

# Phase 1 Study

## Britishvolt Route to UK Synthetic Graphite



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## 1 EXECUTIVE SUMMARY

### Key findings:

- UK localization of synthetic graphite anode production is strategically aligned with Britishvolt's anode supply requirements for Li-ion cell production
  - Synthetic graphite is required for cells supporting BEV and PHEV markets
  - Increases anode supply stability and removes risks from today's largely China dominated anode supply chain
- UK anode production produces a positive ESG result for Britishvolt, reducing the environmental impact compared to sourcing anode from the current global supply chain, and achieved by implementing best-in-class manufacturing
  - 25-35% lower energy
  - >35% lower carbon footprint
  - significant emissions reductions and reduced logistics impact
- Technology to produce synthetic graphite anode delivering supply and ESG benefits is readily available
  - Product specifications defined by current materials already in high end Li-ion battery use today
  - Raw material available from locally sourced Phillips 66 needle pitch coke that is already used as precursor to synthetic graphite anode materials
  - Production process defined with best-in-class induction furnace graphitization technologically proven
- Intellectual property risks to Britishvolt and for UK synthetic graphite anode production are considered low as core anode technologies of interest have been well established for >20 years; however Freedom-to-operate has not been formally conducted in this study and is recommended for anode products once they are well-defined
  - This report identifies key anode patents that can support future FTO studies
- Key risks for UK synthetic graphite anode production are
  - Time to availability is estimated at 3-5 years and past initial need for Li-ion cell start of production
  - Complete costs analysis for UK anode production is required to support business case and competitiveness against established global supply chain
- Global sourcing of anode materials is required to align with cell production timing and until a UK source can be relied upon
- Opportunities for Britishvolt to establish differentiated anode materials are identified and can contribute to Britishvolt's future technology and IP portfolio

### Recommended key next-steps:

- Secure globally sourced anode products that define and support Britishvolt's anode material
- Construct a cost model for UK produced synthetic graphite anode that can support business decisions to move forward towards UK anode production

- Engage and align the necessary business partnerships to deliver UK anode production, including consideration of Phillips 66 sourced raw material and Morgan Advanced Materials operation of anode manufacturing
- Initiate anode R&D focused on
  - Formulating sourced anode materials into target specification anodes
  - Developing blended anode solutions using a combination of synthetic graphite, natural graphite, and Si/SiO<sub>x</sub> materials, and defining conductive additives and binders that can support a range of Li-ion cell products
  - Testing process equipment and conditions that enable validation of a UK anode production process and validation of the material from that process
  - Establishing capabilities for ongoing anode technology development delivering advanced products, lower cost, and aligned with Britishvolt's cell roadmap

Cadenza presents a study on the feasibility of establishing a UK based, state-of-the-art, synthetic graphite (SG) anode production plant that supports Britishvolt's anticipated Li-ion cell production starting in 2023. This study reviews and sets a framework for global anode sourcing options, establishes a target SG anode material design, defines a SG anode manufacturing process, and describes advantages and risks for a UK anode plant. The study includes a technical analysis of relevant patents in the SG anode field and considers opportunities to develop new technology and novel IP in support of world class Li-ion anode supply.

A path forward is proposed and arguments are presented that support UK source SG graphite anode material aligned with Britishvolt business, ESG (Environment, Social and Governance) and product goals for world-leading Li-ion cell production. Such production is expected to be highly desired by UK and EU markets, including automobile manufacturing customers, and reduces dependence on a supply chain that is entirely based in China, Japan and Korea today, with increasing dominance by China. The considered UK anode plant delivers ESG improvements, greatly reducing energy consumption and carbon footprint compared to sourcing anodes from today's established suppliers. In addition, a UK anode plant in collaboration with Britishvolt can serve as a center-for-excellence in the development of anode technology for Li-ion batteries.

Key advantages of a UK SG anode plant are summarized in the below table as a comparison to sourcing within the existing global supply chain.

Metric	UK Plant Advantage	Perspective
Energy consumption (anode production)	25-35% reduction	<ul style="list-style-type: none"> <li>• Access innovative graphitization technologies available today</li> <li>• Path to additional 40% reduction identified for development</li> </ul>
Carbon footprint	>35% reduction Additional 10-14x reduction via renewables is possible	<ul style="list-style-type: none"> <li>• Baseline reduction based on energy</li> <li>• Access to renewables critical to achieve largest benefit and carbon footprint reduction</li> </ul>
Emissions (anode production)	Sulfur: 15-25% reduction Organics: 20-25% reduction	<ul style="list-style-type: none"> <li>• Emissions should be captured by all operations but increased certainty with UK production</li> <li>• Less emissions reduces cost for capture and disposal</li> </ul>

Supply & Logistics	Supply assurance, localized supply, improved reliability	<ul style="list-style-type: none"> <li>Strong collaborative anode-cell relationship removes supply risks and offers collaborative development paths</li> <li>Widely recognized benefits in reducing carbon footprint and improving supply stability; not further quantified in this study</li> </ul>
Technology	Global-leadership in anode production sustainability  Center-of-excellence for anode technology development	<ul style="list-style-type: none"> <li>Aligns with strong interests insustainability for UK/EU governments and customers</li> <li>Development opportunities drive competitive advantages in cell production</li> </ul>

The study evaluates today's Li-ion anode materials and concludes that SG anodes are currently, and expected to remain for significant time, a critical component required for Li-ion batteries. Current state-of-the-art anode materials include SG and natural graphite (NG), with Si/SiOx increasingly used in small amounts of <10% by weight and blended with graphite. Both SG and NG are expected to remain critical for Li-ion batteries used in electric vehicle (EV) applications including battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV), with SG expected to support BEV and PHEV applications for the significant future (>10 years) with no clear alternatives to graphite anodes demonstrated today. SG is the traditionally preferred material for long-life BEV, while NG competes on lower cost and has been narrowing performance gaps relative to SG. Si/SiOx blends with graphite are a significant trend but do not inhibit strong market growth expected for graphite. Competing technologies such as high content Si/SiOx and lithium metal anodes are not sufficiently mature to support automotive EV growth plans. Only graphite anodes are sufficiently established in cell designs and at mass scale production volumes to align with predicted Li-ion battery growth. Thus, investment into a UK SG anode production plant is considered to have very limited risks associated with loss of market opportunity for a period of the next 20 years.

The study considers anode supply into Britishvolt's Li-ion cell plant and concludes that global sourcing must be exercised in order to assure anode supply aligned with the timing of Britishvolt's cell production start at the end of 2023 to a initial scale capacity of 10 GWh and with capability to scale to 30 GWh. This conclusion considers that a UK anode plant is likely a minimum of 3-5 years away from being able to support Britishvolt cell production and that any anode material source needs clear visibility and sample availability by an estimated 18-24 months prior to cell start of production in order to generate test and qualification samples and support definition of cell plant processes. The study recognizes that, in addition to SG anodes, NG and Si/SiOx materials are likely to be used in Britishvolt products and require sourcing solutions. Initiating and growing anode supply partnerships is considered critical to Britishvolt's success and allows for paths to support cell production that, although not realizing the many advantages identified in this report, are independent from timelines and risks associated with starting a new anode production plant.

A target UK SG anode product is described and based on a needle coke precursor material, such as that available from Phillips 66, with local UK supply capability. This Phillips 66 needle coke is a known precursor to SG anode materials today. The finished anode product is expected to be a SG anode powder material with average particle size in the range of 10 – 20 µm and comprised of smaller, primary graphite particles bound together. The plant is expected to be capable of making a number of finished anode products with engineered surface coatings that are either graphite or amorphous carbon in structure – both styles of product are in use today and will remain a viable base product for at least the next 15 years.

A UK anode plant is outlined, delivering SG anode material in support of Britishvolt Li-ion cell demand. The UK plant anode material is expected to meet the requirements for sale to other Li-ion cell

manufacturers. The plant outline presented is capable of making a range of SG anode products that are suitable for BEV and PHEV applications, as well as being suitable for many other Li-ion battery applications, including batteries used in battery energy storage systems (BESS) for renewable energy storage and utility grid interface improvements. A plant design is provided that is scaled to 10,000 metric tons annual production, an amount capable to meet the supply demands of up to 10 GWh of Li-ion cell batteries. The plant design leverages successful designs in operation today, the main difference being the use of induction furnace graphitization equipment that achieves significant energy and environmental benefits.

This study considers risks associated with the proposed plant, including the proposed progressive use of induction furnace technology that enables improved energy and environmental conditions for anode production. The plant will deliver a proven material design, using established process steps and is considered to have no fundamental technical risks. Use of induction furnace graphitization at the scale proposed to achieve the target material output has not been demonstrated within the industry to-date. Key operational risks are highlighted, some of which are easily addressed, such as design and certification of globally sourced equipment to UK standards, while others require further investigation to resolve, such as operational costs of the proposed facility which targets use of a large number of duplicated induction furnaces, and UK production costs compared to today's largely China-based supply. It is recommended that a detailed cost analysis be performed prior to fully committing to plant development to ensure that a UK anode plant can exist competitively in an established global market, however expectations based on this report are that this indeed can be accomplished.

Definition of anode plant ownership and operation remains an open question and thus a risk until resolved. This study does not specifically address this issue, however the study findings are expected to offer paths to resolve such questions. Likely interested parties include Britishvolt as the anode plant customer, Phillips 66 as the raw material supplier, Morgan Advanced Materials as a potential plant operator, the UK government in alignment with strategic manufacturing development, jobs creation, and ESG improvements, and potential financial investors.

Results of an Intellectual Property Rights (IPR) study suggests no significant risks in bringing a UK SG anode product portfolio to market. Production and use of the target UK anode material is viewed as low IP risk based on patents identified that are >20 years since issuing, describing graphite anode material consisting of secondary particles with graphite or amorphous carbon surface coating. Further development of Li-ion cell anode materials consisting of synthetic graphite blends with NG or Si/SiO<sub>x</sub> is viewed as low IP risk based on patents identified that are >20 years since issuing. Market trends and opportunities for novel IP development are highlighted through the performed IPR study. This includes opportunity to develop (1) increased utilization of Si/SiO<sub>x</sub> materials together with graphite, (2) anode materials capable of higher power capability and enabling automotive fast charge, and (3) processing technologies that further improve on graphitization cost, especially development of continuous furnace processing. Harper International, a maker of high temperature processing equipment, is identified as a potential development partner to realize novel technology enabling continuous graphitization processing. The study recommends that a formal legal review of IP risks be conducted once decisions to move forward commercially are made and product and process definition are clear.

At the conclusion of this report, Cadenza identifies paths forward in support of anode supply into a Britishvolt Li-ion cell plant and including establishment of UK SG anode production. In addition, critical areas are identified where Cadenza can offer ongoing product support to Britishvolt in becoming a world-class provider of Li-ion batteries. To support the realization of a UK anode plant, Cadenza can also offer support in areas of supply chain development, anode design aligned with cell design (anode formulation, cell format, and cell cathode and electrolyte chemistry), and development of technologies aimed at advancing the ability to produce SG anodes at lower cost, lower energy and lower environmental impact.

## 2 SCOPE

Cadenza Innovation (Cadenza) reports the results of a feasibility study for Britishvolt to define and deliver a UK based synthetic graphite (SG) state-of-the-art anode plant in support of Britishvolt's targeted Li-ion cell production plant. Cadenza presents the results of this Phase 1 anode feasibility effort and presents continuing, Phase 2 activity, that aims to deliver against the proposed options in support of anode supply. Cadenza's team brings many years' experience in both materials development and Li-ion cell design/manufacturing, supporting review of carbon anode delivery where we can bring pragmatic views, direct global anode industry experience, and a strong track record on innovation and state-of-the-art laboratory capabilities to augment the Britishvolt team.

In this report, Cadenza leverages the direct experiences of Cadenza team members to research, develop and commercialize Li-ion technology, including development of anode and cathode materials, and design and production of Li-ion cells. Opinions and data are presented based on this experience and without formal reference. Where available, Cadenza presents well established references to support key data.

Anode production and supply is presented within the context of Britishvolt's cell production targets which include establishing start of production (SOP) capability by the end of 2023 for 10 GWh capacity. Total production capacity is expected to be able to scale to 30 GWh.

Cadenza addresses solutions for Britishvolt to leverage multiple anode supply options, including established anode suppliers and products, and suggests pathways to support the feasibility of a UK-sourced solution. These solutions include key tasks that define target anode products and solutions to supply anode products. This includes descriptions of anode (1) product definition, (2) sourcing, and (3) UK production. Also, this considers the need for blended anode products, accessing natural graphite (NG) and Si/SiO<sub>x</sub> anode materials that are established and available for use in the industry today.

UK anode production focuses on SG anode production based on needle pitch coke supplied from Phillips 66. This needle coke material is known and established within the SG anode supply chain, representing one of the most used precursors in the industry today. Other sources of needle coke are expected to be suitable for use at the same anode plant. Details for sources of carbon other than needle coke have not been considered and other sources of precursor carbon are expected to require additional process development and may require changes to plant equipment compared to what is presented in this report.

The detailed scope of work has been described in the signed Britishvolt – Cadenza agreement, dated February 18, 2021, “Revised Cadenza Offer Agreement to Support Britishvolt’s Route to UK Synthetic Graphite – Phase 1 Proposal considering Britishvolt input provide on 2021-02-07 and 2021-02-17”. This detailed scope of work presents nine task categories to be addressed. These are described in Table 1.

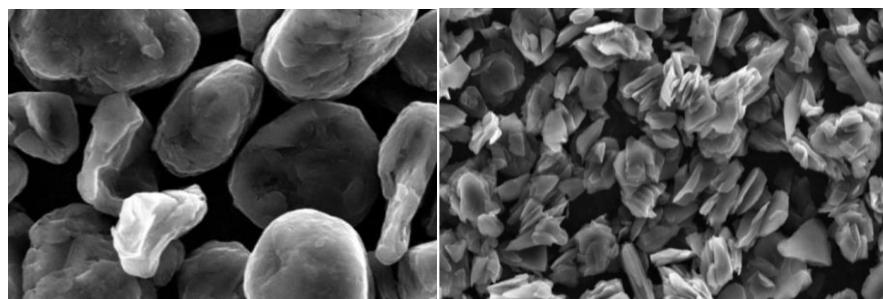
**Table 1: Phase 1 Anode Study Tasks**

Anode Study Scope	
A	Concept Development - UK Synthetic Graphite Synthesis and Manufacturing Concept
B	Development of Plant - Headline summary of Plant (specs, requirements, indicative costs) to produce the above
C	Market IPR study - Summary report on market landscape and IP risks A&B.
D	ESG - Analysis and report on how concept may deliver against sustainability and impact.
E	Development Plan - A summary project plan for delivery of concept to plant
F	Definition of Initial Trials - Summary definition of experimental scope and program through initial trials from a pilot plant
G	Outline of possible BV Total Anode Material Strategy - Where above would fit into an anode strategy for BV, based on assumed delivery of above, matched against cell requirements.
H	Further Support - Indication of how Cadenza Innovation may support the above beyond initial Feasibility Study, i.e. supporting the management of experimental pilot trials; the project management of delivering a manufacturing solution and plant; the support for entire Britishvolt Anode strategy
I	General anode market data

### 3 BACKGROUND

Graphite materials far dominate the usage of Li-ion battery anode materials and have done so historically since near the beginning of Li-ion battery commercialization in the early 1990s. This is primarily due to the feature of graphite being able to intercalate  $\text{Li}^+$  ions into the graphite planar structure at voltages just slightly above (i.e. before) that for Li metal deposition. This results in a relatively safe ability to hold a high voltage charge  $>4.0$  V, when referenced against typical cathode materials (e.g. LCO, LNO, LMO, NMC, LFP) in a high voltage stable organic electrolyte system, without issues that arise from Li metal deposition and dendrite formation, enabling repeated charge and discharge cycling.

As Li-ion battery products have demonstrated successful mass commercialization, first in consumer electronics, then followed by portable power tools, automotive, industrial and grid storage applications, graphite materials have remained the dominate choice for anodes. As such, battery grade graphite material production has scaled to meet Li-ion cell anode production demand. The result is that today, only graphite materials possess the commercial scale and cost, roughly and broadly \$4-\$20/kg, that is required for the rapidly growing demand from automotive markets for battery electric and plug-in hybrid vehicles (BEV, PHEV). Similarly, utility grid scale application for renewable energy storage and improved power infrastructure, are leveraging the established commercial scale of Li-ion batteries, and hence, graphite anode manufacturing.



**Figure 1: SEM high magnification images of two common graphite anode materials a) NG from BTR and b) SG from BTR**

There are two main types of graphite anode materials, natural (NG) and synthetic (SG), with examples of each shown in high magnification SEM images in Figure 1. NG is sourced from geological resources and processed into finished battery grade anode material. SG is synthesized from precursor carbons, so-called “soft carbons” that can be graphitized and that originate from either petroleum or coal resources. Both NG and SG share significant market use for Li-ion battery anodes. Other sources of carbon, including hard carbons (non-graphitizable) and mesophase carbons, such as mesophase carbon micro beads (MCMB) exist and have been utilized as Li-ion anode materials but are not considered cost effective for mass commercial scale in Li-ion batteries.

Historically, the choice between NG and SG has been one of cost vs. performance. In more recent years, anode material technology, including powder particle formation, sizing and coating, have allowed NG materials to close the performance gap while improved manufacturing processes and scale of lower the cost of SG. Still, a difference remains and applications including BEV and PHEV are viewed as high-end applications requiring the highest performing material with SG generally commanding a greater share of the anode market. Table 2 shows general features and differences for NG and SG anode materials.

**Table 2: Comparison of natural and synthetic graphite key properties for Li-ion cell anodes**

Natural graphite (NG)	Synthetic graphite (SG)
Source: graphite mining with purification and processing into battery grade	Source: soft carbons graphitized at >2800 °C, typically from coal or petroleum pitch, processed into battery grade
Key properties: <ul style="list-style-type: none"> <li>• High capacity &gt; 360 mAh/g</li> <li>• Lower cost vs. SG</li> <li>• Lower rate and cycle life performance vs. SG</li> <li>• Larger electrode expansion vs. SG</li> </ul>	Key properties: <ul style="list-style-type: none"> <li>• High grade capacity 350 – 360 mAh/g (low and mid-grade ranges from &lt;340 up to 350 mAh/g)</li> <li>• High cycle life and rate performance vs. NG</li> <li>• Low electrode expansion vs. NG</li> </ul>

Electrode formulations using synthetic graphite sometimes utilizes mixtures with natural graphite. While one of the drawbacks of natural graphite traditionally has been low cycle life, this blending of synthetic graphite with highly tailored natural graphite particles has allowed mixed electrode formulations to deliver long life at lowered cost and somewhat higher capacity.

## 4 TASK A – CONCEPT DEVELOPMENT

Concept development answers the question about what a UK source anode should look like in the context of supporting Britishvolt Li-ion cell production and products. In collaborative discussions between Britishvolt and Cadenza, Li-ion cell product and production targets have been identified and guide this effort. These targets include the following:

- Li-ion cell plant start of production (SOP) by the end of 2023 at an initial phase production volume capable of ramping to 10 GWh
- Li-ion cell products targeted at the automotive market for battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV); Cadenza notes that these products would not be restricted to automotive markets and are expected to be well-suited for a wide range of market applications, including use in battery energy storage systems for renewable energy storage and utility grid power improvements
- Two types of cell construction formats that include a cylindrical and a pouch cell format
- Cell designs that include use of the Nickel-Manganese-Cobalt metal oxide (NMC) class of cathode materials, including use of NMC cathodes with relatively high Ni-content at a fraction relative to Mn and Co of  $\geq 0.5$
- Specific cell design targets provided by Britishvolt are summarized in Table 3

**Table 3: Britishvolt Li-ion cell design targets**

Variant	Cell ID	Description	Nominal Potential (V)	Capacity (Ah)	Nominal Energy (Wh)
1	BV-PN90-HE	Pouch – BEV – NMC	3.65	80 – 100	329
3	BV-INR-21700-AN53	Cylindrical – BEV – NMC	3.65	5 – 5.6	19.3
4	BV-21700-BN48	Cylindrical – PHEV – NMC	3.65	4.5 – 5	17.3

An additional requirement for a UK source anode includes improving upon the environmental impact of graphite anode production compared to standard processes used today. Environmental impacts of anode synthesis are discussed in more detail in Section 7 of this report, but the requirement is important to understand as a UK source target anode is defined. The energy required to graphitize the anode powder is one of the most important aspect of establishing environmentally sustainable practices of anode materials and represents an immediate opportunity for Britishvolt that can differentiate its Li-ion batteries.

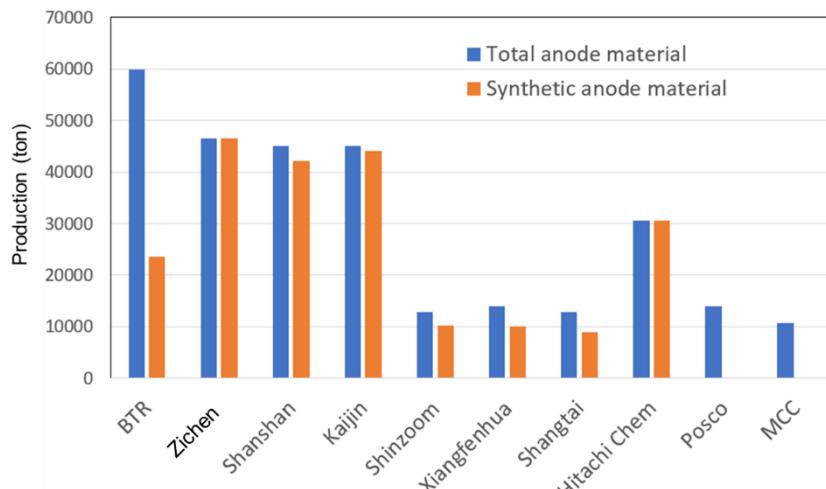
In addition to these targets, an SG anode made from needle pitch coke was used as a strongly influential guide for UK anode production target. SG anodes are widely used in today's Li-ion cell industry, including use in high-end BEV and PHEV applications, and are required to support Britishvolt's intended cell design targets. Further, SG anodes can be synthesized from a needle pitch coke precursor supplied by Phillips 66 from a plant located locally in the UK. This localization offers numerous advantages, improving supply chain logistics, lessening environmental impact, ability to customize precursors for Britishvolt use, and supporting creation of a broad Li-ion industry capability.

#### **4.1 REVIEW OF SYNTHETIC GRAPHITE ANODE PRODUCTS FROM KEY MANUFACTURERS**

High performing SG anode materials exist in the market today. A review of existing products accomplishes two key objectives. First, it identifies supply options suitable for supporting Britishvolt Li-ion cell production. Until a UK source is established, other sourcing options must be considered. Second, such a review allows a model product specification to be created. This model specification can be used to define a production process that will generate relevant data to support decision making about moving forward towards an actual UK anode production plant.

This review analyzes key SG anode materials used for EV application and supplied from the global top 6 synthetic graphite Li-ion anode material manufacturers to identify the highest performing products. This includes both high capacity products targeted for BEV, and high power products targeted for PHEV. Key attributes are identified for these highest performance products, including material bulk properties, particle morphologies and surface properties, all of which impact performance as a Li-ion anode material. Based on this review, a model product concept is proposed for supporting definition of manufacturing processes to produce the model product anode.

The top 10 global Li-ion anode suppliers in 2019 are presented in Figure 2. Seven of the top 10 anode manufacturers are Chinese companies, and only one non-Chinese company, Hitachi Chemical (now Showa Denko Materials), is among the top 5 manufacturers. Of these top 10 suppliers, Zichen, Kaijin, Shanshan, Hitachi Chemical, and BTR are, in that order, the top 5 SG anode producers from 2019.



**Figure 2: Global top ten Li-ion anode manufacturers in 2019.** Source: huaon.com (<https://www.huaon.com/channel/trend/614152.html>); ICC (<https://www.163.com/dy/article/F33GKIN0518SQ5.html>)

The Chinese dominance of global Li-ion anode supply chain is a direct result of China's growing manufacturing capability. In fact, over the last 10 years, there has been a very significant investment in China which has earned Chinese anode suppliers significant market share from previous market leaders in Japan and Korea. Unless there is significant focus in other geographies, this trend is expected to continue, which would put China in a controlling position of Li-ion carbon-based anodes.

Cadenza studied SG products from the top 6 manufacturers and including which customers were using those products. Table 4 shows the list of SG products for each top manufacturer and their customer base.

**Table 4: SG anode products from top global producers and their customers. \* Note that customers may source additional products to those listed, including NG, from the listed anode manufacturer**

Manufacturer	Selected key SG anode products	Key customers *
Zichen	G49, GT, KT, NT	CATL, ATL, SDI, LG Chem, BYD
Shanshan	EV7, QCG-series, P-15, EP-15	CATL, ATL, SDI, LG Chem, BYD
Kaijin	AML850, AML830	CATL, Farasis
Showa Denko (Hitachi Chemical)	MAGE, MAG3	Tesla/Panasonic
BTR	S360, AGP	SDI, LG Chem, Panasonic, CATL, BYD
Shinzoom	MD-4C, PE1-X	BYD, CATL, ATL

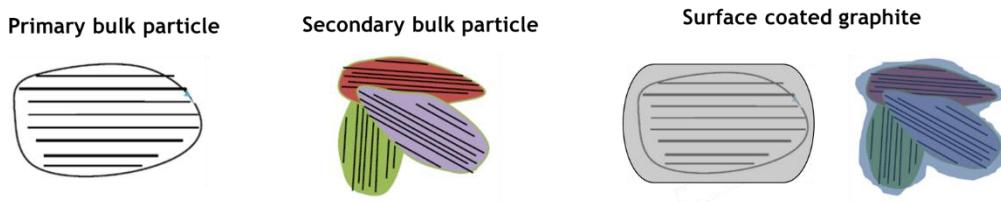
One can observe in the customer list for SG anode products, the top BEV/PHEV Li-ion cell manufacturers in the world today. It is widely understood in the industry that these listed SG products support a large portion of EV Li-ion anode usage.

Analysis of these top SG anode products shows consistent materials properties and the top SG anode products demonstrated the following features in key physical categories:

- Bulk particles consisting of primary particles assembled (bound) into larger secondary particles
  - Primary bulk particles consisting of graphite particles made from graphitization of a single precursor particles
  - Secondary bulk particles made from graphitization of agglomerated precursor particles
  - Note that the graphitization mentioned above can occur at the same process step for both the primary and secondary particles

- Surface coated graphite (secondary) particles where either
  - a layer of carbon precursor is coated on the surface of single precursor particles or agglomerated precursor particles, followed by graphitization to generate graphite coated anode material; or
  - a layer of carbon precursor is coated on the surface of primary graphite particles or secondary graphite particles, followed by carbonization to generate amorphous coated anode material.

These particle characteristics are illustrated in Figure 3.



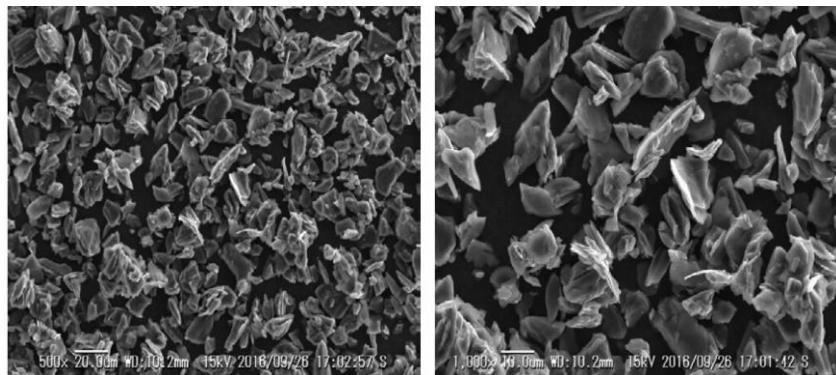
**Figure 3: Illustration if key SG anode material particle features**

A detailed review was performed on all the SG products listed in Table 4. The results are presented in Appendix 2. For ease of discussion, only Zichen's products are discussed in more detail here. Zichen is the current top SG anode producer in the world and their products are viewed as representative of top performing SG anode material. Four Zichen SG anode products are reviewed (G49, GT, KT and NT). Products from the other identified suppliers can be considered competitive and broadly similar to these Zichen generated products.

Based on Zichen's product literature, GT is suitable for pouch cells due to low electrode swelling, and NT is suitable for cylindrical cells due to high electrode press density ( $>1.8 \text{ g/cm}^3$ ). KT is offered as suitable for both cell types, and all four products are presented as suitable for both BEV and PHEV Li-ion cells.

General observations are that all four products exhibit good battery performance characteristics that include high capacity ( $>350 \text{ mAh/g}$ ), high first cycle efficiency ( $>93\%$ ), and high electrode press density ( $>1.60 \text{ g/cm}^3$ ). Key particle physical features include a D50 between 13 and 21  $\mu\text{m}$  and a surface area of approximately 1-2  $\text{m}^2/\text{g}$ .

High magnification SEM imaging for one of the products, Zichen KT, is presented in Figure 4 and is representative of a typical SG anode material used today.



**Figure 4: SEM image of Zichen KT SG anode material**

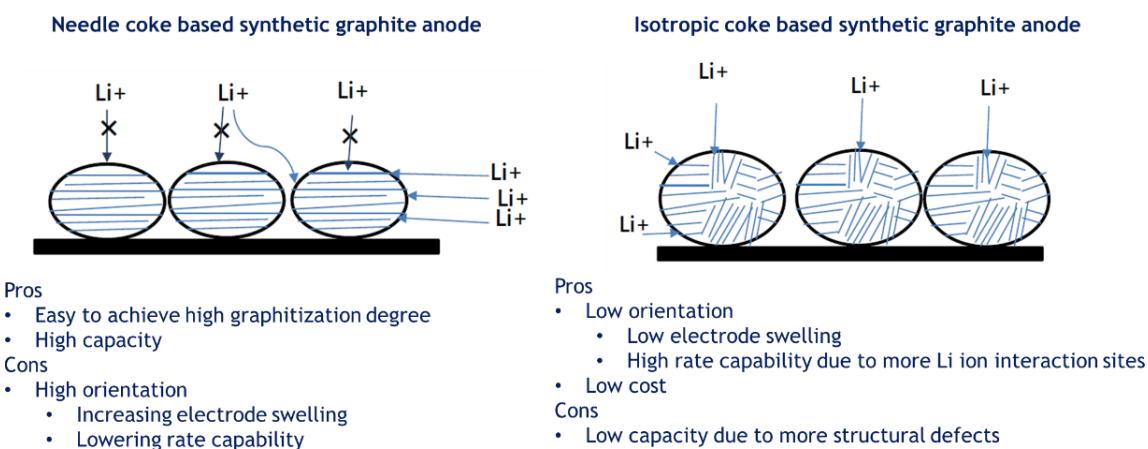
## 4.2 ANALYSIS OF KEY ATTRIBUTES OF HIGH-PERFORMANCE SYNTHETIC GRAPHITE ANODE MATERIALS

The review of SG anode allows for analysis of features consistent in these materials. The majority of SG anode materials are based on needle coke precursors. This is aligned with the fact that there is a strong supply base, including Phillips 66 needle coke, established processes and that needle coke material has good orientation as a “soft” carbon to support graphitization to a high degree, which is required to deliver high capacity. Figure 5 show images of needle coke before and after graphitization.



**Figure 5: Needle coke precursor and SG from needle coke after milling and graphitization**

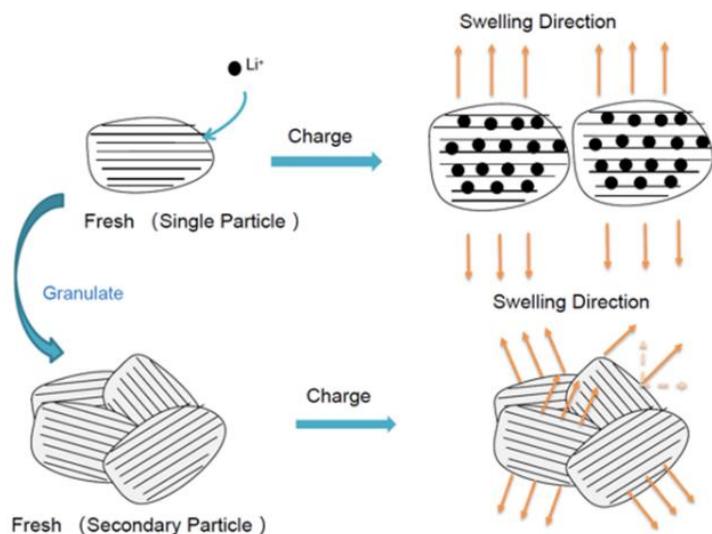
The preference of needle coke as a precursor to SG anode materials can be explained by the fact that needle coke has greater alignment in its carbon structure prior to graphitization. During the graphitization process, these aligned carbon layers more easily form the graphite planes required to store Li<sup>+</sup> ions in a Li-ion battery compared to other type of precursors. It also allows for less time/temperature of graphitization, thus lowering processing costs. In contrast, other types of cokes, such as isotropic cokes, have a more randomized orientation of carbon layers that lower the ability to fully graphitize, resulting in lower capacity materials. Still, these isotropic cokes have been used as precursors for SG anode and can exhibit beneficial features related to high power and less expansion (swelling). Figure 6 presents a comparison of needle and isotropic coke as a precursor for SG anodes.



**Figure 6: Comparison of needle vs. isotropic coke as a precursor for SG anodes**

The top SG anodes all consist of bulk secondary particles made from smaller primary particles. Technical arguments for why this secondary structure dominates graphite anode usage are that it allows for randomization of the graphite planes which lessens expansion (swelling) during use and improves life performance. The secondary particle structure is also expected to improve material utilization in the anode synthesis process and thereby allow for lower costs. Figure 7 illustrates this effect. The

randomized orientation also increases the sites for intercalation of the Li-ion and avoids directional effects during electrode manufacturing processes, which in returns delivers a battery anode with high power capability compared to structures that are oriented along the coating plane. A key consideration in the formation of secondary particles is the use of binder to agglomerate the primary particles prior to heat treatment. Typically, a coal tar or petroleum pitch is used, accomplishing the aggregation of primary particles and also being able to achieve some degree of graphitization and thus contribute to the capacity of the anode material, rather than lower the capacity in proportion to the amount used. Typically, pitch coating processes are optimized for SG anode materials to minimize the amount of pitch while achieving the necessary particle tailoring features.



**Figure 7: Comparison of graphite plane orientation on the net expansion (swelling) during Li insertion on charge. Primary particles exhibit a high degree of orientation resulting in large expansion. Secondary particles allow for randomization of the expansion, reducing the net impact.**

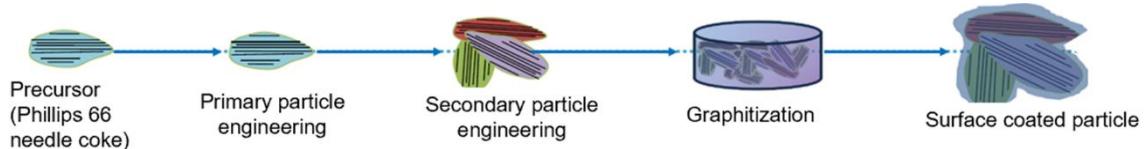
Leading SG anodes include surface modification. This is due to the fact that surface coatings can improve performance and are a necessary feature of forming bulk secondary particles. Performance improvements in part result from a reduction in surface area and include increase to first cycle efficiency, improved life, and increased electrical conductivity. For almost all products, a graphite surface coating is used due to enabling higher capacity and likely being lower cost as this is consistent with one-step graphitization of the primary precursor particles into graphitized secondary particles. Some products use a carbonized surface coating instead of a graphitized surface coating. Carbonized surface coatings are expected to have improved power performance and fast charging capability, an important consideration for EV application. However, capacity is lower and cost is expected to be higher in the case of SG anode materials. Both carbonized and graphitized coatings are used in the market and application requirements may influence selection, but graphite coated materials appear to be much more dominating for SG anodes.

#### 4.3 PROPOSED CONCEPT OF SYNTHETIC PRODUCTS AND MANUFACTURING PROCESS

Based on the review and analysis of market leading SG anode materials Cadenza proposes a strategy of employing a secondary bulk particle and surface modification for Britishvolt to develop high performance synthetic anode materials in UK. This will serve as the basis for defining a UK anode production plant. The production process will be flexible to produce high capacity SG anode material with the ability to vary particle size distribution, tap density, surface area, and coating details. This will enable tailoring to ideal or target features including specific capacity, rate capability, life performance

and processibility. The process is expected to be capable to produce the range of SG materials reviewed in this study, as well as incorporate material and process optimizations.

The proposed SG anode material originates from needle pitch coke, such as that supplied by Phillips 66, and concludes with a graphitized coated secondary particle. This transition is illustrated in Figure 8. In addition, the same precursor material can follow a similar path and end with a carbonization step after graphitization, that enable a carbonized-coated surface. Since such products are of interests in the market, this additional product path is recommended to remain as a product option until a firm product definition is achieved.



**Figure 8: Material transitions for the proposed UK SG anode, starting from needle pitch coke and ending in a graphite surface coated secondary particle consisting of agglomerated graphitized needle pitch coke primary particles.**

A representative model SG anode material specification is shown in Table 5. The model material specification allows for definition of a process to achieve the stated requirements. Note that an actual final SG anode product specification is expected to somewhat narrow the range of properties exhibited in this model material. One can readily see that the material described is similar and consistent with market leading products as shown with Zichen's materials in Table 4 as well as with other materials reviewed.

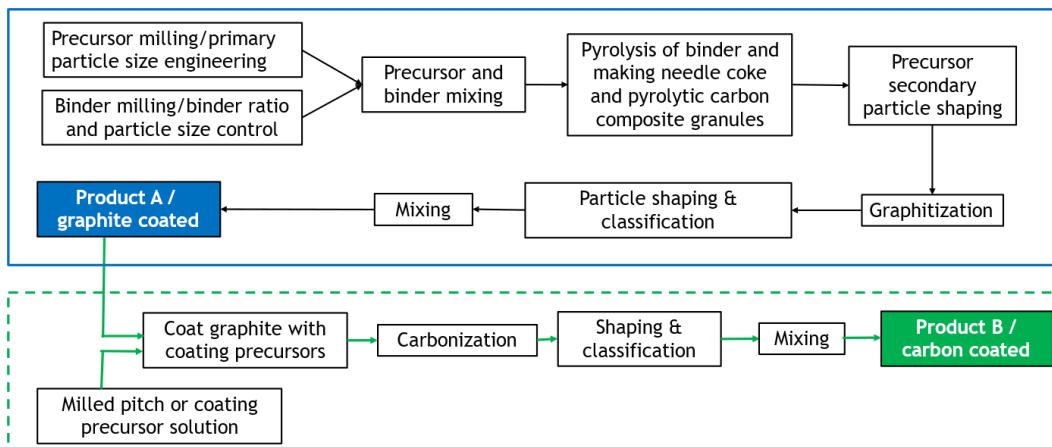
**Table 5: Model SG anode specification**

Particle size	Tap density	Specific surface area	Discharge capacity	1st cycle coulombic efficiency	Electrode press density
D50 (um)	g/cc	m <sup>2</sup> /g	mAh/g	%	g/cc
10-20	0.8-1.2	1.0-2.0	350-360	92-94	1.70-1.75

## 5 TASK B – DEVELOPMENT OF PLANT

### 5.1 OVERVIEW OF PROCESS FOR SYNTHETIC GRAPHITE PRODUCTION

Based on the model target SG anode material, a process flow is defined to achieve that target material. Cadenza describes this process flow and then identifies process equipment achieving the targeted material. The review is high level and exact details will depend on key final material and process design decisions. The proposed process considers options to form two general types of finished product, one with a graphite surface coating and one with a carbon surface coating. In the case of SG anode material, the carbon surface coated product process flow follows sequentially after the graphite surface coated product process flow. This is shown in Figure 9. However, detailed product features could be different between these two products, requiring different process settings be used on the equipment. Therefore, depending on specific targets for each type of product, a specific carbon-coated SG anode material might not flow directly from a specific graphite-coated SG anode product.



**Figure 9: Synthetic graphite anode process flow leading to either a graphite-coated final product (Product A) or a carbon-coated final product (Product B).**

Table 6 categorizes the main process steps and describes the objective. The ongoing discussion in this report references back to these categories.

**Table 6: Synthetic graphite anode production process steps**

Step	Processes	Purpose	Additional Details
1	Precursor milling and pitch mixing	Prepare precursor into target primary particle size and combine with binder for further processing	<ul style="list-style-type: none"> <li>• Incoming precursor</li> <li>• Milling precursor to target particle size</li> <li>• Incoming pitch</li> <li>• Milling pitch to target particle size</li> <li>• Mixing precursor with pitch</li> </ul>
2	Pyrolysis and granulation	Heat the pitch above the softening point. The viscous pitch binds coke primary particle to form granules. Pyrolyze the pitch binder to form composite for further processing	<ul style="list-style-type: none"> <li>• Reaction in a reactor</li> <li>• Heat treatment with mechanical stirring</li> <li>• Pyrolysis</li> </ul>
3	Milling and shaping	Reduce composite to target particle size and shape particle morphology (generally, shaping decreases aspect ratio of particles)	<ul style="list-style-type: none"> <li>• Mild impact mechanical processing</li> <li>• Classification of material into target particle size range</li> </ul>
4	Graphitization	Form target chemical structure for anode material	<ul style="list-style-type: none"> <li>• High temperature heat treatment under inert atmosphere</li> </ul>

5	Graphite shaping	Form final target particle size range and shape; blend multiple batches or segments of processed materials	<ul style="list-style-type: none"> <li>Mild impact mechanical processing</li> <li>Classification of material into target particle sizes</li> <li>Blending of materials to form final particle size range and homogeneous</li> </ul>
End Product A	Finished product	Prepare for customer shipment	<ul style="list-style-type: none"> <li>Quality control testing</li> <li>Packaging for shipment</li> <li>Alternatively, material transfer to next product line</li> </ul>
6	Coating	Mix pitch or other carbonaceous precursors with graphite (from step 5)	<ul style="list-style-type: none"> <li>Incoming pitch or other carbonaceous precursors</li> <li>Milling/preparing coating material</li> <li>Mixing graphite with coating material</li> </ul>
7	Carbonization	Heat to carbonization temperatures to form coating	<ul style="list-style-type: none"> <li>Heating from 800 – 1300 °C under nitrogen atmosphere</li> </ul>
8	Graphite shaping	Same process as Step 5	
End Product B	Finished product	Prepare for customer shipment	<ul style="list-style-type: none"> <li>Quality control testing</li> <li>Packaging for shipment</li> <li>Alternatively, material transfer to next product line</li> </ul>

Briefly, the process takes the core primary particle material (needle coke) and combines with a binder (pitch), then process towards a finished SG anode product. The process starts with mixing and milling coke and pitch into small, micrometer-sized particles, the mixture is combined to form mm-sized granules in a reactor under nitrogen at a specified pressure (usually less than 3 bar), in which pitch acts as a binder to bind small coke particles, and the pitch is finally heat treated to form a pyrolytic carbon. Initially, the mixture is heated to above the softening point of the pitch, ~300 °C, stirred for several hours and then heated to ~400-600 °C to pyrolyze the pitch. The resulting composite granules, mm-sized, consist of coke particles and pyrolytic carbon. These are milled and shaped to specific requirements, typically 10-20 µm in size, and then proceed to graphitization. After graphitization, the graphite powder, some in free particle form and some in agglomerated form, is milled and shaped to a desired particle size distribution, matching the specification shown below in Table 7.

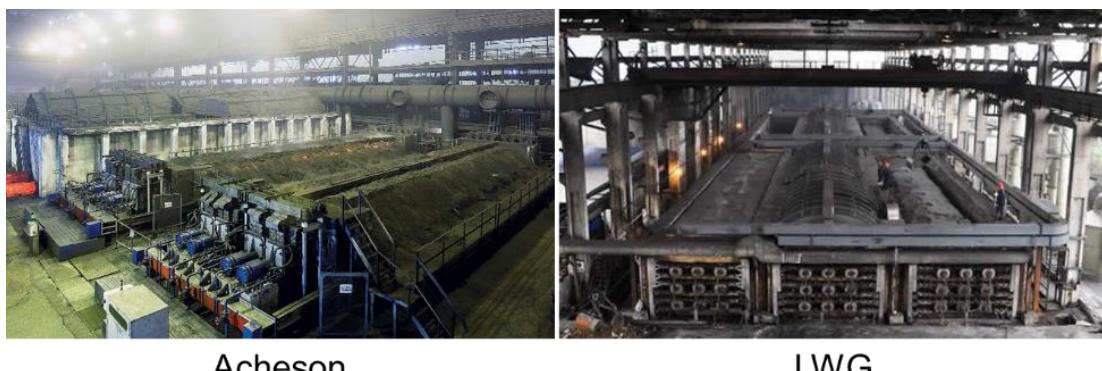
**Table 7: Typical values for selected Zichen synthetic graphite anode products**

Items	Unit	G49	GT	KT	NT
Particle size distribution	D10 (um)	5.8	12.4	6.2	8.9
	D50 (um)	13.9	20.9	13.6	14.5
	D90(um)	28.8	34.5	28.1	25.1
True density	g/cc	2.25	2.25	2.25	2.24
Tap density	g/cc	1.10	0.88	1.00	0.90
Graphitization degree	%	94.01	93.17	93.34	94.01
Ash content	%	0.02	0.02	0.02	0.03
Specific surface area	m <sup>2</sup> /g	1.60	0.75	1.92	1.06
Discharge capacity	mAh/g	354.4	351.5	355.7	357.5
1st cycle coulombic efficiency	%	93.8	93.8	94.4	93.2
Electrode press desity	g/cc	1.65-1.70	1.60-1.70	1.70-1.75	≥1.8

The high temperature used in the graphitization process poses a particular challenge to the Li-ion anode industry, as temperatures close to 3000 °C are required to fully convert the carbon to graphite. A less than perfect crystal structure will not have the storage capacity required and therefore the powders must be homogeneously processed without any thermal gradients. Two main types of graphitization processes currently dominate the SG anode industry. These are: a) the Acheson furnace and b) the lengthwise graphitization (LWG). For the purposes of this report, both processes are treated as established and effective at producing SG anode material. While noting that both processes are considered unacceptable for a UK SG anode production plant, they are considered here for comparison to more energy efficient and environmentally acceptable methods. A brief comparison of these two graphitization methods is provided in Table 8 and images for each method are shown in Figure 10.

**Table 5: Comparison of established graphitization processes used today for SG anodes**

Methods	Pros	Cons
a) Acheson	<ul style="list-style-type: none"> <li>• Mature technology</li> <li>• Low CAPEX</li> <li>• High material loading</li> </ul>	<ul style="list-style-type: none"> <li>• Low energy efficiency</li> <li>• High pollution (emissions)</li> <li>• Long production cycle, 20-30 days</li> </ul>
b) LWG	<ul style="list-style-type: none"> <li>• Improved energy efficiency and reduced emission compared to Acheson</li> <li>• Shorter cycle times, ~20 days</li> <li>• Lower production cost</li> </ul>	<ul style="list-style-type: none"> <li>• Less effective at volatile removal</li> <li>• Less effective at achieving high degree of graphitization</li> <li>• Despite improvements vs. Acheson, still high levels of energy and emissions</li> </ul>



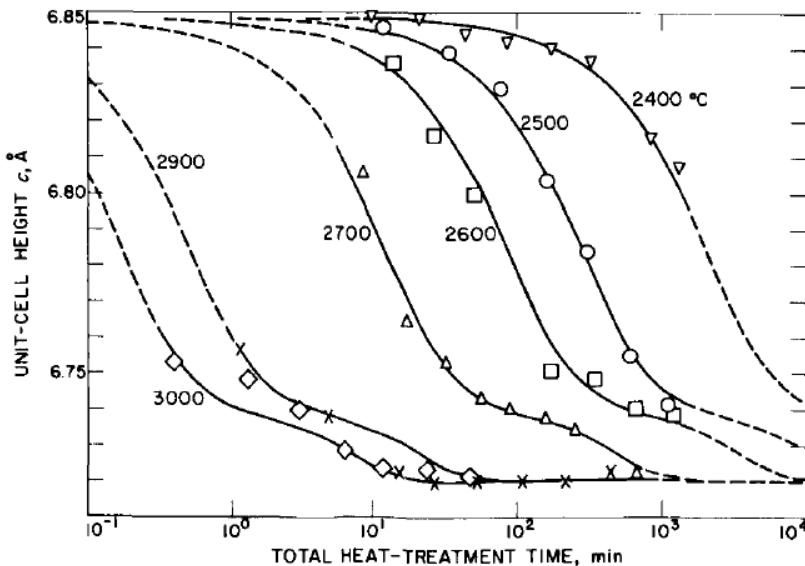
Acheson

LWG

**Figure 10: Images of production equipment for two types of graphitization.**

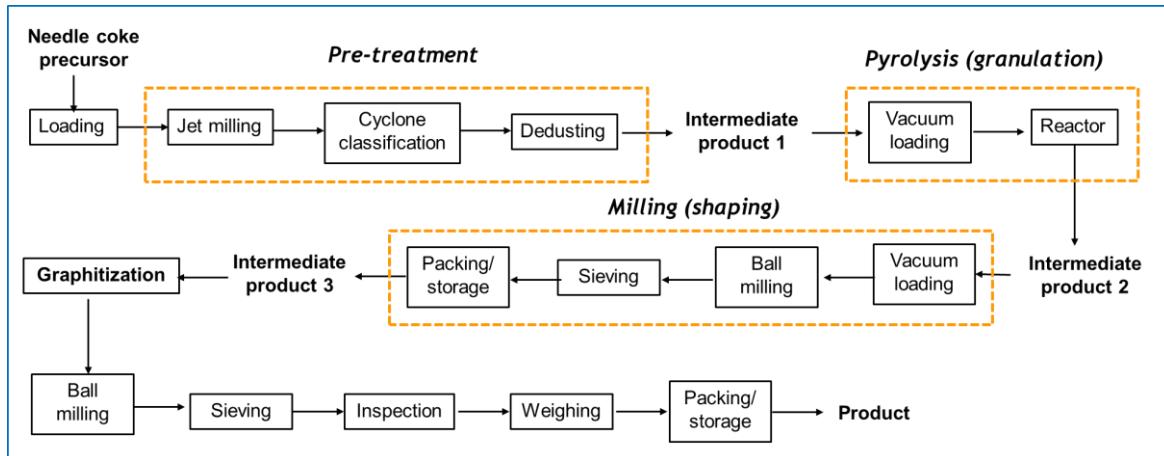
Studies show that graphitization can be very fast as long as temperatures get close to 3000 °C. It is well established that such high temperatures are hard to reach in continuous furnaces and therefore long furnacing times are prevalent in the industry at high cost. However, with advances in induction furnace technology, a continuous graphitization process may become feasible as it will significantly reduce the processing cost and carbon footprint. Figure 11 shows the kinetic effect of temperature to the graphitization process, which at 3000 °C was found to be seconds to minutes. By lowering temperature by only 100-200 °C, the processing time approaches hours. The induction furnace itself is also a more environmentally friendly technique than the Acheson and LWG techniques and will in the future be the method of choice as the industry refines its techniques and market expectations around reduced carbon footprint. Section 7 in this report highlights additional comparisons between the graphitization techniques available and illustrates the significant opportunity of environmental differentiation and lowered cost that Britishvolt can establish by developing a continuous graphitization process. This will require research not only establishing the furnace equipment itself, but also the precursor chemistry,

process timing, and crucible technologies, all of which greatly affects the effectiveness of the graphitization process. Promising options exist yielding advantageous technology options. In addition, collaboration partners are already identified and are available to Britishvolt for execution on this path.



**Figure 11: C-Axis unit cell parameters as a function of heat treatment time and graphitization temperature.**  
 [Reference D.B. Fischbach, Jet Propulsion Laboratories; Technical Report No. 32-852 (1966)]

Figure 12 shows the process flow specific to Zichen, the top global SG anode supplier. The process follows the general description provided above.



**Figure 12: Zichen's synthetic graphite anode production process starting from needle pitch coke.**

## 5.2 REVIEW OF KEY PROCESS EQUIPMENT

Generally, and except for the graphitization process, other equipment used in the production of SG anode materials is well established with use in multiple industries where powder processing and heat treatment is required. As such, a broad supplier base and range of equipment options exists. The critical aspects of equipment arise in the sequence and operating conditions to achieve the target anode material properties. Not considering graphitization, this study did not identify any critical issues related to anode material production equipment or being able to build an anode production plant in the UK based on established industry practices.

Proper selection of milling, shaping and classifying equipment are critical to form the correct particle size range and morphology, while minimizing material losses. Well-established equipment manufacturers include Netzsch and Hosokawa Alpine. A selection of equipment from these manufacturers is listed in Appendix 3.

Graphitization processes pose challenges for equipment manufacturers due to the high temperatures required to achieve graphitization at over 2600 °C and up to 3000 °C and higher. While graphitization methods are well established and in use in the SG anode industry today, these are considered unacceptable for a UK anode production plant due to high energy requirements and high environmental impact. More recent developments in processing technology offer two additional options for graphitization: induction furnaces and continuous furnace processing.

While induction graphitization furnaces have been available for many years, they are a relatively new type of furnace technique for graphite anodes. The technology has been widely demonstrated and many equipment makers exist for this furnace type. Induction furnace processing offers advantages of improved energy consumption, less environmental impact, shorter production times, and better control of graphitization conditions. Three induction furnace options are presented in Table 9. These equipment options are considered suitable for use in a UK anode production plant. China sources of equipment would be recommended to go through design review for necessary certifications for UK use. US and EU sources exists, but their experience in anode processing is limited.

**Table 6: Induction graphitization furnaces**

<p>Supplier: Zhou Zhou Guang Ji Chang Technology</p> <p>Working zone dimension <math>\phi \times L</math> mm: 1000×2000</p> <p>Long-time operation temperature: 2800 °C</p> <p>Max operation temperature: 3000 °C</p>	
<p>Supplier: Yuan Hang Industrial Furnace</p> <p>Furnace dimension <math>\phi \times H</math> mm : 700×1600</p> <p>Long time operation temperature: 2800 °C</p> <p>Max temperature: 3000 °C</p>	
<p>Supplier: Fullad</p> <p>Working zone dimension <math>\phi \times H</math> mm : 600×1200</p> <p>Long time operation temperature: 3050 °C</p> <p>Max temperature: 3100 °C</p>	

Continuous furnace processing is considered highly attractive for use in graphitization due to its ability to reduce energy consumption and shorten processing times. However, such technology is not well demonstrated and there is no commercial use of this equipment currently in the SG anode supply chain. The current state of technology is limited to 2800 °C, which may not be sufficient to support an anode production plant. Pusher furnace technology is a type of continuous processing that is demonstrated for industrial use but not for SG anode materials. Table 10 shows examples of equipment and suppliers of continuous furnace graphitization technologies. None of these are currently considered ready for use in a UK anode plant. However, activity is ongoing in this field and both equipment makers and anode manufacturers are actively looking at continuous furnace graphitization as a future solution for anode production. Cadenza anticipates such development can be successful with a properly directed program involving a cross functional team of furnace experts and Li-ion scientists.

In addition, Harper is a maker of graphitization furnace equipment and has designs for continuous graphitization furnaces. Harper has presented information about their continuous graphitization furnace capability to both Britishvolt and Cadenza. Based on Harper's presentation and other activity ongoing in this area, Cadenza believes that continuous graphitization furnace technology is approaching commercial readiness. This is an area of opportunity for Britishvolt to engage with partners to realize this technology. This opportunity is further discussed later in this report.

**Table 7: Examples of continuous graphitization furnaces**

<p>Supplier: ACME          Product output (kg/h): 50-120          Long time operation temperature: 2800 °C          Max temperature: 3000 °C</p>	
<p>Supplier: Fullad          Product output (kg/h): 20-40          Long time operation temperature: 2600 °C          Max temperature: 2650 °C</p>	
<p>Supplier: Harper          Pusher furnace          Max temperature: 2800 °C</p>	
<p>Supplier: ACME          Pusher furnace          Max temperature: 2600 °C</p>	

### 5.3 REFERENCE SYNTHETIC GRAPHITE PRODUCTION PROCESS AND EQUIPMENT

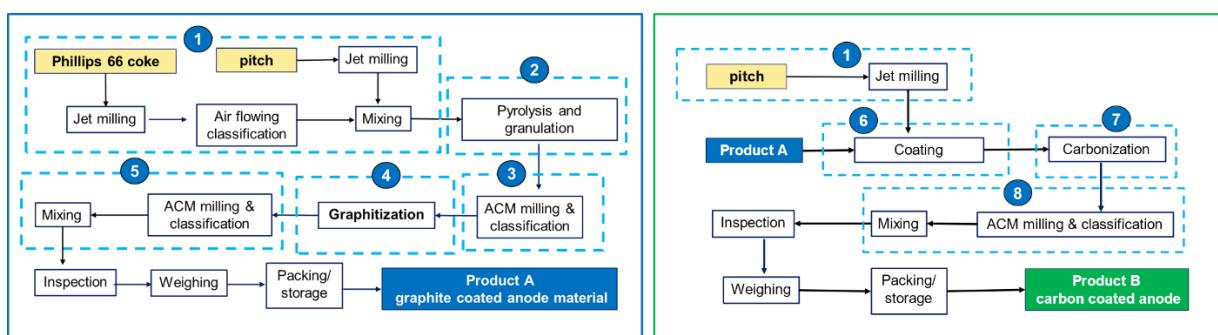
A SG anode production process, including equipment, is defined as a reference design for a UK anode facility. This reference design is consistent with anode production processes in use today and is expected to be capable of making SG anode materials in use today and as described in this report.

The plant is designed to a production capacity of 10,000 metric tons. This amount is aligned with a supporting anode material to a cell production capacity of 10 GWh. The plant is designed with the capability to produce both graphite and carbon surface coated SG anode products. For purposes of estimating equipment and energy consumptions, it is assumed that the plant allocates 2/3 of total production (6700 metric tons) to a graphite coated SG anode, and 1/3 of total production (3300 metric tons) to a carbon coated SG anode. To produce 10,000 metric tons of SG anode product, total input raw materials is approximately 11,000 MT/year, based on calcined needle coke and petroleum pitch precursors, corresponding to a 90% yield.

Table 11 lists key equipment information for an anode plant producing 10,000 metric tons of SG anode material. Figure 13 shows the process flow for this facility, achieving the two described types of anode product and consistent with that presented in Figure 9. Additional cost for chemical scrubbing of off-gases and materials transport will additionally affect CAPEX of processing equipment, as well as establishing electrical power to the highly intense processes.

**Table 8: Estimated production equipment information for a 10,000 metric ton anode plant**

Equipment line for process	Precursor milling	ACM & classification	Mixing	Pyrolysis & granulation	Graphitization	Coating	Carbonization
Vendor	Netzsch	Hosokawa / Alphine	Chang Zhou Xuanyu Drying Equipment	Fushan BANGDETH	Zhu Zhou Guang Chang Technology	Fushan BANGDETH	Jiangsu Qian Jing Furnace
Model	CGS120	ACM300	10,000 L double cone mixer	High temperature reactor	Super large induction graphitization furnace	LiB anode material coating reactor	Carbonization pusher furnace
Estimated price for single line (\$USD)	995,000	680,000	43,846	158,000	400,000	158,000	353,846
Single line space (m <sup>2</sup> )	100	100	21	23	40	23	208
Single line power (kW)	45	486	22	180/55/22	800	180/55/22	600-250
Single line throughput (kg/h)	1,000	2,500	750	100	42	167	160
Single line output <sup>1</sup> (MT/year)	7,200	18,000	5,400	720	300	1,200	1,152
Total production input (ton/year)	11,140	25,474	25,474	11,000	10,000	3,474	3,474
For Product 1	11,000	22,000	22,000	11,000	10,000	0	0
For product 2	140	3,474	3,474	0	0	3,474	3,474
Number of lines needed	2	2	5	16	34	3	4
Estimated CAPEX for total lines <sup>2</sup> (\$USD)	1,990,000	1,360,000	219,231	2,528,000	13,600,000	474,000	1,415,385
Estimated space for total lines(m <sup>2</sup> )	200	200	105	369	5440	69	1104
Space for total lines and operation <sup>3</sup>	300	300	157.5	553	8160	104	1656
Estimated energy consumption (kWh/MT)	36	195	20	625	8,000	341	844
Estimated energy for total lines (kWh/year)	401,040	4,956,140	498,152	6,870,600	80,000,000	1,184,981	2,930,921



**Figure 13: Process flow for SG anode plant**

The equipment and process described here has the capability to take needle pitch coke starting material, such as that from Phillips 66, can produce a SG anode product with specifications consistent to products currently used in Li-ion cell products, with those cells used in BEV and PHEV applications. The described

equipment has a CAPEX of approximately \$22M USD. Complete facility and integration costs, as well as operational costs have not been evaluated in this review and remain an important metric needing clarity. Note that prices for equipment from Chinese suppliers shown in Table 11 are based on the local market, additional costs are expected for the UK market. The production equipment has a total annual energy requirement of 100,000 MWh. The energy consumption is unsurprisingly dominated by the graphitization process. Note that costs and energy for full plant design, construction, and qualification have not been evaluated.

The main differences between the process flow described here and that established in the industry today is that this process uses induction furnaces for graphitization. Such equipment has demonstrated capability to produce the desired target anode material. However, such equipment has not been demonstrated to support a high-volume anode production plant. This represents the key risk with the proposed process and Cadenza recommends further detailed investigation into the production operation of induction furnace technology to the scale needed to support 10,000 metric ton and more annual SG anode production. Specifically, the OPEX cost for operating such a facility needs to be well-defined.

Multiple induction furnaces operating in parallel are required to support the desired anode material output. For the proposed production line, 34 graphitization process lines are required, with each line operating 4 induction furnaces, for a total of 136 furnaces. The costs to operate and maintain this equipment, including operator costs and cost for replacing crucibles used to hold the product material, needs to be evaluated.

#### **5.4 HIGH LEVEL ESTIMATE FOR SPACE TO PRODUCE 10,000 MT/YEAR SYNTHETIC ANODE MATERIALS**

The total space needed for a 10,000 metric ton SG anode facility has been estimated at 23,000 m<sup>2</sup>. This includes the same assumptions discussed earlier for SG anode production, including delivery of two types of products with either a graphite or carbon surface coating.

This number was arrived at by comparing to known anode production facilities in China. Table 12 shows results for two China anode production facilities and the resulting estimate made here.

**Table 9: Space estimate for UK anode plant derived from two reference plants in China. (Note 1 – Jiangxi graphitization process is outsourced; Note 2 – Chengdu does not have a carbon coated product.)**

Items	UK synthetic graphite anode plant	Jiangxi Nan Neng New Material	Chengdu Ai Min Te New Energy Technologies
Total production capacity (MT/y)	10,000	10,000	5,000
Synthetic graphite (MT/y)	6700	6360	4500
Coated graphite (MT/y)	3300	3640	Note 2
Space for process, excluding graphitization, (m <sup>2</sup> )	14,850	14,850	10,800
Space for graphitization space (m <sup>2</sup> )	8,160	Note 1	4,464
Total space (m <sup>2</sup> )	23,010	14,850	15,264

Basically, all processes excluding graphitization are similar to the China reference plant, Jiangxi Nan Neng New Material, with similar production capacity, 10,000 metric tons/year. Thus, the space, 14,850 m<sup>2</sup> in the China reference plant without graphitization process (Note1), is used for the UK plant. The space for graphitization process, 8,160 m<sup>2</sup>, is estimated based on the required space of production lines plus 50% operational space. The total space for the 10,000 metric tons/year UK plant, 23,010 m<sup>2</sup>, is less than 2x of the 5,000 metric tons/year China reference plant (Note 2), 30,528 m<sup>2</sup>.

## 6 TASK C – INTELLECTUAL PROPERTY REVIEW (IPR)

Cadenza performed an IPR study on published patents related to anode materials. The study focused on anode patents in key areas determined to be specifically relevant to Britishvolt. This included the following IPR topics:

- Technical assessment of IP risks related to using current anode materials available in the marketplace
- Overview of IPR related to key anode material topics of interest to Britishvolt and for application of anodes into Li-ion cells for BEV and PHEV application
  - Si and SiO<sub>x</sub> based high-capacity anode materials
  - Anode materials for high power and fast charging
- Preliminary IP analysis of continuous graphitization processes and production of synthetic graphite materials using Phillips 66 type precursors i.e., needle pitch coke

All Cadenza IP assessments are based on technical analysis and industry experience and do not constitute a legal opinion. Cadenza recommends that Britishvolt seeks expert legal advice for subjects of critical concern. Further, freedom to operate (FTO) studies conducted by legal experts can identify risks that may not be identified in this effort, or if no risks identified, support intended commercialization plans for products. Such FTO studies may also identify areas of value for further development and creation of IP aligned with Britishvolt goals.

### 6.1 TECHNICAL ASSESSMENT OF IP RISKS RELATED TO CURRENT ANODE MATERIALS

Li-ion batteries have been using graphite anode materials since the 1990s, including both NG and SG, and many patents were filed before or during that time. Thus, initial patents in this area are well over 20 years old and have expired protection in the UK, US and other markets. These technologies are disclosed and widely available for use with minimal risk of patent infringement.

For this IPR study, patents related to additional graphite anode technologies widely in use today were studied. Patents were searched prior to 2001 to establish known art in this field that has expired beyond the time allowed for patent protection. Topics studied include:

- Surface modified graphite anode materials, including carbon or graphite surface coated spherical graphite powders (particles)
- Anode materials with composite graphite particles, including carbon or graphite surface coated spherical graphite
- Anode materials consisting of NG and SG composites, including blending of particles or secondary particles consisting of NG and SG blends
- Basic anode materials consisting of a graphite and Si/SiO<sub>x</sub> composite

The following databases and search engines were used in this study:

- WIPO – World Intellectual Property Organization (<https://www.wipo.int/portal/en/>)
- USPTO – United States Patent and Trademark Office (<https://www.uspto.gov/patents>)
- Google patents search engine (<https://patents.google.com/>)

Results for patent searches in these identified databases for the listed topics are presented.

### 6.1.1 Surface modified graphite anode materials

Two patents for surface modified graphite anode materials were identified that have expired. This indicates that there is low IP infringement risk to use the described carbon surface coated anode materials. The two identified patents are

- US 6,403,259 B1 with a priority date of May 29, 1998, and from Mitsubishi Chemical. This patent claims an anode consisting of carbonaceous surface coating where the coating can be either graphitized or non-graphitized (Claims 1 and 6) and use of both NG and SG (Claims 6 and 8);
- US 5,908,715 with a priority date of May 30, 1997, and from Hughes, an electronics company. This patent claims non-graphitized carbon coated graphite anode material and the core graphite material is either NG or SG.

In Cadenza's opinion, these expired patents disclose technology that is similar to what Britishvolt might choose to use in anode material for Britishvolt's product lithium-ion cells. That anode material could be sourced from a qualified supplier or produced through a newly created UK anode source. Such materials are considered state-of-the-art and deliver performance equivalent to best-in-class materials for electrodes used by the industry today.

### 6.1.2 Composite graphite particles

Two patents for anodes consisting of composite graphite particles were identified, both from Hitachi Chemical. Composite graphite particles include primary particles of graphite that are agglomerated through use of a binder and then further treated and processed to form a secondary "composite" particle. The two patents identified are

- WO 1998/0066 with a priority date of August 8, 1996. This patent claims graphite particles which are flat particles aggregated or combined in such a way that their orientation faces are not parallel with each other; graphite particles whose aspect ratio is not larger than 5, whose specific surface area is not larger than 8 m<sup>2</sup>/g, or whose crystallites have a size of not less than 500 Å along the c-axis and a size of not larger than 1000 Å in the face direction. This patent was only granted in Japan;
- JP 2001089118A, a Japanese patent with a priority date of September 16, 1999. This patent claims a material and process to produce the material. The claims include the process of mixing a graphitizable aggregate or graphite with a graphitizable binder and a step of firing the mixture obtained in the step at 500 to 2000 °C, and a method for producing graphite particles, comprising a step of pulverizing to an average particle diameter of 10 to 100 µm and a step of graphitizing the pulverized product obtained in the above step at 2500 °C or higher.

In Cadenza's opinion, these patents disclose an anode material consisting of a secondary particle which consists of primary graphite particles aggregated together and is similar to an anode material that might be sourced or produced by Britishvolt. Taking this material together with the surface modified material is a technically viable path that would deliver state-of-the-art electrodes that can compete in today's Li-ion market and seems to steer clear of any technology that has active patent protection based on Cadenza's patent search.

### 6.1.3 Anode materials consisting of composites or blends of NG and SG

Patents have been identified which disclose the use of composites or blends combining NG and SG. Blending of NG and SG is common practice in the Li-ion industry and has the purpose of using anode materials that leverage benefits from both types of material to optimize for both cost and performance. Identified patents include:

- WO 2005078829 with a priority date of February 12, 2004, from Mitsubishi Chemical. This patent claims blending of NG and SG. This patent was only granted in China and the US application was abandoned;

- JP2000-182617 with a priority date of December 16, 1998, from NKK Corp, also discloses particles that are a combination of NG and SG.

In Cadenza's opinion, combinations of NG and SG anodes have been well disclosed in patents that do not have the ability to block use by Britishvolt in product Li-ion cells. From this perspective, Britishvolt should be able to mix NG and SG, as long as they fall within the description of the expired patent. Cadenza's opinion is that the descriptions will enable anode blends that can be highly competitive from a cost and performance perspective.

#### **6.1.4 Basic composite/blends of Si and SiO<sub>x</sub> materials with graphite**

Use of Si materials combined with graphite is increasing in commercial Li-ion cells, typically with Si content from a few up to 10% by weight. Si anode technology has long been under development and patents related to Si and combinations of Si and graphite extend back to the 1990s. The following patents disclosing such technology have been identified:

- US 5,624,606 with a priority date of May 3, 1994, from Moli Energy, disclosing a composite of Si and amorphous carbon;
- JP 3856525, dated May 21, 1997, from Asahi, disclosing carbon coated Si particles;
- US 6,383,686, dated January 26, 1999, from Mitsui Mining, disclosing carbon coated Si particles;
- JP 2000-203818, dated January 13, 1999, from Hitachi Chemical, disclosing amorphous carbon coated graphite and Si composite anode;
- US 6,641,955, dated September 28, 1999, from Samsung SDI, disclosing a composite anode made of Si or SiO<sub>x</sub> thin film coated on carbon surface;
- JP 2001118568A, dated October 21, 1999, from Denki Kagaku Kogyo, disclosing a SiO<sub>x</sub> anode.

In Cadenza's opinion, the prevalence of expired patents related to Si materials, enables Britishvolt use of Si materials in low percentages up to 10% by weight with little risk of infringement on IP rights, as long as the silicon-based materials follow the description of the expired patents

## **6.2 IP LANDSCAPE OF KEY ANODE MATERIAL TECHNOLOGIES**

Cadenza performed additional IPR study into two specific topics related to anode materials and considered particularly relevant to Britishvolt planning for Li-ion cell production into automobile markets. The purpose here is to understand market trends, competitive activity and possible development opportunities related to these key topics. It is anticipated that these results can serve as a reference to possible future R&D work supporting Britishvolt Li-ion cell and anode materials development.

First, Si and SiO<sub>x</sub> anode materials were further investigated to understand progress towards high content Si anode that deliver can potentially delivered improved capacity anode that enable higher energy density Li-ion cells. Success of high content Si anodes represents a threat to the use of graphite anode materials. To-date, high content Si anodes have not demonstrated sufficient capability to support adoption into Li-ion batteries and are not considered a near-term threat to the expanded use of graphite anode for at least 10 or more years.

Second, anode patents related to high power and fast charging capability were investigated. Higher power and faster charging are well known desires for BEVs and are viewed as one of the key performance criteria limiting faster and more widespread adoption. Britishvolt will need to continue to watch this area of the patent field, as narrow ranges of certain mixtures can carve out certain performance areas. To-date, Cadenza has not found any patents of concern related to such mixtures.

### 6.2.1 Si and SiO<sub>x</sub> anode materials

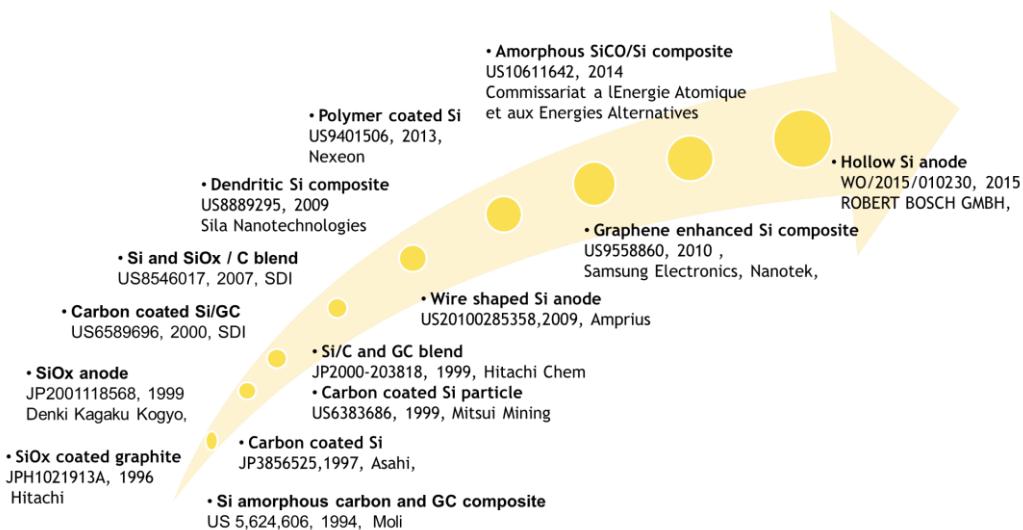
Since 2010, the majority of patents and patent applications in Li-ion anode materials fall into the category of Si and SiO<sub>x</sub> high-capacity materials. This is consistent with the view that Si materials represent the most promising next-generation candidate for Li-ion anodes. Both Si and SiO<sub>x</sub> materials are generally used interchangeably in terms of patent filings, likely as researchers do not fully know best practice and simply list these compounds as part of their filings, but also as both materials behave similarly from a chemical perspective inside a Li-ion cell. Both can theoretically deliver higher anode capacity compared to graphite anodes and operate at similar voltage ranges.

The main deficiencies preventing successful use of Si anode materials are cycle inefficiencies that waste valuable Li and the very large expansion of Si-based anodes during lithiation or charging in a Li-ion cell. Repeated charge and discharge cycles results in large expansion and contraction which strains the anode particles and the cell components, leading to increasingly poor performance.

The majority of Si or SiO<sub>x</sub> patents and applications are related to use in carbon composites as a way to mitigate the deficiencies. Most of these describe a carbon matrix that incorporates the Si material. For low amounts of Si containing materials (<10% by weight), these carbon composites appear to be effective in delivering functional electrodes. Anode material capacities in the range of 400 – 600 mAh/g vs 355 mAh/g typical of graphite only anodes are delivered in such composites and are simply the weighted average of the graphite and silicon capacity. Patent filings cover a broad range of Si usage levels with many filings for high usage, levels enabling 600 – 1000 mAh/g anode materials, and ultra-high usage, levels enabling >1000 mAh/g anode material. However, there is no indication that a commercially viable solution has been disclosed to-date. Thus, any new solutions that incorporate high levels of Si materials in a way that demonstrates commercially viable Li-ion cells is viewed as an area open for innovation. It should be noted that due to the different voltage of the silicon compared to the graphite, the silicon is the first material to be charged and the last to be discharged, which is why the low amount of silicon in graphite electrodes is effective for increased capacity. Due to the nature of many applications, including electric vehicles, batteries are rarely fully discharged, and the silicon therefore receives a very low number of “cycles”. This preserves the silicon-based material’s crystal structure that typically degrades quickly with cycling. The higher the battery capacity, the more unlikely the silicon is to be used. Battery management systems can also be tailored to lower the charge and discharge current allowance in the silicon voltage range, which can further extend life of the silicon containing batteries. This area of electronic control in conjunction with Li-ion batteries containing silicon was not searched, but such patents are more likely to reside with EV manufacturers and would not be a concern for a Li-ion battery manufacturer, such as Britishvolt.

Cadenza’s analysis identified 50 patents that were determined to be of a critical or important nature, meaning that they showed ability to make progress towards commercial viability. Among these patents, 60% patents involve Si or SiO<sub>x</sub> and carbon composites and 22% patents involve carbon matrix composites. Additional patents identified specific types of Si material morphologies or composites with polymer materials.

Figure 14 lists the critical Si patents identified in this search and presents them in sequence of priority date.



**Figure 14: Critical patents and patent applications for Si anode materials**

Appendix 4 provides a complete list of the 50 critical or important patents identified related to Si anode materials. Further, analysis is provided on specific patents that may be of technical interest for future anode and cell product development.

### 6.2.2 High power and fast charging anode materials

Fewer patents related to high power and fast charging were identified compared to Si anode materials. For this high power patent category, patents are classified based on the anode material physical property that is claimed and associated with the improved performance feature. Three main subdivisions of patents based on physical property were identified. These included (1) optimized graphite composite materials, (2) surface modified anode materials, and (3) bulk engineered graphite anode materials.

Since 2010, more activity was identified in the area of composite graphite materials. Activity included filings by SDI, LG and CATL, all significant suppliers of Li-ion cells into automotive applications. NEC was identified as holding several patents under the topic of high power and fast charge, including patents disclosing graphite composites and bulk engineered materials. Since NEC is not directly active in the supply of anode materials, there may be opportunities for licensing such patents.

Given the high automotive interest in this performance feature, and a lack of major progress demonstrated in patents, this area is open for novel developments with potential to have high impact in commercial applications.

A more detailed listing and analysis of patents under this topic is provided in Appendix 5.

## 6.3 IP ANALYSIS OF CONTINUOUS GRAPHITIZATION PROCESS AND PRODUCTION OF SYNTHETIC GRAPHITE MATERIALS USING PHILLIPS 66 TYPE PRECURSORS

This IPR study includes focus on two specific technologies categories that are particularly relevant to this work. These are the use of continuous graphitization processing, which is envisioned as a possible advanced production process that could be implemented in support of a UK source anode, and the production of SG from Phillips 66 type precursors (needle pitch coke), the assumed precursor for a UK source anode. In both cases, very few patents were identified.



Five patents related to continuous processing were identified, with 4/5 patents having been filed in China. All the patents may be useful references and help guide efforts to realize continuous graphitization, but none are considered as posing significant risks.

Cadenza notes that in meetings with Harper International during this work, Harper shared with Cadenza concepts for achieving continuous graphitization. Harper mentioned that IP filing were underway for this technology. Partnering with Harper or another equipment manufacturer is considered an effective means for moving continuous graphitization technology forward to commercial practice for Li-ion anodes.

Four IP filings related to Phillips 66 type precursors were identified, all filed by ConocoPhillips. Two applications were abandoned, and two granted patents exist (US 7,964,240 and US 7,785,661). These ConocoPhillips' Li-ion anode patents were acquired by Pyroteck, Inc. These patents should be considered in more detail when proceeding with anode production using the Phillips 66 precursor, however in Cadenza's view they pose no risk to establishing UK anode products.

The identified continuous graphitization patents show methods that are common to continuous furnace processing and originate mainly from equipment makers and as such equipment would be available from these suppliers and poses minimal risk to any future Britishvolt effort. One patent details use of a metal chloride catalyst to lower the graphitization temperature and the subsequent continuous furnace processing of such a precursor.

For Phillips66 precursor and adjustment, any adjustment that is tested and modified from the Britishvolt side could create a unique technology that could describe precursor additive or adjustments that are particularly suited for Li-ion anode materials of synthetic graphite and as such could be a core patent to Britishvolt. Given Phillips66 being the needle coke produced at the highest amount currently, technologies patented that leads to cost or performance advantages would be highly valuable.

The lack of many patents in these two areas indicates opportunities for novel IP development. Investment into a UK anode production plant would be well supported by ongoing R&D in these areas that can help build IP value for the business. As noted above, development in the area of continuous graphitization might be most effective when done in collaboration with a knowledgeable equipment provider.

## 7 TASK D – ESG

Cadenza presents results from a review of energy consumption, carbon footprint, and plant emissions in support of an Environmental, Social and Governance (ESG) review of the proposed UK anode plant. This review focuses on process equipment specific to manufacturing a SG anode product. Estimates are made for contributions from non-production auxiliary equipment and facility support. Analysis of this data shows that the reduced carbon footprint available by using hydropower and deploying suitable graphitization furnace technology are two straight forward ways of improving ESG parameters for Britishvolt Li-ion batteries. Research optimizing induction furnace methods, both stationary and continuous, is recommended.

### 7.1 PRODUCTION PROCESS ENERGY CONSUMPTION

The process and equipment defined in section 5 of this report, describes an anode production line capable of delivering 10,000 metric tons of SG anode per year. The equipment is estimated to require 100,000 MWh annual energy use.

Table 13 provide a detailed breakdown of the equipment energy consumption, excluding graphitization, which is addressed next. The equipment is estimated to require 17,000 MWh annual energy. Assuming an additional 15% energy contribution from auxiliary equipment and facilities, a total annual energy consumption of 20,000 MWh is estimated. The table determines energy consumption from specific equipment known to be in use in anode production today, using an estimated utilization or “up time” of 80%. Alternative equipment options are available and expected to require similar energy. Opportunities to improve energy efficiency are assumed possible but not focused on in this review due to the dominating role of graphitization in energy consumption.

**Table 10: Energy consumption for anode production equipment (excluding graphitization)**

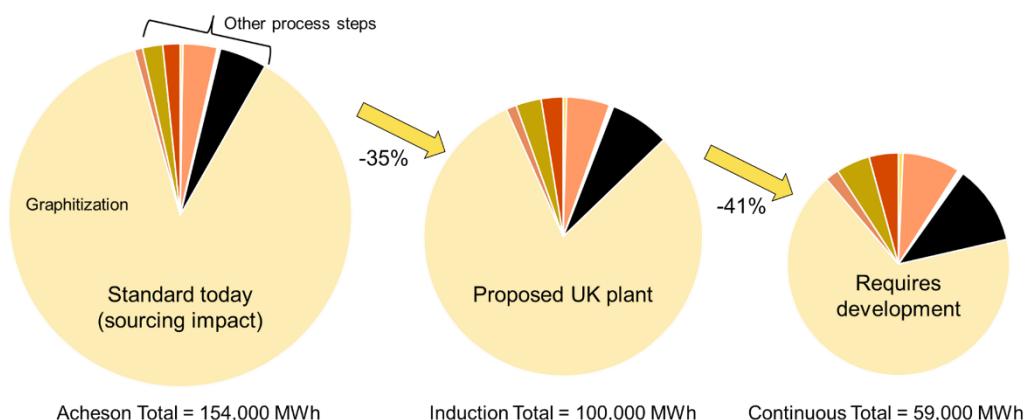
Equipment line	Precursor milling	ACM & classification	Mixing	Pyrolysis & granulation	Coating	Carbonization	Total energy consumption (kWh)
Vendor	Netzsch	Hosokawa / Alpine	Chang Zhou Xuanyu Drying Equipment	Fushan BANGDETH	Fushan BANGDETH	Jiangsu Qian Jing Furnace	
Model	CGS120	ACM300	10,000 L double cone mixer	High temperature reactor	LIB anode coating reactor	Carbonization pusher furnace	
Single furnace power (kW)	45	486	22	180/55/22	180/55/22	600-250	
Number of lines	2	2	5	16	3	4	
Total material input (MT/year)	11,140	25,474	25,474	11,000	3,474	3,474	
Estimated unit energy consumption (kWh/MT)	36	195	20	625	341	844	
Estimated energy for total lines (kWh/year)	401,040	4,956,140	498,152	6,870,600	1,184,981	2,930,921	16,841,834

Table 14 shows the energy consumption for the graphitization process using the proposed solution of vacuum induction furnaces. These values have been supplied by the equipment vendor. Separate conversations with Harper International, another equipment vendor, confirm these estimates. The total energy consumption is 80,000 MWh per year or 8 MWh/metric ton. We note that Ar gas is used to create an inert gas atmosphere during operation and the usage is estimated at 30 L/min per line. Assuming an 80% utilization, that equates to 430 ML per year.

**Table 11: Energy consumption for anode production induction furnace graphitization**

Equipment line	Graphitization
Vendor	Zhu Zhou Guang Chang Technology
Model	Super large induction graphitization furnace
Single furnace power (kW)	800
Number of lines (4 furnaces and 1 control system per line)	34
Total product (MT/year)	10,000
Estimated unitmenergy consumption (kWh/MT)	8,000
Estimated energy for total lines (kWh/year)	80,000,000

Clearly, graphitization dominates energy consumption for an anode plant, consuming 77% of the total energy. For comparison, energy consumption is estimated for standard technology in use today, Acheson furnace graphitization, and for the opportunity presented by continuous graphitization processing. This is shown in Figure 15. Other processes remain constant for energy consumption in this comparison.



**Figure 15: Comparison of energy consumption between different graphitization processes for a 10,000 metric ton anode plant.**

Figure 15 demonstrates a key value of localizing anode production in the UK using state-of-the-art graphitization technology. Li-ion cell production requires anode supply, only available from global sources using Acheson, or the slightly lower energy LWG processes. Using induction furnace technology, a UK anode plant would reduce energy consumption by an estimated 35%. Further, opportunity exists to develop process technology and establish world-class leading capability through continuous furnace technology, achieving a further reduction of 38% in energy consumption, over 60% reduction compared to Acheson processing used today.

## 7.2 CARBON FOOTPRINT

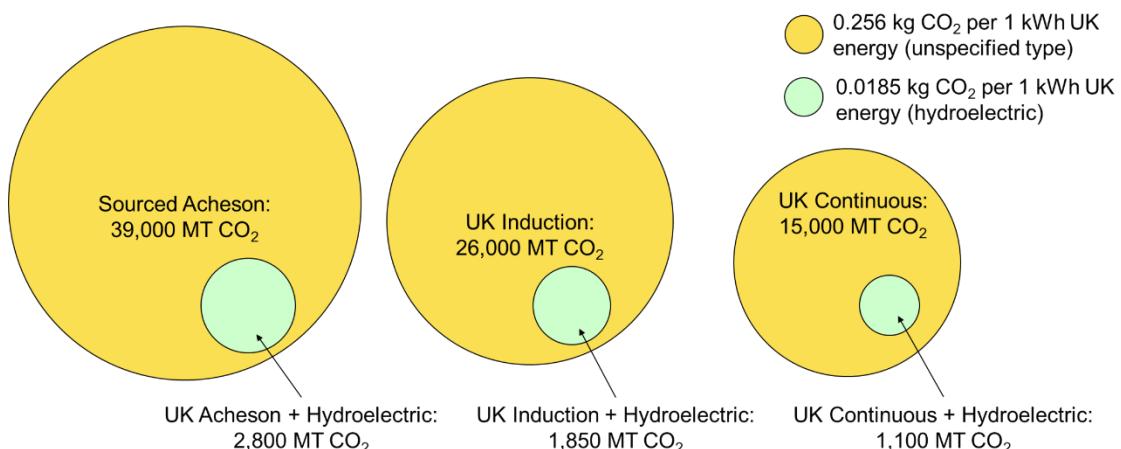
The anode production plant energy consumption can be translated into a carbon footprint. The same assumptions remain, that the plant produces 10,000 metric tons anode material annually. UK government greenhouse gas (GHG) conversion factors<sup>1</sup> are used to estimate the carbon footprint based on the anode plant total energy consumption of 100,000 MWh per year. The UK GHG conversion factor

<sup>1</sup> (a) UK Government GHG Conversion Factors for Company Reporting: conversion factors 2019; (b) IPCC2014/IHA2018

for 1 kWh electricity is 0.256 kg CO<sub>2</sub> equivalents. Using this conversion factor, the induction furnace graphitization plant has a carbon footprint of 25,600 metric tons CO<sub>2</sub> equivalents.

UK electricity generation is dominated by ~40% natural gas, ~37% renewables including wind, solar, biofuels and hydro, and ~17% nuclear<sup>2</sup>. There is a UK government estimate for CO<sub>2</sub> equivalents if the power source is exclusively hydroelectric. This is considered here since Britishvolt has a possible opportunity to locate an anode production plant at a site that receives predominantly, or exclusively hydroelectric power transferred from Norwegian sources via the North Sea Link (<https://northsealink.com>). The hydroelectric CO<sub>2</sub> equivalent factor is 0.0185 kg, nearly 14 times lower than the standard factor. This results in a carbon footprint of 1,850 metric tons CO<sub>2</sub> equivalents for an induction graphitization furnace anode plant using hydroelectric power.

Similar to Figure 14, a comparison between graphitization processes can be made for carbon footprint. The comparison can be made for operation in the UK and considering either the standard CO<sub>2</sub> equivalent factory (0.256 kg) or the hydroelectric factor (0.0185 kg). The result is shown in Figure 16.

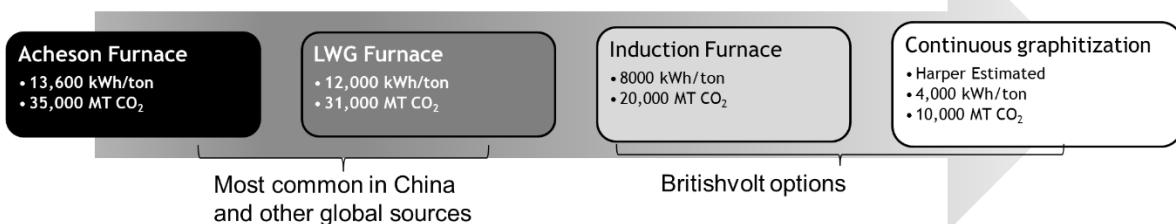


**Figure 16: CO<sub>2</sub> footprint for UK anode production using different graphitization processes and different electricity sources.**

Figure 16 illustrates that the ability to access renewable sources of energy has an overwhelmingly dominating affect in reducing GHG emissions. Such opportunities should be aggressively explored and considered. In some cases, renewable sources of energy may have higher costs or reduced availability and these factors also need to be considered, however the ESG benefit from renewable energy is clear.

We note that the reductions offered by more modern graphitization processes such as induction and continuous processing, are significant even if seemingly small in comparison to accessing renewable energy. Thus, regardless of electricity source, a UK anode plant offers a path to industry leading Li-ion anode production in terms of ESG. A UK anode plant allows bypassing existing supply chain sources that use higher energy processing. This is illustrated in Figure 17 that shows the graphitization energy and the resulting carbon footprint (graphitization only) for different types of graphitization processes.

<sup>2</sup> "UK Energy in Brief 2020", <https://www.gov.uk/government/statistics/uk-energy-in-brief-2020>



**Figure 17: Improving energy efficiency with changing graphitization technique.**

### 7.3 PLANT EMISSIONS

Li-ion anode production produces significant emissions which should be considered. Emissions will vary by type of incoming materials used and by process equipment, especially by graphitization process. Emissions can be managed by a variety of methods and use of induction graphitization furnaces allows for improved emissions control compared to Acheson and LWG.

The key impurities in SG anode precursor raw materials are Sulfur and organic volatiles, which are released during heat processing as exhaust gas emissions. Here, the emissions analysis for a UK anode plant assumes (1) the same 10,000 metric tons annual production, (2) a product split of 2/3 graphite surface coated SG and 1/3 carbon surface coated SG, (3) the precursor material is Phillips 66 needle coke, and (4) the coating / binder material is coal tar pitch characterized by a softening point of ~250 °C. Other sources of precursor and pitch material are expected to produce similar emissions results. Table 15 shows the amount of emissions for this anode plant. Emissions are shown for two types of needle coke. Either may be sourced for anode production. The total emissions from the anode plant will be reduced if sourcing calcined, or heat-treated needle coke, compared to green (untreated) needle coke. However, it should be recognized that both start from the same precursor and ultimately have the same total emission profile. The difference being the location of emissions, either at the anode production site or at a supplier site. A comparison of sourcing calcined vs. green coke to optimize total needle coke emissions was not performed.

**Table 12: Emissions analysis for proposed UK anode plant starting from sourced Phillips 66 needle coke.**

Item	Phillips 66 calcined coke		Phillips 66 green coke		Pitch (PP250 type)	
	Content (%)	Weight (MT)	Content (%)	Weight (MT)	Content (%)	Weight (MT)
Raw material	N/A	10,500	N/A	11,800	N/A	710
Sulfur impurity	0.3-0.4	42	~0.5	59	<0.5	4
Volatiles	< 0.5	53	~5	590	~30	213
Fixed carbon	>99	10,406	87-89	11,151	~70	493

The data in Table 15 shows relatively consistent emissions for Sulfur of approximately 0.5% by weight. This results in total Sulfur emissions of 46-63 metric tons per annual production of 10,000 metric tons SG anode, with the lower end of this range using calcined needle coke and the upper range using green needle coke. The volatile emissions will be greatly different depending on the type of sourced needle coke. If sourcing calcined needle coke, the anode plant volatile emissions will be approximately 266 metric tons. If sourcing green needle coke, the anode plant volatile emissions will be approximately 803 metric tons.

The Sulfur is released during heat processing that occurs at multiple anode production steps including (1) pyrolysis, (2) graphitization, and (3) carbonization. About 30% is released at the first heating step of pyrolysis where temperatures are typically 600 to 1300 °C. Most of the remaining Sulfur, about 70%, is then released during graphitization when temperature begin exceeding 1300 °C. There is little release

during carbonization due to the fact most of the material has already been heat treated, however Sulfur emissions may still need to be managed at this process step.

The Sulfur exhaust from these processes will be in the form of SO<sub>2</sub> and this is routinely captured for controlled disposal. A common method used is to capture the SO<sub>2</sub> in a solution of sodium carbonate, where the Sulfur is captured and CO<sub>2</sub> is released as a by-product (Na<sub>2</sub>CO<sub>3</sub> + SO<sub>2</sub> → Na<sub>2</sub>SO<sub>3</sub> + CO<sub>2</sub>).

Organic volatile emissions mainly occur in the same heating steps as described for Sulfur emissions and for the same reason most is released in the pyrolysis and graphitization steps. Whether calcined or green needle coke is used as the precursor will have a large impact on the amount of volatiles released and the distribution amongst the different process steps.

The volatiles will release as a variety of carbon compounds including CO, CO<sub>2</sub>, benzopyrene, and small molecular weight hydrocarbons. The benzopyrene and hydrocarbons will be captured and further converted into CO<sub>2</sub> for emission. Typically, lower temperature emissions during pyrolysis can be captured through use of an electric detarring precipitator method, and higher temperature emissions during graphitization can be burned in the presence of natural gas to for CO<sub>2</sub>.

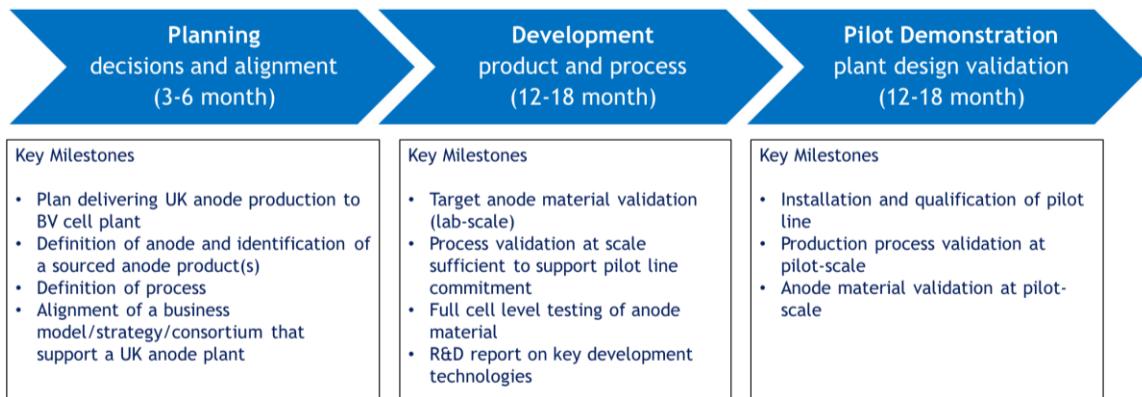
Table 16 shows a comparison of emissions for the proposed UK plant design compared to two existing plants in China. Because the UK plant used induction furnace graphitization and the China plants use Acheson furnace graphitization, the UK plant has a roughly 20% lower emissions profile for Sulfur and organic volatiles. This is due to the fact Acheson processing includes additional carbon materials that produce emissions. As stated above, starting from calcined coke can have a significant further reduction to emissions at the anode production plant.

**Table 13: Emissions comparison for a UK anode plant compared to typical anode plants used today in China**

Item	BV UK synthetic graphite plant		Chengdu Ai Min Te New Energy Technologies	Fujian Xiang Feng Hua
	Calcined coke	Green coke	Green coke	Green coke
Production capacity (MT)	10,000	10,000	5,000	3,000
Synthetic graphite (MT)	6,700	6,700	5,000	3,000
Surface coated graphite (MT)	3,300	3,300	0	0
Sulfur release	From raw material (MT)	46	63	25
	From auxiliary material in Acheson furnace (MT)	0	0	12
	Total (MT)	46	63	37
	Unit release (kg/MT)	5	6	7
Volatiles release	From raw material (MT)	266	803	500
	From auxiliary material in Acheson furnace (MT)	0	0	38
	Total (MT)	266	803	538
	Unit release (kg/MT)	27	80	108
Note			2000 MT furnace coke used in Acheson furnace	1573 MT petcoke used in Acheson furnace

## 8 TASK E – DEVELOPMENT PLAN

A high-level overview is provided for a development plan that leads to a UK anode production plant. This considers 3-stages of activity, planning, development and pilot demonstration. These stages, with key milestones, are illustrated in Figure 18.



**Figure 18: UK anode development plan through pilot scale demonstration.**

The planning stage is expected to deliver a detailed analysis of budget and activity over the course of work. This stage will also consider options for technology development associated with making plant improvements, however no new technology is expected required to achieve completion. Critical outputs at this stage will include clear definition of specific target anode products aligned with Britishvolt's Li-ion cell production, and definition of specific equipment and processes to achieve target products. It is expected that activity in this stage can, in parallel, support sourcing activity for Li-ion cell anodes, as UK anode production is not expected to be ready in time for the SOP of Britishvolt's cell production. Finally, definition during this stage is needed for UK anode plant financing and ownership. This effort will support into a business model that defines a UK sourced anode solution, which in turn can be decided upon by the relevant stakeholders.

The development stage will produce the target anode material at a lab scale to begin establishing clear material specification and performance metrics that can align with cell development. Also, SG anode material will be produced on a small-scale process highly representative of the expected pilot and production scale. We envision the ability to demonstrate the process through collaboration with equipment manufacturers who will be motivated by installing equipment at the proposed facility. In addition, equipment and process operation conditions and procedures will be developed during this stage of work. Sufficient SG anode material will be produced at this stage to support full cell evaluations, potentially aligned with specific Britishvolt products. We envision R&D activity ongoing during this stage to work towards process improvements that can further reduce cost and improve environmental impact.

The final stage will deliver an operational pilot line capable of producing significantly large quantities of materials that can allow full validation of material and process, supporting design and decision making for development of a full-scale production plant. The scale of the pilot line will be determined in the planning stage. This may range from smaller scale that allows critical development and validation activity at minimum cost, or up to significantly higher scale, such as a fully operational production line unit for induction graphitization. This could be 1 of 34 lines used to model the production plant and could support approximately 300 metric tons of anode production. A larger scale pilot operation could also be the beginning of a full-scale production plant.

This same development plan can be re-envisioned in terms of ownership during different phases of progression towards UK anode production. This ownership view, with key expected outcomes may look as follows:

- Phase 1 – Led by Britishvolt
  - Key activities source an anode that becomes the UK production target and define UK anode production cost to support business case
  - At the conclusion of this phase, it should be very clear exactly what anode product(s) are required from the UK plant
- Phase 2 – Lead to be determined, likely Britishvolt in consortium with interested stakeholders
  - Key activity here is to validate an anode material and process that sufficiently represents UK anode production and gives full confidence to a potential anode plant operator that they have a recipe and customer for their product
  - Leverage equipment suppliers for validation and to establish anode plant equipment supply chain
  - At the conclusion of this phase, an anode plant operator should be able to take the lead
- Phase 3 – Led by Morgan Advanced Materials (or other aligned anode production operator)
  - Key activity is implementing a pilot-scale operation for UK anode production
  - Success at this stage will support initial, low volume supply into Britishvolt and decisions to invest in full scale anode production

The net time to completion for this project is expected to be approximately 3 years. However, opportunities to accelerate will be considered during the planning stage. In addition, time to full production scale will be considered. For example, pilot demonstration can be pulled in by placing equipment orders early during the development stage. Key equipment is not likely to change definition, rather development focuses more on achieving known process conditions operating the defined equipment to achieve desired anode material products. Also, the target sizing and location of the pilot scale can be used to accelerate towards full mass production.

An additional overview of tasks during this work is outlined here:

Planning	Development	Pilot Demonstration
<ul style="list-style-type: none"> <li>• Create detailed development plan through pilot stage validation           <ul style="list-style-type: none"> <li>• Fully analyze cost</li> </ul> </li> <li>• Establish business model           <ul style="list-style-type: none"> <li>• Phillips 66 precursor</li> <li>• Morgan manufacturing</li> </ul> </li> <li>• Fix target product(s)           <ul style="list-style-type: none"> <li>• Spec., graphite vs. carbon coated</li> <li>• Align with target anode formulation (NG, Si, additives)</li> </ul> </li> <li>• Fix target process           <ul style="list-style-type: none"> <li>• Induction graphitization</li> <li>• Coating type</li> <li>• Green vs. calcined needle coke</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• Produce and validate target anode(s) – lab scale</li> <li>• Demonstrate process at small scale           <ul style="list-style-type: none"> <li>• Induction process development</li> <li>• Sizing and coating processes</li> <li>• Collaboration with vendors</li> <li>• Define pilot scale</li> </ul> </li> <li>• Produce and test material in full cell evaluation</li> <li>• In parallel, R&amp;D (separate timeline)           <ul style="list-style-type: none"> <li>• Continuous graphitization</li> <li>• Precursor modification</li> <li>• Crucible development</li> </ul> </li> <li>• Ongoing sourcing support</li> </ul>	<ul style="list-style-type: none"> <li>• Validate production equipment and process in pilot scale</li> <li>• Validate products produced in the pilot line/plant</li> <li>• Identify improvements and guidance for the full-scale production line/plant</li> <li>• Production plant design and schedule</li> <li>• Ongoing R&amp;D and sourcing support</li> </ul>

<ul style="list-style-type: none"> <li>• Develop continuous?</li> <li>• Sourcing – identify and start benchmarking sourced SG options</li> </ul>		
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## 9 TASK F – DEFINITION OF TRIALS

Additional details are defined for specific development tasks achieving a UK anode plant. These development activities establish clear target specifications and well-defined process conditions to mass produce qualified SG anode product. A high-level outline is provided here, and further definition will occur during the planning stage of the proposed work. Each task below includes the setup of a laboratory process and equipment that allows the work. One exception is the design and build of a unique graphitization furnace that can assimilate a 3000 °C continuous furnace in small scale. Such setup is not described in detail in the task but would be detailed and budgeted at the planning onset following a Britishvolt decision to initiate the work. Smaller equipment from vendors listed in this report would be selected, as it assures methods are available for scaling the laboratory results to mass production machinery. Graphitization can also be achieved by stationary furnaces or through tolling.

- **Primary and secondary particle engineering**

- Experimental scope: optimize primary particle and secondary size distribution
  - Achieve optimal yield and throughput in selected equipment
    - First by a sequence of vendor trials (which only requires analytical labs and Li-ion test cells at Britishvolt)
    - Second by installation of pilot lines of throughput that assures scalability to mass production equipment (which requires a pilot site for graphite manufacturing)
  - Achieve targeted electrode properties: tap density, SSA, material processibility in anode formulation, electrode press density, electrode spring-back, electrode swelling,
  - Achieve targeted electrochemical performance: capacity, rate capability, cycle life, storage behavior/calendar life
  - Build a pilot line where results from laboratory trials can be tested for suitability of mass production and equipment design parameters for establishing mass production can be validated
- Experimental range
  - Needle coke particle size range for screening: 2-5um, pitch: 1-4 um
  - Secondary particle size range for screening: 10-20 um
- Milestone 1: identify optimized primary particle and secondary size distribution and associated milling and particle shaping process conditions for the pilot line run
- Milestone 2: Installation of pilot line representative of mass production process

- **Binder/needle coke precursor ratio formulation**

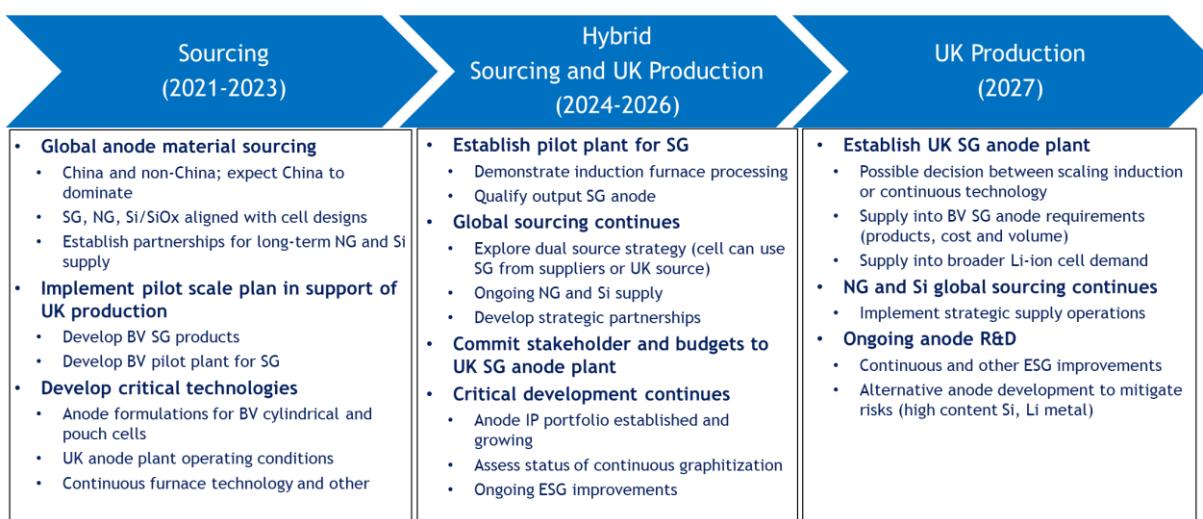
- Experimental scope: optimize pitch/needle coke ratio
  - Achieve target electrode properties
  - Achieve targeted electrochemical performance
  - Identify lowest temperature of graphitization to guide furnace technology design
- Experimental range
  - 3-20wt% of binder
- Milestone: identify optimized binder/needle coke ratio and associated pyrolysis / granulation process conditions for the pilot line run

- **Surface coating thickness/ratio**

- Experimental scope: optimize surface coating thickness graphite coating and carbon coating
  - Achieve target electrode properties
  - Achieve targeted electrochemical performance
- Experimental range
  - Graphite coating thickness: adjust binder/coke ratio to allow the graphite surface coating at 1-5wt%
  - Carbon coating thickness: 1-5wt%
- Milestone: identify optimized coating ratio (graphite and carbon coating) and associated process conditions for the pilot line run
- **Lowering graphitization temperature**
  - Experimental scope: explore the catalyzed graphitization paths to lowering graphitization temperature for continuous graphitization furnace
  - Experimental range
    - Catalysts: transition metals, salts, and boron
    - Graphitization conditions: temperature: 2400-2800 °C, time: TBD
  - Milestone: identify suitable catalyst and utilization quantity and associated graphitization conditions (temperature and time) for the pilot line run
  - Note: It is well established in scientific literature that below 1800 °C 2-dimensional graphite plane growth occurs, which is studied by measuring X-ray data. Above 2200 °C, 3-dimensional growth occurs (interplanar). Such growth affects the degree of graphitization. A high degree of graphitization is required for capacity close to the theoretical for graphite, 372 mAh/g, which is close to achievable in most NG, which are well graphitized due to long geological time scales. The best SG usually reports between 350-360 mAh/g. It is also well established that temperatures close to 3000 °C can create graphitization within minutes, while 100-200 °C lower temperature common in most graphitization furnaces takes tens of hours.
- **Study graphite conversion timing at 3000 °C**
  - Experimental scope: explore Harper's furnace design at 3000 °C and minimization of the zone where full graphitization takes place. Build a laboratory furnace that allows timing experiments, so that parameters for mass production can be established.
  - Experimental range:
    - Time at temperature as a function of degree of graphitization and capacity (mAh/g)
    - 2700 to 3100 °C desired
    - Crucible allowing >50 g of graphite powder to be processed (enough for coin cell testing)
  - Milestone: Demonstration of continuous furnace parameters suitable for high temperature continuous mass production furnaces that delivers a materials capacity >350 mAh/g.

## 10 TASK G – OUTLINE OF POSSIBLE BRITISHVOLT TOTAL ANODE MATERIAL STRATEGY

A very high-level overview of a possible anode strategy and roadmap is provided here. Such input provides a big picture view, with details expected to develop and evolve over time as plans and deliverables are scrutinized and new information becomes available. As stated previously, establishing sourced solutions is critical to meet cell production timelines. Then, a UK anode plant first delivers a replacement for the selected sourced product, and likely a drop-in replacement by targeting a duplicate anode material specification. This delivers potential for significant anode cost reduction as well as significantly lowered carbon footprint. Second, the plant will start production of next-generation anodes with targeted performance features and opportunity for even lower carbon footprint and reduced cost. For this second state, continuous furnace processing can be considered based on progress in development ongoing in parallel under this plan. All UK SG anode products can be formulated into the necessary anode materials and electrodes, including blending with NG and Si materials.



## 11 TASK H – CADENZA PROPOSAL TO SUPPORT BRITISHVOLT

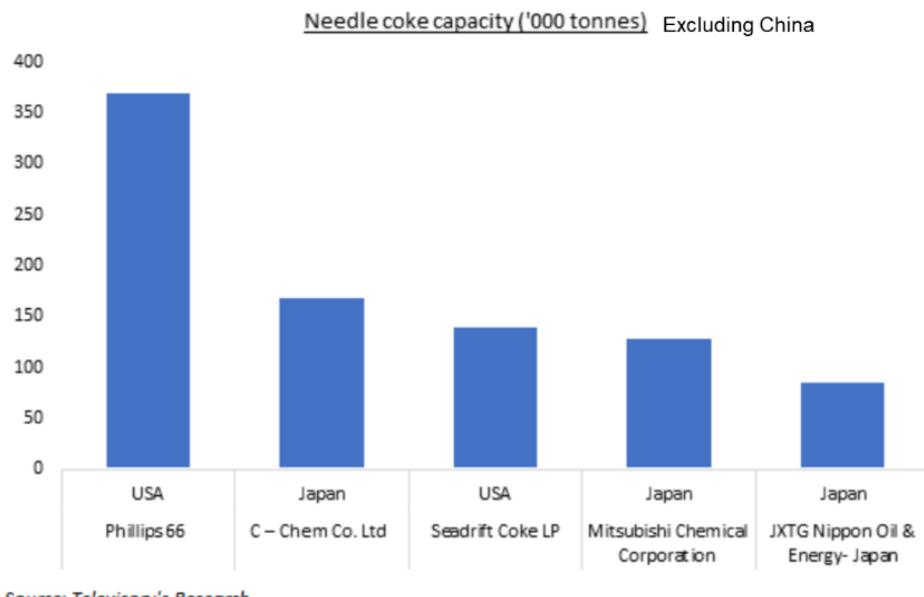
The Cadenza team includes a wide breadth of experience in the Li-ion battery industry, including materials and technology development, battery product (cell, modules, packs) development and commercialization, and technology and business analysis of market conditions and trends. In support of Britishvolt's ongoing objective to bring high volume Li-ion cell production to the UK and ongoing consideration towards establishing a UK SG anode production plant, the following proposed topics are offered for consideration where Cadenza can work to support to Britishvolt. In all laboratory efforts, Cadenza can offer long-term relationship under exclusivity with both in-house and extended laboratory and characterization support. Cadenza would in this option manage all workflow and maintain all testing standards in addition to managing data collection and interpretation. A few areas to explore are presented as Britishvolt considers Cadenza to be an extension of the organization with detailed responsibility for the following options:

1. Anode materials sourcing – directly support Britishvolt cell design and anode procurement teams to identify and qualify anode materials for use in cell production.
  - a. Identify and support introductions to and negotiations with global anode suppliers
  - b. Support lab-scale testing to characterize and qualify sourced anodes, including ongoing coin cell electrochemical testing and physical characterizations
  - c. Support anode material supplier quality metrics
  - d. Ongoing competitive market support to understand anode supplier dynamics that include price and technology/product trends
2. Anode electrode design – directly support Britishvolt cell design team to design anode electrodes that support multiple cell product designs
  - a. Optimize formulations for anodes, including consideration of NG and Si/SiO<sub>x</sub> blends, binders and conductive additives
  - b. Review and support anode electrode design against cell product requirements, including considerations for dimensions, thickness, capacity balancing, and interactions with cathode, electrolyte and separator
  - c. Review and support anode processing conditions to achieve optimum anode electrode output during cell manufacturing
  - d. Drive or support cell development optimization between anode, cathode and electrolyte options through both theoretical and experimental work
3. Anode technology development – lead R&D projects aligned with Britishvolt needs for anode materials
  - a. Development of higher content Si/SiO<sub>x</sub> anode formulations
  - b. Development of continuous graphitization process – this development would be done in collaboration with equipment providers such as Harper International
4. Build and test development cell designs – Cadenza to drive or help manage cell designs to pilot / small production facilities inside or outside the Britishvolt network to produce early-stage cells for testing
  - a. Manage IP concerns
  - b. Produce and test cells, such as 21700 formats to Britishvolt target designs
5. Benchmark testing – Testing and tear-down analysis on targeted competitive cell products such as 21700 cell products

- a. Electrochemical evaluation (capacity, life, temperature, rate)
  - b. Cell design features (dimensions, components, electrode design, chemistry)
  - c. Create and manage technical data for marketing and sales comparisons
6. Advanced Li-ion cell R&D – explore advancing concepts for implementation into Britishvolt cell design roadmap
- a. High voltage cell designs, including use of novel electrolyte systems to enable cell stability up to 4.5 V
  - b. Explore and discuss with Britishvolt other cell chemistry and technologies to consider
7. Li-ion cell market intelligence – Beyond anode, support identifying and responding to a broad range of business and technical developments in the Li-ion industry and their impact to Britishvolt business goals
- a. Competitive technologies and trends
  - b. Opportunities for collaboration and joint IP development or IP acquisition
8. UK anode plant Phase 2 – progress towards establishing UK anode production as described in detail in Tasks E and F (Sections 8 and 9)
- a. Planning
  - b. Development
  - c. Pilot demonstration

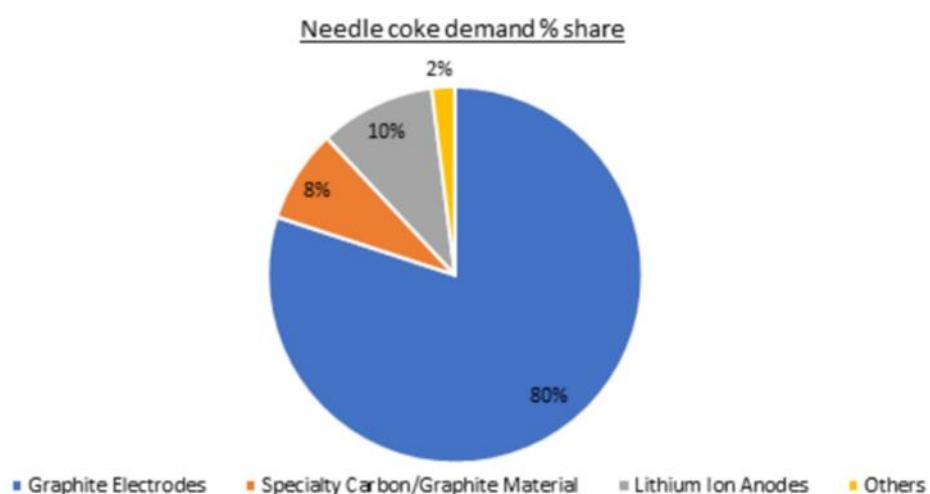
## 12 TASK I – REFERENCE ANODE MARKET DATA

In the execution of this project, Cadenza has identified and used market data related to graphite anode use in Li-ion batteries. A selection of data deemed relevant to Britishvolt is included in this section for reference. This section is not intended to present an exhaustive market review and Cadenza welcomes inquiries around specific data related to the Li-ion anode and battery industry.



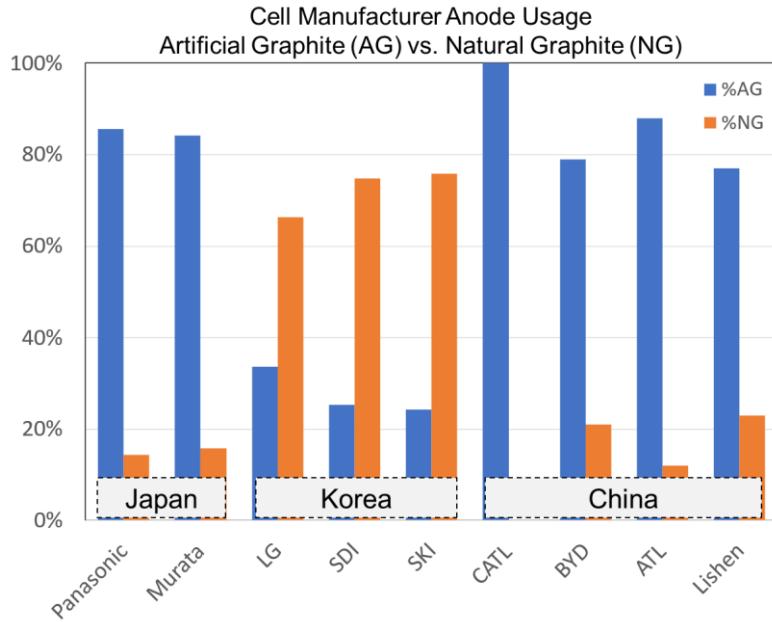
*Source: Televisory's Research*

**Figure 19: Needle coke capacity by manufacturer (excluding China).** Needle coke is considered to be the likely precursor used in a UK synthetic graphite anode production plant. Needle coke is largely produced in the United States, Japan and China. Phillips 66, a spin-off of ConocoPhillips, is the largest manufacturer of oil-based needle coke in the world, with capacities up to 370 kt/a; CNPC Jinzhou Petrochemical Co., Ltd has capacity reaching 170 kt/a as its phase-II needle coke project production kicked off in 2019; Japan-based C-Chem is the biggest producer of coal-based needle coke worldwide, possessing the capacity of 110 kt/a.

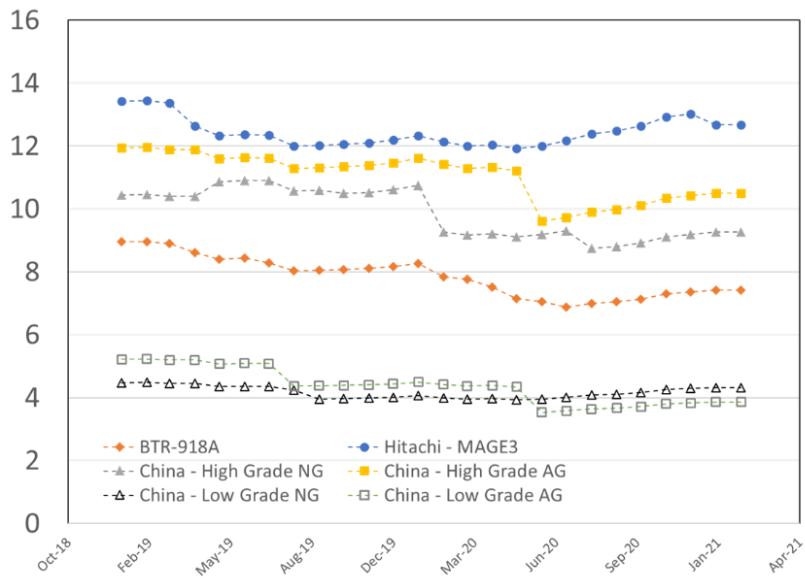


*Source: Televisory's Research*

**Figure 20: Demand share for needle coke.** 10% is for Li-ion anodes, with trend of increasing share. The majority of needle coke is used for graphite electrodes that support the steel making industry.



**Figure 21: Anode usage for AG (SG) and NG by cell manufacturer.** Japan and China show strong preference for SG in EV applications; SG is viewed as preferred for life. Korean manufacturers favor NG, but EV anode use is understood to consist of NG/AG blends. NG favored for cost and coated surface has improved life performance. Source: Cadenza market intelligence, 2019 data.



**Figure 22: Anode Material Price Trends Oct 2018 to Feb 2021.** \$4 - \$13/kg range in graphite anode material depending on type. BTR-918A, high use material, \$8/kg; Hitachi-MAGE3, high performance, \$12/kg; Low grades not suitable for EV cells. “China Grades” as reported by industry, average many supplier’s information without visibility into details. Cadenza notes a \$1-\$2/kg price increase for SG vs. NG; a downward trend through Jun-2020 (10-20%), then an increasing trend more recently (5-10%). Source: Cadenza market intelligence; China Industry Association of Power Source.



## 13 APPENDIX 1 – TEAM MEMBERS

This effort was supported by routine discussion and review of preliminary results by the following team members:

### Britishvolt

- Isobel Sheldon, CSO, [isobel.sheldon@britishvolt.com](mailto:isobel.sheldon@britishvolt.com)
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- Jochen Schmerbitz, Head of Direct Procurement, [jochen.schmerbitz@britishvolt.com](mailto:jochen.schmerbitz@britishvolt.com)
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### Morgan

- Richard Clark, Global Lead, Energy Storage, [Richard.Clark@morganplc.com](mailto:Richard.Clark@morganplc.com)

### Cadenza Innovation

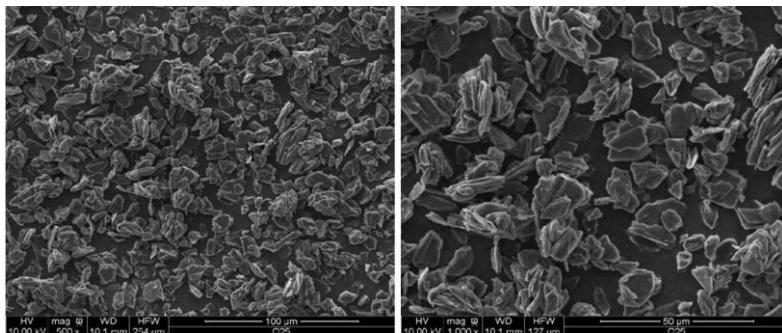
- Christina Lampe-Onnerud, Ph.D., CEO, [clo@cadenzainnovation.com](mailto:clo@cadenzainnovation.com)
- Per Onnerud, Ph.D., CTO, [ponnerud@cadenzainnovation.com](mailto:ponnerud@cadenzainnovation.com)
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- Steven Lin, Director of Operations, [sli@cadenzainnovation.com](mailto:slin@cadenzainnovation.com)
- Amanda Riddell, Executive Assistant to CEO, [ariddell@cadenzainnovation.com](mailto:ariddell@cadenzainnovation.com)

## 14 APPENDIX 2 – EXAMPLES OF MARKET-LEADING SG ANODE PRODUCTS

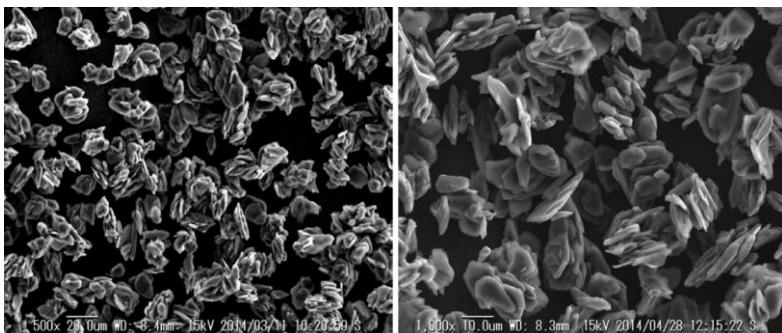
### 14.1 ZICHEN

Items	Unit	G49	GT	KT	NT
Particle size distribution	D10 (um)	5.8	12.4	6.2	8.9
	D50 (um)	13.9	20.9	13.6	14.5
	D90(um)	28.8	34.5	28.1	25.1
True density	g/cc	2.25	2.25	2.25	2.24
Tap density	g/cc	1.10	0.88	1.00	0.90
Graphitization degree	%	94.01	93.17	93.34	94.01
Ash content	%	0.02	0.02	0.02	0.03
Specific surface area	m <sup>2</sup> /g	1.60	0.75	1.92	1.06
Discharge capacity	mAh/g	354.4	351.5	355.7	357.5
1st cycle coulombic efficiency	%	93.8	93.8	94.4	93.2
Electrode press desity	g/cc	1.65-1.70	1.60-1.70	1.70-1.75	≥1.8

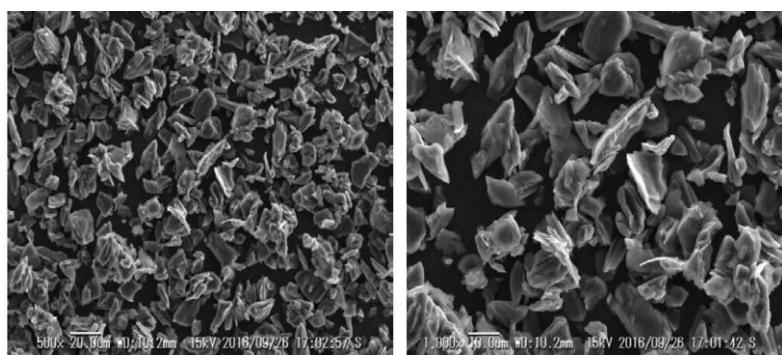
G49 SEM images:



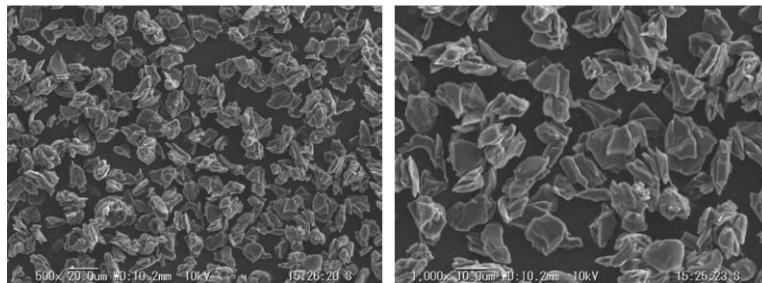
GT SEM images:



KT SEM images;



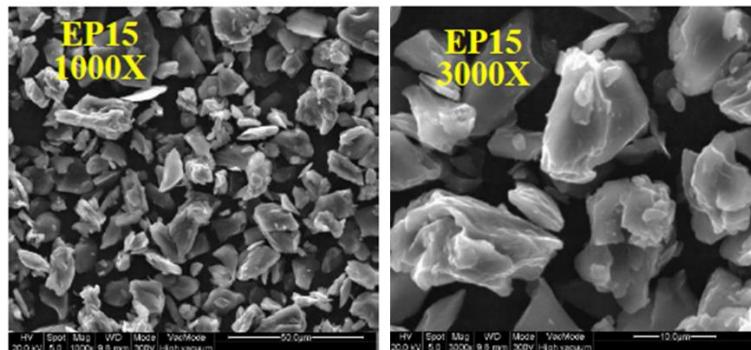
NT SEM images:



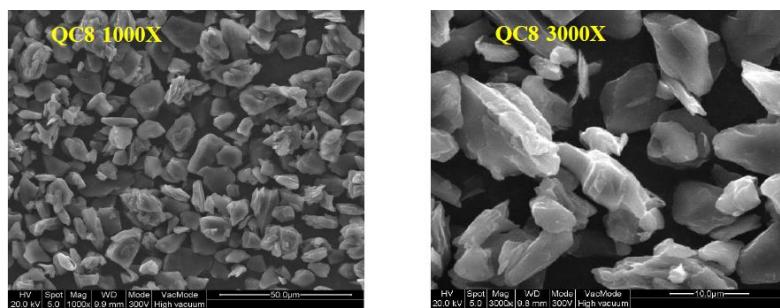
## 14.2 SHANSHAN

Items	Unit	EP15	QC8	EV7	QCG-X9
Particle size distribution	D10 (um)	6.0	5.5	4.2	8.7
	D50 (um)	12.6	10.5	14.5	14.1
	D90(um)	23.7	18.5	21.7	21.9
True density	g/cc	2.24	2.26	2.25	2.24
Tap density	g/cc	1.13	1.12	0.97	1.01
Ash content	%	0.01	0.01	0.01	0.01
Specific surface area	m <sup>2</sup> /g	1.5	1.6	1.6	1.1
Discharge capacity	mAh/g	353.0	352.0	354.5	354.7
1st cycle coulombic efficiency	%	94.2	93.5	92.7	92.5
Press density	g/cc	1.62-1.73	1.6-1.65	1.65-1.7	1.69

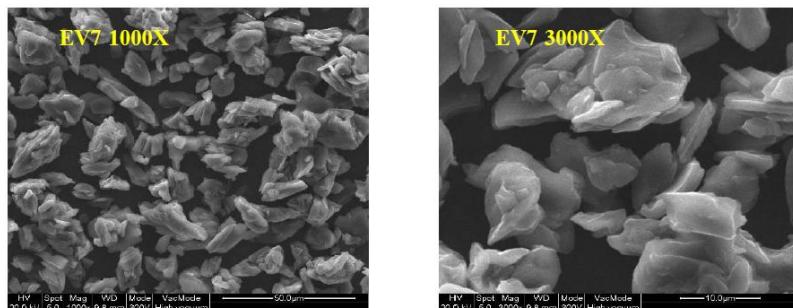
EP-15 SEM images:



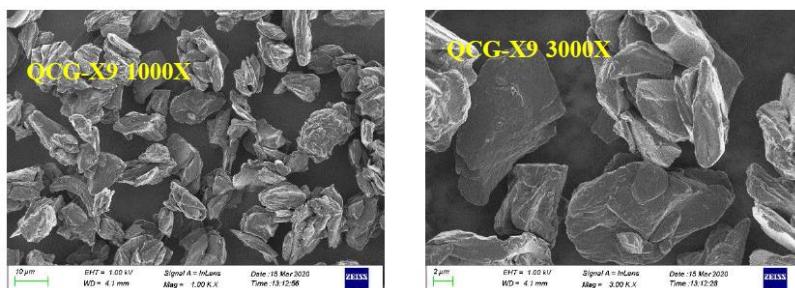
QC8 SEM Images



### EV7 SEM Images



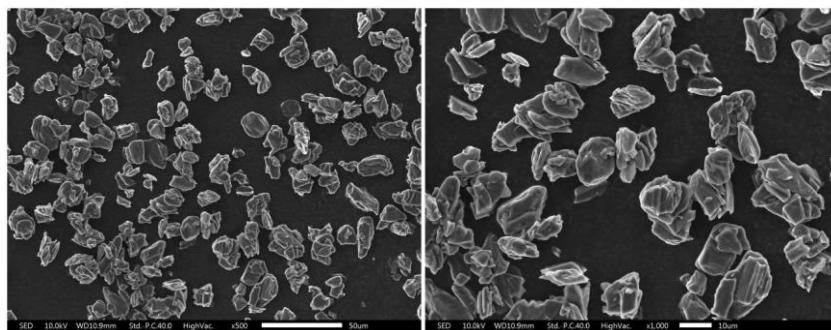
### QCG-X9 SEM Images



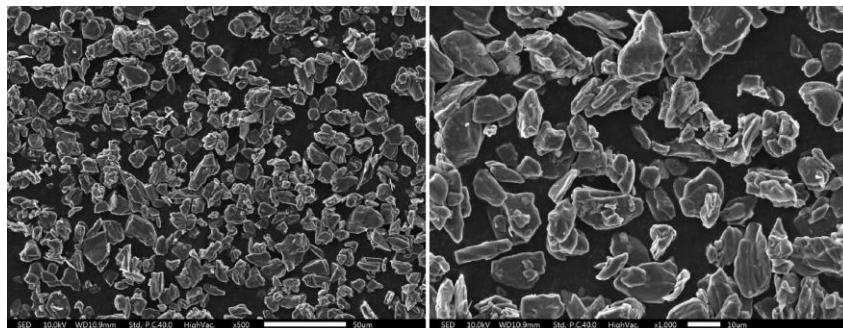
### 14.3 KAIJIN

Items	Unit	AML830	AML850
Particle size distribution	D10 (um)	8.78	8.97
	D50 (um)	17.6	17.65
	D90(um)	30.9	31.3
Tap density	g/cc	1.03	1.09
Specific surface area	m <sup>2</sup> /g	1.23	1.18
Discharge capacity	mAh/g	357.6	356.2
1st cycle coulombic efficiency	%	93.4	93.5
Press density	g/cc	1.7	1.7

### AML830 SEM Images:



AML850 SEM Images:

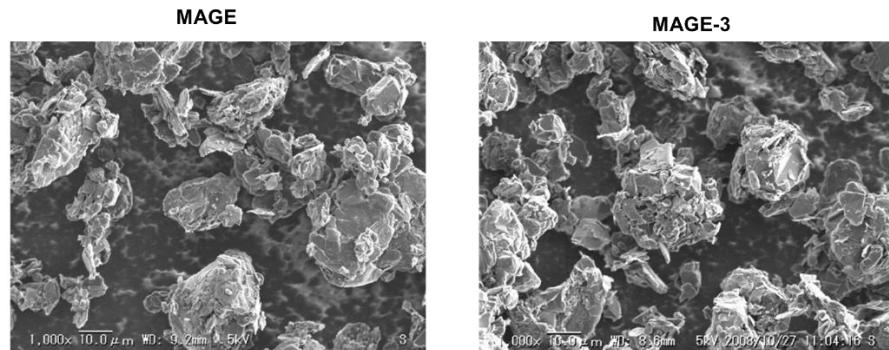


#### 14.4 SHOWA DENKO MATERIALS

Formerly Hitachi Chemical

Items	Unit	MAGE-Y	MAGE3
Particle size	D50 (um)	23	23.7
Tap density	g/cc	0.92	0.92
Specific surface area	m <sup>2</sup> /g	3.7	3.8
Discharge capacity	mAh/g	361	358
1st cycle coulombic efficiency	%	94.1	93.6
Press density	g/cc	1.7	1.7

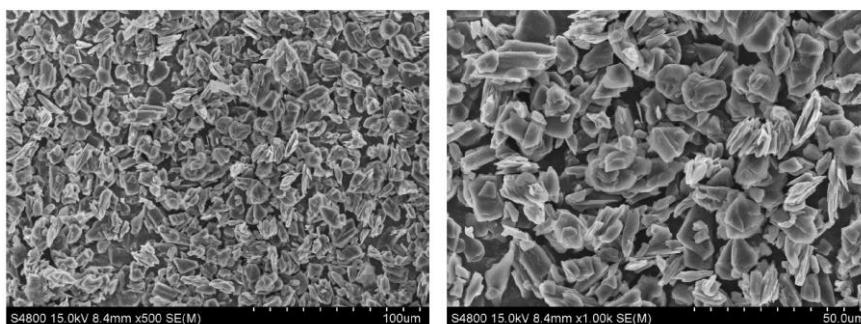
SEM Images:



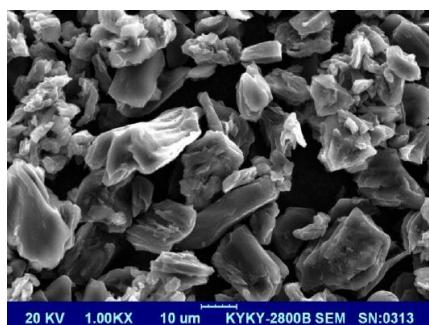
#### 14.5 BTR

Items	Unit	S360-L2-H	AGP-2L-S
Particle size distribution	D10 (um)	6.55	8.32
	D50 (um)	15.1	16.4
	D90(um)	27.64	29.9
Tap density	g/cc	0.869	1.01
Specific surface area	m <sup>2</sup> /g	1.968	1.28
Discharge capacity	mAh/g	356.2	345.2
1st cycle coulombic efficiency	%	95.5	94.2
Press density	g/cc	1.75	1.6-1.65

S360-L2-H SEM Images:



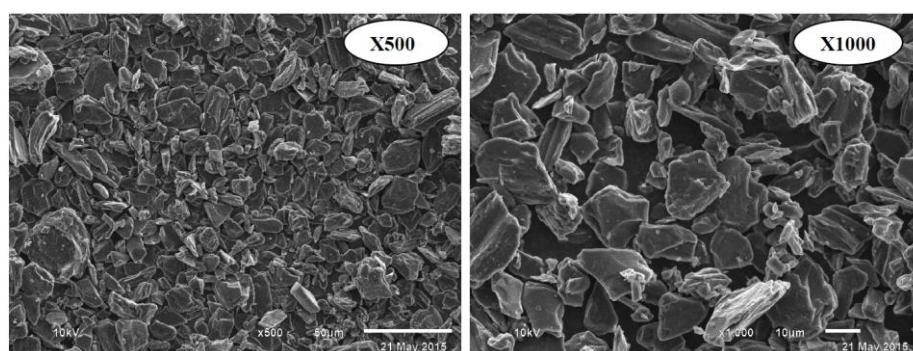
AGP-2L-S SEM Image:



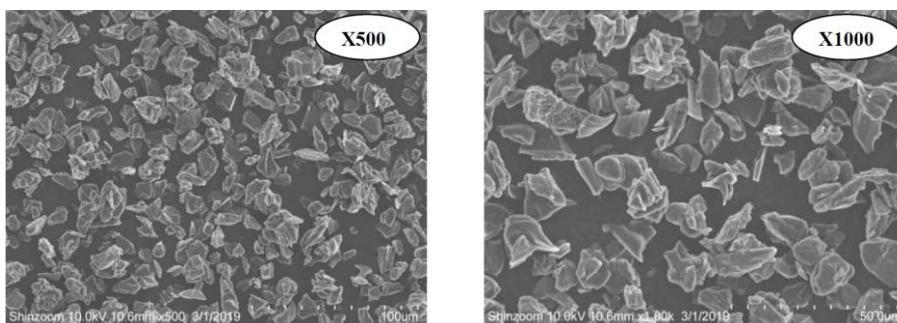
#### 14.6 SHINZOOM

Items	Unit	MD-4C	PE-1X
Particle size	D50 (μm)	13.6	13.7
Tap density	g/cc	1.18	1.01
Ash content	%	0.06	0.02
Specific surface area	m <sup>2</sup> /g	1.54	1.71
Discharge capacity	mAh/g	355.1	356.8
1st cycle coulombic efficiency	%	95	95.2
Press density	g/cc	1.60-1.65	1.70-1.75

MD-4C SEM Images:



PE-1X SEM Images:



## 15 APPENDIX 3 – SELECTION OF PARTICLE SIZING EQUIPMENT

Milling and shaping equipment: Netzschi fluidized bed jet mill

**Netzschi fluidized bed jet mill CGS**

Technical data		CGS 150	CGS 180
Capacity factor	9	12	35-170 kg/hr coke
Air flow *	m <sup>3</sup> h <sup>-1</sup>	8 930	11 660
Number of milling nozzles	pcs.	4	4
Nozzle diameter	mm	22.4	25.6
Milling chamber **	mm	1 800	2 100
Classifier wheel power max.	kW	75	90
Max. speed	min <sup>-1</sup>	1 700	1 400
Fineness d <sub>97</sub> ***	µm	5 - 90	5 - 90
Length (A)	mm	3 600	4 200
Depth (B)	mm	3 600	4 200
Height (C)	mm	7 000	7 700
Weight (approx.)	kg	24 000	29 000

Milling and shaping equipment: Hosokawa air classifying mill

**Hosokawa air classifying mill**

**ACM-300**

Model	ACM-	15H(HC)	30H(HC)	60H(HC)
Motor	Mill (kW)	11	22	45
	Classifier (kW)	1.5	5.5	11
	Feeder (kW)	0.2	0.4	0.4
Air volume	(m <sup>3</sup> /min)	15	30	60
Max. grinding rotor speed	(rpm)	7800	5800	3600
Std. classifying wheel speed	(rpm)	3210	2375	1637
Max. classifying wheel speed	(rpm)	7000	5400	3600
Dimensions	Width (W) (mm)	1350	1500	2040
	Depth (D) (mm)	750	860	1240
	Height (H) (mm)	1075	1400	1680
Approx. mass	(kg)	600	1100	3000

Coarse Milling → Fine Milling ACM Pulverizer → Superfine Milling  
 10mm 1mm 100µm 10µm 1µm 100nm

Milling and shaping equipment: Hosokawa micron separator

**Hosokawa micron separator**

Model	MS-	1	2	3	4	5	6	7
Motor	(kW)	0.75	1.5	2.2	5.5	11	15	22
Wheel speed	(rpm)	2300	1700	1500	1100	800	300	200
Air volume	(m <sup>3</sup> /min)	10 ~15	25 ~40	50 ~75	100 ~150	200 ~300	400 ~600	800 ~1200
Scale up factor	(-)	1	2.8	3.9	8.5	16	35	64
Minimum theoretical cut point (µm)		6.8	7.3	8.3	8.4	9.9	21.7	29.7
Dimensions	Width (mm)	700	830	1200	1500	2300	2600	3300
	Height (mm)	1500	2150	2700	1560	5500	6700	8000
Approx. mass	(kg)	130	250	500	1000	3000	5500	12000

## 16 APPENDIX 4 – SI ANODE MATERIAL PATENTS AND ANALYSIS

Listing of identified patents (and patent applications) ranked as critical or important relative to possible interest in future anode technology development.

Patent/app #	Publication (priority) date	Title	Areas	Assignee
US5624606	4/29/1997 (5/3/1994)	Carbonaceous host compounds and use as anodes in	Si or SiOx and carbon composites	Moli
JPH1021913A	1/23/1998 (7/5/1996)	Battery chargeable and dischargeable reversibly for	Si or SiOx and carbon composites	Hitachi
JP3856525	12/23/2006 (5/21/1997)	Secondary battery	Si or SiOx and carbon composites	Asahi Chemical
US6383686	5/7/2002 (01/26/1999)	Anode material for lithium secondary battery, lithium secondary battery using said anode material, and method for	Si or SiOx and carbon composites	Mitsui Mining
JP2000-203818A	7/25/2000 (1/13/1999)	Composite carbon particle, its production, negative pole material, negative pole for lithium secondary battery or cell	Si or SiOx and carbon composites	Hitach Chemical
JP2001118568A	4/27/2001 (10/21/1999)	Nonaqueous secondary battery	Si or SiOx	Denki Kagaku Kogyo Kk
US 6,589,696	7/8/2003 (6/16/2000)	Negative active material for rechargeable lithium battery and	Si or SiOx and carbon composites	Samsung SDI
US8048339	11/1/2011 (12/19/2006)	Porous anode active material, method of preparing the same, and anode and lithium battery	Si or SiOx and carbon composites	Samsung SDI
US8546017	7/2/2009. (12/28/2007)	Composite for anode material, anode materials and lithium battery using the same	Si or SiOx and C matrix composites	Samsung SDI

Patent/app #	Publication (priority) date	Title	Areas	Assignee
US20100285358	11/11/2010 (5/7/2009)	Electrode Including Nanostructures for Rechargeable Cells	Si or SiOx with specific morphologies	Ampruis
US8889295 &US10,629,898	11/18/2014 (09/29/2009) 4/8/2011 (04/09/2010)	Electrodes, lithium-ion batteries, and methods of making and using same	Si or SiOx and C matrix composites	Sila Nanotechnologies
US9558860	1/31/2017 (9/10/2010)	Graphene-enhanced anode particulates for lithium ion	Si or SiOx and carbon composites	Samsung Electronics, Nanotek
US10611642	9/11/2017 (11/06/2014)	SiOC COMPOSITE ELECTRODE MATERIAL	Si or SiOx and C matrix composites	Commissariat a l'Energie Atomique et aux Energies Alternatives, JNC Corp
US9276261	3/1/2016 (5/7/2015)	Surface treated silicon containing active materials for electrochemical cells	Polymer and Si or SiOx composites	Nexeon
WO/2015/010230	1/29/2015 (07/22/2013)	METHOD FOR PREPARING HOLLOW SILICON SPHERES AS WELL AS HOLLOW SILICON	Si or SiOx with specific morphologies	Robert Bosch GmbH, Tsinghua University

Patent/app #	Publication (priority) date	Title	Areas	Assignee	Summary of disclosure
US6641955	11/4/2003 (9/28/1999)	Anode material for lithium secondary battery, an electrode for lithium secondary battery and a lithium secondary battery	Si or SiOx and carbon composites	Samsung SDI	Anode made of micro Si or SiOx particles attached on graphite particles followed by carbon coating
JP2002260651A	2/28/2001	Silicon oxide powder and its manufacturing method	Si or SiOx	Shin Etsu Chem	Anode material based on SiOx with $1.05 \leq x \leq 1.5$ and BET specific surface of 5-
WO/2004/114439	12/29/2004 (06/25/2003)	Anode material for lithium secondary cell with high capacity	Si or SiOx and carbon composites	LG Chem	Anode made of composite particle with amorphous carbon Si particles followed further coated with crystalline carbon
US9209456	12/8/2015, (10/22/2010)	Composite structures containing high capacity porous active materials constrained in shells	Si or SiOx with specific morphologies	Ampruis	Provided are novel electrode material composite structures containing high capacity active materials formed into porous base structures. The structures also include shells that encapsulate these porous base structures.
US8048339	11/1/2011 (12/19/2006)	Porous anode active material, method of preparing the same, and anode and lithium battery employing	Si or SiOx and carbon composites	Samsung SDI	Anode material made of a composite of graphite and porous carbon filled with fine Si or SiOx particles
US8617746	12/31/2013 (06/27/2007)	Si/C composite, anode active materials, and lithium battery including the same	Si or SiOx and C matrix composites	Samsung SDI	An anode active material comprising an Si/C or SiOx/C composite, including Si or SiOx particles having pores, and carbon embedded within the pores of Si or SiOx particles and/or coated with the Si or SiOx particles
US8936874	1/20/2015 (06/04/2008)	Conductive nanocomposite-based electrodes for lithium batteries	Si or SiOx and C matrix composites	Nanotek Instruments Inc	Anode material made of amorphous carbon and Si or SiOx nanoparticles on a 3D conductive network consisting of micro carbon plates
US8772174	4/8/2011 (04/09/2010)	Method of fabricating structured particles composed of silicon or silicon-based material and their use in lithium rechargeable batteries	Si or SiOx	Nexeon	A method of treating Si to form elongate structures on a treated surface
US10,411,290 &US9786947	9/10/2019 (2/7/2011)	Stabilization of li-ion battery anodes	Si or SiOx and C matrix composites	Sila nanotech	Anode material made of composite particles of Si, carbon and polymer binder with a protective coating layer on the composite particle. The coating layer can be selected from polymers , oxides , fluorides , carbon , combinations thereof,

Patent/app #	Publication (priority) date	Title	Areas	Assignee	Summary of disclosure
CN 103022435	9/20/2011	A Si/C composite anode material for Li-ion battery and means to prepare	Si or SiOx and carbon composites	Shanshan Tech	A method of making Si/C and graphite composite anode material
US8,734,674	5/27/2014 (04/26/2011)	Method of enhanced lithiation of doped silicon carbide via high temperature annealing in an inert atmosphere	Si or SiOx and carbon composites	Northwestern Univ	Anode made of a doped SiC produced by heat treating the silicon carbide in an inert atmosphere
US9,601,228	3/21/2017 (05/16/2011)	Silicon oxide based high capacity anode materials for lithium ion batteries	Si or SiOx and carbon composites	Envia	Silicon oxide based materials, including composites with various electrical conductive compositions, are formulated into desirable anodes.
US8642214	2/14/2014 (08/25/2011)	Silicon-carbonaceous encapsulated materials	Si or SiOx and carbon composites	UChicago Argonne	A process for making carbon coated Si anode material
CN 102394287 B	11/24/2011	A Si/C anode material for Li-ion battery and means to prepare	Si or SiOx and carbon composites	BTR	The anode material is made by mixing Si/C complex with graphite. The Si/C complex is made by adhering nano carbon tube or nano carbon fiber on nano
US10,135,063	11/20/2018 (6/29/2012)	Crumpled graphene-encapsulated nanostructures and lithium ion battery anodes made therefrom	Si or SiOx and carbon composites	Northwestern Univ	Anode material made of capsules comprising crumpled graphene sheet shells encapsulating Si nanoparticles
US10693130	10/25/2013 (10/26/2012)	Negative electrode material for lithium ion secondary battery, negative electrode for lithium ion secondary battery, and lithium ion secondary battery	Si or SiOx and carbon composites	Hitach Chemical	An anode material consisting of SiOx and carbon, where carbon coated on SiOx surface partially or fully.
EP2887431	6/24/2015 (9/12/2013)	Silicon core/shell nanomaterials for high performance anode of lithium ion batteries	Si or SiOx and carbon composites	Nano and Advanced Materials Institute	Anode material made of carbon coated Si nano agglomerates
EP279330	5/22/2019 (2/19/2013)	Si/C composite, method for manufacturing same, and cathode active material including the same for lithium secondary battery	Si or SiOx and carbon composites	LG Chem	A method to produce Si/C composite

Patent/app #	Publication (priority) date	Title	Areas	Assignee	Summary of disclosure
US10,476,076	11/1/2019 (2/3/2014)	Anode compositions and alkali metal batteries comprising same	Si or SiOx and C matrix composites	Univ. Tel-Aviv	Anode material and production method made of Si particles encapsulated within a volume enclosed by a shell or matrix which conducts lithium ion.
US9548490	01/17/2017 (2/26/2014)	Anode active material, lithium battery comprising the same, and method of preparing the anode active material	Si or SiOx and C matrix composites	Samsung Electronics	An anode active material includes: a core including Si; and a plurality of coating layers on a surface of the core, each coating layer including a metal oxide, an amorphous carbonaceous material, or combination thereof.
US10418629	9/17/2019 (3/25/2014)	Composite active material for lithium ion secondary batteries and method for producing same	Si or SiOx and carbon composites	TOSOH Corp	Anode material produced by mixing Si and graphite particles followed by carbon coating
20150295227	10/15/2015 (4/14/2014)	Silicon and graphene-incorporated rechargeable lithium batteries with enhanced energy delivery and cycling life by using silicon and graphene based anode for energy storage	Si or SiOx and carbon composites	Bluestone Global Technology Ltd	Anode material made of carbon coated Si and graphene composite
US10,483,529 & US10,637,052	11/19/2019 (12/23/2014)	Composite powder for use in an anode of a lithium ion battery, method of preparing such a composite powder and method for analysing such a composite powder	Si or SiOx and C matrix composites	Umicore	Anode consisting of a carbon matrix material and Si particles embedded in this matrix material
US10,263,245	4/16/2019 (4/24/2015)	Complex for anode active material, anode including the complex, lithium secondary battery including the anode, and method of preparing the complex	Si or SiOx and C matrix composites	SDI	A complex for anode active material, the complex including: a conductive framework having a spherical skein shape; and Si or SiOx particles dispersed in the conductive framework.
US9,917,299	3/13/2018 (11/24/2015)	Method and material for lithium ion battery anodes	Si or SiOx and carbon composites	Conring	Anode materials consisting of Si or SiOx core with some MgO in the core and carbon is coated on the core surface
CN 105552333	05/04/2016 (01/01/2016)	A method to prepare graphene-Si-conductive polymer composite anode material	Polymer and Si or SiOx composites	Three Gorges Uni.	A method to make the graphene/Si / conductive polymer composite anode material involves to mix oxidized graphene, Si powder and conductive polymer monomers, followed to polymerize to form a composite anode film.
US9,406,927	8/2/2016 (2/4/2016)	Method of preparing an anode for a Li-ion battery	Si or SiOx and carbon composites	STOREDOT	Anode made of Si and graphite blend

Publication (priority) date	Title	Areas	Assignee	Summary of disclosure
10/05/2017 (3/30/2016)	ELASTOMER-ENCAPSULATED PARTICLES OF HIGH-CAPACITY ANODE ACTIVE MATERIALS FOR LITHIUM BATTERIES	Polymer and Si or SiOx composites	Nanotek Instruments, Inc	Anode material consisting of high-capacity anode active material (e.g. Si, Ge, Sn, SnO <sub>2</sub> , Co <sub>3</sub> O <sub>4</sub> , etc.) that is encapsulated by a thin layer of elastomeric material. The elastomer material has a lithium ion conductivity no less than 10-75cm (preferably no less than 10-55/cm) at room temperature and it forms a shell with a thickness from 1 nm to 10 μm.
1/1/2019 (6/7/2016)	Alkali metal battery having an integral 3D graphene-carbon-metal hybrid foam-based electrode	Si or SiOx and C matrix composites	Nanotek Instruments, Inc	Anode material made of 3D graphene-carbon-Si hybrid form
11/5/2019 (4/6/2017)	Graphite-carbohydrate active material particles with carbonized carbohydrates	Si or SiOx and carbon composites	STOREDOT	Methods of making anode materials include milling graphite particles with carbohydrate particles to yield graphite-carbohydrate particles, milling the particles with Si particles and carbonizing to form composite anode material particles. The anode materials thus produced are provided with an at least partially porous carbon-graphite coating with both electronic and ionic conductivity.
4/28/2020 (5/30/2018)	Silicon anode materials	Si or SiOx and carbon composites	GM	A Si anode material comprises a plurality of carbon-encased silicon clusters, where each carbon-encased silicon cluster includes a volume of silicon nanoparticles encased in a carbon shell having an interior volume greater than the volume of the silicon nanoparticles.
7/28/2020 (6/1/2018)	Method of producing multi-level graphene-protected anode active material particles for battery applications	Si or SiOx and carbon composites	Global Graphene Group	Anode material made of graphene sheets encapsulated primary particles (Si or SiOx) of an anode active material
9/3/2020 (02/27/2019)	Synthesis of graphitic shells on silicon nanoparticles	Si or SiOx and carbon composites	The Regents Of The University Of California	Method for making an anode material comprising Si nanoparticles and a graphite carbon coating thereon. The method includes coating Si nanoparticles with an amorphous carbon shell, followed by converting the carbon shell to a graphite shell.
2/11/2021 (08/07/2019)	ANODE MATERIAL AND ELECTROCHEMICAL DEVICE AND ELECTRONIC DEVICE INCLUDING THE SAME	Si or SiOx and C matrix composites	Ningde Ampere Technology	An anode material includes a lithiated silicon oxide material, an inorganic coating layer, and a polymer coating layer, wherein the inorganic coating layer and the lithiated silicon oxide material at least have Si-O-M bonds therebetween, and M includes at least one of an aluminum element, a boron element, and a phosphorus element.

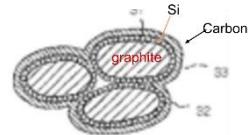
A more detailed analysis is presented on the following patents identified as critical.

- US 5, 624,606 – Carbonaceous host compounds and use as anodes in rechargeable batteries Si or SiOx and carbon composites
  - Publication date: 4/29/1997; priority date 5/3/1994, Moli
  - Status: expired on 2015-04-25
  - Major claims: Claim1. A carbonaceous insertion compound comprising: a pre-graphitic carbonaceous host C having organized and disorganized structural regions; and atoms of an element B selected from the group consisting of Sn, Al, Si, Cd, Pb, Bi and Sb, incorporated into, and compatible with, the host C wherein the structure of the organized regions of the host C is substantially unaffected by said incorporation.

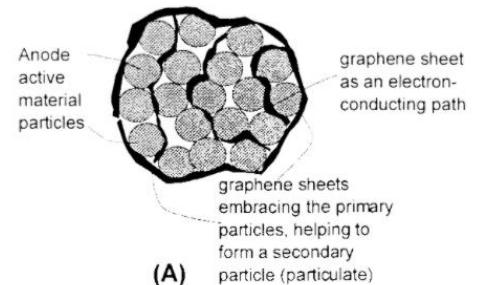
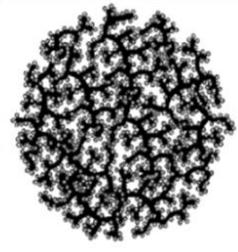
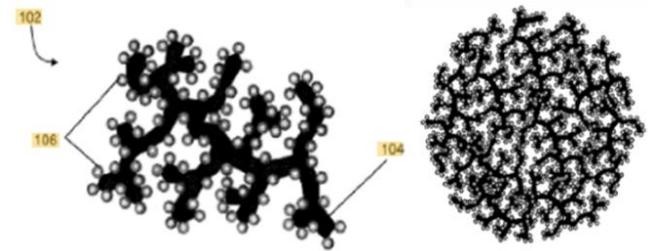
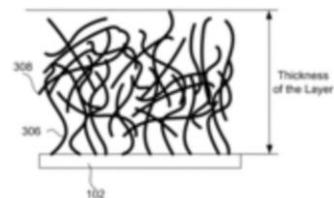
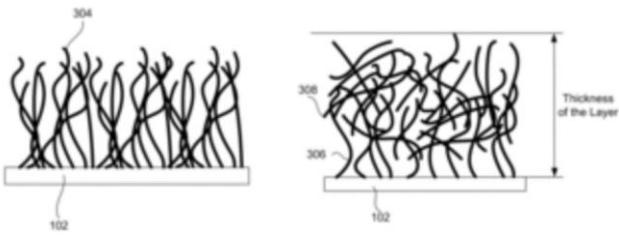
- Implication: This is the early patent claimed for amorphous carbon and Si composite, which technically allow FTO of such a type of Si/C composite.
- JPH1021913A – Battery chargeable and dischargeable reversibly for plural times
  - Publication date: 1/23/1998; priority date: 7/5/1996; Hitachi
  - Status: no indication of patent granting, if it was granted, it expired in 2016
  - Major claims: In a secondary battery containing a non-aqueous electrolytic solution, a material produced by coating the surface of a carbon-based material, to and from which lithium is intercalated and released, with an oxide containing one or more elements selected from Li, Ge, Sn, Pb, Sb, Bi, B, Al, Si, and In is used as a negative electrode active material. As the carbon based material, to and from which lithium is intercalated and released, natural graphite, artificial graphite, pitch coke, hollow carbon molecule, amorphous carbon, etc., may be usable.
  - Implication: This is the early patent claimed for SiO<sub>x</sub> coating the carbon particles, including graphite particles. This patent enables technical FTO for use SiO<sub>x</sub> graphite composites
- JP3856525 – Secondary battery
  - Publication date: 12/23/2006; priority date: 5/21/1997; Asahi
  - Status: expired on 5/21/2017
  - Major claims: In a secondary battery in which Li-occluded alloy particles are used as a negative electrode active material, the alloy includes two or more metals or metals including any one selected from the group consisting of Al, Ge, Si, and Zn in the composition A secondary battery , wherein the alloy particles have a particle diameter of 1 to 50 µm and the surface is coated with a layer made of carbon.
  - Implication: This is the early patent claimed for carbon coated Si anode material with a large Si particle size. Since most current Si based material is nanoparticle based, this leaves a gray area, since the particle size 1-50 um can be the size of agglomerate of Si nanoparticles. This may allow to use carbon coated Si without IP issues.
- US 6,383,686 – Anode material for lithium secondary battery, lithium secondary battery using said anode material, and method for charging of said secondary battery Si or SiO<sub>x</sub> and carbon composites.
  - Publication date: 5/7/2002; priority date: 01/26/1999; Mitsui Mining
  - Status: expired
  - Major claims: Claim 1: An anode material for a lithium secondary battery, comprising a particulate core comprising silicon, boron or titanium; and a carbon layer covering the surface of the particulate core, wherein the carbon content in the anode material is 5 to 50% by weight.
  - Implication: This is the early patent claimed for carbon coated Si anode material, may allow to use carbon coated Si without IP issues
- JP2000-203818A – Composite carbon particle, its production, negative pole material, negative pole for lithium secondary battery or cell and lithium secondary battery or cell
  - Publication date: 7/25/2000; priority date: 1/13/1999; Hitachi Chemical
  - Status: no indication of patent granting, if it was granted, it expired in 2019
  - Major claims: Claims: 1. Composite carbon particles containing a graphite portion, an amorphous carbon portion and silicon. 2. The composite carbon particle according to

claim 1, having a structure in which a plurality of graphite particles coated with amorphous carbon containing silicon are aggregated.

- Implication: This is the early patent claimed for carbon coated Si, graphite composite anode material, may allow to use carbon coated Si /graphite anode material without IP issues.
- JP2001118568A – Nonaqueous secondary battery
  - Publication date: 4/27/2001; priority date: 10/21/1999; Denki Kagaku Kogyo KK
  - Status: granted, it expired in 2019
  - Major claims: Claims: 1. 1. A non-aqueous electrode active material, wherein an electrode active material capable of inserting and extracting lithium ions is a SiO<sub>x</sub> (where x = 1.05 to 1.60) powder having a specific surface area of 20 m<sup>2</sup> / g or more.
  - Implication: This is the early patent claiming SiO<sub>x</sub>.
- US 6,589,696 – Negative active material for rechargeable lithium battery and method of preparing same
  - Publication date: 7/8/2003; priority date: 6/16/2000; Samsung SDI
  - Status: adjusted expiration 09/19/2021
  - Major claims: Claims: 1. A negative active material for a rechargeable lithium battery comprising: at least one graphite particle; at least one silicon micro-particle attached on a surface of the graphite particle; and an amorphous carbon film coated on the graphite particle and the silicon micro-particle.
  - Implication: This is the early patent claiming carbon coated Si/GC composite and allows low risk use of Si/GC-C composite materials. Expected to soon reach the adjusted expiration date.
- US 8,048,339 – Porous anode active material, method of preparing the same, and anode and lithium battery employing the same
  - Publication date: 11/1/2011; priority date: 12/19/2006; Samsung SDI
  - Status: active, adjusted expiration 08/30/2030
  - Major claims: Claims: 1. A porous anode active material comprising: fine particles of metallic substance capable of forming a lithium alloy; a crystalline carbonaceous substance; and a porous carbonaceous material coating and binding the fine particles of metallic substance and the crystalline carbonaceous substance, the porous anode active material having pores exhibiting a bimodal size distribution with two pore diameter peaks in a Barrett-Joyner-Halenda (BJH) pore size distribution as measured by a nitrogen adsorption test.
  - Implication: This is the early patent claiming composite anode material made of carbon bond Si or SiO<sub>x</sub> and graphite blend. The bimodal size distribution of pores is a key for this patent to differentiate from others. When sourcing Si/GC/C composite anode material, this patent needs to be reviewed for potential IP risks.
- US20100285358 – Nanostructures for rechargeable cells
  - Publication date: 11/11/2010; priority date: 5/7/2009; Amprius
  - Status: abandoned



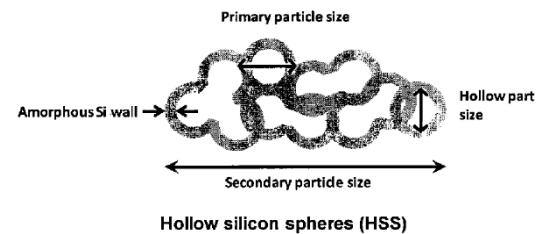
- Major claims: Claims: 1. A lithium-ion battery electrode comprising: a conductive substrate; and silicon containing nanowires substrate rooted to the conductive substrate and configured for inserting and removing lithium ions during battery cycling maintaining capacity of at least about 1500 mAh/g after at least 20 cycles, the nanowires including a conductivity enhancement component for reducing electrical resistance of the nanowires.
- Implication: This is the early patent disclosing use of special morphology (nanowire) to enable application of Si anode.
- US 8,889,295 – Electrodes, lithium-ion batteries, and methods of making and using same
  - Publication date: 11/18/2014; priority date: 09/29/2009; Sila Nanotechnologies
  - Status: Active, adjusted expiration 02/17/2031
  - Major claims: Claims: 1. A porous composite comprising: a plurality of agglomerated nanocomposites, wherein each of the nanocomposites comprises: a plurality of dendritic particles, wherein the dendritic particles comprise a three-dimensional, randomly-ordered assembly of nanoparticles of carbon; a plurality of discrete non-porous nanoparticles of silicon disposed on the outer surface of the dendritic particle; an electrically conductive material joining the nanocomposites together, wherein at least a portion of the nanocomposites are in electrical communication with each other through the electrically conductive material; and a lithium ion permeable layer disposed on at least a portion of the surface of the joined nanocomposites and forming a total pore volume within the porous composite that has a range of about 1.5 to about 20 times the volume occupied by all of the nanoparticles in the porous composite.
  - Implication: This is the early patent disclosed to use a special morphology (dendritic) carbon network to form C-Si composite, which may provide a path for further exploration in this concept.
- US 9,558,860 – Graphene-enhanced anode particulates for Li-ion batteries
  - Publication date: 1/31/2017; priority date: 09/29/2009; Samsung Electronics, Nanotek
  - Status: Active, adjusted expiration 09/06/2033
  - Major claims: Claims: 1. A lithium-ion battery anode comprising: multiple nano graphene-enhanced particulates, wherein at least one of said particulate is formed of a single or a plurality of graphene sheets and a plurality of fine anode active material particles with a size smaller than 10 µm, and the graphene sheets and the particles are mutually bonded or agglomerated into said particulate with at least a graphene sheet embracing inside an envelope constituted by



the graphene sheet or multiple graphene sheets said anode active material particles and said a single or plurality of graphene sheets, and wherein said graphene sheets are in an amount of at least 0.01% but less than 99% by weight and said anode active material is in an amount of at least 0.1% by weight, all based on the total weight of said particulate.

- Implication: This is the early patent identified to disclose graphene to make Si or SiOx/C composite material. More patents/applications disclosed graphene as a mean to make Si-C composite later.
- US 10,611,642 – SiOC COMPOSITE ELECTRODE MATERIAL
  - Publication date: 9/11/2017; priority date: 11/06/2014; Commissariat a l'Energie Atomique et aux Energies Alternatives, JNC Corp
  - Status: Active
  - Major claims: Claims: 1. A silicon oxycarbide (SiOC) composite material formed with microparticles, wherein the microparticles are formed, in whole or in part, of an amorphous SiOC matrix, with Si ranging from 20 wt % to 60 wt %, O from 20 wt % to 40 wt % and C from 10 wt % to 50 wt %, based on a total weight of the amorphous SiOC matrix, wherein amorphous or crystallized silicon particles are embedded within said amorphous SiOC matrix, and wherein the microparticles are of a core/coating structure with a core formed of said amorphous SiOC matrix and coated with a pyrolyzed coating containing at least one amorphous carbon layer.
  - Implication: This is the early patent identified to disclose amorphous SiOC matrix to make Si /C composite material. This patent opened a new path for developing Si/C-SiOx composite anode materials.
- US 9,276,261 – Surface treated silicon containing active materials for electrochemical cells
  - Publication date: 3/1/2016; priority date: 5/7/2015; Nexeon
  - Status: Active
  - Major claims: Claims: 1. An active material for use in electrochemical cells, the active material comprising a powder formed by discrete particles, each particle in the powder comprising: a silicon containing structure comprising a core and an external surface; a treatment layer covering at least a portion of the external surface of the silicon containing structure, wherein the treatment layer comprises one or more treatment materials selected from the group consisting of an aminosilane, a poly(amine), a poly(imine), and an amine functionalized alkoxy siloxane; and a carbon shell covering at least a portion of the treatment layer, wherein the carbon shell comprises carbon particles having a particle size of less than 1 micrometer
  - Implication: The polymer coating effectively improved the performance of anode materials. A path worthwhile to explore for developing Si or SiOx based anode materials, particularly for high Si loading systems.
- WO/2015/010230 – METHOD FOR PREPARING HOLLOW SILICON SPHERES AS WELL AS HOLLOW SILICON SPHERES PREPARED THEREFROM
  - Publication date: 1/29/2015; priority date: 07/22/2013; Robert Bosch GmbH, Tsinghua University
  - Status: Active

- Major claims: Claims: 1. A method for preparing hollow silicon spheres, comprising: using nano particles as a template, a silicon coating layer is formed on the nano particles using a silicon source by means of chemical vapor deposition, followed by template removal and purification. 2. The method of claim 1, wherein the size of the nano particles is in a range of 10 nm to 100 nm.
- Implication: This patent disclosed a method to make a special morphology Si, hollow Si particle, which may allow better cyclability. A path worthwhile to explore for developing Si or SiO<sub>x</sub> based anode materials, particularly for high Si loading systems.



## 17 APPENDIX 5 – HIGH POWER AND FAST CHARGE PATENTS AND ANALYSIS

Listing of identified patents (and patent applications) ranked as critical or important relative to possible interest in future anode technology development.

Patent / app#	Publication (priority) date	Title	Areas	Assignee
CN 103337634 B	10/02/2013 (7/4/2012)	Graphite cathode material of Surface coating titanium nitride conductive network film and preparation method thereof	Surface modification	Zibo Huirenzh
CN 104103820 A	10/15/2014 (4/13/2013)	Spherical porous channel graphite negative electrode material of lithium ion battery and preparation method thereof	Bulk engineered graphite particles	Wan Taipeng
US20180248187	8/30/2018 (09/09/2015)	Fast chargeable carbon anode material with inner channels	Bulk engineered graphite particles	NEC CORPORATION
US10,461,323	10/29/2019 (04/07/2016)	Composite lithium borates and/or phosphates and polymer coatings for active material particles	Surface modification	STOREDOT
US10,505,181	12/10/2019 (1/25/2017)	Composite anode material made of ionic-conducting electrically insulating material	Surface modification	STOREDOT
US20200251736	8/6/2020 (11/06/2017)	ANODE ACTIVE MATERIAL FOR LITHIUM SECONDARY BATTERY AND LITHIUM SECONDARY BATTERY COMPRISING SAME	Optimized graphite composite	Samsung SDI
EP3770999	1/27/2021 (12/17/2018)	ANODE ACTIVE MATERIAL FOR SECONDARY BATTERY, ANODE COMPRISING SAME, AND METHOD FOR MANUFACTURING SAME	Optimized graphite composite	LG Chem
WO/2020/187106	9/24/2020 (03/21/2019)	ANODE MATERIAL, ANODE AND ELECTROCHEMICAL DEVICE COMPRISING ANODE MATERIAL	Optimized graphite composite	NINGDE AMPEREX TECHNOLOGY

Patent / app#	Publication (priority) date	Title	Areas	Assignee	Summary of disclosure
US10,505,181	12/10/2019 (1/25/2017)	Composite anode material made of ionic-conducting electrically insulating material	Surface modification	STOREDOT	Core-shell particles, composite anode material, anodes made therefrom, lithium ion cells and methods are provided, which enable production of fast charging lithium ion batteries. The composite anode material has core-shell particles which are configured to receive and release lithium ions at their cores and to have shells that are configured to allow for core expansion upon lithiation. The cores of the core-shell particles are connected to the respective shells by conductive material such as carbon fibers, which may form a network throughout the anode material and possibly interconnect cores of many core-shell particles to enhance the electrical conductivity of the anode. Ionic conductive material and possibly mechanical elements may be incorporated in the core-shell particles to enhance ionic conductivity and mechanical robustness toward expansion and contraction of the cores during lithiation and de-lithiation.
US10714752	07/14/2020 (01/13/2016)	Hierarchical oxygen containing carbon anode for lithium ion batteries with high capacity and fast charging capability	Bulk engineered graphite particles	NEC Corp University of Hyogo	An anode material for a lithium ion battery, comprising an oxygen-containing carbon where oxygen is in the form of functional groups, the oxygen being distributed gradient from the surface to the inside of the carbon, and the carbon having an interlayer space d002 larger than 0.3357 nm; and a porous graphene layer covering the oxygen-containing carbon, the graphene being in the form of monolayer or few-layer graphene.
US20200044236	2/6/2020 (4/10/2017)	High energy density fast charge Li ion battery and the method of preparing the same	Bulk engineered graphite particles	Nano and Advanced Materials Institute Ltd	A fast charge lithium ion battery capable of being charged or discharged with 80% capacity retention at C rate of at least 2C is provided in the present invention, which includes a fast charge graphite-based anode; a cathode; and a separator, wherein the anode includes an anode current collector and a fast charge graphite layer deposited on at least one surface of the anode current collector, the fast charge graphite having a lattice constant equals to or larger than 0.3374 nm, a D-band to G-band integrated area ratio (ID/G) of 0.03 to 0.3, and a surface morphology of a plate-like crystal structure under a scanned electron microscope; the cathode includes a cathode current collector and one or more active materials deposited on at least one surface of the cathode current collector.

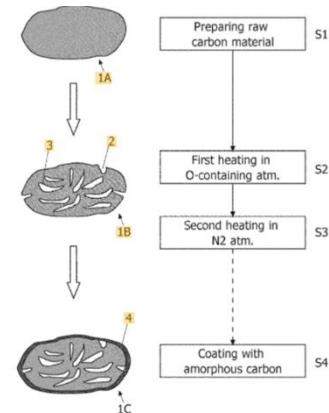
Patent / app#	Publication (priority) date	Title	Areas	Assignee	Summary of disclosure
US20190379039	12/12//2019 (06/06/2018)	Multi-level graphene-protected anode active material particles for fast-charging lithium-ion batteries	Surface modification	Global Graphene Group Inc	Provided is graphene-embraed particulate for use as a lithium-ion battery anode active material, wherein the particulate comprises primary particle(s) of an anode active material and multiple sheets of a first graphene material overlapped together to embrace or encapsulate the primary particle(s) and wherein a single or a plurality of graphene-encapsulated primary particles, along with an optional conductive additive, are further embraced or encapsulated by multiple sheets of a second graphene material, wherein the first graphene and/or the second graphene material is attached to a redox partner species (e.g. sulfonyl group, —NH2, etc.) capable of reversibly forming a redox pair with lithium. The invention also provides an anode electrode and a battery comprising multiple graphene-embraed particulates having redox forming species bonded thereto.
US20200028205	01/23/2020 (07/18/2018)	Fast-chargeable lithium battery electrodes	Surface modification	Global Graphene Group Inc	Provided is a lithium-ion battery containing an anode, a cathode, a porous separator, and an electrolyte, wherein the anode comprises particles of an anode active material that are packed together to form an anode active material layer having interstitial spaces to accommodate a lithium ion reservoir disposed therein and configured to receive lithium ions from the cathode and enable lithium ions to enter the particles in a time-delayed manner, wherein the reservoir comprises lithium-capturing groups selected from (a) redox forming species that reversibly form a redox pair with a lithium ion when the battery is charged; (b) electron-donating groups interspersed between non-electron-donating groups; (c) anions and cations wherein the anions are more mobile than the cations; (d) chemical reducing groups that partially reduce lithium ions from Li+1 to Li+δ, wherein 0<δ<1; (e) an ionic liquid; (f) borate salt or phosphate salt; or (g) a combination thereof.

A more detailed analysis is presented on the following patents identified as critical.

- CN103337634B – A graphite anode material with surface covered with titanium nitrogen conductive network
  - Publication date: 10/2/2013; priority date: 7/4/2012, Zibo Huirenzh
  - Status: granted in China, active
  - Major claims: Claim 1: A TiN surface coated graphite anode material consisting of a high conductive TiN network covering the graphite surface. A process is that preparing the

material includes mixing graphite, solid nitrogen source and titanium compound in a media with ball milling or ultrasonic mixing. Dry the mixture at 80-150oC, followed calcine the mixture at 500-950oC in inert atmosphere for 3-12hr to produce the material. The weight ratio of conductive TiN network is 0.5-6% of the graphite.

- Implications: Surface coating of TiN to increase power capability of the anode material may be effective. No indication of patents granted in other regions except China. May open opportunities for production/application outside of China.
- CN104103820 A – Spherical porous channel graphite negative electrode material of lithium ion battery and preparation method thereof
  - Publication date: 10/15/2014; priority date: 4/13/2013; Wan Taipeng
  - Status: granted in China, active
  - Major claims: Claim 1: the spherical porous passage graphite cathode material of lithium ion battery, it is characterized in that: it is that the crystalline flake graphite matter particles agglomerate that distribution of orientations is different is combined into that described spherical porous passage graphite cathode material possesses core, its space, inner distribution microchannel, surface is the coated core-shell type spherical structure of material with carbon element.
  - Implications: No indication of patents granted in other regions except China. May open opportunities for production/application outside of China.
- US20180248187 – Fast chargeable carbon anode material with inner channels
  - Publication date: 8/30/2018; priority date: 09/09/2015; NEC Corp
  - Status: pending
  - Major claims: Claim 1: An anode material for a lithium ion battery, the material comprising a spherical particle of graphite or graphite-carbon composite provided with pores on the surface and inner channels in the core part of the particle, the inner channels being interconnected to the pores.
  - Implications: This is a modification of the state-of-art graphite material to achieve fast charging ability. Since NEC Corp is not a anode manufacturer and does not make Li-ion battery, if interested, licensing opportunity may be worthwhile to explore.
- US10,461,323 – Composite lithium borates and/or phosphates and polymer coatings for active material particles
  - Publication date: 10/29/2019; priority date: 04/07/2016; StoreDot
  - Status: active
  - Major claims: Claim 1: Anode active material particles comprising: metalloid cores comprising at least one of Si, Ge and Sn, having diameter in a range of 20-500 nm, and a composite coating on said metalloid cores, said composite coating comprising lithium borates and/or lithium phosphates and polymer molecules, wherein the lithium borates and/or lithium phosphates alternate with polymer molecules within the composite coating, with the lithium borates and/or lithium phosphates interconnecting the polymer molecules, and wherein the polymer molecules are anchored by the lithium borates and/or lithium phosphates to the metalloid cores.



- Implications: It is claimed that the coating layer on the surface of active material particles builds up a buffer zone to prevent lithium deposition and dendrite formation, which enables fast charging. It may allow Si/SiO<sub>x</sub> based anode to have fast charging ability. StoreDot is an Israel Li-ion maker.
- US20200251736 – ANODE ACTIVE MATERIAL FOR LITHIUM SECONDARY BATTERY AND LITHIUM SECONDARY BATTERY COMPRISING SAME
  - Publication date: 8/6/2020; priority date: 11/06/2017; Samsung SDI
  - Status: pending
  - Major claims: Claim 1. An anode active material for a lithium secondary battery comprising two kinds of crystalline carbon, with a ratio (I3R(101)/I2H(100)) of peak intensity at a 3R(101) face relative to a peak intensity at a 2H(100) face ranging from 0.55 to 0.7, in an X-ray diffraction pattern. Claim 2. The anode active material for a lithium secondary battery of claim 1, wherein the two kinds of crystalline carbon comprise a first graphite and a second graphite. Claim 3. The anode active material for a lithium secondary battery of claim 2, wherein the first graphite is natural graphite and the second graphite is artificial graphite
  - Implications: It is claimed synthetic graphite and natural graphite composite with specific features as fast charging anode material. This may cause some concerns for using synthetic graphite and natural graphite composite anode materials. Detailed FTO is required if concerns are arising in product roadmap development.
- EP3770999 – ANODE ACTIVE MATERIAL FOR SECONDARY BATTERY, ANODE COMPRISING SAME, AND METHOD FOR MANUFACTURING SAME
  - Publication date: 1/27/2021; priority date: 12/17/2018; LG Chem
  - Status: pending
  - Major claims: Claim 1. A negative electrode active material for a secondary battery, wherein the negative electrode active material is a mixture of artificial graphite and spheroidized natural graphite, and wherein the spheroidized natural graphite has an average particle diameter (D 50) of 12 µm or less, and D 90 - D 10 value is 5 to 12 µm. Claims 2. The negative electrode active material of claim 1, wherein the artificial graphite of 65 to 85% by weight based on the total weight of the negative electrode active material is contained in the negative electrode active material, and the spheroidized natural graphite of 15 to 35% by weight based on the total weight of the negative electrode active material is contained in the negative electrode active material.
  - Implications: It is claimed synthetic graphite and natural graphite composite with specific features as fast charging anode material. This may cause some concerns for using synthetic graphite and natural graphite composite anode materials. Detailed FTO is required if concerns are arising in product roadmap development.
- WO/2020/187106 – ANODE MATERIAL, ANODE AND ELECTROCHEMICAL DEVICE COMPRISING ANODE MATERIAL
  - Publication date: 9/24/2020; priority date: 03/21/2019; NINGDE AMPEREX TECHNOLOGY (CATL)
  - Status: pending
  - Major claims: Claim 1. An anode material, which meets the following relationship equations: 0.8≤0.06 x (Dv50)<sup>2</sup>-2.5 x Dv50+Dv99≤12 (1), and 1.2≤ 0.2 x Dv50-0.006 x (Dv50)<sup>2</sup>+BET≤5 (2) wherein Dv50 represents a value in the volume-based particle size distribution of the anode material that is greater than the particle size of 50% of the



particles, Dv99 represents a value in the volume-based particle size distribution of the anode material that is greater than the particle size of 99% of the particles, and BET is a specific surface area of the anode material, wherein Dv50 and Dv99 are expressed in  $\mu\text{m}$  and BET is expressed in  $\text{m}^2/\text{g}$ . Claim 2. The anode material according to claim 1, comprising a group consisting of natural graphite, artificial graphite, and a combination thereof, wherein at least a part of the surface of the anode material comprises amorphous carbon.

- Implications: It is claimed synthetic graphite and natural graphite composite with specific features as fast charging anode material. This may cause some concerns for using synthetic graphite and natural graphite composite anode materials. Detailed FTO is required if concerns are arising in product roadmap development.

## 18 APPENDIX 6 – CONTINUOUS GRAPHITIZATION AND NEEDLE PITCH COKE PATENTS AND ANALYSIS

### 18.1 CONTINUOUS GRAPHITIZATION

Patents and patent applications identified as critical related to a continuous graphitization process.

Patent/app #	Publication (priority) date	Title	Assignee	Summary of disclosures
CA2470686C	07/10/2003 (12/28/2001)	Process for continuous graphitization	SGL Carbon	Process for continuous graphitization, carried out in a tunnel furnace having a transport device, heat locks at the inlet and outlet of the furnace and in the interior of the furnace at least one heating section whose length is less than the length of the bodies to-be graphitized and whose heating power is altered according to the movement of the bodies, in particular for cathode blocks which are used in the electrolytic reduction of aluminum oxide.
CN109368632A	2/22/2019 (12/17/2018)	Graphitized carbon material and preparation method thereof	XIN'AO GRAPHITE TECHNOLOGY CO., LTD.	The present invention provides graphitized carbon materials and preparation method thereof. The preparation method for preparing graphitized carbon material includes: to mix carbon source and transition metal chloride, to obtain the first mixture;
CN110054183A	7/26/2019 (2/21/2019)	The graphitizing furnace of high-efficient energy-saving environment friendly continuous production lithium cell anode material	WAN XIN LIAONING TECHNOLOGY MATERIALS CO., LTD	The present invention relates to making anode material for Li-ion battery with a graphitizing furnace of high-efficient energy-saving environment friendly continuous production of the anode material
CN210237133U	4/3/2020 (7/16/2019)	Continuous graphitizing furnace for lithium battery negative electrode material	SHANXI SANYUAN CARBON CO., LTD	The utility model provides a continuous graphitizing furnace for making Li-ion anode materials
CN106938844A	7/11/2017 (4/21/2017)	PREPARATION METHOD FOR HIGH-CAPACITY LOW-EXPANSION SINGLE-PARTICLE SYNTHETIC-GRAFITE NEGATIVE-ELECTRODE MATERIAL	NINGBO SHANSHAN NEW MATERIAL TECHNOLOGY CO., LTD	The invention specifically relates to a preparation method for a high-capacity low-expansion single-particle synthetic graphite anode materials for Li-ion battery

A more detailed analysis is presented on the above patents identified as critical.

- CA2470686C – Process for continuous graphitization
  - Publication date: 7/10/2003; priority date: 12/28/2001; SGL Carbon
  - Status: Expired - Fee Related
  - Major claims: Claim 1. A process for continuous graphitization, carried out in a tunnel furnace having a transport device, heat locks at the inlet and outlet of the furnace and in the interior of the furnace at least one heating section whose length is less than the length of the bodies to be graphitized and whose heating power is altered according to the movement of the bodies.
  - Implications: This is a process equipment patent for a specific design of continuous graphitization furnace. No risks for implementation since it expired. It will be very useful to further investigate whether SGL has implemented this technique/equipment in its graphitization process. SGL and Hitachi Chemical established some kind partnership in graphite anode business.
- CN109368632A – Graphitized carbon material and preparation method thereof
  - Publication date: 2/22/2019; priority date: 12/17/2018; Xin'Ao Graphite Technology
  - Status: pending
  - Major claims: Claim 1. A method for preparing graphitized carbon material characterized by comprising (1) carbon source and transition metal chloride are mixed, to obtain the first mixture ; (2) first mixture is made to carry out graphitization reaction, to obtain the graphitized carbon material. Claim 5. according to the method described in claim 3, it is characterized in that, it is described graphitization reaction temperature be 800 ~1500°C, Time is 0.5 hour~12 hours. Claim 7. according to the method described in claim 4, it is characterized in that, the transition metal chloride is selected from iron chloride, protochloride At least one of iron, nickel chloride and cobalt

chloride ; And the carbon source is selected from least one of petroleum coke, pitch, semicoke, anthracite, bituminous coal and lignite.

- Implications: This is a process patent for graphitization at low temperature (800-15000C) with transition metal catalyst to achieve graphitization degree 66%. Opportunity to use continuous graphitization method. This application has not been granted yet, and no indication for filing outside of China. Opportunity to implement outside of China.
- CN110054183A – Graphitization furnace used for high-efficiency energy-saving environmental-protection continuous production of lithium battery anode materials
  - Publication date: 7/26/2019; priority date: 2/21/2019; Wan Xin Liaoning Technology Materials
  - Status: pending
  - Major claims: Claim 1. The invention relates to an efficient energy-saving and environment-friendly graphitization furnace for continuously producing a lithium battery negative electrode material.
  - Implications: This is equipment patent application with specific furnace design. No threat to graphite material makers.
- CN210237133U – Continuous graphitizing furnace for lithium ion battery anode material (a design patent)
  - Publication date: 4/3/2020; priority date: 7/16/2019; Shanxi Sanyuan Carbon
  - Status: active
  - Major claims: Claim 1. The utility model provides continuous graphitization stove for making a Li-ion anode material, which characterized in that includes: the horizontal furnace body is internally provided with a preheating section, a heating section and a cooling section in sequence; the feeding mechanism and the discharging mechanism are respectively arranged at the feeding end and the discharging end of the horizontal furnace body; the heating mechanism is arranged at the heating section of the horizontal furnace body and used for heating, and the cooling mechanism is arranged at the cooling section of the horizontal furnace body and used for cooling.
  - Implications: This is an equipment design patent with specific furnace design. No threat to graphite material makers.
- CN106938844A – PREPARATION METHOD FOR HIGH-CAPACITY LOW-EXPANSION SINGLE-PARTICLE SYNTHETIC-GRAphite NEGATIVE-ELECTRODE MATERIAL
  - Publication date 7/11/2017; priority date: 4/21/2017; Ningbo Shanshan New Material Technology
  - Status: pending
  - Major claims: Claim 1. Preparation method of high-capacity and low-expansion single-particle artificial graphite negative electrode material, which comprises the following steps:
    - 1) raw material grinding and powder treatment: mechanically grinding the artificial graphite raw material to obtain raw material powder with the particle size of 7.5-9.5 µm; the artificial graphite raw material is petroleum coke or asphalt coke or a mixture of both;

- 2) continuous carbonization coating treatment: the raw material powder is subjected to continuous carbonization treatment in a continuous carbonization furnace, the temperature of the first stage of continuous carbonization is 200-450oC, and the heat preservation time is 2-5 hours; the temperature of the second stage of continuous carbonization is 450-780oC, and the heat preservation time is 1-3 hours; the method comprises the following steps:
  - 3) crushing and depolymerizing a coating body: crushing and depolymerizing a coke coating body to obtain a coke coating powder material with the D50 particle size of 15-18 µm;
  - 4) mixing: carrying out self-mixing treatment on the coke coating powder material, so that the materials are more uniform;
  - 5) shaping: putting the coke coated body powder subjected to mixing treatment into a rotating shaping device, and carrying out surface modification and shaping;
  - 6) high-temperature graphitization treatment: carrying out high-temperature graphitization treatment at 2400-3000oC in a graphitization furnace at 2400-3000oC for 68-79 hours to obtain the artificial graphite negative electrode material with the D50 particle size of 13-16 µm.
- Implications: This is a process to make synthetic graphite anode material, which exerts low risk for IP issue for synthetic graphite makers. The claimed process could be easily gotten around. No indication of patent has been filed outside of China, low risk for makers outside of China. The process may be good reference for making synthetic graphite from petroleum coke or pitch.

## 18.2 PHILLIPS 66 NEEDLE PITCH COKE PRECURSOR

Patents and patent applications identified as critical related to use of Phillips 66 needle pitch coke.

Patent/app #	Publication (priority) date	Title	Assignee
US7964240	06/21/2011 (01/19/2009)	Producing coated graphitic anode powders by extracting pitch from high volatile matter coke and coating the same in-situ	ConocoPhillips Co
US7785661	08/31/2010 (12/19/2003)	Methods of preparing composite carbon-graphite-silicon particles and using same	ConocoPhillips Co
US20090242830	10/01/2009 (03/31/2008)	Anode powders for batteries	ConocoPhillips Co
US20110256449	10/20/2011 (4/19/2010)	Organic coated fine particle powders	ConocoPhillips Co

Note: ConocoPhillips' Li-ion anode patents have been acquired by Pyroteck, Inc., and applications US20090242830 & US20110256449 were abandoned.

A more detailed analysis is presented on the above patents identified as critical.

- US 7,964,240 – Producing coated graphitic anode powders by extracting pitch from high volatile matter coke and coating the same in-situ
  - Publication date: 06/21/2011; priority date: 01/19/2009
  - Status: Expired - Fee Related

- Major claims: Claim 1. 1A process for making carbon coated graphitic anode powder for use in batteries wherein the process comprises:
  - a) providing green coke having high volatile matter of at least about ten weight percent volatile matter;
  - b) mixing the high volatile matter green coke with a liquid solvent at a selected solvent to carbon ratio to form a solvent suspension and also to extract volatile matter from the green coke, wherein the solvent is selected from the group consisting of toluene, benzene, and xylene;
  - c) altering the solvent strength of the solvent suspension and cause volatile matter that has been extracted from the green coke to precipitate on the coke particles and form a coating thereon, wherein the altering the solvent strength comprises adding anti-solvent to the solvent suspension and the anti-solvent is selected from the group consisting of pentane, hexane, heptane, octane, and nonane;
  - d) separating the solvent with residual dissolved volatile material from the coated green coke particles;
  - e) stabilizing the coated green coke particles by oxidative stabilization while heating to a temperature of at least 200 °C. in an oxygen containing environment;
  - f) carbonizing the stabilized coated green coke particles to a temperature of at least 600 °C. in an inert environment; and
  - g) graphitizing the coated carbonized coke particles to a temperature of at least 2200 °C.
- Implications: This is a process patent. Since it expired, no threat to graphite material makers to use the process. May provide a reference and opportunity for process to make such type of anode materials.
- US 7,785,661 – Methods of preparing composite carbon-graphite-silicon particles and using same
  - Publication date: 08/31/2010; priority date: 12/19/2003
  - Status: Expired - Fee Related
  - Major claims: Claim 1. A method comprising the steps of: preparing a liquid suspension comprising particles of carbonaceous material and a solution of carbon residue-forming material with a solvent; forming coated carbonaceous particles by subjecting the suspension to conditions that permit precipitation of the carbon residue-forming material onto the carbonaceous material; adding silicon particles to the suspension once the coated carbonaceous particles are formed; and forming coated silicon-carbon composite particles by subjecting the suspension to conditions that permit precipitation of the carbon residue-forming material onto the silicon particles and the coated carbonaceous particles together.
  - Implications: This is a process patent, no threat to graphite material makers to use the process. May provide a reference for process.

## 19 APPENDIX 7 – PATENT SEARCH APPROACH

The following details describe the approach taken when searching patent databases. Multiple searches were performed with varying criteria. The objective of searches was to identify the most relevant patents related to the topics of interest. In most cases, many results were found, and those results were quickly screened in order to narrow down the results and focus on what was determined as the most highly relevant patents. In some cases, not all patent results were reviewed.

- Search one: WIPO database; Searching input phrases: anywhere includes “graphite” / “anode” / “Li-ion battery”; 19387 results; Reviewed about 2000 results
- Search two: WIPO database; Searching input phrases: anywhere includes “graphite anode” / “Li-ion battery”; 654 results; Reviewed all results
- Search three: USPTO patent database; Searching key word: claim includes “Anode” and includes “Li-ion battery” anywhere; 755 results; Reviewed all results
- Search four: WIPO database; Searching input phrases: anywhere includes “anode” / “fast charging” / “Li-ion battery”; 657 results; Reviewed all results
- Search five: WIPO database; Searching input phrases: abstract includes “anode”, description includes “Li-ion”, and claim includes “Si”; 944 results; Reviewed all results
- Search six: WIPO database; Searching input phrases: abstract includes “anode”, description includes “carbon coated graphite”, and claim includes “core shell”; 37 results; Reviewed all results
- Search seven: WIPO database; Searching input phrases: front page includes “continuous graphitization”; 178 results; Reviewed all results
- Search seven: WIPO database; Searching input phrases: includes “continuous graphitization” anywhere and “anode” anywhere; 8 results; Reviewed all results
- Search at WIPO and USPTO patent databases for “continuous graphitization” anywhere and “Li-ion” anywhere, no results were found.
- Search eight: WIPO database; Searching input phrases: anywhere includes “needle coke” and anywhere includes “graphite anode”; 96 results; Reviewed all results
- Search eight: USPTO patent database; Searching input phrases: claim includes “needle coke” and claim includes “Li-ion”; 0 results
- Search nine: USPTO patent database; Searching input phrases: assignee includes “Conocophillips” and description includes “graphite anode”; 2 results
- Search ten: USPTO patent application database; Searching input phrases: assignee includes “Conocophillips” and description includes “graphite anode”; 4 results
- Search eight: USPTO patent database; Searching input phrases: assignee includes “Pyrotek Inc.” and description includes “graphite anode”; 0 results

The following graphic visually illustrates the patent search approach.

