Reimagining the Coal Industry through Carbon Dots

By Gaurav Roy ⋮⋮ 1/10/2024

In Dec. 2023, 198 signatory countries at the Conference of Parties (COP) collectively agreed that the world must “transition” away from fossil fuels like coal in a “just, orderly, and equitable manner” in order to cut greenhouse gas emissions to nearly zero by 2050. However, there are no timelines yet, so fossil fuels are going to be the pillar of economies everywhere in the years to come.

Coal is the world's most dominant and most carbon-intensive source of energy. Four main types of coal include:

(i) Anthracite
(ii) Bituminous
(iii) Subbituminous
(iv) Lignite

This fossil fuel accounts for more than 37% of the global electricity supply, playing a fundamental role in powering homes and industries and alleviating the world's energy poverty. Even today, about 860 million

people across the globe live without access to electricity. As such, modern life is simply unimaginable without coal.

Global coal usage actually reached a record high in 2023 as demand for the fossil fuel increased 1.4% in the year to exceed 8.5 billion metric tons for the first time, reported the International Energy Agency (IEA). Its global consumption is forecast to remain well over 8 billion metric tons in 2026.

Coal is an essential resource for tackling the challenge of rapidly increasing energy consumption due to being significantly cheaper and more accessible than other fossil fuels. Unlike oil and gas, it can be found in abundance all over the world.

The thing with coal is it does not require high-pressure pipelines, costly processing, or expensive protection during transport, making it easier to store and transport than other highly flammable fossil fuels. Also, before it is used, coal only needs to be mined, unlike other fossil fuels, which require a lengthy and costly refining process.

Not to mention, coal reserves are distributed a lot more equally around the planet. As of Jan. 2020, the US has the world's largest coal reserves, constituting nearly 90% of all fossil fuel reserves, with an estimated 250 billion tons.

Besides being cheaper and accessible, coal is also very versatile and can be used in a range of processes. Coal is primarily used for power generation worldwide and is actually an affordable form of energy, with electricity generated by coal being less expensive than electricity generated by other sources.

Even in the US, coal is used to produce electricity by burning the fossil fuel in power plants. The resulting heat from that is used to change water into high-pressure steam, which drives a turbine, which then produces electricity. In 2019, about 23% of all electricity in the US was generated by coal-fired power plants, as per the US Energy Information Administration.

This fossil fuel is also used for producing steel and concrete and is a core component in iron making, as well as other metals like aluminum and copper. Coal and its by-products are further used in water filters and air purification systems, in the construction of airplanes and automobiles, in medicines, and in chemical processes to extract rare earth elements.

Then there are gasification and liquefaction use cases of coal, with the majority of coal-to-gas projects located in the USA and China, with a few in Australia, Canada, India, South Africa, and Indonesia. In addition to producing chemical building blocks, such as ammonia, methanol, and urea, coal is also used in the paper, textile, and glass industries. Along with the manufacture of carbon fiber, it provides ingredients like silicon metals, which are used to produce components for the personal care and household sectors.

Despite coal's abundance, affordability, and reliability, the industry faces challenges in the form of developing technologies and pathways to zero emissions, which is identified as a factor in climate change.

Click here to learn if prevention or treatment is the way to tackle atmospheric CO2.

Reevaluating Coal's Economic Role

As countries around the world pledge to transition to other means of energy production due to their contribution to climate change, researchers and scientists are looking at other ways to utilize coal.

To reevaluate the fossil fuel's economic role, the Taiwan Semiconductor Manufacturing Company, the National Energy Technology Laboratory, the University of Illinois Urbana-Champaign, and Oak Ridge National Laboratory came together for a joint research effort and demonstrate the critical role coal can play in next-generation electronic devices.

In recent years, a lot of research has been happening in the field of 2D materials due to their electrical, optical, and mechanical properties. The synthesis of a range of atomically thin 2D materials opens a new platform for layer-by-layer materials that enable the exploration of unknown properties, promising a range of new technologies.

2D layered semiconductors possess features like high mobility, low-power switching, relatively large bandgap, and the availability of large-area growth methods, which makes them a promising candidate for the next generation of electronics. Now, coal is being experimented with for usage in such electronics.

> “Coal is usually thought of as something bulky and dirty, but the processing techniques we've developed can transform it into high-purity materials just a couple of atoms thick.”

– said Qing Cao, a U. of I. materials science & engineering professor who co-led the effort.

He also noted:

> “Their unique atomic structures and properties are ideal for making some of the smallest possible electronics with performance superior to the state of the art.”

Under this collaboration, the researchers developed a process that converted coal char into extremely small carbon disks, which are called “carbon dots.”

As shown by the research group, these nanoscale carbon disks can be connected to create atomically thin membranes. These membranes can be used for applications in technologies like two-dimensional (2D) transistors and memristors. According to researchers, these technologies will be critical in constructing more efficient electronics.

While carbon-based materials, whether it's traditional industrial carbon like carbon black or new industrial carbon like graphite and carbon fibers, play significant roles in the development of material science, macroscopic carbon material can't really be used as an effective fluorescent material due to a lack of the appropriate band gap. This is where carbon dots (CDs) have emerged as a promising solution.

Carbon dots or CDs are a new type of carbon-based nanomaterial that have garnered much attention and research interest due to their diverse physicochemical properties. Carbon dots are meticulously formulated and usually smaller than 10 nm in size. This carbon-based nanomaterial has features like small size, ecofriendliness, low cost, low toxicity, high stability, good biocompatibility, electron mobility, high quantum

yield, abundant functional groups, and unique optical properties, including strong absorption, photoluminescence, and phosphorescence.

All of these qualities make this new material in the carbon family so popular and have many applications. This includes:

- Sensors
- Information encryption
- Photocatalysis
- Light-emitting diodes
- Chemical sensing
- Solar cells
- Supercapacitors
- Rechargeable batteries
- Bioimaging
- Phototherapy
- Gene delivery
- Drudge delivery
- Explosive detection
- Nanomedicine
- Food safety
- Anticounterfeiting

Learn how methane may be the key to meeting climate goals.

Coal to Play a Vital Role in Next-generation Electronics

Researchers and scientists around the world have been working on making smaller, faster, and more advanced electronics. This means devices made with materials that are only one or two atoms thick operate much more quickly and consume far less energy.

Towards these devices, a lot of studies have been done regarding ultrathin semiconductors, but now there needs to be extensive research done on atomically thin insulators in order to construct working electronic devices like transistors and memristors.

When it comes to materials, they are divided into conductors, semiconductors, and insulators based on their ability to conduct an electric current. Materials like copper, brass, steel, gold, and aluminum that easily conduct electricity due to low electrical resistivity are called conductors.

Insulators are materials such as glass, air, wood, plastic, and rubber, which do not readily conduct electricity. Meanwhile, materials like silicon (Si), germanium (Ge), and selenium (Se), as well as compounds like gallium arsenide (GaAs) and indium antimonide (InSb), have an electrical conductivity value that falls between that of a conductor and an insulator.

A semiconductor's resistance falls as its temperature rises, while the conductivity of a semiconductor rises as the temperature increases.

Insulators have a wide range of applications, including wall insulation to regulate the heat flow, furnace insulation for thermal and dielectric barriers, sound insulation to prevent disturbances, and electrical insulation in household circuitry and capacitors in commercial and consumer goods. Semiconductors are also all around us, such as tiny transistors that are in almost every gadget we use and solar cells used in solar panels to turn sunlight into electricity.

In insulators, the energy gap between valence and conduction bands is very large (about 15 eV) while in a semiconductor, this gap is very small (about 1 eV).

As per the latest study, atomically thin layers of carbon with disordered atomic structures can function as an excellent insulator for constructing 2D devices, which the team created from coal char-derived carbon dots.

Now, to show the potential of coal-derived carbon layers, the researchers used them as the gate dielectric in 2D transistors. Built on semiconductor molybdenum disulfide, the team created a device operating speed over two times faster with lower energy consumption.

These coal-derived carbon layers do not have “dangling bonds,” which are abundant on conventional 3D insulators' surfaces. By effectively functioning as “traps,” they alter 3D insulators' electrical properties, slowing down the transport of mobile charges resulting in the transistor switching speed.

However, the new coal-derived carbon layers, unlike other atomically thin materials, are amorphous, and the undesired electrical currents flow through the insulator, leading to substantial additional power consumption during device operations. Mr Qing Cao said:

> “It's really quite exciting, because this is the first time that coal, something we normally see as low-tech, has been directly linked to the cutting edge of microelectronics.”

Yet another application demonstrated by the researchers is memristors, electronic components that can store and operate on data, significantly improving the implementation of Artificial Intelligence (AI). These devices store and represent data by modulating a conductive filament.

By using carbon layers that are ultrathin as the insulator, the researchers were able to have the fast formation of such filament with low energy consumption that enabled the device to operate at high speed with low power. Additionally, atomic size rings in these coal-derived carbon layers trap the filament to improve the reproducible device operations for more data storage reliability.

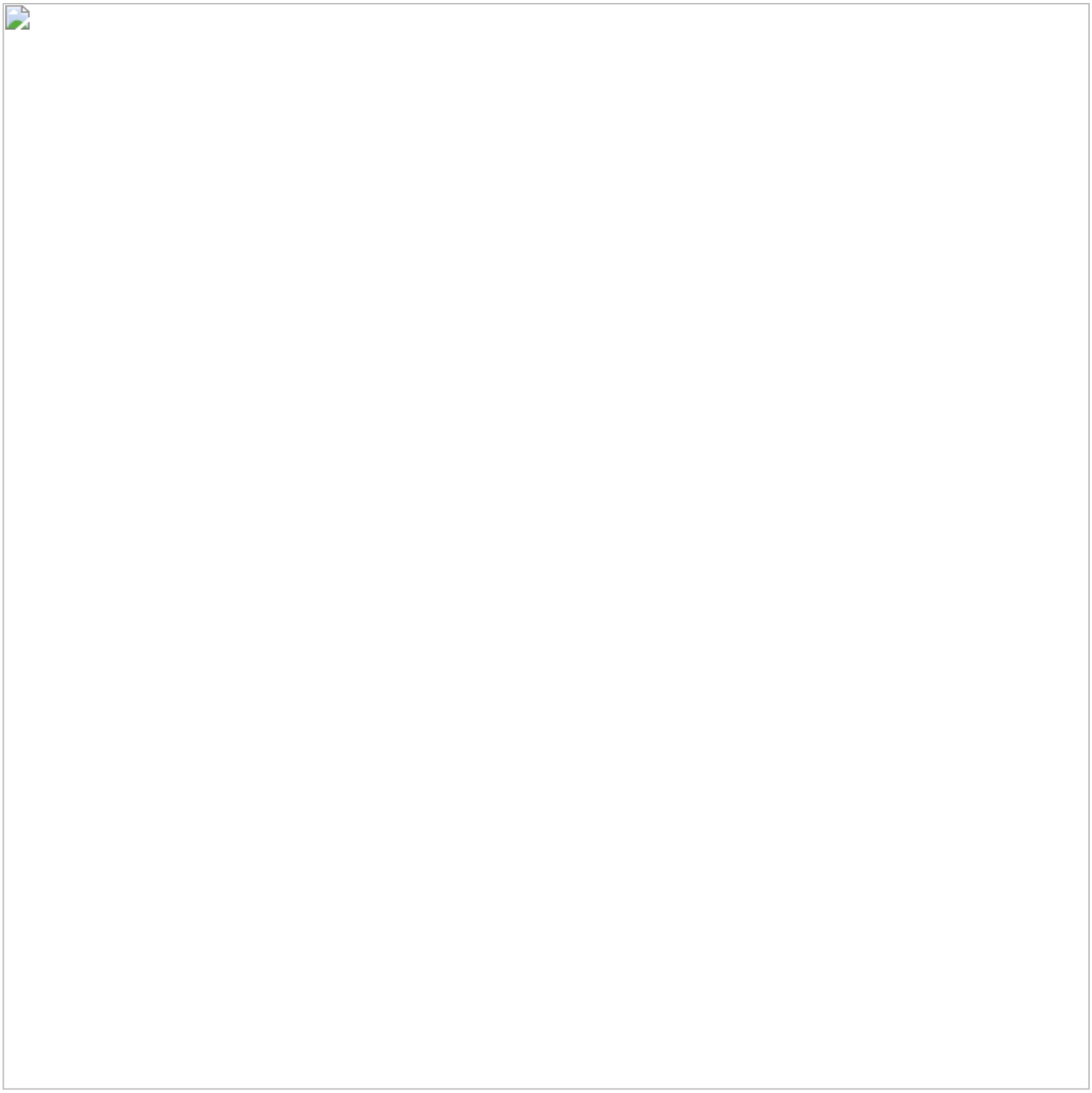
These new devices demonstrate that coal char-derived carbon layers can be used in 2D devices. In the next step, the collaborative effort will move towards developing a “fabrication process for coal-based carbon insulators” that can be applied on a large scale.

Leveraging the New Approach

While the world is transitioning away from carbon due to an increasing focus on cutting down greenhouse gas emissions, the ongoing research in the industry to reassess carbon can see different industries, such as semiconductor manufacturers, leverage its new forms in the future. So, let's take a look at some of the companies that can adopt such approaches.

Taiwan Semiconductor Manufacturing

This is the world's largest chip manufacturer that utilizes the most advanced process technologies in the industry. Taiwan Semiconductor Manufacturing Co. is known for serving the needs of many high-profile clients, including NVIDIA, AMD, Intel, and Apple. The company's product application range covers the broad electric industry, and it has been slowly expanding all over the world with factories spread over three continents.



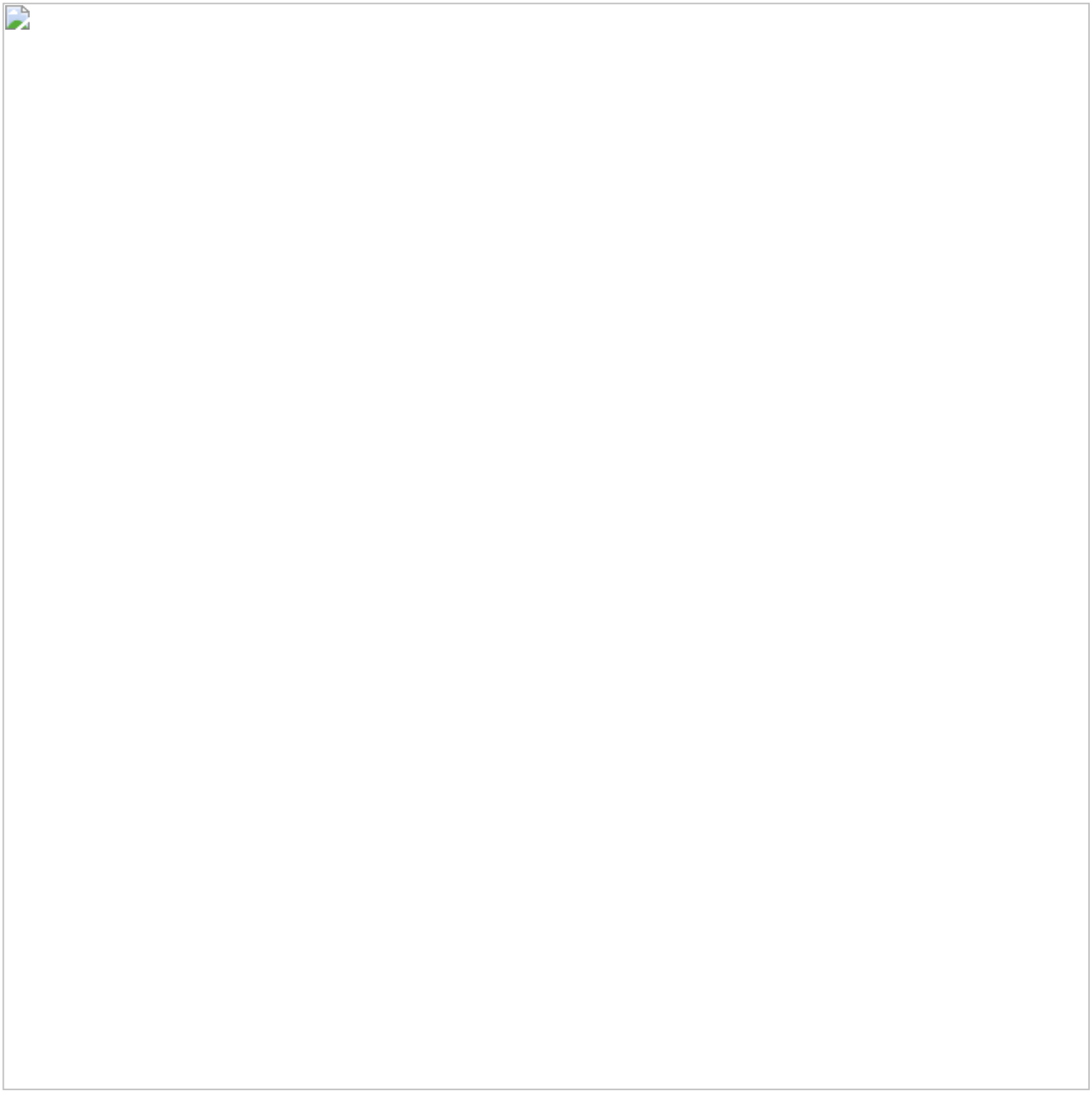
With a market cap of $530.26 billion, TSM shares are currently trading at $101.40, down 1.69% year-to-date (YTD). The company posted a revenue trailing twelve months (TTM) of $69.84 bln while having EPS (TTM) of 5.36, P/E (TTM) of 19.08, and ROE (TTM) of 29.43%. Taiwan Semiconductor Manufacturing also pays a dividend yield of 1.88%.

NVIDIA Corporation

This company develops hardware and software for gaming, laptops, data centers, and apps and is specifically known for creating graphics processing units (GPUs) for a variety of applications, including games, crypto

mining, and AI.

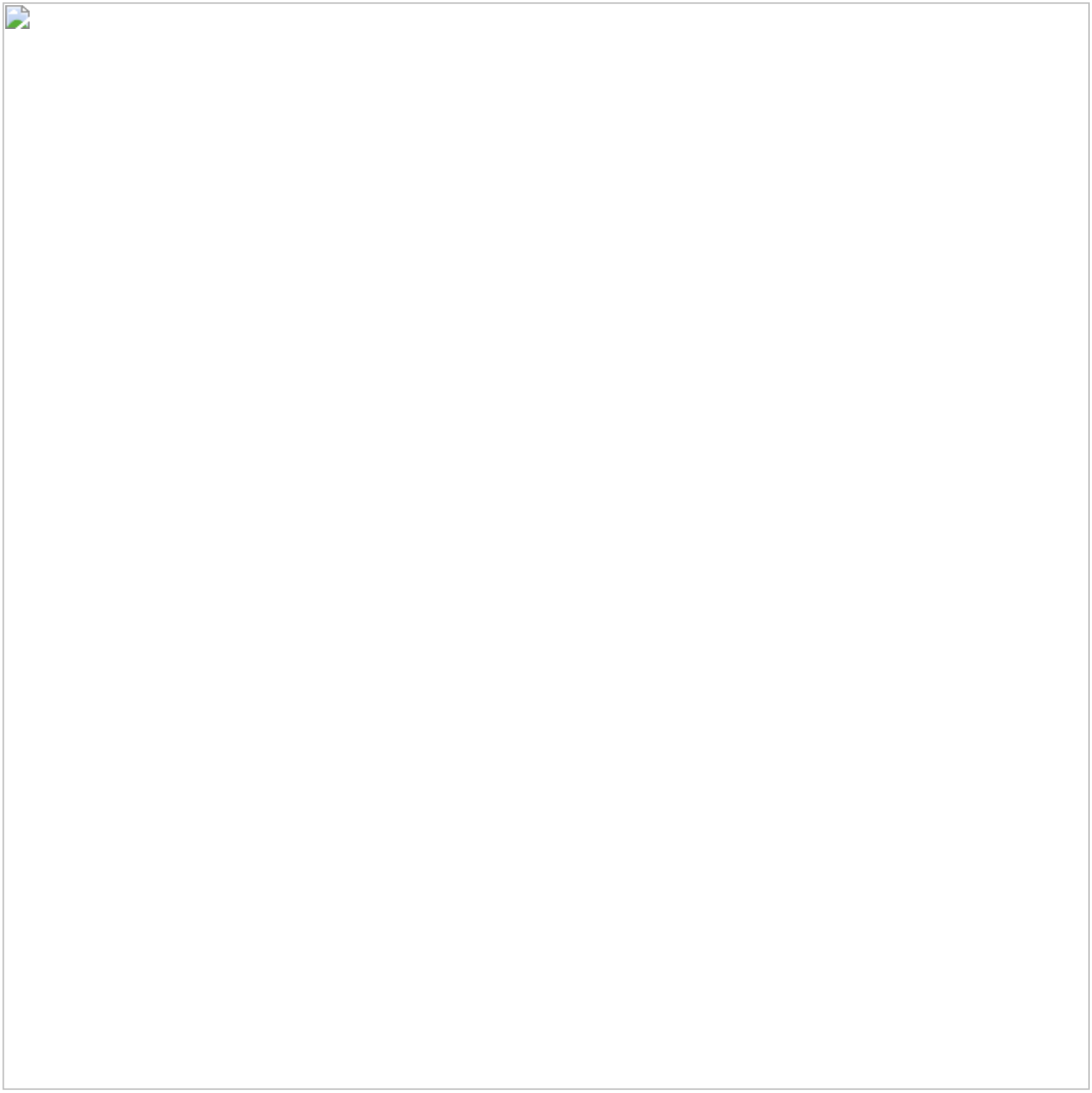
Most recently, Nvidia unveiled its new desktop graphics processor, the GeForce RTX 40 SUPER Series, for video game enthusiasts as well as to run AI applications locally. Nvidia is also expanding its reach in China's EV sector as it announced that four Chinese EV brands will use its technology for automated driving systems.



With a market cap of $1.29 trillion, NVDA shares are currently trading at $522.58, up 5.5% year-to-date (YTD). The company posted a revenue trailing twelve months (TTM) of $44.87 bln while having EPS (TTM) of 7.57, P/E (TTM) of 68.99, and ROE (TTM) of 69.17%. Nvidia also pays a dividend yield of 0.03%.

Advanced Micro Devices, Inc.

This CPU and GPU designer is one of the biggest chip companies that recently announced the Ryzen 8000G series, headlined by the Ryzen 7 8700G, which AMD says features the fastest integrated graphics accelerator. Meanwhile, Advanced Micro Devices' latest GPU, the Radeon series, caters to the lower and middle end of the gamer market.



With a market cap of $236.154 billion, AMD shares are currently trading at $145.21, down 0.83% year-to-date (YTD). The company posted a revenue trailing twelve months (TTM) of $22.11 bln while having EPS (TTM) of

0.13, P/E (TTM) of 1,152.84, and ROE (TTM) of 0.38%.

Conclusion

So, as we can see, the coal industry is being transformed with scientists and researchers working on revealing its value and the role it serves by creating carbon dots that showcase some unique properties that can make them really useful in the next generation of electronic devices. This way, the coal industry can help shape the future of electronic technologies in a sustainable manner.

Related Topics:

Don't Miss

2024 and Beyond – Which Sectors are Primed to Evolve Most?

Gaurav Roy

Gaurav started trading cryptocurrencies in 2017 and has fallen in love with the crypto space ever since. His interest in everything crypto turned him into a writer specializing in cryptocurrencies and blockchain. Soon he found himself working with crypto companies and media outlets. He is also a big-time Batman fan.