

# **FUTURE PROSPECTS OF NATURAL GRAPHITE AS A HIGH-TECH MATERIAL FOR ENERGY APPLICATIONS**

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Natural graphite presents significant potential as a high-tech material in energy applications, especially for lithium-ion batteries (LIBs), where it serves as a crucial anode material. Ukraine, endowed with extensive graphite reserves, including the Zavallivske deposit, has an opportunity to become a major supplier of high-purity graphite to the global market. However, current extraction and purification technologies in Ukraine do not yet meet the required purity standards for advanced energy storage applications. This paper examines recent advancements in chemical purification methods using sulfuric acid and ammonium fluoride to achieve ultra-high purity graphite suitable for high-performance LIBs. Experimental results indicate that chemically treated graphite can achieve up to 99.98% carbon purity, providing an efficient, cost-effective solution for the energy industry. This study explores the potential of natural graphite in the energy sector and discusses the technological and economic impact of advancing graphite purification techniques in Ukraine.

## **Introduction**

Graphite, a naturally occurring crystalline form of carbon, has become an essential material in numerous high-tech applications, particularly in the energy sector. It is extensively used as an anode material in LIBs due to its high electrical conductivity, thermal stability, and mechanical strength. As LIBs power the expanding market for electric vehicles (EVs) and renewable energy storage solutions, the demand for high-purity graphite is continuously rising. Achieving the required purity for LIB anodes is challenging, as the batteries necessitate high-purity graphite (over 99.95% carbon content) to ensure longevity, capacity, and stability [1,2].

The global demand for high-purity graphite is expected to grow exponentially. Projections indicate that over 1.5 million metric tons of natural graphite will be required annually for LIB production by 2030. This demand is driven by the expansion of EV production, energy storage systems for grid

stability, and the shift toward renewable energy sources. Furthermore, policy shifts toward sustainable energy and decarbonization are pushing the need for graphite as a key component in clean energy technologies, including LIBs, fuel cells, and supercapacitors. High-purity graphite thus presents a strategic material in the transition to a low-carbon economy, emphasizing the need for scalable and economically viable purification techniques [3].

Ukraine has one of the largest graphite deposits in Europe, notably the Zavallivske deposit, and has the potential to become a significant supplier of high-quality graphite to the global market. However, technological limitations in the extraction and purification processes restrict Ukrainian industries from achieving the levels of purity demanded by the energy storage sector. This paper aims to explore the future of natural graphite as a high-tech material for energy applications, focusing on novel purification methods that could enable Ukraine to compete in the global graphite market [4,5].

### **Analysis and Discussion**

High-purity graphite has become increasingly critical in modern energy applications due to its unique physical and chemical properties. In particular, lithium-ion batteries (LIBs), which are essential for electric vehicles (EVs), renewable energy storage systems, and portable electronic devices, rely on high-purity graphite as a primary anode material. The electrochemical stability, high conductivity, and mechanical strength of graphite make it ideal for high-energy and high-power applications, where purity levels of over 99.95% carbon content are often required to ensure performance, longevity, and safety of energy storage systems.

In LIBs, high-purity graphite is used as an anode material because of its exceptional ability to undergo lithium-ion intercalation: a process where lithium ions move between layers of graphite during charge and discharge cycles. This intercalation process depends on the high structural integrity and low impurity content of graphite to maintain efficiency and prevent performance degradation over time. Impurities in graphite can lead to undesired side reactions, impacting

battery capacity, increasing resistance, and shortening battery lifespan. Thus, achieving ultra-pure graphite is essential for optimizing LIB performance, especially in high-energy applications such as EVs, where demand for longer-lasting and safer batteries is rapidly growing.

High-purity graphite has become increasingly critical for other applications such as:

### ***Applications in Fuel Cells and Hydrogen Storage***

Beyond LIBs, high-purity graphite is also crucial in fuel cells, where it acts as both a conductive and a supportive structure in proton exchange membrane (PEM) fuel cells. In these cells, graphite serves as bipolar plates that facilitate the flow of electrons and gases across the cell while providing mechanical stability. The high conductivity and corrosion resistance of graphite are necessary to sustain the harsh environments of PEM fuel cells. Additionally, the demand for hydrogen storage solutions is driving research into advanced materials, and high-purity graphite is a potential candidate for adsorbing and storing hydrogen, especially in the form of graphene or nano-structured graphite.

### ***Supercapacitors and Emerging Energy Storage Technologies***

Supercapacitors, which require materials with high surface area and conductivity, also benefit from high-purity graphite. Unlike batteries, supercapacitors can store and deliver energy at much faster rates, making them ideal for applications that demand rapid charge and discharge cycles. The purity of graphite impacts the performance of supercapacitors by influencing the specific capacitance and rate capability. Emerging energy storage technologies, such as hybrid capacitors and solid-state batteries, are also exploring high-purity graphite for its adaptability and compatibility with different electrolytes and charging methods.

### ***Importance in Thermal Management and Conductivity Applications***

High-purity graphite's exceptional thermal conductivity makes it valuable for managing heat in electronic devices, solar panels, and high-power electronics. The demand for efficient heat dissipation materials has increased with the rise of

high-density electronics, where overheating can cause performance issues and reduce device lifespan. Graphite's thermal conductivity helps maintain stable temperatures, while its low coefficient of thermal expansion reduces stress on materials that undergo temperature fluctuations. In energy applications, these properties are vital to ensure the longevity and efficiency of systems where consistent thermal management is crucial, such as power inverters in solar energy systems.

### ***Challenges in Graphite Purification***

Traditional purification methods, including mechanical, thermal, and physicochemical treatments, each come with limitations:

#### ***Mechanical Purification:***

Mechanical purification methods are straightforward and low-cost but are generally ineffective for achieving high purity as they fail to remove fine impurities.

#### ***Thermal Purification:***

Thermal purification, which involves heating graphite to extremely high temperatures (over 2400°C), can remove certain impurities. However, this process is energy-intensive and risks altering the graphite structure, making it less suitable for LIB applications.

#### ***Physicochemical Methods:***

Physicochemical methods, such as flotation and electrolysis, combine physical and chemical treatments to improve purity. Although these methods can increase purity, they do not meet the standards required for LIB-grade graphite.

#### ***Chemical Purification:***

Chemical methods involving acid and alkaline treatments are currently the most effective for achieving high-purity graphite. Alkaline treatments effectively remove silicate impurities, while acid treatments eliminate residual contaminants, achieving up to 99,98 % purity when used in combination.

Researchers at the Kyiv National University of Technologies and Design (KNUTD) have developed an innovative one-stage chemical purification method under the Horizon Europe project GR4FITE3. This technique utilizes diluted sulfuric acid solutions with ammonium fluoride to achieve efficient and cost-effective purification. The method includes several key stages:

1. Sample preparation. Graphite samples, with initial purity levels ranging from 92% to 99%, are treated with sulfuric acid solutions (1,0–5,0 M) containing ammonium fluoride in concentrations from 0,01 to 1,00 M.

2. Chemical Treatment. The purification process is conducted at temperatures between 60–80 °C for 30–120 minutes, which facilitates the optimal removal of impurities.

3. Post-Treatment Processing. After chemical treatment, the graphite samples are rinsed with distilled water to achieve a neutral pH, followed by drying at 105°C to remove any residual moisture.

The experimental process demonstrated a substantial improvement in graphite purity following chemical treatment. Table 1 shows the purity levels of graphite samples treated with sulfuric acid and ammonium fluoride, highlighting the effectiveness of the proposed method. For example, the GUPG-92 graphite sample, treated with a 40 % sulfuric acid solution and ammonium fluoride, achieved a final carbon content of 99,56 %. A second purification step may be necessary for graphite samples with high ash content, such as GUP-92 and GEO-94. In contrast, the GAK-2 graphite sample, treated with a 20% sulfuric acid solution and ammonium fluoride, reached a final carbon content of 99,98%.

**Table 1** – Purity Levels of Graphite Samples After Chemical Treatment

<b>Graphite Grade</b>	<b>Acid Solution Composition</b>	<b>Carbon Content Before Purification (%)</b>	<b>Carbon Content After Purification (%)</b>
GUPG-92	H <sub>2</sub> SO <sub>4</sub> (40%), NH <sub>4</sub> F	92.67	99.56
GEO-94	H <sub>2</sub> SO <sub>4</sub> (40%), NH <sub>4</sub> F	94.46	99.60
GAK-2	H <sub>2</sub> SO <sub>4</sub> (20%), NH <sub>4</sub> F	99.19	99.98

The obtained results showed that after chemical purification with sulfuric acid solutions, GAK-2 graphite achieved a purity level that meets the requirements for use as an anode material in lithium-ion batteries (LIBs).

### **Conclusion**

The growing demand for high-purity graphite in the energy sector requires efficient and cost-effective purification techniques. With substantial natural graphite reserves, Ukraine is well-positioned to benefit from advancements in graphite production. Techniques based on chemical purification processes, such as sulfuric acid and ammonium fluoride treatments proposed by the KNUTD research team, enable the production of graphite with 99,98 % carbon purity, meeting the stringent requirements for LIBs and other energy applications. By advancing graphite purification technologies, Ukraine could emerge as a key player in the global energy materials market, contributing to the sustainable growth of the energy storage industry.

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