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SILICON AND BEYOND: UNVEILING THE HIDDEN ELEMENTS POWERING MODERN TECHNOLOGY

Odoh B. I.[1], and Ezealaji I. P.[2*]

[1]Department of Geophysics, Faculty of Physical Sciences, Nnamdi Azikiwe University, Awka, Nigeria.
email: bi.odoh@unizik.edu.ng

[2]Department of Geological Sciences, Faculty of Physical Sciences, Nnamdi Azikiwe University, Awka, Nigeria.
Email: ip.ezealaji@unizik.edu.ng; Tel.: +234(0)7067060280

[*]Corresponding Author's Email: ip.ezealaji@unizik.edu.ng

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ABSTRACT: *In today's rapidly evolving technological landscape, silicon may dominate the conversation, but the true story of modern technology is far more complex. Behind every smartphone, electric vehicle, and renewable energy system lies a network of critical elements—lithium, cobalt, rare earth elements, and so forth—that are just as essential as silicon in driving innovation. These materials form the backbone of modern devices, but their extraction, availability, and environmental impacts present significant challenges. This article delves into the critical roles these elements play, examining their unique properties, applications, and the geopolitical and ethical considerations surrounding their acquisition. Through a detailed exploration of current research and case studies, we uncover the often-overlooked building blocks of the digital age and highlight pathways toward sustainable sourcing and recycling.*

KEYWORDS: Technology, Battery, Semiconductor, Electric vehicles, Cobalt, Lithium, Rare earth metals.

INTRODUCTION

Silicon has long been heralded as the cornerstone of the digital revolution, powering the devices and systems that define contemporary life. Yet, as we continue to push the boundaries of technology, it is becoming increasingly clear that silicon is only part of the story. The digital era is built on a complex array of elements, each contributing uniquely to the devices that power our world. In this article, we explore the essential elements driving modern technology, from lithium and cobalt in batteries to rare earth elements in magnets, and examine the challenges and opportunities associated with their extraction and use.

The Central Role of Silicon

Silicon remains fundamental to modern technology, particularly in semiconductors, where its properties make it ideal for use in integrated circuits and transistors. Semiconductors are the heart of computers, smartphones, and a wide array of other devices. According to the Semiconductor Industry Association, the global semiconductor market was valued at over $439 billion in 2020, with silicon chips accounting for the majority of this market. Silicon's dominance, however, has limitations, particularly as we seek to develop more advanced and efficient technologies.

Beyond Silicon: The Elements Shaping Modern Innovation

A. Lithium: The Power Behind the Battery Revolution

Lithium, often referred to as "white gold," is indispensable in modern energy storage solutions, especially in lithium-ion batteries that power everything from smartphones to electric vehicles (EVs). The global lithium market was valued at approximately $4.3 billion in 2020 and is expected to grow at a compound annual growth rate (CAGR) of 14.8% from 2021 to 2028. The demand for lithium is driven primarily by the rise of EVs, with electric vehicle sales projected to increase from 3.1 million in 2020 to 14 million by 2025. However, lithium mining, particularly in regions like the Atacama Desert in Chile, has raised significant environmental concerns due to water scarcity and habitat disruption.

B. Cobalt: A Critical Component in Battery Technology

Cobalt is another essential element in battery technology, particularly in cathodes for lithium-ion batteries, which provide higher energy density and stability. In 2020, over 70% of the world's cobalt production came from the Democratic Republic of Congo (DRC), where mining conditions have sparked significant ethical concerns, including child labor and human rights abuses. Companies like Tesla and Apple have been under pressure to ensure ethically sourced cobalt, with initiatives such as the Fair Cobalt Alliance aiming to improve conditions in the DRC.

C. Rare Earth Elements: The Backbone of Modern Electronics

Rare earth elements (REEs) are vital in high-tech applications, from electric vehicles to smartphones. Despite their abundance, REEs are difficult and costly to extract and process. China currently controls over 80% of the global REE supply, leading to geopolitical tensions, especially as demand increases for green technologies like wind turbines and electric vehicles.

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The U.S. Department of Energy has identified rare earth elements as critical to national security, emphasizing the need for domestic production and recycling.

D. Graphite: The Unsung Hero of Modern Batteries

While lithium and cobalt often dominate discussions, graphite is just as critical, particularly in the anodes of lithium-ion batteries. The global graphite market was valued at $14.3 billion in 2020 and is expected to grow at a CAGR of 4.8% from 2021 to 2028. However, like other materials, graphite extraction poses environmental challenges, particularly in China, which dominates global production.

Technological Advancements and the Role of Essential Elements

A. Electric Vehicles (EVs) and Renewable Energy

Electric vehicles and renewable energy technologies are driving significant demand for critical materials. According to the International Energy Agency (IEA), the demand for lithium and cobalt could increase by 40 and 20 times, respectively, by 2040 if the world transitions to net-zero emissions. This surge in demand presents both opportunities and challenges, particularly in ensuring sustainable sourcing and reducing the environmental impacts of mining.

B. 5G and Telecommunications

The rollout of 5G networks relies heavily on rare earth elements, particularly for high-frequency antennas and capacitors. The global 5G infrastructure market is expected to grow from $8 billion in 2020 to over $200 billion by 2026, driving increased demand for materials like neodymium and tantalum. Ensuring a stable supply of these materials will be critical to the successful deployment of 5G technology.

C. Medical Devices and Advanced Technologies

The medical field also relies heavily on essential elements, from cobalt in medical implants to rare earth elements in imaging equipment. The global medical device market was valued at $457 billion in 2020, and as technology advances, the demand for these critical materials is expected to grow .

1. Ethical and Environmental Implications

The extraction and use of essential elements in technology present significant ethical and environmental challenges. From the human rights issues in cobalt mining to the environmental degradation caused by lithium extraction, there is a growing need for more sustainable and ethical practices in the sourcing of these materials. Companies are increasingly turning to recycling and alternative materials to mitigate these impacts. For example, the European Union has set ambitious targets to recycle 95% of cobalt and lithium from used batteries by 2030.

2. Future Directions: Toward Sustainable and Ethical Sourcing

As technology continues to evolve, the demand for critical materials will only increase. To meet this demand sustainably, the industry must focus on several key areas:

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1. Recycling and Circular Economy: Increasing the recycling of critical materials can reduce reliance on mining and mitigate environmental impacts. For instance, researchers are developing new methods to extract lithium and cobalt from used batteries more efficiently.

2. Ethical Sourcing: Ensuring that materials are sourced ethically is crucial, particularly in regions like the DRC. Initiatives like the Fair Cobalt Alliance and blockchain-based supply chain tracking can help improve transparency and conditions in mining.

3. Alternative Materials: Research into alternative materials that can replace critical elements like cobalt and rare earth elements is ongoing. For example, solid-state batteries and silicon anodes offer potential alternatives to current lithium-ion technology.

CONCLUSION

The future of modern technology is inextricably linked to the availability and sustainability of essential elements. While silicon remains at the core, elements like lithium, cobalt, and rare earth elements play equally vital roles in shaping our technological landscape. As demand for these materials continues to grow, addressing the ethical and environmental challenges associated with their extraction and use will be critical. By focusing on sustainable sourcing, recycling, and the development of alternative materials, we can ensure that technology continues to advance while minimizing its impact on the planet.

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