BMAC Battery Metals Association of Canada

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FOCUS ON

GRAPHITE

FROM

ROCKS

TO

POWER

Strategies to Unlock Canada's Critical Minerals for Global Leadership in Energy Storage, EVs, & Beyond

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From Rocks to Power: Strategies to Unlock Canada's Critical Minerals for Global Leadership in Energy Storage, EVs, and Beyond

Focus on Graphite

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About Us

BMAC | Battery Metals Association of Canada

The Battery Metals Association of Canada (BMAC) is a national non-profit association of industry participants and champions from across all segments of the battery metals value chain. From mining to specialty chemical refining, manufacturing, end use and recycling, BMAC is focused on coordinating and connecting the segments of this value chain, ensuring Canada captures the economic potential of the sector and is able to attain its electrification targets. Together, our members collaborate to accelerate the development of the battery metals ecosystem in Canada.

The Transition Accelerator | L'Accélérateur de transition

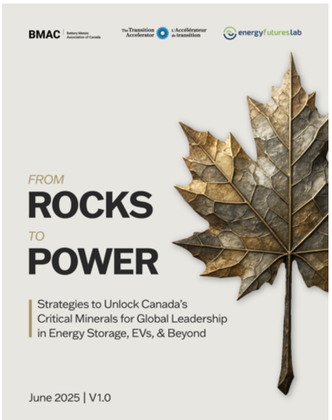
The Transition Accelerator drives projects, partnerships, and strategies to ensure Canada is competitive in a carbon-neutral world. We're harnessing the global shift towards clean growth to secure permanent jobs, abundant energy, and strong regional economies across the country. We work with 300+ partner organizations to build out pathways to a prosperous low-carbon economy and avoid costly dead-ends along the way. By connecting systems-level thinking with real-world analysis, we're enabling a more affordable, competitive, and resilient future for all Canadians.

energy futures lab

The Energy Futures Lab is an award-winning, Alberta-based not-for-profit that brings together a diverse network of innovators, influencers, and system actors from across Canada's energy landscape. Established in 2015, the Lab was created to address growing polarization around Canada's energy transition and respond to its most pressing challenges.

Through trusted leadership and creating non-partisan spaces for collaboration, the Lab convenes stakeholders and Rights and Title Holders to generate and test innovative, enduring solutions to complex, system-level issues. By empowering communities and change-makers to work across divides, the Lab fosters the conditions for meaningful progress toward a shared vision of a resilient and sustainable energy future.

About This Report



This chapter is part of a larger report, *From Rocks to Power: Strategies to Unlock Canada's Critical Minerals for Global Leadership in Energy Storage, EVs, and Beyond*. The full report identifies clear, investable priorities in eight minerals, each of them critical to building resilient EV and energy storage value chains. By looking at specific opportunities and providing detailed justifications for its recommendations, *From Rocks to Power* offers a way out of our perpetual planning cycle and towards a new momentum for Canada's critical minerals sector—and our future economic prosperity.

Read the full report here »

Additional chapters are available for download below:

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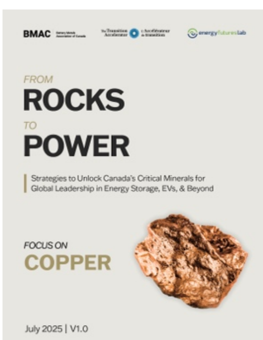

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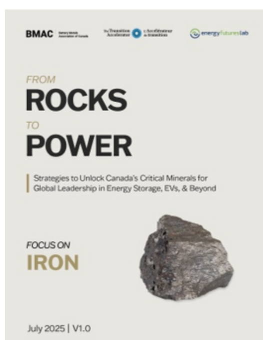

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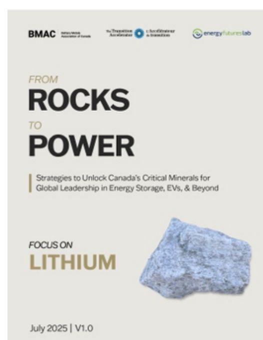

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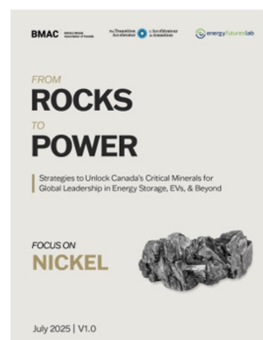

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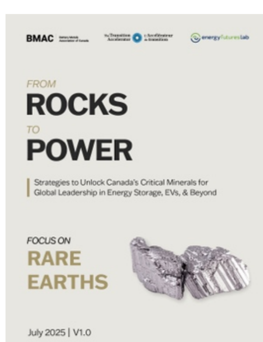

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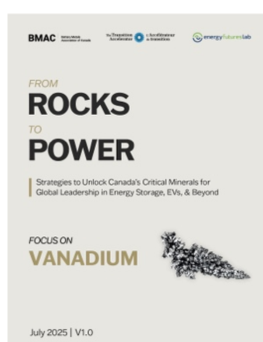

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1 The Canadian Strategy for Graphite

1.1 Graphite in Canada

Table 1 Non-exhaustive selection of former and future graphite extraction and processing projects in Canada

Selection of Operational and Future Natural Graphite Extraction Projects				
Project Name	**Company**	**Province**	**Type**	**Status**
Lac Knife	Focus Graphite	QC	Flake Graphite	Updated FS 2023
Lac Carheil	Metals Australia	QC	Flake Graphite	PFS underway
Lac Tetepisca	Focus Graphite	QC	Flake Graphite	Exploration
Lac des Iles	Northern Graphite	QC	Flake Graphite	Operational
La Loutre	Lomiko	QC	Flake Graphite	PEA 2021
Matawinie	Nouveau Monde Graphite	QC	Flake Graphite	Updated FS 2025
Miller & Asbury	Canada Carbon	QC	Vein (Lump) Graphite	Exploration
Uatnan	Nouveau Monde Graphite + Mason	QC	Flake Graphite	PEA 2023
Albany	Zentek	ON	Hydrothermal Graphite	PEA 2015
Bissett Creek	Northern Graphite	ON	Flake Graphite	FS 2012, Updated EA 2018
Graphite West	Empire Metals Corp	ON	Hydrothermal Graphite	Exploration
Kearney	G6 Energy Corp	ON	Flake Graphite	DFS 2018
Manitouwadge	Volt Carbon Technologies	ON	Flake Graphite	Exploration
Black Crystal Mine	Eagle Graphite	BC	Flake Graphite	Unknown
Selection of Operational & Future Graphite Processing Facilities				
Project Name	**Company**	**Province**	**Product Type**	**Status/Commercial Start**
Regen Resources Recovery	Regen Resources Recovery	ON	Synthetic Graphite Recovery	Unknown
Graphite & Carbon Terrebonne Facility	Imerys	QC	Exfoliation & Processing	Operational
Bécancour Anode Material Plant	Nouveau Monde Graphite	QC	Anode Material	2027 or before
Baie-Comeau Anode Material Plant	Northern Graphite	QC	Anode Material	2027
Innova Cleantech	Innova Cleantech	AB	Methane to Graphite + Hydrogen	Pilot
Graphene & Anode Material Plant	NanoXplore	QC	Anode Material*	2026

GraphPure & GraphRenew Facility	Green Graphite Technologies	QC & ON	Purification & Recovery	Pilot
Air Classifier Facility	Volt Carbon Technologies	ON	Dry Beneficiation Equipment	2025

*NanoXplore's Future Products: Silicon/Graphene; Coated Spherical Purified Graphite; Conductive Graphene

Canada is a notable player in the graphite industry. According to the U.S. Geological Survey, Canada ranked 7th for world natural graphite extraction in 2022, with 13,000 tonnes of graphite produced, and 9th for global reserves, representing 5,700,000 tonnes. More optimistic reporting by Natural Resources Canada indicates that Canada ranked 6th in 2022, not considering South Korean production but with similar figures as the USGS. NRCan also discloses a higher graphite reserve, amounting to 5,900,000 tonnes.[1,2]

All Canadian production comes from a single site: the Northern Graphite-operated Lac-des-îles mine in Québec.[3] The company recently acquired Mousseau West, an area close to the first production site, to prolong its activities.[4] No milling, shaping, purification or coating facilities operate in Canada.

Northern Graphite started to develop a mining project in Bissett Creek, Ontario,[5] and has collaborated to open a graphite anode refinery in Baie-Comeau, Québec.[6–8] The company Nouveau Monde Graphite is opening up a graphite mine in Matawinie, Québec,[9] while they started the construction of a battery anode material plant in Bécancour, Québec, in 2025 to better integrate the graphite supply chain vertically. Mitsui and Panasonic participated.[9,10] Finally, they are collaborating with Mason Graphite on a joint mine/concentrator in Lac Guéret, Québec, for the Uatnan mining project, which is thought to have one of the richest graphite deposits in the world.[11–13] Meanwhile, Canada Carbon Inc. plans to re-use former lump/vein mines in Québec (Miller and Asbury) to produce high-quality graphite products for nuclear application.[14] Volt Carbon Technologies, a company developing lithium solid-state batteries and an innovative graphite flake particle separator called Air Classifier, also holds properties in the Manitouwadge flake graphite project in Ontario and in Lochabar, Québec.[15,16] Their process could replace graphite flotation steps, thus avoiding water usage, chemical use and decreasing energy consumption. The company is building a demonstration plant in Scarborough, Ontario.

Lomiko recently received funding from the Natural Resources Canada (NRCan) and the U.S. Department of Defense for its La Loutre exploration project in southern Quebec.[17]

Lithion Technologies, a Quebec-based company specializing in black-mass processing to extract lithium, cobalt, and nickel from recycled batteries, is also interested in developing solutions for graphite circularity in partnership with Nouveau Monde. Similarly, Green Graphite Technologies, a company based in Montreal and Kingston, is developing modular purification solutions for natural graphite. Those include novel processing steps from natural graphite feeds or graphite recovery methods from recycled sources to produce battery-grade graphite. Green Graphite Technologies has secured collaborations with Nouveau Monde and Eagle Graphite, and has recently received $3.5 million from NRCan.[18] Finally, NanoXplore, a Montreal-based company and the world's largest producer of graphene, is treating natural graphite to convert it into graphene products. They plan to produce anode materials for batteries, such as silicon/graphene; coated spherical purified graphite and conductive graphene. Their parent company, VoltaXplore, is developing silicon-graphene-based li-ion batteries.

Canadian startups focusing on biographite R&D, which processes biowaste into graphite, are represented by CarbonIP Technologies and previously by NanoTerraTech.

1.2 Target

Our 2022 report, 'Roadmap for Canada's Battery Value Chain,' established the following objectives for graphite. As it should be needed in anodes for the next two decades and due to the solid Canadian reserves, Canada should seek to capture far more than 10% of the North American EV market by 2030. A leader scenario to reach 35% of the North American market can be considered.

Table 2 Graphite targets

Graphite Mandated Benchmark (10% of 2030 North American Market)		
	2030	**2040**
Graphite (ktpa CSPG)	111	223
Anode active material plants needed	3	5
New refining facilities	1	2
Graphite Leader scenario (35% of 2030 North American Market)		
Graphite (ktpa elemental)	350	750
Anode active material plants needed	3	5

1.3 Scenario Outline

Canada should maximize natural graphite extraction and processing by following an ambitious, multifaceted strategy to become the primary North American supplier of coated spherical purified graphite for electric vehicle (EV) battery anodes. This comprehensive approach involves several key initiatives that leverage Canada's geographical and industrial strengths.

- The development and expansion of graphite mines and milling/shaping facilities should be prioritized, focusing on British Columbia (BC) and Québec. In BC, the current projects should be accelerated, while in Québec, existing facilities should be reinforced and upgraded to increase their production capacity and efficiency. These regions are rich in natural graphite deposits, making them ideal for large-scale mining and processing projects.

- Canada should establish two regional coating hubs, one in BC and one in Québec. These hubs would specialize in the crucial process of coating spherical purified graphite, which is essential for battery anodes. By having dedicated facilities in both regions, Canada can ensure a steady and reliable supply of high-quality coated graphite to meet the needs of the rapidly expanding EV market. Collaboration and technology transfer with Japanese, Korean and American companies will be necessary for processing. These hubs would also create job opportunities and stimulate economic growth in their respective regions.
- In addition to natural graphite, a synthetic graphite hub development should be pursued, perhaps in Alberta's industrial heartland or the western provinces. Alberta's and Saskatchewan's existing petrochemical infrastructure and expertise make them ideal locations for this initiative. Pet coke, currently discarded as waste, can be a potential venue. By leveraging the established industrial bases of the two provinces, Canada can aim to produce synthetic graphite, offering a reliable alternative to natural graphite. Biosourced graphite processing technologies and methane pyrolysis coupled with hydrogen production could also be advanced locally. Diversifying graphite sources would enhance the country's resilience and flexibility in the global market.

1.4 Signature Projects

- Advance and strengthen mining and shaping/milling projects in QC and BC
- Strengthen a QC anode and coating hub with initiatives like the Bécancour Nouveau Monde facility and the VoltaXplore one.
- Develop a coating and anode hub in BC.
- Build a synthetic graphite processing facility and pursue R&D in Edmonton.

1.5 Strategic Priorities

- **An Ambitious Production Goal & Aggressive Piloting and Scaling for Processing:**
  - **Ambitious Targets:** Canada should aim for an accelerated production rate, targeting 2-3 million tonnes per annum of raw graphite. This approach is intended to deplete existing graphite reserves within 10 to 15 years rather than 20. This accelerated depletion strategy ensures that Canada rapidly meets growing market demand and maximizes the utilization of its graphite resources while they are most needed.
  - **Immediate Initiatives:** Launch aggressive piloting and scaling efforts without delay. This includes initiating pilot programs that test and refine graphite processing methods to ensure they are scalable and economically viable.

Immediate action will also involve setting up facilities and infrastructure to support the rapid expansion of graphite production and processing.

- **Direct Support for Pilot:** Implement direct financial incentives specifically for processing pilot programs. These incentives should address the current lack of funding in graphite processing and aim to unlock financial bottlenecks in the midstream part of the supply chain. By providing targeted financial support, the government can stimulate the development of necessary processing technologies and infrastructure.
- **Unlocking Projects:** Introduce government incentives similar to the U.S. Inflation Reduction Act (IRA) to unlock critical graphite projects. Such incentives could include tax breaks, grants, and low-interest loans to promote investment in graphite extraction and processing. These measures would provide the financial stability and encouragement companies need to invest in and expand their operations. Bipartisan initiatives could futureproof this method and ensure regulatory stability.

- **Coating Processes in Central Hubs:**
  - **Centralized Processing:** Consider establishing a central node within a hub-and-spoke system, where smaller milling and shaping facilities are closer to graphite mine sites. These smaller facilities would feed semi-processed graphite into more extensive central coating facilities. This system optimizes logistics and ensures efficient processing by reducing transportation distances and costs.
  - **Strategic Locations:** Develop large regional coating hubs in British Columbia (BC) and Québec. These hubs would serve as major centres for coating spherical purified graphite. Existing projects, such as Northern Graphite's Baie-Comeau project, Nouveau Monde Graphite's Bécancour project and VoltaXplore, should be reinforced and expanded to serve as the foundation for these hubs.
  - **Specific Plans for British Columbia:**
    - **Two-Year Pilot Program:** Propose a two-year pilot program to establish a coating facility in BC. This pilot facility will test processes and provide valuable data, paving the way for constructing a larger plant targeted to start as soon as possible.
    - **Integration with Trail Smelter Area:** Explore the possibility of integrating the BC coating processing hub with the existing Trail Smelter. The smelter's established industrial infrastructure, transportation networks, and access to clean power sources make it an ideal location for a coating facility.
  - **Operational Models:**
    - **Vertical Integration:** Coating facilities could be vertically integrated within existing mining firms, ensuring streamlined supply chain management and enhanced control over production.

        - **Or Independent Operation:** Alternatively, these facilities could operate independently, fostering competition and innovation within the graphite processing industry.
    - **Financial Support:** Unlocking government funding is crucial for developing these coating hubs. Government grants, subsidies, and incentives can provide financial support for initial setup, research and development, and ongoing operations.
- **Research & Development:**
    - **Investigate and Support Alternative Graphite Sources:** Several technologies have shown promising results, such as the pyrolysis of wood waste to graphite, as demonstrated by the New Zealand company CarbonScape's process. Domestic companies, such as CarbonIP Technologies, or NanoTerraTech, which previously aimed to produce biographite as an anode material, should be supported and scaled. The pre-combustion carbon capture technology proposed by Innova Cleantech or Aurora Hydrogen in Alberta has shown promising results, converting methane and natural gas into hydrogen and graphite. Such technologies should be supported and tested at the demonstration level.
    - **Reducing & Optimizing Waste:** Focus on optimizing and limiting waste produced during natural graphite processing. Implement advanced techniques to minimize environmental impact and enhance resource efficiency.
    - **Sulfur Management:** Investigate and address sulfur-related issues in graphite processing. Develop strategies to effectively manage and utilize sulfur waste, turning potential environmental liabilities into value-added products.
    - **Cleaner Hydrometallurgical Processes:** Optimize clean hydrometallurgy purification methods for graphite. Emphasize developing processes that are less harmful to the environment and more energy-efficient. Avoid hydrofluoric acid steps.
    - **Energy Efficiency for Synthetic Graphite Processes:** Advance synthetic graphite production methods that demand less energy and produce fewer carbon emissions. Focus on innovative technologies that reduce the overall environmental footprint of synthetic graphite manufacturing.
    - **Recycling:** Enhance graphite circularity by developing robust recycling processes. Promote the reuse of graphite materials to create a more sustainable and resilient supply chain.
    - **Pilot Support:** Provide piloting support across all Technology Readiness Levels (TRLs). Current support often starts at TRL 6 and above, so expanding support to earlier stages can foster innovation and accelerate the development of new technologies.
- **A Potential Synthetic Graphite Hub in the West:**
    - **Leverage Petrochemical Infrastructure:** Establish a synthetic graphite hub in the Edmonton region to capitalize on the existing petrochemical

infrastructure and expertise. This hub would leverage Alberta's industrial strengths to produce synthetic graphite efficiently. Saskatchewan could also be a viable alternative. Consider using pet coke that is currently wasted and buried. It is obtained as a by-product of refineries and can be valued and converted into anode-grade synthetic graphite, along with pitch imported from the U.S.
  - **Alternative Locations:** Consider processing synthetic graphite in BC using hydroelectric power to reduce carbon emissions and exploit the province's clean energy resources.
  - **Utilizing Existing IP:** Benefit from U.S. and Canadian intellectual property in cleaner synthetic graphite processes, similar to those of Novonix. Implement these technologies to create a more sustainable synthetic graphite production chain.
  - **Carbon Management:** Develop a clear strategy for carbon capture, utilization, and storage (CCUS) to mitigate synthetic graphite production's high energy and carbon intensity. Integrate clean energy solutions to reduce the environmental impact further.
- **Engagement, Education and Workforce:**
  - **Building Expertise:** Create a comprehensive knowledge base and training programs to educate stakeholders on the importance of anode production. Building expertise from the ground up is crucial with no existing North American anode plant.
  - **National Commitment:** Foster a national commitment to reducing greenhouse gas emissions and establishing a robust domestic battery supply chain. Engage with communities to ensure widespread support and understanding of the benefits.
  - **Stakeholder Relationships:** Develop strong relationships with First Nations communities to ensure successful mining operations. Respectful and meaningful engagement with these stakeholders is essential for project certainty and community support.
  - **Future Leader Narrative:** Position Canada as a potential future leader in graphite production, especially in light of China banning graphite exports from December 1st, 2023. Control the narrative to highlight Canada's strategic importance in the global graphite market.
  - **Education and Public Engagement:**
    - **Critical Minerals Awareness:** Educate the public on the importance of critical minerals, emphasizing their role in sustainable energy and technological advancements. Increased public knowledge and pressure can encourage the government to focus on critical mineral spending and support.
    - **Technoeconomic Analyses:** Provide techno-economic analyses and job creation estimates to convince stakeholders and the general public of the economic benefits of investing in graphite production and processing.

- **Skill Retooling:** Address the limited workforce by retooling general skills and developing specialized training programs. Ensure that the workforce is equipped to meet the demands of the growing graphite industry.

- **Protection from Price Volatility and Secure Off-takers:**
  - **Strategic Partnerships:** Secure long-term partnerships with Korean and Japanese anode companies to establish a stable market for Canadian graphite. These partnerships will ensure a consistent demand and provide financial stability.
  - **Technology Transfer Agreements:** Negotiate fair technology transfer agreements to facilitate the adoption of advanced processing technologies. Ensure that these agreements benefit both Canadian companies and their international partners
  - **Price Stability Mechanisms :**
    - **Government Procurement:** Implement government procurement policies, contracts for differences, and government-guaranteed future purchases of locally sourced critical minerals to enforce price stability.
    - **Buffer Stock Mechanisms:** Establish buffer stock mechanisms similar to those used in the potash industry to de-risk the market. A Canadian buffer stock would provide a stable source of graphite during geopolitical disruptions and stabilize prices for suppliers.
  - **Recycling Incentives:** Provide incentives for recycling graphite and building up the back end of the supply chain. This will enhance the resilience and sustainability of the graphite supply chain.
  - **Direct Intervention:** Recognize that other governments actively intervene in the graphite supply chain. Canada must also take proactive measures to ensure its market remains competitive and secure.

- **Regulatory Tools:**
  - **Investor Confidence:** Ensure transparent pricing to alleviate uncertainty for investors. Clear and consistent pricing information will attract investment and support the growth of the graphite industry.
  - **Streamlined Approvals:** Expedite the permitting process for critical minerals, including graphite. Government support for Preliminary Economic Assessments (PEA), Pre-Feasibility Studies (PFS), and Feasibility Studies (FS) will accelerate project development.
  - **Carbon Credits:** Implement carbon credits for critical minerals projects to encourage environmentally sustainable practices. These credits will incentivize companies to reduce their carbon footprint and adopt cleaner technologies.

2 Graphite: The Dominant Material for Lithium-Ion Battery Anodes

2.1 General Properties

Graphite, diamond, and ‘amorphous’ microcrystalline structures are naturally occurring forms of elemental carbon. Graphite deposits are thus labelled natural graphite, while synthetic graphite is manufactured from petroleum by-products. Graphite can also be sourced from biomass after pyrolysis and processing of lignocellulose, or obtained from methane/natural gas pyrolysis.[19–21]

In all cases, graphite is composed of stacked layers of carbon atoms arranged in honeycomb-like hexagonal rings. Within each layer, the intra-planar bonding is quite strong, but the forces holding the different sheets together are relatively weak, allowing them to slide over each other easily. Due to the molecular and electronic structure across layers, graphite has good electrical conductivity. All those structural features give this grey-black mineral the properties of both a metal and a non-metal.[22] The metallic properties include thermal and electrical conductivity; the non-metallic ones include high thermal resistance and lubricity. Additionally, graphite is stable over various temperatures, resistant to corrosion and most acids, and chemically inert. These properties make it suitable for many industrial applications. Some primary end uses of graphite are in refractories, lubricants, brushes for electrical motors, friction materials, electrodes for furnaces, steelmaking, pencil leads, headphones, neutron moderator for nuclear reactors, batteries, and fuel cells.[22–24] It is important to note that the graphite electrodes used in electric arc furnaces make graphite an important element for electrifying metallurgical processes for several key metals and critical minerals. The U.S., the E.U., and Canada currently list graphite as a critical mineral or raw material.[25–27]

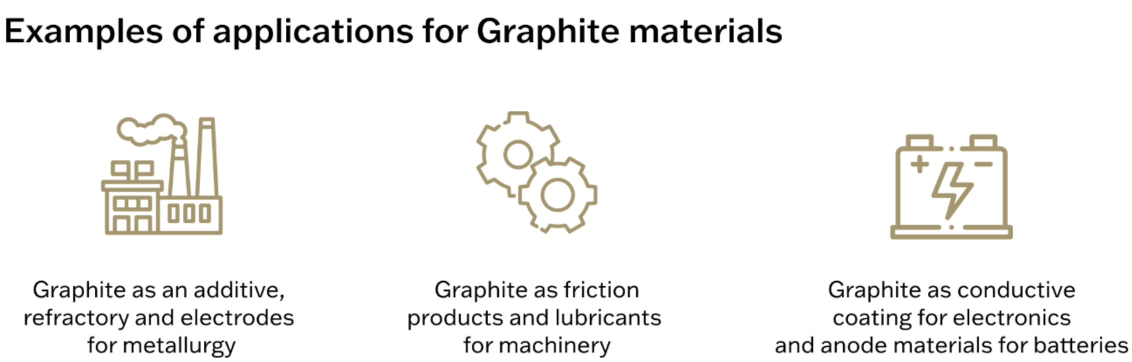


Figure 1 Examples of applications for graphite materials

2.2 Role in Energy Storage

Graphite anodes are a primordial element of Li-ion batteries. They are the single-largest component used and represent 28% of the total weight of EV batteries, up to 70 kg of graphite in an EV *vs.* 10 kilograms in a hybrid vehicle.[28,29] Each battery can also contain 10 to 20 times more graphite than lithium by weight.[30] Their use is also widespread: graphite anodes are fundamental to every Li-ion battery type, while the cathode materials may vary: from lithium iron phosphate (LFP) to nickel cobalt manganese (NMC), lithium cobalt oxide (LCO), lithium manganese oxide (LMO), or lithium nickel cobalt aluminum oxides (NCA), all types contain graphite anodes.

Two main reasons can explain the superior properties of graphite for battery anode usage: firstly, its capacity to reversibly accumulate and release lithium ions from/to the electrolyte, thus supporting the storage of electricity and creation of an electrical current; secondly, the relative stability against degradation at the electrode/electrolyte interface occurring by the creation of solid electrolyte interphase. This area acts as a protective layer, which prevents further electrolyte decomposition while maintaining the required cycling ability of the battery.[31]Additionally, graphite is relatively low-cost, abundant, and has a long cycle life. For fuel cells, graphite is the leading material for constructing bipolar plates, which distribute the fuel and oxidant evenly to the cells.

2.3 Substitutes

in the short to medium-term future, graphite anodes are still expected to dominate the battery market. However, newer technologies for anodes might replace graphite in the longer term. Those alternative anode materials include silicon (higher energy density, but a higher volume expansion/contraction leading to degradation), lithium titanate anodes (long life cycle, lower energy density, faster charging/discharging), lithium metal anodes (only in the case of solid-state batteries, would potentially boost energy density, but dendrite formation could lead to safety problems, and even more lithium resources would be required), tin oxides, titanium oxide, niobium and molybdenum sulfide. Projections, however, place those anode technologies 5 to 10 years away from market deployment, but with large uncertainty.[32] Worley Consulting Insights estimates a market share of 8% in 2030 and further 16% in 2016 for silicon-based anodes, 7% for lithium titanate in 2040%, and 7% for lithium metal anodes the same year.[33]

2.4 Supply and Demand

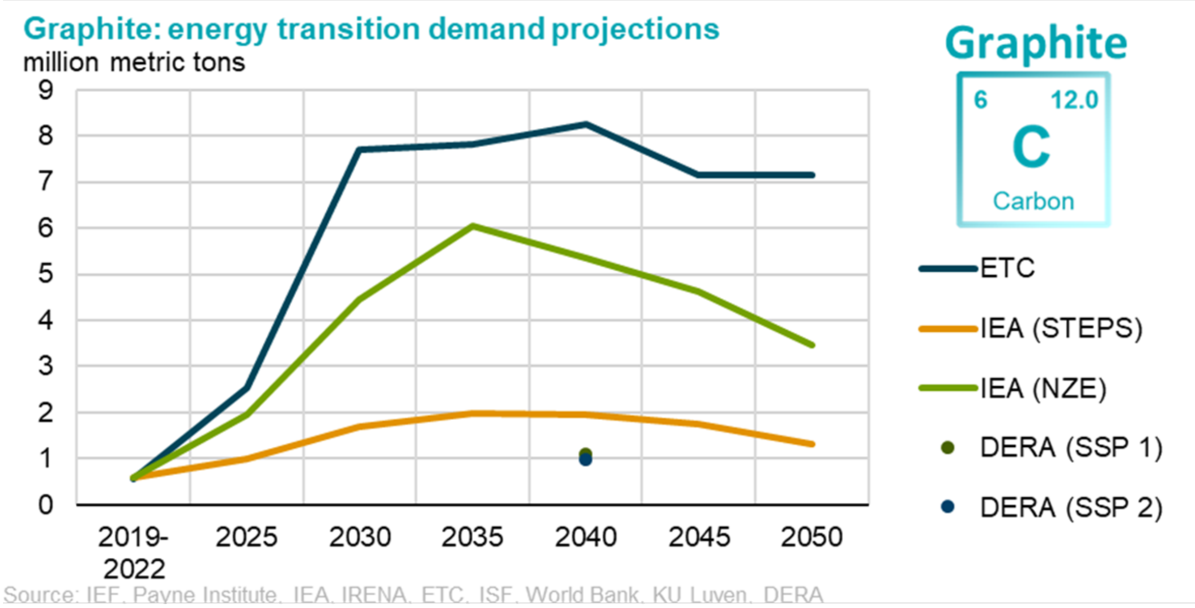


Figure 2 Graphite demand projections to 2050 according to various energy transition scenarios[34]

The World Bank Group estimates a 494% growth in graphite demand by 2050 compared to 2018 production levels, representing a demand of 4.5 million tonnes of graphite in 2050.[32] Benchmark Mineral Intelligence evaluated the demand for natural graphite for anodes at 2.8 million tonnes in 2030 *vs.* 0.18 million tonnes allocated for this purpose in 2020.[35] That's why a predicted supply shortfall of 30% for graphite is forecasted by 2040.[36] Those constraints are further exacerbated by a lower battery anode material fabrication yield: making a single tonne of anode material can take 3 tonnes of natural flake graphite, which is higher than for other minerals.[35]

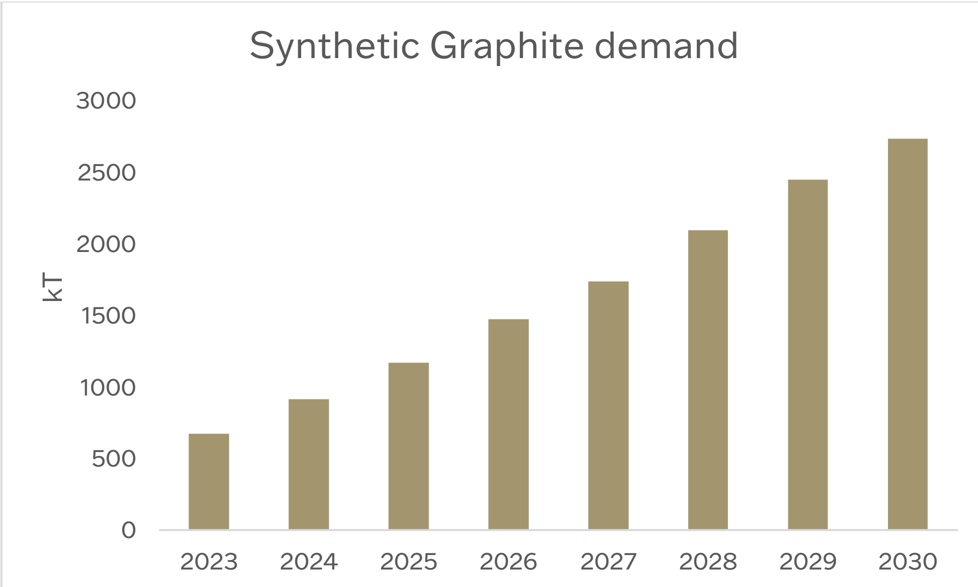


Figure 3 Global Synthetic Graphite Demand Projection to 2030[33]

The global demand for synthetic graphite was around 674 kT in 2023 and is expected to grow to 2,734 kT by 2030.[33] As for feed materials, Needle Coke demand by the battery market is expected to grow more than 13% CAGR between 2024 and 2030. Calcine Pet Coke demand by the battery market is anticipated to grow more than 36% CAGR from 2024 to 2030. China will lead the pet coke market followed by North America, Europe, and rest of the countries.[33]

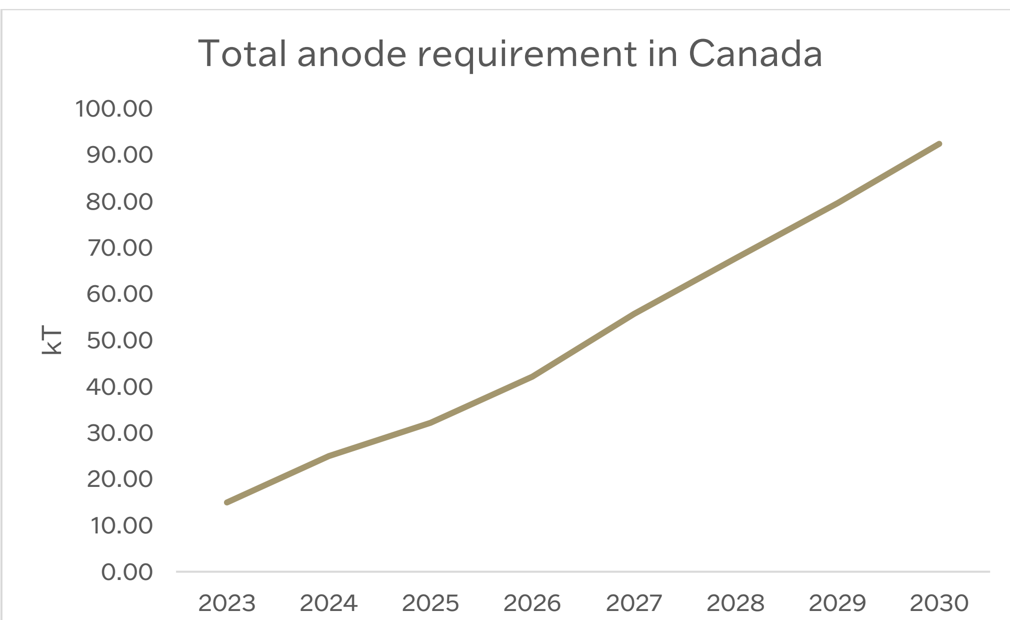


Figure 4 Anode material demand projection in Canada[33]

Worley Consulting Insights estimates demand for battery anode material to reach around 93 kT by 2030.[33]

3 The Two Graphite Flowsheets: Natural or Synthetic

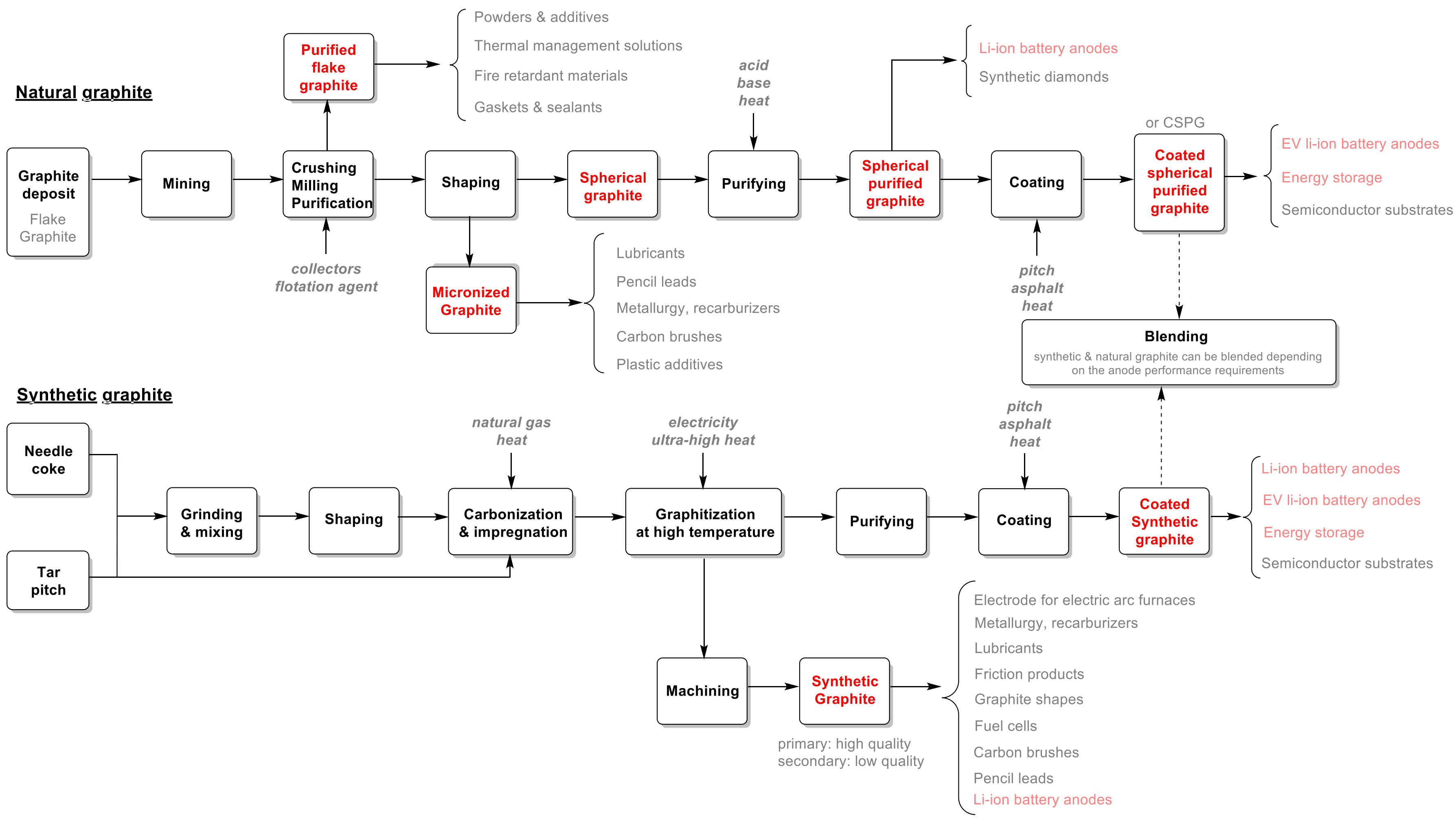


Figure 5 Simplified flowsheet of natural and synthetic graphite

3.1 Natural Graphite Ores & Reserves

Carbon is between the 12th and 17th most abundant element in Earth's crust, and its estimated concentration ranges from 180 to 270 parts per million.[37] Carbon's behaviour in its geochemical cycle is influenced by its different forms. Most carbon in the crust (80–90%) is found in carbonate rocks, and the remaining exists in living and fossil organic matter, as well as in the form of CO_2 in the atmosphere or dissolved in the ocean. These forms of carbon dominate the carbon cycle. Graphite, which accounts for less than 0.5% of carbon in the Earth's crust, is primarily formed through high-temperature thermal alteration of organic matter from biogenic sources deposited in sedimentary rocks and subsurface reservoirs. It is stable and unreactive in the crust and remains mostly unchanged under surface weathering conditions. It tends to recrystallize only through burial and thermal metamorphism. As a result, graphite remains largely isolated from the previously described overall carbon cycle.

Graphite ore is classified into three types: **lump** or **vein graphite**, known for its high quality; **flake graphite**, used in electric vehicles and fuel cells; and **amorphous graphite**, the most abundant and lowest grade, used in lubricants, crucibles, and steel production. Flake size also affects battery performance, with larger flakes being more effective but costly. Jumbo flakes can expand when heated, making them suitable for gaskets, seals, and flame retardants, while smaller flakes are used in lower-value industries and small electronic devices.[38]

China, Brazil, Madagascar, Mozambique, Tanzania and Russia are the most important graphite reserves. According to the data provided by the U.S. Department of Geological Survey, those 6 countries make up over 83% of the world's estimated reserves.[1] The reserves from Sri Lanka are unique as they represent the only large deposit of vein/lump graphite, which is of the highest quality grade.

Table 3 Estimated reserves & mining production of natural graphite by country in tonnes[1]

Country	Mining Production in 2022[a] (tonnes)	Country	Reserves in 2024[a] (tonnes)
United States	/	United States	/[b]
Germany	170	Austria	/[b]
Austria	500	Germany	/[b]
Vietnam	500	Ukraine	/[b]
Ukraine	1,000	Vietnam	/[b]
Mexico	2,000	Norway	600,000
Sri Lanka	2,600	Sri Lanka	1,500,000
Turkey	2,800	South Korea	1,800,000
Tanzania	6,120	North Korea	2,000,000
North Korea	8,100	Mexico	3,100,000
Norway	10,380	**Canada**	**5,700,000**
India	11,000	Turkey	6,900,000
Canada	**13,000**	India	8,600,000
Russia	16,000	Russia	14,000,000
South Korea	23,800	Tanzania	18,000,000
Brazil	72,000	Madagascar	24,000,000
Madagascar	130,000	Mozambique	25,000,000
Mozambique	166,000	Brazil	74,000,000
China	1,210,000	China	78,000,000
World total (rounded)	**1,680,000**	**World total (rounded)**	**280,000,000**

[a]Data from the 2024 U.S. Geological Survey, NRCan's dataset differs slightly.[1,2]
[b]Reserves included in 'World Total'.

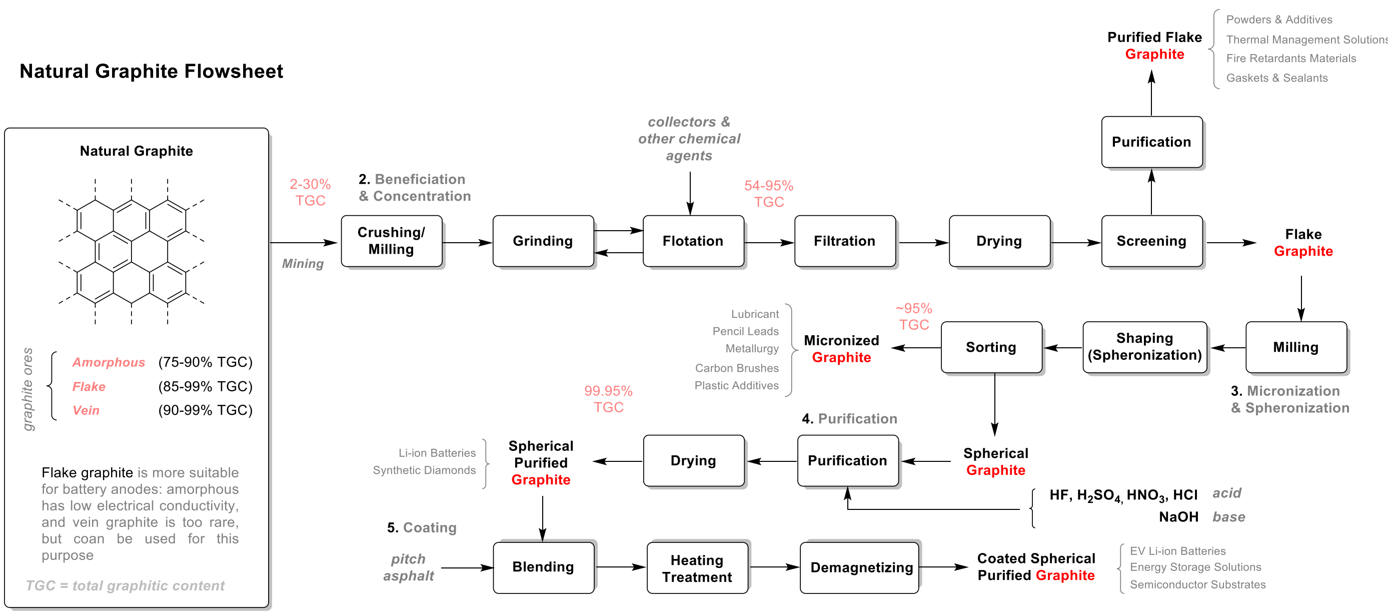
China is undeniably the key graphite player, making up 72% of natural graphite production in 2022. Chinese flake graphite production has shifted from older Shandong mines to newer ones in the Heilongjiang province; the recent decline in larger flake sizes is due to aging mines, rising costs, resource depletion, and stricter environmental regulations, while the main Heilongjiang mines focus on smaller flake graphite production to meet the demand for lithium-ion batteries.[15,16] However, the worldwide ratio of the Chinese output is expected to drop from 72% last year to 48% in 2030, while the ones from Madagascar should rise to 8% and up to 22% in Mozambique.[39] Other African countries such as Tanzania and Namibia are forecasted to host large-scale graphite mining projects, while additional projects are being developed in Australia and Sweden. A graphite anode plant is particularly commissioned to be opened there.[1]

In 2021, 66% of the global use of graphite was from synthetic sources and only 34% from natural ones.[2] In the same year, 52% of synthetic graphite was used for industrial electrodes (electric arc furnaces, refining furnaces, industrial silicon, *etc.*), 14% for recarburizing, and 14% for battery anodes.[40] China also dominates the synthetic graphite industry, representing 58% of the total synthetic graphite production in 2021, Japan 15% and the U.S. 8%.[41]

3.2 Processing

3.2.1 Natural Graphite Processing

Natural Graphite Flowsheet



1. Mining of graphite ores, mostly flake graphite in the case of battery anode purposes, can be performed in open air or underground. Ammonium Nitrated Fuel Oil (ANFO) is commonly used as an explosive.

2. Beneficiation & Concentration is a series of multiplealternating stages of crushing, attrition milling and flotation milling to separate graphite from other rocks. Additives such as pine oil, kerosene, diesel, methyl isobutyl carbinol and sodium silicate are used in small quantities as foaming agents, collectors, flocculant and depressant. Concentrated flake graphite is obtained after drying and screening.

3. Micronization & Spheronization: the graphite concentrate is pulverized and spheronized to produce spherical graphite, with particle size ranging from 10 to 25 microns. Lower-value micronized graphite is collected as a by-product.Spherical shape improves packing & density for battery uses, while allowing a uniformly thin spread on the anode.

4. Purification steps can include several chemical or thermal processes, sometimes in combination. **Acid-washing** removes organic & mineral impurities by using corrosive acids (HF, H_2SO_4, HNO_3, HCl). **Acid-base method** removes metal, sulfides and silicon oxides impurities by using acid such as sulfuric acid H_2SO_4 and base such as sodium hydroxide (soda) NaOH and heating (100-550°C). **High temperature method** uses ultra-high heating (2000-3000°C) in inert gas or chlorine to vaporize impurities.

5. Coating: a thin layer of pitch or asphalt is added onto the spherical purified graphite, which are then baked during a carbonizing step at over 1,200°C. The coating prevents degradation during charge cyles and inhibits side-reaction with the electrolyte, thus improving battery capacity and life.

Figure 6 Flowsheet from natural graphite to coated spherical purified graphite

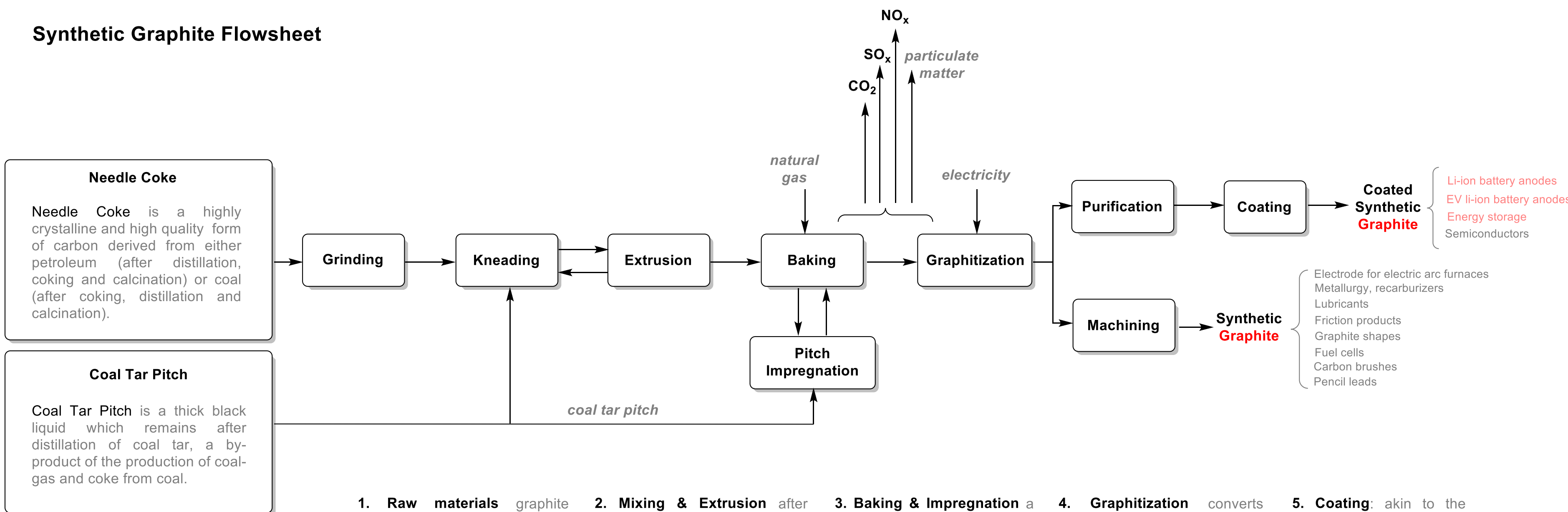
Graphite ores, mainly flake graphite, are more available and suitable for battery anode applications and can be extracted through open-pit or underground mining. Once the graphite ore is mined, the next crucial step is beneficiation and concentration. This involves multiple alternating stages, including crushing, attrition, milling, and flotation milling. These stages are designed to separate the valuable graphite from other rock materials. Various additives are used in small quantities during this process to enhance the separation efficiency. These additives include pine oil, kerosene, diesel, methyl isobutyl carbinol, and sodium silicate, and they are used as foaming agents, collectors, flocculants, and depressants. Through these processes, a concentrated form of graphite is obtained after the drying and screening stages, which removes excess moisture and refines the material. Those concentrated flake graphite products are suitable for thermally resistant materials and carbon additives.

Concentrated graphite is then subjected to further processing, where it is pulverized and spheronized to produce spherical graphite. After this spheronization process, sometimes called spheroidization, the particle sizes of this spherical graphite typically range from 10 to 25 microns. The spherical shape of the graphite particles is essential for improving the packing density and uniformity when the end-product graphite is applied to battery anodes, enhancing the batteries' performance. During this process, lower-value micronized graphite is also collected as a byproduct; those micronized graphite products are suitable for lubricant, electric furnace electrodes, carbon brushes, *etc.*

Following spheronization, graphite undergoes purification, which can involve several chemical or thermal processes, sometimes combined. One standard method is acid washing, where corrosive acids such as hydrofluoric acid HF, sulfuric acid H_2SO_4, nitric acid HNO_3, and hydrochloric acid HCl remove organic and mineral impurities. Another method involves acid-base treatments that remove metal, sulfides, and silicon oxide impurities using acids like sulfuric acid and bases such as sodium hydroxide NaOH at elevated temperatures ranging from 100 to 550°C. Alternatively, the high-temperature method involves ultra-high heating between 2,000 and 3,000°C in an inert gas or chlorine atmosphere to vaporize any remaining impurities. This high-quality graphite product for high-performance electronic applications is called Spherical Purified Graphite (SPG). Purification steps, whether chemical or thermal treatments, are the most environmentally impactful processes of the natural graphite value chain: Toxic and hard-to-handle acids are used, and the thermal purification process is energy-intensive.

The final step in the process is the coating technique for producing Coated Spherical Purified Graphite (CSPG). This involves applying a thin layer of pitch or asphalt to the spherical purified graphite. The coated graphite is then baked during a carbonizing step at temperatures exceeding 1,200°C. The coating is not just an additional step but a crucial one, as it prevents degradation of the graphite material during battery charge cycles and inhibits side reactions with the electrolyte. This step significantly improves the overall battery capacity and longevity, making the graphite more suitable for anode applications.

3.2.2 Synthetic Graphite Processing



1. Raw materials graphite synthesis requires needle coke from pet coke as the main raw material while coal tar pitch (15-30% content of the mixture) serves as the binder. Both materials come from the petroleum/coal industry, and most processes used to obtain them (distillation, coking, calcination) are energy-intensive and emit significant GHGs over their lfe-cycle.

2. Mixing & Extrusion after milling and grinding needle coke, the grains are screened to obtain appropriate size requirement. Coal tar pitch is added as a binder in a mixer to blend raw materials into a paste. The mixers are heated to allow the pitch to penetrate the pores of the coke. An extruder or press shapes the hot mixture into the suitable form.

3. Baking & Impregnation a natural gas-fired furnace heats the mixture at 800-1200°C in a step also called carbonization. The pitch is carbonized into coke, and the mixture is now tightly combined. Organic matter and impurities are volatilized, resulting in toxic gas emission on top of GHG ones. Baking lasts 18-24 h. Subsequent addition of pitch during impregnation and re-baking helps to reduce porosity. Several cycles are sometimes necessary.

4. Graphitization converts coke precursor to highly crystalline graphite. Ultra-high temperature (2800-3200°C) is required in the absence of oxygen in an Acheson electric furnace. Remaining organic impurities are volatilized. The process takes 3-5 days, and cooling can take up to 3 weeks.

5. Coating: akin to the natural graphite process, a thin layer of pitch or asphalt is added onto synthetic graphite. A 1,200 °C carbonizing step is also necessary. The coating prevents degradation during charge cyles and inhibits side-reaction with the electrolyte, thus improving battery capacity and life.

Figure 7 Flowsheet of synthetic graphite

Primary synthetic graphite is expensive to produce but has a high purity and significant electrical and thermal conductivity due to a process that creates almost perfectly shaped graphite crystals. Secondary synthetic graphite is a by-product of the production of primary synthetic graphite; it is considered a lower-cost material, typically used in powder.

Despite its better purity and predictability, synthetic graphite requires calcined petroleum needle coke and tar pitch as feedstock. Calcined petroleum needle coke is an environmentally harmful residual product from petroleum refining. It must be heated at high temperatures to pre-process it and make it eligible for graphite production.[42] Coal tar pitch is the remaining liquid obtained after the distillation of coal tar. It is a by-product of coal gas and coke production. Both materials necessitate energy-intensive steps and emit a significant amount of GHGs.[43] Needle coke is the primary raw material for graphite, while coal tar pitch is used as the binder and accounts for only 15–30% of the mixture's content. It should be noted that pet coke can also be eligible for synthetic graphite without upgrading to petroleum needle coke. A significant quantity of pet coke is produced as a by-product of refineries/upgraders. It is often buried as it does not meet the requirements for mainstream off-takers, but it is potentially usable for battery-grade synthetic graphite. Valuing this 'waste' for energy storage could be a potential pathway.

Needle coke first undergoes grinding and milling steps before a screening process to obtain grains of the required size. Coal tar pitch is then added as a binder in a mixer to blend raw materials into a paste. Additionally, the mixers are heated to allow the coal tar pitch to penetrate pores at the surface of the needle coke particles. An extruder or press shapes the hot mixture obtained into suitable forms. A natural gas-fired furnace will heat the mixture at 850–1,200 C in a baking step. This high temperature will allow the carbonization of the coal tar pitch onto the surface of the coke particles, thus tightly combining the mixture. Impurities and organic compounds are volatilized, which results in toxic gas emissions such as NOx, SOx and particulate matter on top of GHG emissions. This baking process can last 18-24 hours. Pitch is then re-added to the mixture during impregnation steps before re-baking to reduce the product's porosity. Several impregnation/baking steps are sometimes necessary.

During graphitization, the intermediate product is converted to highly crystalline graphite. An Acheson electric furnace heats the precursor at very high temperatures (2,800–3,200 C) without oxygen, allowing the remaining organic impurities to be volatilized. The process takes 3-5 days, and the necessary cooling takes up to 3 weeks. The obtained graphite can then be machined and sold for various uses, such as lubricant recarburizers, electrodes for electric furnaces, *etc.*

Several post-processing steps, such as milling, shaping (such as spheronization), or classification and coating, are also possible for synthetic graphite. However, the variety of industrial processes and the general lack of information concerning the necessity of these steps compared to the natural graphite route do not paint a uniform picture of the synthetic graphite pathway to anodes. It would seem that synthetic graphite has been used directly as an active anode material in some processes, while other routes included post-processing before the fabrication of anodes. The U.S. Argonne National Laboratory did not include these steps in their GREET model.[44]

A broader consensus indicates that the coating step, similar to the natural graphite processing route, is necessary to produce lithium-ion battery anodes. It starts with adding a thin layer of pitch or asphalt to synthetic graphite and requires a subsequent 1,200 C carbonizing step.

3.2.3 Alternative Graphite Sources: The Pyrolysis of Wood Waste or Methane

Biographite, a sustainable alternative to traditional graphite, is emerging as a key material, and can be suitable for battery anode purposes. Derived from bio-based sources such as agricultural and forestry waste, biographite offers significant environmental benefits, including reduced carbon emissions, valuing biowaste and resource conservation.[33]

Several companies are pioneering biographite production. Graphjet Technology has launched the world's first commercial biographite facility in Malaysia, using palm kernel shells to produce 3,000 tonnes annually, enough to support 40,000 EV batteries per year. This process emits significantly less CO_2—2.95 kg per kg of graphite and creates 200 local jobs. CarbonScape, operating in New Zealand, produces carbon-negative biographite from wood for lithium-ion batteries in partnership with Northvolt. Meanwhile, Birla is advancing Biocrude Derived Anode Material (BDAM) for lithium-ion batteries, focusing on renewable feedstocks to improve sustainability and efficiency in graphite production. In Canada, CarbonIP Technologies is an Alberta-based company focusing on biographite research and production.

Methane pyrolysis offers a novel approach to hydrogen production by converting natural gas into hydrogen and valuable solid carbon byproducts like carbon black, graphite, and carbon nanotubes.[33] Unlike traditional steam methane reforming (SMR), which emits significant CO_2, methane pyrolysis operates without direct CO_2 emissions and requires lower energy inputs than electrolysis. This method integrates seamlessly with current systems by utilizing existing natural gas infrastructure, minimizing the need for new investments. However, challenges remain in achieving widespread commercial adoption due to higher natural gas requirements and the relative immaturity of the technology, rated between three and eight on the International Energy Agency's readiness scale. Scaling production and reducing energy inputs remain critical research areas.

Innovative companies like Hazer Group. Innova Cleantech and Aurora Hydrogen are leading advancements in methane pyrolysis. Hazer's Commercial Demonstration Plant (CDP) in Perth, Australia, marks the world's first commercial-scale facility to produce clean hydrogen and high-purity graphitic carbon using methane pyrolysis with an iron ore catalyst. This dual benefit of hydrogen and valuable carbon products enhances its commercial appeal, with applications in batteries, aerospace, and manufacturing. Meanwhile, Aurora Hydrogen, based in Edmonton, employs a patented microwave-based method producing sand-sized carbon particles. These versatile byproducts support diverse industries, from steelmaking and construction to advanced materials like synthetic graphite and graphene.

3.2.4 Comparison of the Natural and Synthetic Graphite Production Processes

An estimation evaluated that the carbon footprint of natural graphite is 1–2.15 kg of CO_2 emitted per kg of graphite produced, while producing 1 kg of synthetic graphite would emit an equivalent of 4.86 kilograms of CO_2, 79.8 g of nefarious sulfur oxide gas (SO_x), 13.5 g of toxic nitrogen oxides (NO_x) and 5.5 g of particulate matter.[45–47] Accurate figures and life cycle assessments of this sector are still debated. It is accepted that synthesizing graphite from the conventional pathway is more energy-intensive and far from being environmentally friendly, making this route poorly adapted for a decarbonized industrial pathway. The highly GHG-emitting nature of the Chinese energy mix, where most synthetic and natural graphite is processed, is at fault. A more recent analysis by Worley Consulting Insights estimates that manufacturing 1 kg of natural graphite anode material produces approximately 9.6 kg CO_2, while on the other hand, 1 kg of Battery-grade synthetic graphite made from oil feedstock produces about 17 kilograms of CO_2, considering this time new processes that are or will be implemented in the Western world.[33]

Additionally, anode materials per kg are more expensive for synthetic graphite (USD $12–$13) than natural graphite (USD $4–$8).[35] Resource security concerns and high-purity products can still attract industrials to opt for the synthetic route.

In 2021, 40% of battery anodes were fabricated from natural graphite, while 57% came from the synthetic route. Benchmark Mineral forecasted a rise in natural graphite usage in Li-ion batteries, making a 49% share for 2030. Synthetic graphite will decrease to a 41% share, and newer non-graphite-based anode technologies might slowly appear commercially.[48] Currently, many anode manufacturers use a blend of natural and synthetic graphite depending on the performance required by the off-takers, with a higher ratio of synthetic for long-range and high-performance usage such as EV, while lowering this ratio for shorter-range applications such as electric scooters.

3.2.5 Graphite Life Cycle

Most graphite products have a relatively short life span, being worn or dissipated.[49] 71% of wasted graphite ends up in landfills, and most recycled graphite is from broken electrodes and used in recarburizing steps (raising the carbon content of a metal alloy, such as steel). Anode materials account for 5 to 15% of a lithium-ion battery's total cost but 20% by weight.[33] The lack of established graphite recovery technologies has resulted in the disposal of spent graphite as waste, leading to resource loss and environmental contamination. Despite current recycling rates estimated at <1%,[50] graphite recycling, particularly from batteries, has the potential to be environmentally responsible and profitable.

Recycled graphite, which is typically heavily contaminated and historically been unsuitable for reuse in batteries, is now being made feasible by companies like Altilium, and X-Batt. A 2021 review explored nine different pathways, including pyrometallurgical and hydrometallurgical methods, to recycle graphite anodes from used Li-ion batteries.[46]In Canada, Battery X, Graphite One, Lab4 Inc., Nouveau Monde Graphite and Lithion are all advancing solutions to recycle graphite for battery purposes. Altilium has also recently proven that over 99% of graphite can be recovered from old EV batteries.[33]

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