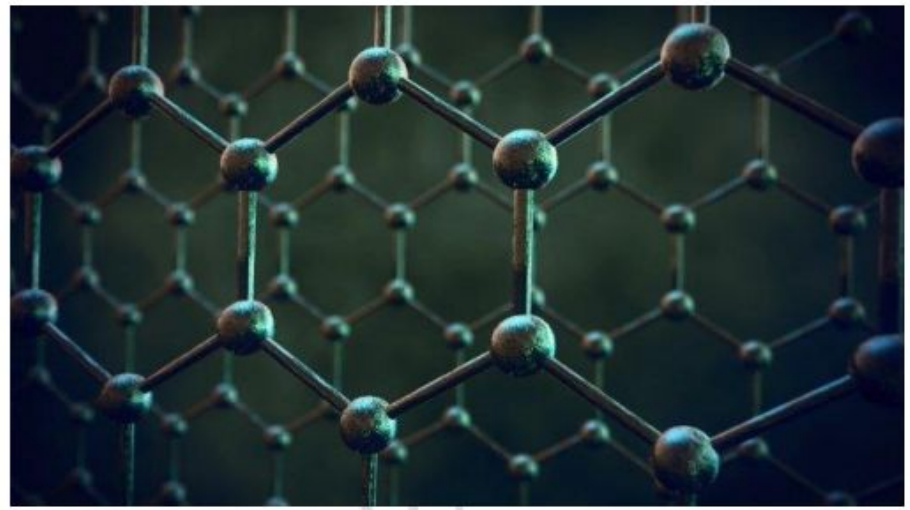
An In-depth Research into

Conductive Agents of Lithium-ion Batteries



First of all, as technological development boosted enormous changes, let's review the past and present history of conductive agents. To begin with, key auxiliary materials for lithium batteries benefit a lot from the development of new energy vehicles. A conductive agent is a key auxiliary material of a lithium battery, which is coated on positive electrode material and negative electrode material. A certain amount of conductive agent will be added during the production of the pole piece to increase the conductivity of electrons and lithium ions. By forming a conductive network on the surface of the active material to speed up the electron transfer rate, it can absorb and maintain the electrolyte at the same time to provide more lithium ions. Multi-electrolyte interface thereby improves battery charging efficiency and extends battery life. There are three types of current mainstream conductive agents, including conductive carbon black, carbon nanotubes, and graphene. The contact area of spherical conductive carbon black is small, and the electrical conductivity is weaker than the other two; tubular carbon nanotubes have excellent electrical conductivity but high price; sheet graphene has certain obstacles to the forward flow of current due to

its shape.

Factors for choosing a conductive agent: conductivity, amount of addition, and cost. Compared with traditional carbon black, the new conductive agent has the following features:

(1) Performance advantages: the lower the impedance, the better the conductivity. According to the prospectus of Tiannai Technology, the impedance of carbon nanotubes is only about 1/2 of carbon black, and the low impedance can improve polarization at the same time. The cycle performance is better.

(2) The additional amount is small. According to the calculation of Gaogong Lithium, the traditional carbon black conductive agent is added in an amount of about 3% by weight of the positive electrode material, while the addition amount of new conductive agents such as carbon nanotubes and graphene is reduced to 0.8%-1.5%, which is low. The additional amount can save space for the positive active material, thereby increasing the energy density.

(3) The unit price is relatively high. According to the market transaction price of Baichuan Yingfu on February 18, the price of adding carbon nanotubes per unit of lithium battery is 4.4-8.2 times the price of conductive carbon black SP. Considering performance and cost, the industry chain is now New traditional composite conductive pastes are mostly used, such as SP+carbon nanotubes, carbon nanotubes+graphene, SP+carbon nanotubes+graphene, etc.

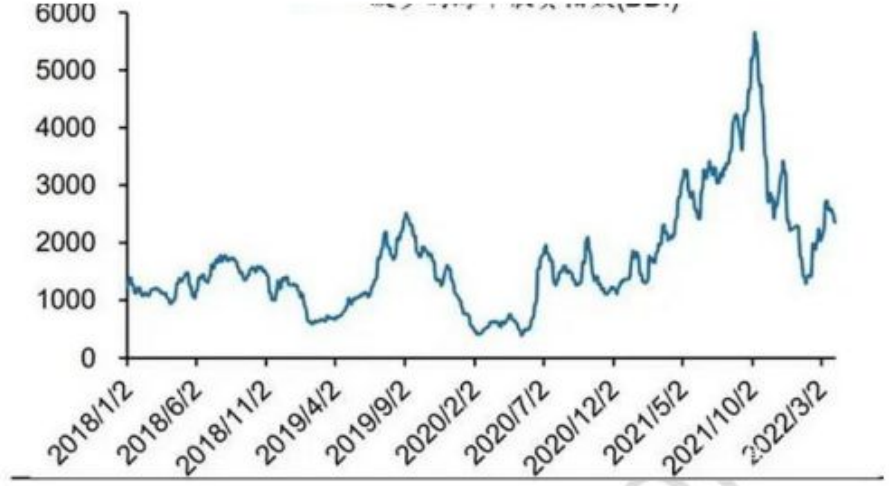
Secondly, after some tough suffering, the substitutes in China have made comparatively huge progress. Before 2014, carbon black is the mainstream conductive agent, and China almost all had to rely on imports. Between 2014 and 2021, the new domestic conductive agent breaks the overseas monopoly, and Tiannai Technology took the lead in the rise. In 2022, the cost and technology of carbon tube have such shining advantages that the domestic production of carbon black seeks a breakthrough.

Here are more details about carbon black. Common conductive carbon black categories include Super P, acetylene black, and Ketjen black. Acetylene black has a larger specific surface area than SP and is difficult to disperse. Ketjen black has better performance but higher price. Therefore, SP is now mostly selected as conductive carbon black in the market. Oil absorption value and metal impurity content are the

core quality control indicators of lithium battery carbon black. The conductivity of carbon black is generally measured by the oil absorption value DBP, the higher the value, the better the conductivity. At present, the domestic conductive carbon black DBP in the non-lithium battery field is only 180ml/g at most, and the conductive carbon black used for batteries needs to reach at least 250ml/g. In addition, for lithium batteries, it is also necessary to consider the metal content added to the positive and negative electrode materials. Too high metal impurities will cause the battery to self-discharge and form a short circuit. The conductive carbon black for lithium batteries has more stringent conductivity indicators and higher purity requirements.

The technical barriers are high, and it does not coincide with the ordinary carbon black production line. Furnace carbon black is the most common production process. The diameter of conventional carbon black reactors is too large, especially the reactor section near the throat section. The insufficient cracking of the raw oil by the gas stream makes the carbon black unable to meet the high oil absorption value and low metal impurity content index. Therefore, it is necessary to redesign the reactor and design a set of metal ion removal solutions. Most of the reaction furnaces of domestic carbon black factories are imported from abroad, and there are few enterprises that independently develop 10,000-ton-scale reaction furnaces, and the purification realization path requires long-term research and development accumulation. Therefore, conductive carbon black present a high-tech threshold, and my country has long relied on overseas imports.

At present, the main domestic suppliers of conductive carbon black for lithium are the foreign-funded enterprise Irystone, which is produced overseas and imported to China, and the foreign-funded enterprise Cabot, which is produced and operated in China. Iridite, which occupies a major domestic share, has no factories in China and can only be produced through overseas factories and imported by sea. In the short term, overseas import prices have an upward trend, mainly due to: (1) Sea freight has soared under the epidemic, and it has fluctuated at a high level in the short term. Affected by the epidemic, the closure of many shipping routes has led to a continuous increase in shipping costs in the past two years. According to the WIND database, the BDI index, which can measure shipping prices, has risen from 616 in early April 2020 to 2357 in the same period in 2022, an increase of +256.6%.



Under the continuous evolution, sea freight rates will remain high and fluctuate in the short term. (2) The rise in crude oil prices under the Russia-Ukraine conflict has put pressure on short-term costs. Overseas carbon black mainly uses crude oil as raw material to produce carbon black. As of March 8, the settlement price of crude oil futures has risen by 56.94% this year. The increase in crude oil prices under the conflict between Russia and Ukraine will be transmitted to the price of imported conductive carbon black.

In terms of our domestic market, we have a mature process layout, oil reserve furnace, and post-treatment method. More merits of domestic situations are as follows.

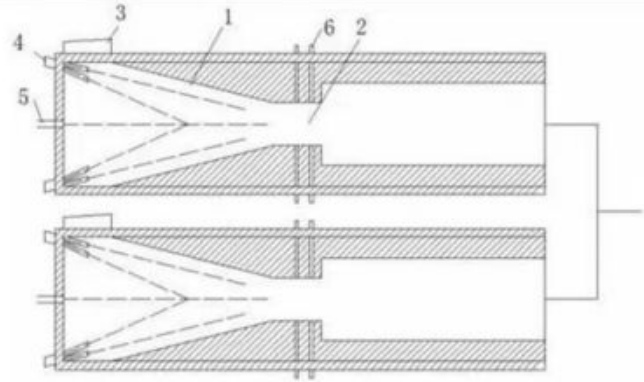
(1) Consolidated technical reserves: carbon black leader has high R&D investment, taking the lead in cutting into high-purity carbon black.

(2) Mature process layout: master the oil furnace method and post-treatment method and produce conductive carbon black in parallel with two lines.

(3) Comprehensive cost advantage: Western energy is dominant, electricity is self-sufficient, and water treatment is self-supporting.

(4) Competitive analysis: external cost advantage, internal technology dividend.

(5) Opportunities and challenges after the localization of conductive carbon black.



The integration of carbon nanotubes increases the possibility of cost reduction and creates sustainable advantages. More details are below.

(1) Powder + purification + dispersion: three core quality control links.

(2) NMP + powder + slurry: integrated layout reduces costs and increases efficiency.

(3) Competitive analysis: cost advantage lays a leading position.

Some leading brands such as 1. Tiannai Technology: It has been deeply cultivated for many years, and its comprehensive strength is in the leading position. 2. Dow Technology: Join hands with BYD to build a carbon material business platform. 3. CATL: Join hands with Chendao Investment to invest in the carbon tube business and accelerate production capacity expansion. 4. OCSiAL: The global single-wall carbon tube unicorn, the entry of domestic intensifies global competition. 5. Companies outside the industry: high technical barriers in the industry, strong customer stickiness, and difficulty in entering the market.

After reading the details above, you may find that the cost and performance can keep a good balance again. Firstly, the conductive agent carbon black, it should take the lead in the application of iron and lithium, and the marketing advantages of those emphasizing cost issues still remain the same.

Lithium iron phosphate batteries have lower energy density requirements than ternary batteries and can accept a large amount of conductive carbon black. The more conductive agent is added, the more lithium ion content inside the battery will be crowded out, thus affecting the energy density of the battery. According to Gaogong Lithium Battery and Battery China.com, the average energy density of ternary

exceeds 250Wh/kg, while that of lithium iron phosphate batteries does not exceed 190Wh/kg. The amount of conductive carbon black added is 3% of the positive electrode material, and the amount of carbon nanotubes added does not exceed 1% of the positive electrode material. We believe that lithium iron phosphate batteries with low energy density requirements are more accepting of conductive carbon black than ternary batteries.

Conductive carbon black meets the low-cost characteristics of lithium iron phosphate batteries. The conductivity of lithium iron phosphate battery itself is worse than that of ternary battery, so more conductive agent needs to be added. According to GGII, the addition amount of carbon nanotubes in ternary batteries is 0.8-1%, and the addition amount in lithium iron phosphate batteries is 1-1.5%. Assuming that a single GWh battery uses 2500 tons of positive electrode material, carbon nanotubes in a single KWh lithium iron phosphate battery The value of the tube is 33-49 yuan, the value of the carbon tube for a single KWh ternary battery is 26-33 yuan, and the value of the conductive carbon black made in China for a single KWh lithium iron phosphate battery is 3.375 yuan. Therefore, from the cost side, we believe that conductive carbon black is more in line with the low-cost characteristics of lithium iron phosphate batteries and has a greater advantage in the lithium iron phosphate battery market.

The localization of conductive carbon black reduces the cost faster than the integration of carbon tubes. Based on the average market transaction data of Baichuan Yingfu in March 2022, the current transaction price of imported conductive carbon black is 90,000 yuan / ton. Assuming that the domestic conductive carbon black sells for 45,000 yuan / ton, the cost of conductive carbon black can be reduced. up to 50%. In contrast, assuming that the carbon nanotube plant is located in the low-cost energy area in the west, and the acidification business is self-processing and NMP self-supplied 100%, we estimate that the total cost of a single ton of slurry in the three links can be reduced by up to 9,700 yuan, with 52,800 yuan. According to the calculation of the cost per ton of carbon tube slurry, the cost can be reduced by up to 18%. In the short term, the cost reduction speed of carbon tube is not as fast as that of carbon black, and it is difficult to completely replace carbon black in the heavy-cost market.

high. For price-sensitive products, the cost advantage of carbon black over carbon tubes will keep the market demand high. In products that do not require high energy density and need to reduce costs, carbon black will be used more in low-end digital markets such as power banks. According to the calculation of Gaogong Lithium Battery, by 2023, the penetration rate of carbon black in digital batteries in China will still maintain 60.8%.

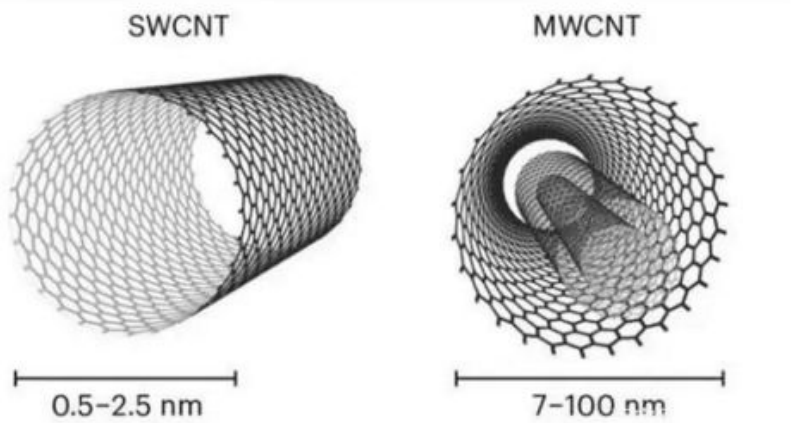
In addition, for carbon nanotubes, it is suggested that we should accelerate our pace to seize the iron-lithium market when the high-performance market is difficult to replace. BYD deploys carbon tubes to help penetrate the lithium iron phosphate market. BYD is the second largest manufacturer of lithium iron phosphate batteries in my country. The self-developed lithium iron phosphate blade battery will be mass-produced in March 2020 and will be equipped with many popular models including BYD Han EV, Tang EV, and Song Plus EV. In April 2022, Dow Technology announced that BYD invested 100 million yuan in its carbon material subsidiary Griffin, and the two parties became strategic partners. Lithium iron phosphate battery leader BYD's investment layout superimposed the continuous improvement of carbon nanotube integration to improve efficiency and reduce costs will inject a booster for carbon nanotubes to compete with conductive carbon black in the lithium iron phosphate market.

New high-quality nanomaterials are difficult to replace in the high-performance power battery market. The excellent performance of carbon tubes is more suitable for high-nickel ternary batteries. The conductivity of high-nickel ternary batteries is worse than that of low- and medium-nickel ternary batteries, but high-nickel ternary batteries have higher requirements on energy density, so only increasing the addition amount cannot take into account both conductivity and energy density. Therefore, the industry chain usually iterates the carbon tube slurry with higher performance to adapt to the high-nickel ternary battery. Taking Tiannai Technology as an example, it has launched a third-generation product with a smaller diameter-to-length ratio and a lower volume resistivity for the elevation nickel ternary battery. Therefore, in the high-nickel ternary battery market, it is difficult for carbon black to replace carbon tubes.

Single-walled carbon nanotubes have better performance. According to OCSiAL's

official website, compared with multi-wall carbon nanotubes, single-wall carbon nanotubes are flexible, have a larger aspect ratio, and the effective addition amount is only 0.1%. It can produce conductive materials and transparent conductive materials of any color, which can maintain or Improve the mechanical properties of the material. Taking OCSiAL products as an example, the aspect ratio of single-wall carbon nanotubes exceeds 3000, and the addition amount is only 0.1%. More walls can improve the energy density of the battery by 10-60 times, and the charge and discharge rate is faster than 50%. Adding 0.04% of single-walled carbon nanotubes to the silicon anode battery formula can increase the battery cycle life by 4 times.

Single-walled carbon nanotubes are now the only solution for the conductivity of silicon-based anodes. Tesla's latest generation 4680 battery uses a silicon-based negative electrode to improve energy density. Since silicon itself does not have electrical conductivity, the silicon-based negative electrode has poor conductivity, and the volume of silicon will expand significantly during the charging and discharging process and cracks will appear, resulting in the silicon negative electrode. Batteries deplete rapidly, affecting cycle life. Single-walled carbon nanotubes are currently the only solution to the problem of electrical conductivity above silicon-based anodes due to their high electrical conductivity, high flexibility, and aspect ratio.



Cost and performance regain the balance. In the short term, after the localization of conductive carbon black, it will seize the market share of lithium iron phosphate batteries with the same low-cost characteristics by virtue of its cost advantage, and at

ternary, silicon-based negative electrodes, and fast-charging power lithium batteries, carbon nanotubes will become the mainstream of the market with their irreplaceable performance advantages. BYD, the leader in iron-lithium batteries, has strategically invested in a subsidiary of Dow Technologies, and selected carbon tubes to deploy conductive agents along the industrial chain, which will support the gradual increase in the penetration rate of carbon nanotubes.