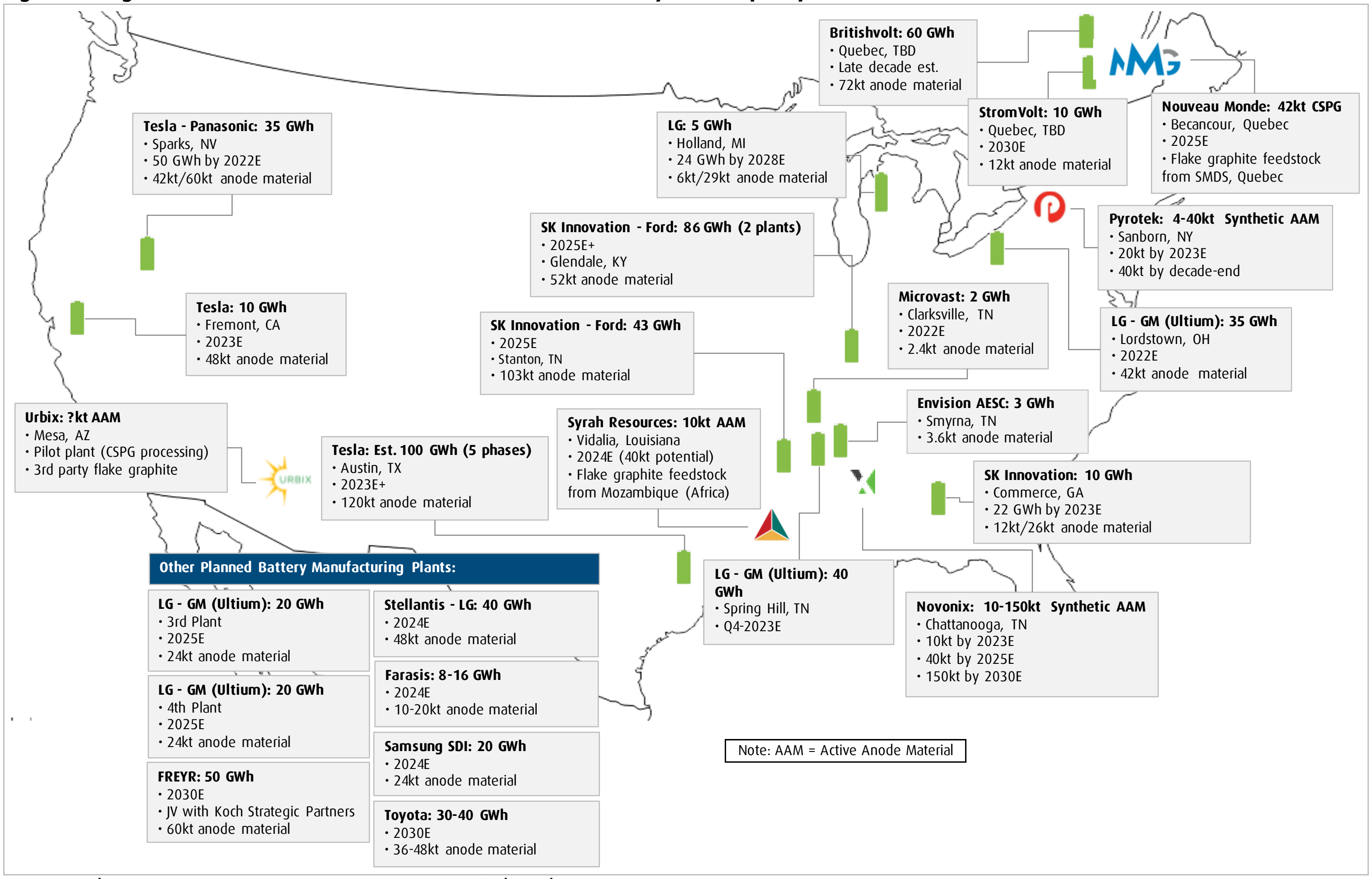
Source: Industry Reports, Company Reports, BMO Capital Markets

Figure 21: Significant Anode Material Needed for European Battery Plant Capacity Growth



Source: Industry Reports, Company Reports, BMO Capital Markets

Figure 22: Significant Anode Material Needed for N.American Battery Plant Capacity Growth



Source: Industry Reports, Company Reports, BMO Capital Markets

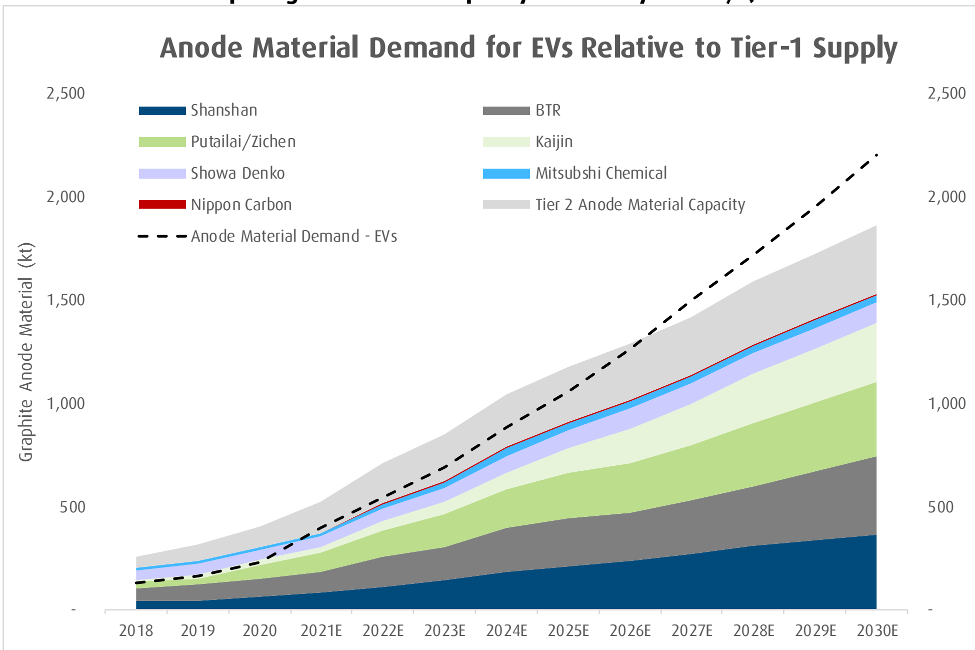
Anode Material Qualification Processes a Key Hurdle for New Entrants

Anode material qualification into EV supply chains for new entrants can take 2-3 years (or even longer)

Prospective new sources of anode material (particularly if used in EV batteries) must undergo extensive product qualification and testing with cell manufacturers that can take up to two years (if production tweaks need to be made), or at best roughly 12 to 18-months. Downstream qualification/testing at the vehicle level is an incremental 9 to 12 months. Anode material is sold directly to cell manufacturers who must ensure the new prospective supplier can *consistently* meet specific requirements, but also has a product that "works" with other battery cell components like the cathode and electrolyte to ensure the battery cell meets performance and safety thresholds. Cell manufacturers monitor the aggregate impurity levels of the entire system, e.g. if the anode material has high levels of a specific impurity that also happens to be present in the cathode material supply, then this could breach impurity thresholds as well. We understand the testing, process familiarization and optimization (with other components at the cell level), which could involve various back-and-forth tweaks to produce required spec, can take up to two years. Part of this timeline is a function of the necessity to prove consistent spec quality across numerous material batches and at larger scale (i.e., beyond pilot plant production levels and certainly beyond lab scale). This is on top of traditional raw material QA/QC period that takes roughly four to six months. In addition, Tier 1 battery manufacturers (required status for EV production) have typically longer qualification timelines with more stringent demands. As a result, anode material is not often interchanged between suppliers and typically a battery OEM will source material from two to three suppliers with the same anode material supplier/spec used for each specific battery cell production line.

- **Key properties required of graphite-based anode material for cell manufacturing.** First, graphite-based anode material must meet specific reverse capacity (energy density) thresholds (i.e., how much energy the anode can hold post-charge) of at least 350 mAh/g. Second, cell manufacturers will assess degradation risk by testing whether the anode's energy density can be sustained over the battery lifecycle and typically must retain ~80% of the original capacity for ~1,500 charge cycles to be useful in an electric vehicle.

Figure 23: Planned Tier 1 and Tier 2 Anode Capacity Growth Insufficient for Expected EV-Based Anode Material Demand Requiring Incremental Capacity to Be Fully Tested/Qualified for EV Battery Use



Source: Company Reports, Industry Reports, BMO Capital Markets

- **Key natural graphite properties required for anode material:**
  - *Purity (% carbon):* battery/auto OEMs require spherical purified graphite (SPG) purity of >99.95% for lithium-ion batteries, but the remaining 0.05% must also not contain select impurities above certain thresholds (this may also change depending on the impurity levels present in other battery components). *Typically, graphite concentrate feedstock for SPG processing is preferred to be 94% purity, with higher purity levels often fetching higher prices partly as resulting anode material processing costs are lowered.*
  - *Particle size (microns; 1 micron = 0.001mm):* this has to do with surface area of the material where the lithium ions attach themselves when the battery is in a charged state. The ideal particle size range is between 5-70 microns (though most are 9-35 microns). If the particle sizes are too large, there are too many voids, lowering the surface area that lithium ions attach themselves to and this reduces energy density potential. In summary, lower micron levels increase energy density and typically garner a price premium to product with higher micron levels. *It is more cost efficient to use smaller natural graphite flake sizes (in microns) for anode material processing, and largely in the form of opportunity costs given variation in graphite concentrate ASPs.*

➢ *As a result, the best natural graphite projects have a balanced flake size distribution containing a sizable portion of small/medium-size flakes (ideal for anode material processing) as well as large/jumbo flakes (typically sold directly to high-value traditional markets at higher prices), in addition to having a deposit that can be economically processed to high purity levels (a function of minimum ore grade but also absent meaningful levels of detrimental impurities, e.g. sulphide).*

Figure 24: Key Factors for Natural Graphite Deposits Are Balanced Flake Distribution and Purity

End-Market Notes	Classification	Mesh Range	Size Range (Microns)	Carbon Purity (Higher = $)	Price Range (US$/t)
Sold directly to high-value traditional markets *(can also be used as anode material feedstock)*	Jumbo Flake	48	500–300	90-97%	$1,500-2,500
	Large Flake	80	180	90-97%	$1,200-1,500
Ideal for anode processing (>94% purity desired); mid-level traditional markets	Medium Flake	100	150	90-97%	$800-1,200
	Small Flake	200	75	90-97%	$600-800
Low-end industrial uses (pencils, etc.)	Amorphous	300		80-85%	$300-400

Source: Industry Reports, BMO Capital Markets

Anode Material Production Process Complexities Not to Be Overlooked

Anode material requires significant value-added processing across various non-trivial/technical steps in order to meet sufficient spec/quality/performance demanded by auto/battery OEMs. This increases process risk for new entrants but also creates higher barriers to entry if process know-how and proven process ability can be achieved. Graphite-based anode material production is dominated by Asian incumbents with refined process know-how; while end-to-end anode material manufacturing process is yet to be replicated at commercial scale outside of Asia. Further still, while there are select companies in Asia that are fully integrated and perform each step in the graphite and anode material processing chain, there are companies that specialize in certain individual steps of the process, i.e., separating the coating stage between SPG and CSPG (i.e., Showa Denko, Mitsubishi Chemical, etc.).

- **Overview of key anode material manufacturing steps beginning with graphite concentrate as feedstock:**
  - *Micronization:* graphite concentrate is reduced in size by ~10x from ~100-300 microns to 10-35 microns. This essentially allows the lithium ions to get in and out of the anode quickly. Lower micron levels are harder to achieve but ensure better battery/vehicle performance and hence typically fetch price premiums.
  - *Spheronisation:* curves the graphite flakes into spheres to increase surface area density and thus energy density potential. There is typically significant yield loss at this stage (~30-70%) as flake edges are prone to breaking. Yield comes down to graphite quality, i.e., if the graphite flakes are too brittle then they can break, as well as particle size with lower micron/sized product (based on micronization step) resulting in lower yields and ultimately more emissions. The material at this stage is tiny and not trivial to handle (e.g. human hair is ~100 microns, dust is ~25 microns vs. 10-35 for anode material). **Process yields have a direct impact on the amount of graphite concentrate feedstock required and consequently on costs as well (average industry anode process yields are ~50%). We understand this process is fairly bespoke, particularly given the very fine material sizing at this stage, with industrial-scale techniques considered high-value IP with spheronization equipment often tweaked post-delivery by anode material producers**
  - *Purification:* this is where impurities are removed to reach spheronized-purified-graphite (SPG) of 99.95%+ purity level suited for battery manufacturing. The two main purification methods are acid purification (hydrofluoric acid, HCl acid, etc.) and thermal purification.

Graphite quality (flake size, grade, etc.) a key factor in anode material process yield/costs...

... the lower the feedstock quality the more costly to process

China's anode production opex/capex advantages partly rely on HF acid purification methods

The main differences include cost (influenced by power source), environmental restrictions, and impurity levels.

- Hydrofluoric acid purification is the main method used in China where environmental and labor safety regulations are less stringent. This method is cheaper (relative to the more energy intensive thermal purification method) but creates issues with wastewater contamination if not properly handled.
- Thermal purification involves putting the material through high-temperature furnaces/kilns (1,500-3,000°C), which is an energy intensive process and hence requires low cost power sources to be cost competitive.

CSPG typically sells for ~$6-8k/t whereas (uncoated) SPG sells for ~$3-4k/t

- *Coating:* a very important step to reach battery-grade anode material (CSPG). Coating provides the following essential benefits: first, it enhances energy density by allowing a smoother surface for a larger number of lithium ions to attach to during battery charging; and second, it increases the safety and longevity of the battery by inhibiting side reactions with the electrolyte causing battery degradation. **Coating is likely the most specialized part of the entire process (select Japanese companies specialize in coating and also license the IP) as there is a very fine line between being too thick (limiting energy density by reducing space for active material) or too thin (reducing battery safety/longevity).**

Appendix: Quick Graphite 101

Graphite is a carbon-based material with a crystalline form that is produced both synthetically and naturally (flake, amorphous, and vein). The most relevant forms of graphite, particularly for graphite-based anode material, are synthetic and flake graphite.

- *Amorphous graphite (5-10% of 2020 supply)*: has the lowest purity level of all four graphite sources with a carbon content of ~70-80% and no visible crystallinity, and thus has limited applications (paint, coating, pencil industries, etc.). It attracts much lower value compared to other graphite types. Amorphous graphite cannot be used for lithium-ion battery anode material.
- *Flake graphite (~30% of 2020 supply)*: the most common form of natural graphite for use in industrial applications and increasingly in lithium-ion batteries as technological advancements have improved quality/purity over time. Flake graphite has various sub-classifications determined by grade (percentage of carbon content) and flake size (fine, small, medium, large, etc.) that often determines appropriate end-use application and pricing. Flake graphite deposits range from 2-30% carbon grade, though following onsite concentration processes can reach purity levels of 90-97%.
- *Vein graphite (<1% of 2020 supply)*: very rare form of high-purity natural graphite with limited economic deposits globally.
- *Synthetic/artificial graphite (~60% of 2020 supply):* produced from byproducts of oil refining such as petroleum needle coke and coal tar pitch following a high-temperature and pressurized process (graphitization). As a result, it is the more expensive production method relative to natural graphite options with high levels of energy required. That said, synthetic graphite has unique properties (higher consistency) that make it better equipped for select industries including electrode production used in electric arc furnaces in the steel industry, as well as anode material for lithium batteries (though natural graphite purity/quality has caught up in recent years).

Overview of some of graphite's key properties:

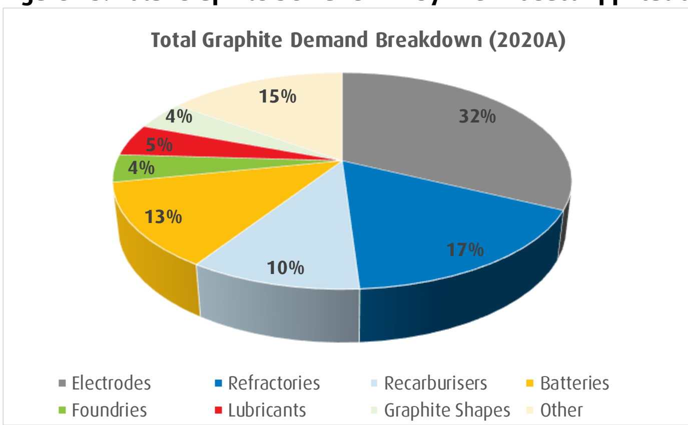
- Excellent conductor of electricity and heat
- High natural strength and stiffness, including in temperatures over 3500°C
- Natural lubricant
- Lightweight
- Chemically inert/stable

Graphite demand (~2.8Mt in 2020; ~7% CAGR to 2030E). Graphite end-markets are largely linked to steel production and other industrial and manufacturing applications (GDP-like growth), as well as increasingly for anode material for lithium-ion batteries (25%+ demand CAGRs).

- Electrodes (~30% of demand): the largest end-use for graphite currently and largely used in electric arc furnace steel production. The electrode production process solely uses synthetic graphite as natural graphite does not provide the consistency needed.
- Refractories (~15% of demand): used in linings for furnaces, incinerators, reactors, etc. with graphite primarily used as an additive to increase refractory product effectiveness and withstanding high temperatures, but also physical corrosion from chemical reagents. Natural graphite is the primary source for refractories.
- Recarburisers (~10% of demand): additives in the steel and cast-iron production process to adjust hardness properties. Natural graphite is the primary source though can also be used with synthetic.

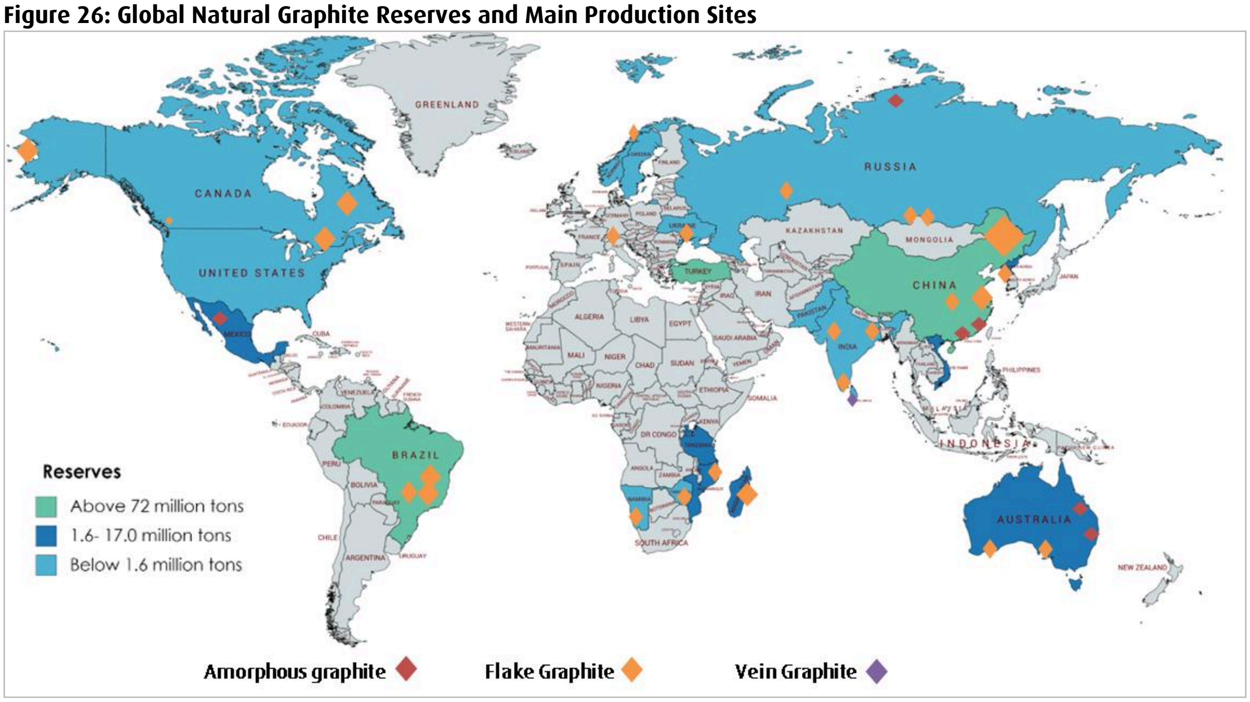
- Batteries (~8% of demand): the largest growth area for graphite demand as a feedstock to anode material used in lithium-ion batteries. Graphite is also used in other more mature battery applications including lead-acid and alkaline batteries.
- Foundries (~5% of demand): used for metal casting/moulding, most commonly sand casting. Natural graphite is applied as a mould prior to casting for protection and increase lubrication.
- Lubricants (~5% of demand): graphite is used as a dry lubricant or mixed with lubricating oil with major applications in air compressors, railway track joints, ball bearings, etc.
- Graphite Shapes (~4% of demand): graphite can be machined into a variety of shapes and handle high temperatures and, therefore, is used in various industrial applications, electronics, aerospace, etc.
- Other (~20% of demand): friction linings of brake pads, seals, glass industry, flame retardants, etc.

Figure 25: Total Graphite Demand Mix by End-Product Application

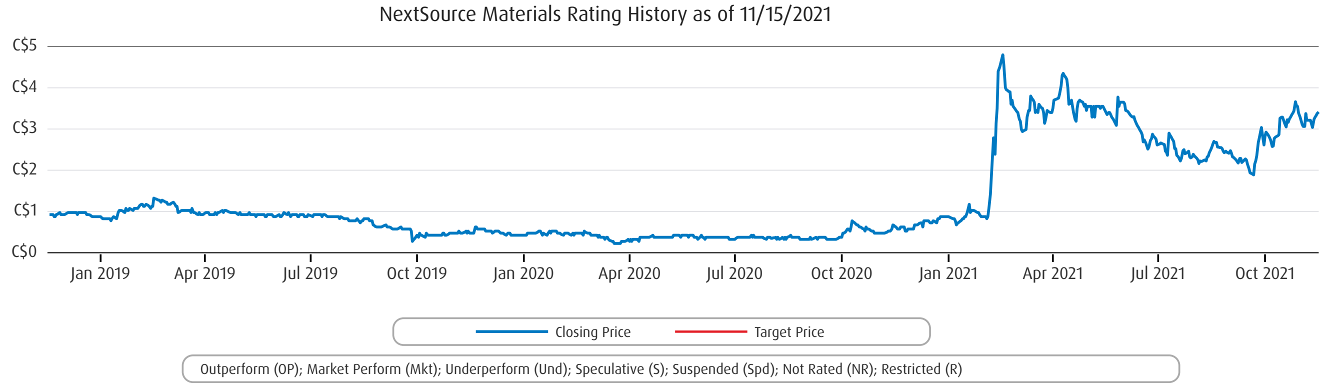


Source: Industry Reports, BMO Capital Markets

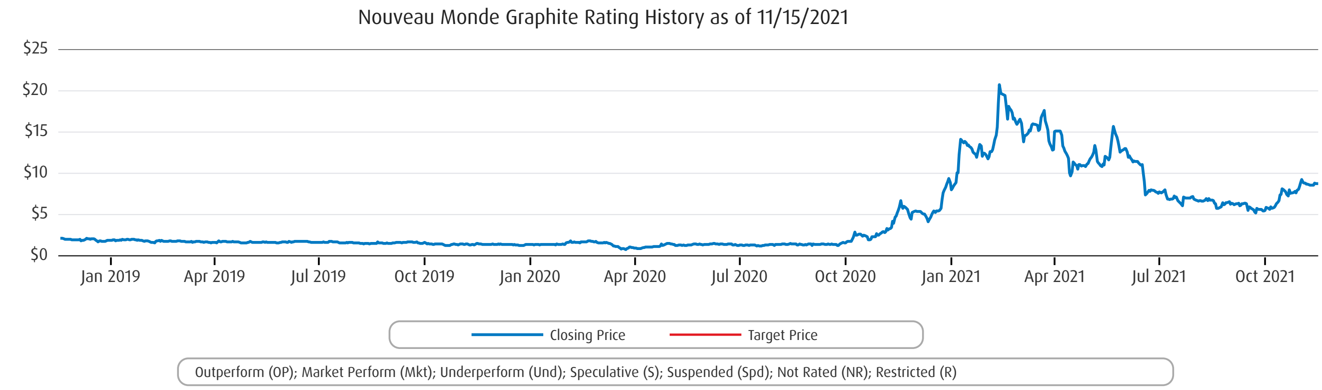
Figure 26: Global Natural Graphite Reserves and Main Production Sites



Source: mapchart.net, USGS, BMO Capital Markets



Source: FactSet, BMO Capital Markets



Source: FactSet, BMO Capital Markets

IMPORTANT DISCLOSURES

Analyst's Certification

I, Robin Fiedler, hereby certify that the views expressed in this report accurately reflect my personal views about the subject securities or issuers. I also certify that no part of my compensation was, is, or will be, directly or indirectly, related to the specific recommendations or views expressed in this report.

Analysts who prepared this report are compensated based upon (among other factors) the overall profitability of BMO Capital Markets and their affiliates, which includes the overall profitability of investment banking services. Compensation for research is based on effectiveness in generating new ideas and in communication of ideas to clients, performance of recommendations, accuracy of earnings estimates, and service to clients.

Analysts employed by BMO Nesbitt Burns Inc. and/or BMO Capital Markets Limited are not registered as research analysts with FINRA. These analysts may not be associated persons of BMO Capital Markets Corp. and therefore may not be subject to the FINRA Rule 2241 restrictions on communications with a subject company, public appearances and trading securities held by a research analyst account.

Company Specific Disclosures

Disclosure 1: BMO Capital Markets has undertaken an underwriting liability with respect to Nouveau Monde Graphite within the past 12 months.

Disclosure 2: BMO Capital Markets has provided investment banking services with respect to Nouveau Monde Graphite within the past 12 months.

Disclosure 3: BMO Capital Markets has managed or co-managed a public offering of securities with respect to Nouveau Monde Graphite within the past 12 months.

Disclosure 4: BMO Capital Markets or an affiliate has received compensation for investment banking services from Nouveau Monde Graphite within the past 12 months.

Disclosure 6A: Nouveau Monde Graphite is a client (or was a client) of BMO Nesbitt Burns Inc., BMO Capital Markets Corp., BMO Capital Markets Limited or an affiliate within the past 12 months: A) Investment Banking Services

Disclosure 9B: BMO Capital Markets makes a market in Nouveau Monde Graphite in United States.

Disclosure 16: A research analyst has extensively viewed the material operations of Nouveau Monde Graphite.

Disclosure 18: A redacted draft of this report was previously shown to NextSource Materials and Nouveau Monde Graphite (for fact checking purposes) and changes were made to the report before publication.

Methodology and Risks to Target Price/Valuation for NextSource Materials (NEXT-TSX)

Methodology: Our target implies a ~20% annual discount to 13x 2026E EV/EBITDA split between anode material earnings (at 15x) and graphite earnings (at 6x).

Risks: First, dissolution of downstream anode material partnerships. Second, project financing is delayed and/or executed under punitive terms. Third, significant opex and capex inflation for phase-2 expansions. Fourth, mine jurisdiction risk. Fifth, advancements in next-gen battery/anode technology impacting graphite-based anode material demand and/or price longer-term.

Methodology and Risks to Target Price/Valuation for Nouveau Monde Graphite (NMG-NYSE)

Methodology: Our target implies a ~20% annual discount to 13x 2026E EV/EBITDA split between anode material earnings (at 15x) and graphite earnings (at 6x).

Risks: First, failure to achieve sufficient vertically integrated CSPG product quality at cost efficient levels. Second, project financing is delayed and/or executed under punitive terms. Third, significant opex and capex overruns for expansions. Fourth, unable to place graphite concentrate volume into higher-end markets as expected. Fifth, does not achieve above-average anode material processing yields as expected. Sixth, anode material price discovery from still to be determined downstream contracts. Seventh, advancements in next-gen battery/anode technology impacts graphite-based anode material demand and/or price longer term.

Distribution of Ratings (November 15, 2021)

Rating category	BMO rating	BMOCM US Universe*	BMOCM US IB Clients**	BMOCM US IB Clients***	BMOCM Universe****	BMOCM IB Clients*****	StarMine Universe~
Buy	Outperform	51.8 %	28.4 %	57.4 %	54.2 %	59.5 %	57.7%
Hold	Market Perform	46.9 %	21.7 %	39.7 %	44.4 %	39.2 %	37.5%
Sell	Underperform	1.3 %	57.1 %	2.9 %	1.4 %	1.3 %	4.8%

* Reflects rating distribution of all companies covered by BMO Capital Markets Corp. equity research analysts.

** Reflects rating distribution of all companies from which BMO Capital Markets Corp. has received compensation for Investment Banking services as percentage within ratings category.

*** Reflects rating distribution of all companies from which BMO Capital Markets Corp. has received compensation for Investment Banking services as percentage of Investment Banking clients.

**** Reflects rating distribution of all companies covered by BMO Capital Markets equity research analysts.

***** Reflects rating distribution of all companies from which BMO Capital Markets has received compensation for Investment Banking services as percentage of Investment Banking clients.

~ As of April 1, 2019.

Other Important Disclosures

For Important Disclosures on the stocks discussed in this report, please go to https://researchglobal0.bmocapitalmarkets.com/public-disclosure/ or write to Editorial Department, BMO Capital Markets, 3 Times Square, New York, NY 10036 or Editorial Department, BMO Capital Markets, 1 First Canadian Place, Toronto, Ontario, M5X 1H3.

Dissemination of Research

Dissemination of fundamental BMO Capital Markets Equity Research is available via our website https://researchglobal0.bmocapitalmarkets.com/. Institutional clients may also simultaneously receive our fundamental research via email and/or via services such as Refinitiv, Bloomberg, FactSet, Visible Alpha, and S&P Capital IQ.

BMO Capital Markets issues a variety of research products in addition to fundamental research. Institutional clients may request notification when additional research content is made available on our website. BMO Capital Markets may use proprietary models in the preparation of reports. Material information about such models may be obtained by contacting the research analyst directly. There is no planned frequency of model updates.

The analyst(s) named in this report may discuss trading strategies that reference a catalyst or event that may have a near or long term impact on the market price of the equity securities discussed. In some cases, the impact may directionally counter the analyst's published 12 month target price and rating. Any such trading or alternative strategies can be based on differing time horizons, methodologies, or otherwise and are distinct from and do not affect the analysts' fundamental equity rating in the report.

Research coverage of licensed cannabis producers and other cannabis-related companies is made available only to eligible approved North American, Australian, and EU-based BMO Nesbitt Burns Inc., BMO Capital Markets Limited, Bank of Montreal Europe Plc and BMO Capital Markets Corp. clients via email, our website and select third party platforms.

~ Research distribution and approval times are provided on the cover of each report. Times are approximations as system and distribution processes are not exact and can vary based on the sender and recipients' services. Unless otherwise noted, times are Eastern Standard and when two times are provided, the approval time precedes the distribution time.

For recommendations disseminated during the preceding 12-month period, please visit: https://researchglobal0.bmocapitalmarkets.com/public-disclosure/.

General Disclaimer

"BMO Capital Markets" is a trade name used by BMO Financial Group for the wholesale banking businesses of Bank of Montreal, BMO Harris Bank N.A. (member FDIC), Bank of Montreal Europe p.l.c, and Bank of Montreal (China) Co. Ltd, the institutional broker dealer business of BMO Capital Markets Corp. (Member FINRA and SIPC) and the agency broker dealer business of Clearpool Execution Services, LLC (Member FINRA and SIPC) in the U.S., and the institutional broker dealer businesses of BMO Nesbitt Burns Inc. (Member Investment Industry Regulatory Organization of Canada and Member Canadian Investor Protection Fund) in Canada and Asia, Bank of Montreal Europe p.l.c. (authorised and regulated by the Central Bank of Ireland) in Europe and BMO Capital Markets Limited (authorised and regulated by the Financial Conduct Authority) in the UK and Australia. Bank of Montreal or its subsidiaries ("BMO Financial Group") has lending arrangements with, or provide other remunerated services to, many issuers covered by BMO Capital Markets. The opinions, estimates and projections contained in this report are those of BMO Capital Markets as of the date of this report and are subject to change without notice. BMO Capital Markets endeavours to ensure that the contents have been compiled or derived from sources that we believe are reliable and contain information and opinions that are accurate and complete. However, BMO Capital Markets makes no representation or warranty, express or implied, in respect thereof, takes no responsibility for any errors and omissions contained herein and accepts no liability whatsoever for any loss arising from any use of, or reliance on, this report or its contents. Information may be available to BMO Capital Markets or its affiliates that is not reflected in this report. The information in this report is not intended to be used as the primary basis of investment decisions, and because of individual client objectives, should not be construed as advice designed to meet the particular investment needs of any investor. Nothing herein constitutes any investment, legal, tax or other advice nor is it to be relied on in any investment or decision. If you are in doubt about any of the contents of this document, the reader should obtain independent professional advice. This material is for information purposes only and is not an offer to sell or the solicitation of an offer to buy any security. BMO Capital Markets or its affiliates will buy from or sell to customers the securities of issuers mentioned in this report on a principal basis. BMO Capital Markets or its affiliates, officers, directors or employees have a long or short position in many of the securities discussed herein, related securities or in options, futures or other derivative instruments based thereon. The reader should assume that BMO Capital Markets or its affiliates may have a conflict of interest and should not rely solely on this report in evaluating whether or not to buy or sell securities of issuers discussed herein.

Additional Matters

This report is directed only at entities or persons in jurisdictions or countries where access to and use of the information is not contrary to local laws or regulations. Its contents have not been reviewed by any regulatory authority. BMO Capital Markets does not represent that this report may be lawfully distributed or that any financial products may be lawfully offered or dealt with, in compliance with regulatory requirements in other jurisdictions, or pursuant to an exemption available thereunder.

To Australian residents: BMO Capital Markets Limited is exempt from the requirement to hold an Australian financial services licence under the Corporations Act and is regulated by the UK Financial Conduct Authority under UK laws, which differ from Australian laws. This document is only intended for wholesale clients (as defined in the Corporations Act 2001) and Eligible Counterparties or Professional Clients (as defined in Annex II to MiFID II).

To Canadian Residents: BMO Nesbitt Burns Inc. furnishes this report to Canadian residents and accepts responsibility for the contents herein subject to the terms set out above. Any Canadian person wishing to effect transactions in any of the securities included in this report should do so through BMO Nesbitt Burns Inc.

The following applies if this research was prepared in whole or in part by Colin Hamilton, Alexander Pearce or Raj Ray:

This research is not prepared subject to Canadian disclosure requirements. This research is prepared by BMO Capital Markets Limited and distributed by BMO Capital Markets Limited or Bank of Montreal Europe Plc and is subject to the regulations of the Financial Conduct Authority (FCA) in the United Kingdom and the Central Bank of Ireland (CBI) in Ireland. FCA and CBI regulations require that a firm providing research disclose its ownership interest in the issuer that is the subject of the research if it and its affiliates own 5% or more of the equity of the issuer. Canadian regulations require that a firm providing research disclose its ownership interest in the issuer that is the subject of the research if it and its affiliates own 1% or more of the equity of the issuer that is the subject of the research. Therefore each of BMO Capital Markets Limited and Bank of Montreal Europe Plc will disclose its and its affiliates' ownership interest in the subject issuer only if such ownership exceeds 5% of the equity of the issuer.

To E.U. Residents: In an E.U. Member State this document is issued and distributed by Bank of Montreal Europe plc which is authorised and regulated in Ireland and operates in the E.U. on a passported basis. This document is only intended for Eligible Counterparties or Professional Clients, as defined in Annex II to "Markets in Financial Instruments Directive" 2014/65/EU ("MiFID II").

To U.S. Residents: BMO Capital Markets Corp. furnishes this report to U.S. residents and accepts responsibility for the contents herein, except to the extent that it refers to securities of Bank of Montreal. Any U.S. person wishing to effect transactions in any security discussed herein should do so through BMO Capital Markets Corp.

To U.K. Residents: In the UK this document is published by BMO Capital Markets Limited which is authorised and regulated by the Financial Conduct Authority. The contents hereof are intended solely for the use of, and may only be issued or passed on to, (I) persons who have professional experience in matters relating to investments falling within Article 19(5) of the Financial Services and Markets Act 2000 (Financial Promotion) Order 2005 (the "Order") or (II) high net worth entities falling within Article 49(2)(a) to (d) of the Order (all such persons together referred to as "relevant persons"). The contents hereof are not intended for the use of and may not be issued or passed on to retail clients.

To Israeli residents: BMO Capital Markets is not licensed under the Israeli Law for the Regulation of Investment Advice, Investment Marketing and Portfolio Management of 1995 (the "Advice Law") nor does it carry insurance as required thereunder. This document is to be distributed solely to persons that are qualified clients (as defined under the Advice Law) and qualified investors under the Israeli Securities Law of 1968. This document represents the analysis of the analyst but there is no assurance that any assumption or estimation will materialize.

These documents are provided to you on the express understanding that they must be held in complete confidence and not republished, retransmitted, distributed, disclosed, or otherwise made available, in whole or in part, directly or indirectly, in hard or soft copy, through any means, to any person, except with the prior written consent of BMO Capital Markets.

Click here for data vendor disclosures when referenced within a BMO Capital Markets research document.

For assistance with accessible formats of online content, please contact research@bmo.com.