Authors
Alexander A. Koukoulas, Ph.D.
Maryam Arefmanesh, Ph.D.
Megan McCormick

Phone
+1 617 407-4266

E-mail
alexander.koukoulas@afry.com

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Advanced Carbon for Energy Storage:

A White Paper Study on Technologies for Using Biomass in Batteries and Opportunities of Canada

Prepared for

CRIBE centre for research & innovation in the bio-economy

by

AFRY Management Consulting, Inc.

295 Madison Avenue, Suite 300
New York, NY 10017 | USA

Contents

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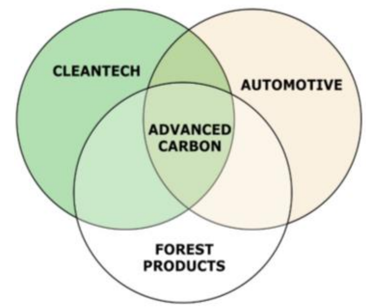
Executive Summary

Nearly 130-yrs following the introduction of the first gas-powered automobile, the North American automotive industry is finally abandoning fossil fuels. As a result of new government regulations that impose limits on climate-alternating greenhouse gas emissions, the industry has committed to transition from gasoline-powered internal combustion engines to zero emission vehicles. Electronic vehicles or EVs will be central to this transition, which will take place over the coming decade.

Global sales of EVs, which are currently 5 million units per year, are expected to rise to 28 million units per year by 2030. However, this unprecedented build out of EV manufacturing capacity will be predicated on developing a resilient battery supply chain and specifically those supply chain factors that impact the production of lithium ion (Li-ion) batteries, which are the dominant energy storage platform in zero emission vehicles.

A potential limiting factor to battery supply will be the availability of raw materials used to manufacture Li-ion batteries. While Canada does have ample reserves of certain raw materials used to manufacture Li-ion batteries, namely nickel and cobalt, it does not have adequate supplies of lithium and graphite, which is used to produce the anode. As a result, Canada must rely on the global markets, which have becoming increasingly unreliable.



Advanced Carbon

- Canada's leading positions in the Automotive, Cleantech and Forest Products sectors provides a nexus for creating an Advanced Carbon industry within Ontario.
- Advanced Carbon has the potential for replacing graphite and fossil-derived hard carbon in the production of lithium-ion batteries.
- Leveraging the strengths of each sector is seen as an opportunity to leap-frog conventional technologies and reshape the Li-ion battery industry in Canada, utilizing over 1 million cubic metres of sustainably derived woody biomass from Ontario forests and creating up to 4,600 forest sector jobs.

One promising approach to meeting the demand for graphite in the Canadian context is to replace graphite, both natural and synthetic graphite made for fossil fuels, with carbon derived from biomass, so-called **Advanced Carbon**. Made from renewable sources of woody biomass, Advanced Carbon has the potential for making Li-ion batteries more sustainable and eliminating the need for natural graphite and synthetic graphic, which is made from fossil-based carbon.

The focus of this white paper is to

- Provide awareness to the growing market for electric vehicles (EVs) and Li-ion batteries, which are the dominant energy storage system used in EVs
- Examine emerging technologies for bio-based A*dvanced Carbon* materials—that can replace graphite and fossil-derived hard carbon in the production of Li-ion anodes
- Discuss how Canada and specifically the Province of Ontario can leverage its forest resources to develop an Advanced Carbon industry that can support the creation of a resilient domestic Li-ion supply chain

- Examine the economic potential for an Advanced Carbon industry within the Province of Ontario

Canada is a leader in the automotive, cleantech, and forest sectors. AFRY believes that emerging technologies used in the production of Advanced Carbon could be the basis for leveraging all three sectors, leading to significant economic activity. A robust domestic EV battery supply chain could support up to **320,000 jobs** and add **$59 billion** to the Canadian economy annually by 2030. By *leap-frogging* traditional methods manufacturing carbon anodes and developing an Advanced Carbon industry, over **1 million cubic metres of wood** will be needed to meet anode demand. Ontario forestry sector could easily supply this as currently has the potential for sustainably harvesting nearly 30 million cubic metres of wood from its public forests, yet only uses 44% of the approved area and volume of harvested area. AFRY estimates that expanded forestry operations needed to supply Advanced Carbon could generate up to **4,600 direct forest sector jobs** in communities across Ontario.

Expected investment in research and development to support the cleantech industry would provide a means for workforce development and training of a skilled workforce. Government support and the creation of public-private partnerships will provide the necessary market signals that can jump-start a bio-based Li-ion battery industry within Ontario. This will support Canada's long-term economic competitiveness, ensure access to a durable supply chain, decarbonize the transport sector, and bring equitable cleantech jobs to Ontario.

1 Background

1.1 The Electrification of the Global Automotive Industry

Government actions to decarbonize their economies and contain the negative impacts of climate change have completely disrupted global transportation. Once dependent only on fossil fuels, the transportation sector—which includes the automotive, aerospace, and marine industries—is seeing widespread electrification, driven largely by government policies. While the automotive sector may be getting the lion's share of attention, electrification of the aerospace and marine sectors is also taking place, albeit at a much slower pace. Nonetheless, electric vehicles (EVs) of all forms are gaining traction in every sector. The transition away from fossil fuels is full speed ahead with no turning back in sight.

Regulations on carbon emissions are driving the transition. In a bold move to decarbonize the automotive sector, Canada's Emissions Reduction Plan requires all new passenger car sales to be zero-emission models by 2035. Across the border, California, New York, Massachusetts, have passed legislation requiring all new cars and light trucks sold to be zero-emission. Some states have gone so far as setting specific targets for EVs. These government mandates have completely disrupted the automotive sector as new entrants, led by Tesla but joined by BYD, Rivian, and a host of others, and incumbents, such as the Big Three—Ford, Chrysler, and General Motors—along with the likes of BMW, Hyundai, Toyota, and Volkswagen, rush to fill the demand for EVs.

1.2 Public Policy and the Impact on EV Markets

As policies pressure automakers to reach net zero carbon emissions, many are ramping up manufacturing of new EV models they hope will attract consumer attention. Globally, automakers see continued high demand for EVs. Most of the major car manufacturers are ramping up EV production capacity, as demand for EVs is expected to climb from its current 5 million units per year to 28 million units per year by 2030. Tesla has announced the highest targets with manufacturing over 20 million per year units by 2030. The traditional automakers have also announced aggressive plans for EV production capacity increases. For example, GM's EV production target is 2 million by 2050, and all its Buick models will be fully electric by 2030.

In 2021, the federal government in Canada announced a mandatory target of reaching 60% zero-emission light-vehicle sales by 2030 and 100% by 2035. Previously, Quebec and British Columbia had enacted targets to reach 100% zero emission sales by 2035 and 2040, respectively, while Ontario had no targets in place. Under this new initiative, the federal government plans to enact additional regulations as well as targeted investments to help reach its electrification goals. This includes consumer incentives for purchasing EVs, investments in charging infrastructure stations across the country, and partnerships with automakers to expand production capacity within Canada.

Since the announcement, the Independent Electricity System Operator (IESO) in Ontario released new EV projections to anticipate the rapid growth in EV demand. IESO has forecasted that the province will reach annual EV production targets of 6.6 million vehicles by 2042, after a swift uptick in the mid-2030s.

In North America, Ontario ranks second only to Michigan in automotive production capacity. Ontario also boasts the largest cleantech sector in Canada and second overall in North America behind California. To maintain and grow its leading position in the automotive sector, Ontario is planning to build at least 400,000 electric and hybrid vehicles by 2030.[1] AFRY believes the Ontario goals are too conservative and will be unable to fulfil the demand for EV's in the Province.

AFRY has used the IESO estimate to create its own view across three different growth scenarios (Figure 1). The "High" scenario represents the case of high economic growth, based on a faster acceleration of EV adoption, and additional policies around the net-zero transition. The "Low" scenario assumes low economic growth and new less aggressive policies. The "Central" scenario, which assumes that current production trends and policy ambitions remain in place, is considered the most probably outcome. By 2035, AFRY's scenarios reach 3.0, 2.5 and 1.8 million EVs per year in the "High", "Central" and "Low" scenarios, respectively. These scenarios provide a good indication of potential paths for EV growth in Ontario, all of which are significantly higher than current production levels and provincial goals. Either way,

[1] Driving Prosperity: The Future of Ontario's Automotive Sector (2022).

meeting these production targets hinges on the ability to create a robust supply of lithium-ion batteries and there is no guarantee that this can be achieved without a secure supply of raw materials.

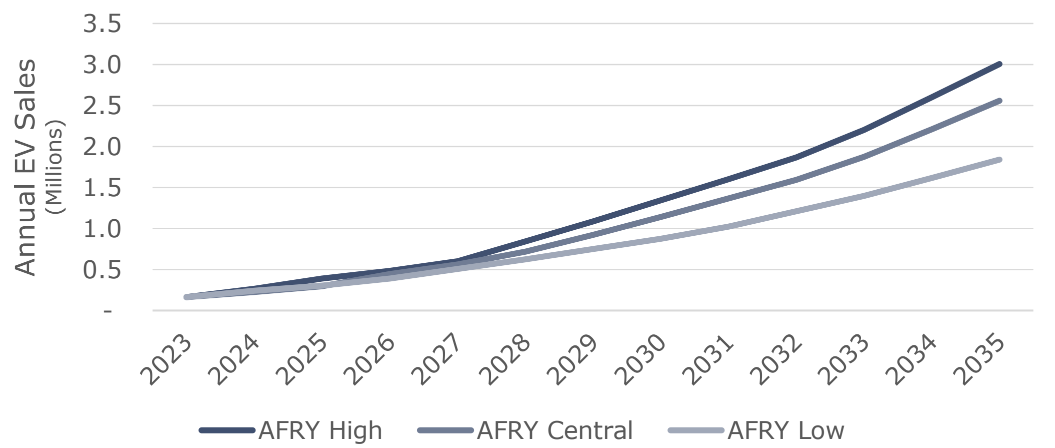


Figure 1 AFRY's estimates of EV demand in Ontario based on Low, High, and Central demand outlooks.

1.3 Lithium-ion Batteries: *The Driver of Electrification*

Powering EVs is the lithium-ion (Li-ion) battery. Invented in the late 1970's, the Li-ion battery has witnessed continuous engineering improvements resulting in enhanced utility. Perhaps most notable were efforts by Sony, which in the early 1990's introduced the first commercial rechargeable Li-ion battery using a lithium cobalt oxide cathode with a carbon anode. This ushered in the widespread use of Li-ion batteries in everyday consumer electronics, such as cellphones and laptop computers, as well as stationary energy storage systems for residential and utilities to manage power demand (see Figure 2).

Continuous innovation in battery design has also dramatically increased its energy-to-weight ratio, a key performance measure, and reduced its production cost. In 1991, a battery with a capacity of one kilowatt-hour (kWh) cost USD 7500. That battery cost only USD 181 in 2018, a 41-fold decrease. AFRY believes that with continued development, battery costs could be as low as USD 20 per kWh by 2030. Large-scale production of Li-ion batteries is now a reality, impacting a range of industries within the transportation sector. As a result, demand for Li-ion batteries is expected to deliver over 2000 GWh in energy storage capacity, creating a market worth over USD 190 billion by 2030, with demand increasing at a stunning annual growth rate of 26% (Figure 3)[2]. To put this in perspective, the average Canadian home uses

[2] Statista Global Battery Demand Forecast

about 11 MWh of energy per year. In other words, installed EV capacity would be able to provide the energy needs of over 180,000 homes.

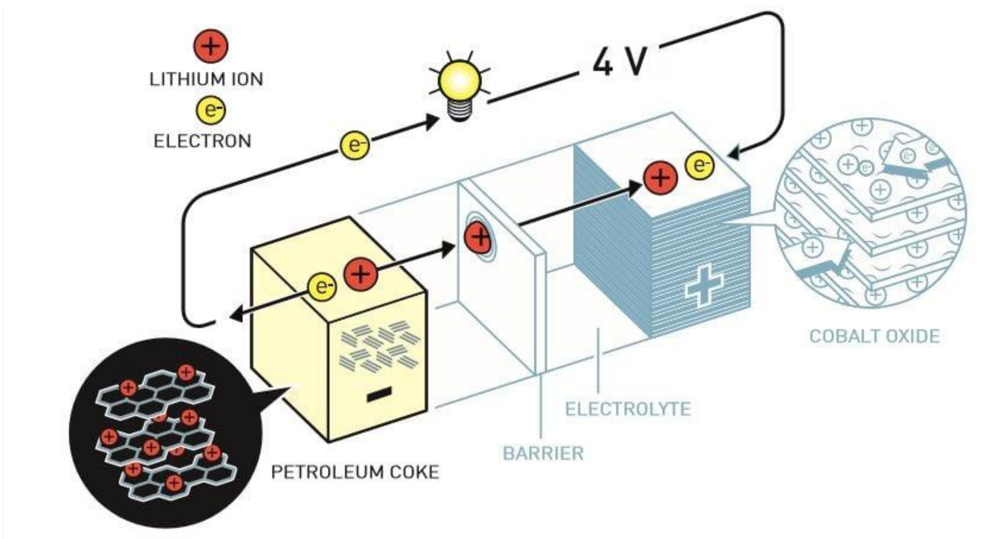


Figure 2 The first commercially viable Li-ion battery developed by Akira Yoshino of Asahi Kasei Corporation. The cathode (blue), which is made from lithium cobalt oxide ($LiCoO_2$), is separated from the anode (yellow), which is made from petroleum coke, by an electrolyte and a membrane. During a discharge cycle, lithium electrons flow from the anode to the cathode creating an electric current. To complete the circuit, lithium atoms pass through the membrane. During charging, the cycle is reversed.

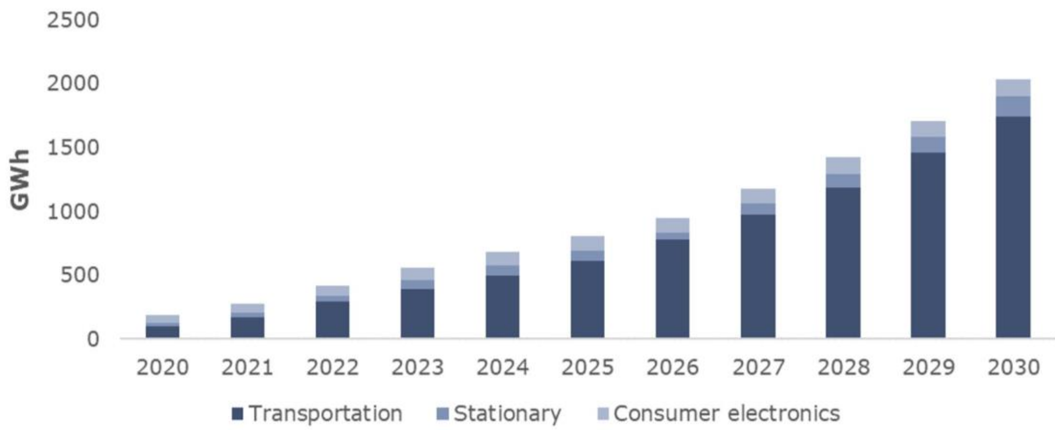


Figure 3 Projected global battery demand per application to 2030.

From the perspective of strategic minerals supply, Canada produces elements critical to the production of Li-ion battery cathodes, namely cobalt and nickel. Canada is also beginning to produce limited amounts of lithium however, Canada has a limited supply of natural graphite, the carbon-based material used to manufacture anodes. Canada's production of natural graphite accounted for only 1% of global supply in 2020, with only the Lac des Iles mine in Canada supplying graphite. In contrast, China, the largest global producer of graphite, supplied nearly two-thirds of global demand. With its strong command of raw materials supply, China will continue to dominate battery production, accounting for 740 GWh in 2030.

1.4 Transitioning from Fossil-fuels: *Impact on the Environment*

Battery energy storage systems are expanding rapidly worldwide, due to the electrification of transportation, the development of smart cities, and the transition to renewable energy, namely wind and solar. Since the start of the Industrial Revolution in the early 1800's, combustion of fossil fuels has contributed greatly to the unprecedented levels of climate-altering atmospheric carbon dioxide (CO_2), raising atmospheric CO_2 from their pre-industrial level of 280 parts per million (ppm) to almost 420 ppm. The rise in atmospheric CO_2 has contributed to a rise in global temperatures exceeding 1.5°C from their pre-industrial levels, resulting in extreme weather and sea-level rise. However, initiatives to decarbonize industrial and transportation sectors could stem the increase. Coupled with carbon sequestration, it is possible that atmospheric carbon levels could be *reduced.* Nonetheless, the United Nations estimates that the transportation sector alone represents 57% of global oil demand and contributes over 25% of global greenhouse gas emissions. Clearly, decarbonizing the transportation sector must be seen as a priority if policies to stem the rise of carbon emissions are to succeed.

In this regard, governments recognize that electrification, through the widespread adoption of EVs, is a pathway that can enable the automotive sector to transition to a zero-emission future. Electrifying transportation and balancing the power grid is not only a crucial component in the transition toward a more sustainable future by combating climate change, but electrification will result in jobs, manufacturing opportunities, and economy growth.

2 Li-ion Batteries and Advanced Carbon

2.1 Creating a Robust Supply Chain and Spearheading Economic Development in Ontario

As discussed in Section 1, Canada's supply chain for Li-ion batteries must be well positioned if it is expected to respond to the robust growth of demand for Li-ion batteries over the next decade. According to Clean Energy Canada, if proper steps are taken, the full economic impact of Canada's EV battery supply chain could contribute over USD 59 billion to the broader economy, creating over 320,000 direct, indirect, and induced jobs. However, this potential will not be realized unless decisive action is taken soon.

To meet the expected domestic demand for EVs, Canada must establish a robust domestic supply chain for Li-ion batteries. Without this, Canada will be forced to navigate unnecessary economic risks due to a reliance on foreign suppliers. However, achieving a secure and robust supply chain will require investment in manufacturing to meet the demands of the growing EV and electrical grid storage markets. It will also require the development of a strategy for securing critical raw materials needed in the production of Li-ion batteries, namely, lithium, used in the production of the cathode, and carbon, in the form of graphite, used to produce the anode.

As the global battery market is dominated by Asian companies, AFRY expects that in the short-term many lithium-ion batteries in Canada will continue to be sourced from China. With continued supply chain and logistics challenges, this creates the need to develop domestic and renewable supply of raw materials for battery production.

Ontario is working to establish a domestic supply chain that supports long- term vision of sustainability and growth of the province. This requires a commitment to support breakthrough scientific discoveries for raw materials alternatives, scientific R&D and early-stage technologies, and the increase in manufacturing capacity to maintain Canada's independence and advance Canada's technology.

2.2 A Brief Survey of Leading Advanced Carbon Technology Developers

Many companies are working to deliver biomass-based solutions for the Li-ion battery markets. Most of the development activity is taking place in Nordic countries, which are working to leverage their considerable woody biomass resource base and provide more environmentally-friendly alternatives to the current suite of technology offerings. Perhaps most notable is Finland-based Stora Enso.

In this section, AFRY looks at some leading companies and provides a brief description of their technology offerings. We assess their technology readiness or technology maturity level using the Technology Readiness Level (TRL) framework (Figure 4).

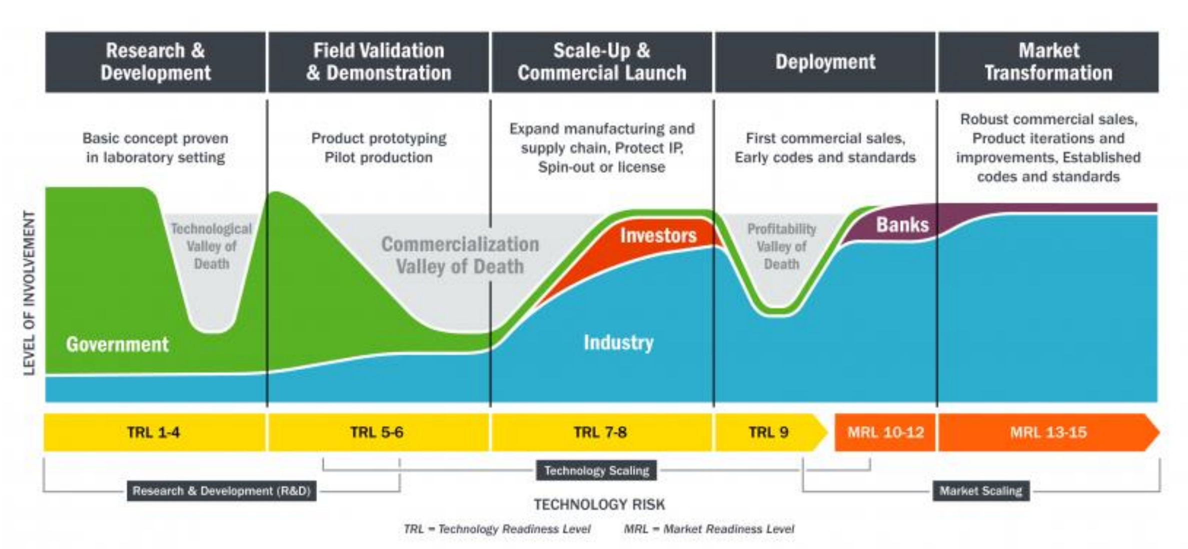


Figure 4 Developed by NASA, the Technology Readiness Levels (TRL) is used to assess the maturity level of a particular technology from discovery (TRL=1) to fully commercial (TRL=9).

2.2.1 Lignode®: Stora Enso's Renewable Hard Carbon TRL = 7

Finland-based Stora Enso recently launched Lignode®, a natural product derived from wood that is being used to produce the anode in Li-ion batteries. Lignode® is derived from lignin, a polymeric constituent found in biomass (see Appendix A). The unique properties of Lignode® deliver faster charging times by 5-6 times that of conventional Li-ion batteries. Faster charge rates reduce the demand for charging infrastructure and enable solutions for smaller batteries. Lignin-based anodes also have better performance at low temperatures compared to graphite. Stora Enso plans to begin commercial production of Lignode® in 2025, ramping up to 20,000 tonnes per year by 2030. This will require upwards of 70,000 tons of lignin, which it will supply from its kraft pulp mills. Stora Enso sees a demand potential for over 300,000 tons of and expects the Lignode® product line to deliver EUR 10 billion in annual sales, with a long term EBIDTA margin potential of 50% and over 20% CAGR.

Stora Enso has signed an agreement with Swedish battery developer and producer Northvolt to develop wood-based batteries. The goal of the partnership is to manufacture batteries using Lignode® as a replacement for fossil-derived graphite. Stora Enso will supply Lignode®, while Northvolt will focus on battery design and scale-up of the technology. Northvolt's first battery gigafactory has started delivering battery cells to European customers. Companies such as Volvo Cars, BMW, and Volkswagen have placed orders for more than USD 55 billion worth of products with Northvolt.

2.2.2 Beyonder Sustainable Battery Technology TRL = 5

The Norwegian tech company Beyonder is developing lithium-ion capacitors (LiCs), a new high-power battery technology for heavy duty vehicles, industrial application and energy backup. Beyonder's patented activated carbon cathode, which is made from sawdust, delivers high-power, long cycle life and quick charge to Li-ion capacitor. The company has been in the pilot stage since 2020 but is targeting commercial-scale product by 2023. Beyonder is also working with Stora Enso to explore applications for Lignode®. If successful, Beyonder may be the first company to develop a bio-based Li-C using biomass in both the anode and cathode. In 2020, Beyonder started pilot production and is targeting large scale production in 2023 with an output of 1500 cells per day.

2.2.3 SuperCap Technologies Sustainable Supercapacitors TRL = 5

SuperCap Technologies is a British Columbia-based consortium along with InnoTech Alberta and Ontario-based Tavrima Canada Ltd. SuperCap is developing ways to make supercapacitors and lithium-sulphur batteries using activated bio-based carbon from lignin. Lignin sourced from Canadian pulp mills is carbonized in a high temperature furnace, then activated using an oxidizing agent and ground to a fine powder.

Recently, the company has shifted its focus to lignin-based hard carbon through collaboration with some of the major forestry companies in Canada such as West Fraser. The company is planning pilot-scale demonstration.

> *Unlike what Stora Enso is doing to connect vertically and horizontally within an integrated value chain in their new partnership with Northvolt, we in Canada feel isolated doing research in labs and not being connected to OEMs.*
> **Tony Pantages**, CEO SuperCap

SuperCap's patent-pending technology could provide a local, sustainable and secure battery supply chain but partnership with cell battery producers and OEMs is crucial for process optimization and scale up of the technology (similar to the Stora Enso partnership with Northvolt).

2.2.4 Bio Graphene Solutions TRLs= 3-4

Bio Graphene Solutions (BGS), a company founded in 2018, manufactures and supplies graphene made from renewable sources of biochar. Located in Ontario, the company is focusing on utilizing the renewable carbon found in biochar to make graphene, primarily for concrete and asphalt applications. Due to its high purity and electrical conductivity properties, the material can be used in energy storage applications. The company claims that their patent-pending technology has a lower carbon footprint compared to the traditional method of graphene exfoliation, which requires harsh chemicals, acids, and solvents.

2.2.5 Bright Day Graphene TRLs= 3-4

Graphene is a two-dimensional network composed of six-membered carbon rings. This unique material has outstanding thermal and electrical conductivity that could be used in batteries and supercapacitors as energy storage. Located in Sweden, Bright Day Graphene has found a way to produce graphene from lignin using a patent-pending technology. Graphene in incorporated in a novel battery design, where it replaces lithium used to produce the cathode. While Bright Day Graphene is an early-stage company, the company is expected to produce pilot-scale quantities of its product of up to 1 tonne per day by the end of 2022.

2.2.6 Other Early-stage Technologies TRLs = 1-3

- A Lakehead University research team led by Professor Pedram Fatehi is working on lignin incorporated energy storage material technologies that could complement Stora Enso's approach to lignin-based anodes, the focus of their study is on lignin-based cathodes as well as lignin-based separators and electrolytes.
- Researchers at RISE Research Institute of Sweden and VTT Technical Research Centre of Finland are actively working on lignin-based carbon materials for energy storage applications including a team led by senior scientist Chamseddine Guizani with the focus on lignin-based carbon for electrochemical energy storage applications
- Recent work at Kung Hee University (Korea) demonstrates how lignin can be used in other components of battery including binder, separator, electrolyte and cathode but these are at the early stage of development.
- A team of scientists from Brown University and the University of Maryland has developed a solid ion conductor that combines copper with cellulose nanofibrils, which are polymer tubes derived from a material found in wood.
- Researchers from Bristol Composite Institute and Imperial College in the UK have developed sodium-and potassium-ion batteries with cellulose aerogels.

3 Opportunities for the Ontario Bioeconomy

3.1 Advanced Carbon as a Means for Replacing Fossil-based Carbon in Li-ion Batteries

Canada is rich in forest resources and a world leader in sustainable forest management. Forestry is also vital to Canada's economy, employing nearly 185,000 people and contributing nearly $25.2 billion to Canada's nominal GDP.[3] However, global competition in certain sectors of the industry as well as the consequences of material substitution and the digitization of print media, have dramatically altered the face of Canada's forest-based industries. The Ministry of Natural Resources and Forestry sums up the situation best: "Ontario is utilizing only half of the wood that could be sustainably harvested." In other words, more than 17 million tonnes of wood that could be available for attracting investments in new domestic and

[3] The State of Canada's Forests Annual Report 2021.

international markets is not used. The opportunity costs in lost revenues and job creation are enormous.

How do Ontario's forest resources potentially address the creation of a robust Li-ion supply chain? Recent advances in forest biomass utilization show that woody biomass can be used to produce Advanced Carbon, which can replace natural graphite and fossil-derived sources of carbon in Li-ion batteries. By sourcing raw materials for battery production locally and from renewable forest biomass, Canada has the potential to leap-frog the traditional sources for the carbon used to produce Li-ion batteries.

Currently, carbon-based anodes are made from graphite, most of which are the form of natural graphite sourced from mines located in China. Although Canada does have graphite reserves, actual production is limited to one mine located in Quebec. While Canada may choose to exploit undeveloped sources of graphite or produce synthetic graphite, these developments would be opposed to the general policy of migrating from fossil-derived sources of carbon. Extracting carbon in the form of graphite from mines or manufacturing synthetic graphite from fossil fuels will only add to the challenges of mitigating CO_2 emissions and addressing climate change. In contrast, biobased sources of carbon could not only achieve the same result—that is provide the necessary supply of carbon for a domestic Li-ion battery industry—it will stimulate a much-needed demand for wood beyond traditional uses.

A wood-based Li-ion battery plays directly to Ontario's strengths in forestry and cleantech. Approximately 75,000 tonnes of natural graphite are required to make 1 million EVs. If wood resources were used instead of graphite, natural graphite could be replaced by Advanced Carbon. The source of Advanced Carbon will depend on the type of technology used. For example, using the Stora Enso process, Advanced Carbon would be made from lignin obtained from kraft pulp mills. Under this production scheme, approximately 260,000 tonnes of kraft lignin would be needed to meet graphite demand. In comparison, if the Advanced Carbon were made from biochar using the Bio Graphene process, the amount of wood needed to meet graphite demand would be upwards of 1.3 million tonnes. AFRY has estimated a 20-30% yield of bio-based graphene when residual biomass such as sawdust is being used as feedstock.

By *leap-frogging* traditional methods of manufacturing carbon anodes, Canada has the potential of creating a competitive advantage and stimulating much-needed economic development in the forestry sector. Significant job creation opportunities in rural areas would be created through the development of an Advanced Carbon industry. Additionally, expected investment in research and development to support this nascent industry would provide a means for workforce development and training of a skilled workforce. Government support and the creation of public-private partnerships will provide the necessary market signals that can jump-start a bio-based Li-ion battery industry within Ontario.

An industry based on Advanced Carbon would provide a model for sustainable development within the EV sector. In Canada, the auto industry is responsible for over 500,000 direct and indirect jobs. In 2019, the auto sector contributed 16% of Ontario's manufacturing GDP and employed over 120,000 workers. A report from Clean Energy Canada (CEC) suggests that with a domestic EV battery supply chain by 2030, Canada could support up to 320,000 direct, indirect, and induced jobs and add $59 billion to the Canadian economy annually but this depends on swift government actions. Domestic battery sourcing and production of EVs are important for Canada not only as part of the transition to a clean-energy economy, but as a key factor for maintaining a competitive workforce.

3.2 Advanced Carbon as a Basis for a Sustainable Li-Ion Battery Industry

As the primary role of battery energy storage is electrification and the reduction of atmospheric CO_2 emissions, steps involved in the production of batteries should strive to be more environmentally friendly. Using bio-based carbon as a replacement for natural graphite and fossil-derived hard carbon from petroleum coke would potentially reduce the carbon intensity of battery production. Additionally, over-reliance on distant suppliers and global conflicts could recreate the severe supply chain disruptions that occurred during the COVID-19 pandemic. Since Canada has the raw materials resources and skilled workforce to create a resilient domestic supply chain, developing this would appear to be in the country's best strategic interests. However, acting on this opportunity will require investment and strategic intent.

A recent report by BloombergNEF ranked Canada as No. 2 in their annual global Li-ion battery value chain survey, ahead of both the United States and Nordic countries, and second only to China. Canada's strong positions in raw materials, manufacturing, innovation, and environmental, social, and governance (ESG) provided the basis for its strong ranking. However, in downstream demand, Canada ranked 15 out of 17 countries surveyed. In other words, Canada has the tools to be the global leader in Li-ion batteries but lacks the downstream pull from domestic customers.

> *Canada's recent investment in its upstream clean energy supply and increasing demand in the US-Mexico-Canada Agreement (USMCA) region increases the country's competitiveness.*
> BloombergNEF (2022)

In contrast, China will continue to dominate the ranking as it has for the past three years due to the strong demand for EVs and the investments China has made to create a robust raw materials supply chain.

Additionally, several factors make Canada highly suitable for a sustainable battery industry based on biomass:

- A national goal to transition to a fossil-free society. The Government of Canada is committed to reaching net-zero emissions by 2050 and supports the decarbonization of heavy-emitting sectors and clean technology that reduce emissions at home and abroad.

- Strong commitments to R&D. As recently stated by the Canadian Council of Forest Ministers: *Canada will be a global leader in the use of forest biomass for advanced bioproducts and innovative solutions.*[4]
- Strong commitments to strategic investments in cleantech. Canada's Net Zero Accelerator (NZA) initiative, which supports Canada's net zero goals to help transform the economy for clean and long-term growth, has committed up to $8 billion in funding to ensure that Canada remains competitive in a net-zero economy and meets national targets to reduce greenhouse gas (GHG) emissions.

Canada has announced more than $15 billion in investments over the past 10 months in areas ranging from critical mineral mining and processing to battery component manufacturing, electric vehicle production and the country's first gigafactory. While Canada aims to boost mining activity to secure raw materials needed to complete the Li-ion battery supply chain, it should also consider alternative technologies with the potential to replace conventional materials with more sustainable alternatives such as biomass. Battery ecosystems can be powerful tools for economic development, and governments that wish to capture the value-creation opportunity of batteries should consider moving quickly and forcefully to build them.

3.3 SWOT Analysis

In this section, AFRY provides a summary of the Strengths, Weakness, Opportunities, and Threats (SWOT) to developing a bio-based Li-ion battery manufacturing base. Long-standing strengths, such as the abundance of biomass resources and R&D capabilities, can be undercut by under-investment in these sectors. Developing appropriate funding policies will be critical if bio-based solutions are to become part of a resilient domestic EV supply chain.

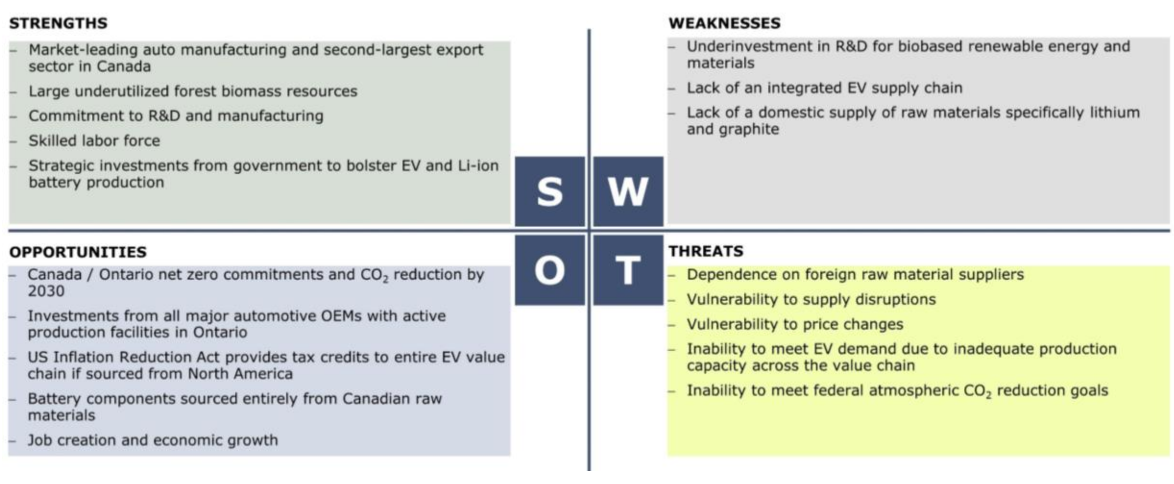


Figure 5 SWOT analysis.

[4] A Forest Bioeconomy Framework for Canada (2017).

Appendix A: Stora Enso's Advanced Carbon Process

Figure 6 provides an overview of Stora Enso's Lignode® process. Lignocellulosic material, preferably lignin, is carbonized at high temperature (up to 1400°C). The product is then post-processed to produce the Li-ion anode.

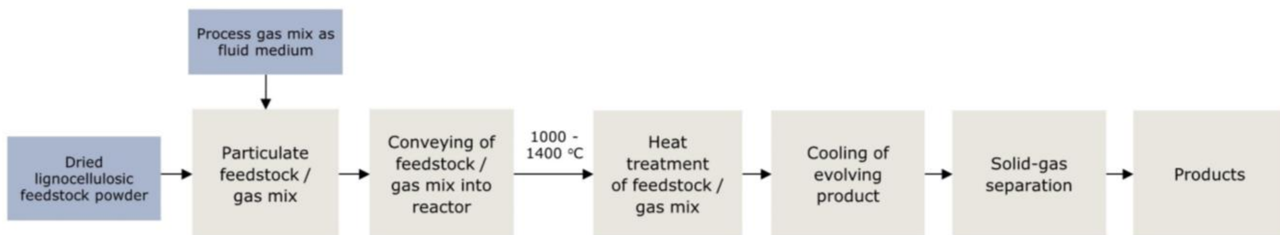


Figure 6 Stora Enso's Lignode® process flow diagram.