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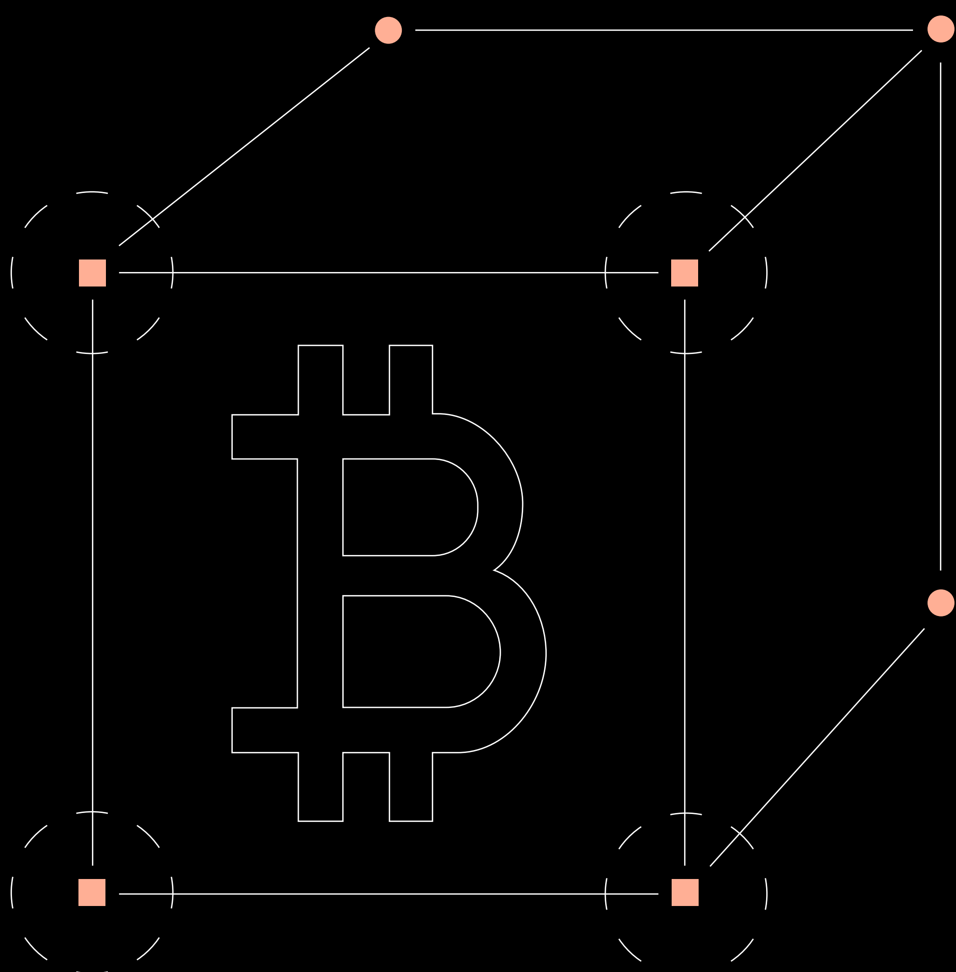
Galaxy Research

# Bitcoin Mining & Energy

## A Symbiotic Relationship

JULY 2024



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This report is a product of Galaxy Research, a research organization within Galaxy, the leading provider of financial services in the digital assets, cryptocurrency, and blockchain technology sector. Galaxy Research provides top-tier market commentary, thematic views, tactical insights, and deep protocol research.

This report was written June 2024.

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# Contents

# Introduction

Bitcoin is many things: a non-sovereign monetary asset, a peer-to-peer computer network, and a decentralized software platform. Regardless of how one views Bitcoin or through which lens one believes Bitcoin should be viewed, Bitcoin is powered, secured, and its ledger advanced by computing power. The mitochondria of Bitcoin are **bitcoin miners**, who compete with computation to receive rewards and for the right to advance the ledger by appending new blocks of transactions. Miners deploy vast amounts of computational resources in a system that is both self-interested and serves the broader collective network, competing with one another to deliver valid proof of work (PoW) to the network in exchange for the right to grow the blockchain. That computation, and the competition that drives it ever higher, makes Bitcoin a highly secure computer network, but it also draws criticism due to the vast amount of electricity consumption it requires. In this paper, we explain the purpose and mechanism of Bitcoin mining, examine its history and evolution, and explore both the impact and opportunities Bitcoin mining has on and provides to the environment and the world's electrical infrastructure.

# What is Proof of Work (PoW)?

Proof-of-Work (PoW) is the process by which the Bitcoin network reaches consensus on the order of blocks and the transactions within those blocks. In PoW, miners perform computational work to solve a cryptographic puzzle. They compete to be the first to solve the puzzle, which grants them the right to build and propagate a block of transactions. The successful miner for each block earns both a block reward (which halves approximately every four years) and the transaction fees associated with the block. The computational work required to generate a block incentivizes miners to act honestly to earn rewards, while the ease of verifying a block of transactions ensures that invalid blocks are rejected. Hashrate measures the computational power of Bitcoin miners and quantifies the number of attempts a miner (or a network of miners) makes to solve the cryptographic puzzle necessary to add a new block to the Bitcoin blockchain. Hashrate is usually measured in hashes per second (h/s).The computational work required for PoW can be energy intensive, making electricity one of the largest operational expenses for Bitcoin miners. Unlike Proof-of-Stake (PoS) networks, which use capital rather than computation to earn the right to extend the ledger (and thus use considerably less electricity), Bitcoin's PoW mechanism ties its digital nature to a physical work process with physical costs. While factors such as the bitcoin price, machine fleet efficiency, and power hedging are important, minimizing electricity costs is one of the primary ways miners ensure they are mining profitably.

## Differences between PoW & PoS

Participating in Bitcoin's PoW does not require providing any advanced notice to the network and is completely permissionless. Any party can present a valid proof that sufficient work was completed to the decentralized network and earn the right to extend the blockchain (as well as collect any associated rewards or transaction fees), even if that party has never appeared on the network before. This is a crucial difference between PoW systems and PoS systems, which typically require validators to remain active and online within the network, ready to provide a block whenever their proverbial "number is called." Miners in a PoW system cannot be **slashed** for perceived bad behavior; they either present valid work or they do not, while PoS validators can be penalized or ostracized from the network by the protocol or by the other validators through mechanisms such as "social slashing".

# Evolution of Bitcoin Mining

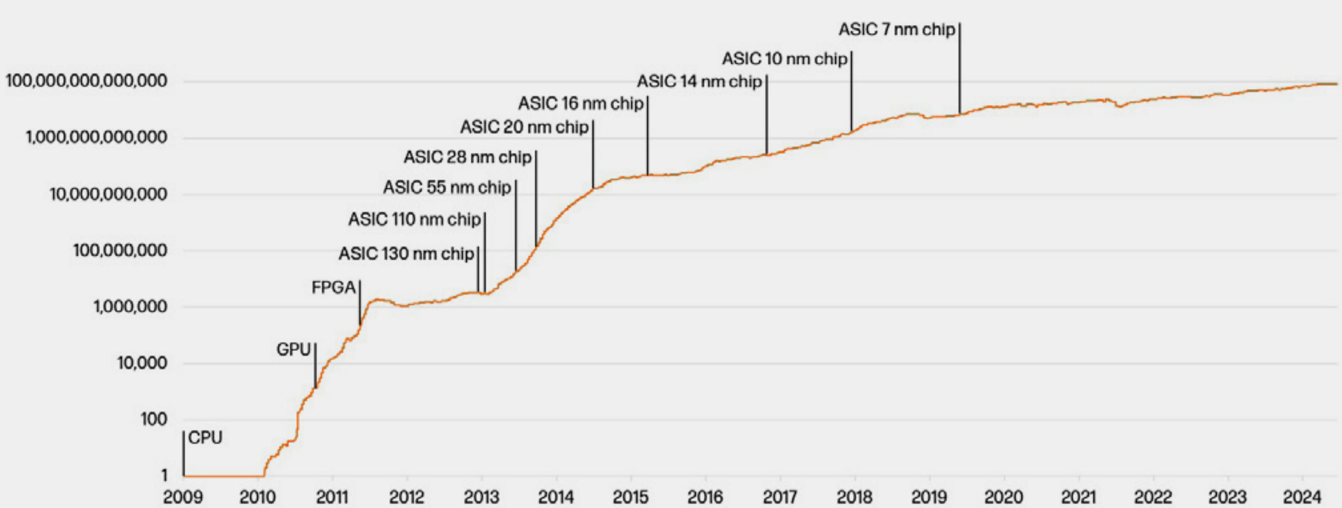
When Satoshi Nakamoto mined the first Bitcoin block ("the Genesis Block") on January 3, 2009, it was done using a common central processing unit (CPU). Bitcoin's mining process is designed to adjust its difficulty such that a new block is found and appended to the chain approximately every 10 minutes. The small number of miners competing meant that the difficulty was very low…so low that it was possible to mine Bitcoin successfully on a common computer. As more participants joined the network to compete for newly minted BTC, Bitcoin mining's difficulty increased, making it impractical to mine on a home computer as the likelihood of submitting valid proof of work before the competition became effectively impossible. Over the years, miners have deployed increasingly sophisticated machinery to mine Bitcoin, exponentially increasing the mining difficulty, as illustrated in the chart below.

- **CPUs (2009-2010):** Bitcoin was first mined using the central processing units (CPUs) found in standard laptops or desktop computers. CPUs are built to handle a wide range of tasks rather than being optimized for a specific one, and so are less efficient at mining bitcoin than purpose-built chips. During this period bitcoin's mining difficulty was very low, making it practical to mine using a CPU.
- **GPUs (2010-2012):** In October 2010 a new mining device leveraging Graphic Processing Units (GPUs) was introduced. GPUs can be better optimized for mining bitcoin because they can compute in parallel. The introduction of GPUs is estimated to have made mining six times more efficient than the existing CPU process.
- **FPGAs (2011-2012):** GPU efficiencies were soon overtaken by Field Programmable Gate Arrays (FPGAs). These chips could be custom designed for bitcoin mining, increasing their efficiency relative to a GPU. A typical FPGA mining setup could offer efficiencies of around 1-2 watts per MH/s, compared to about 10 watts per MH/s for GPUs.
- **ASIC (2013 – Present):** In 2013 the first applications-specific integrated circuits (ASICs) were introduced. ASICs quickly became the dominant form of mining. As the name indicates, ASICs are specifically designed for mining bitcoin and bitcoin only. They provide incredible efficiency gains in return for a more limited scope of what could be achieved.

Over the years, Bitcoin mining operations have become more sophisticated, advancing beyond merely y increasing the efficiency of hashing machines. While early miners were often solo operators using an at-home setup – whether CPUs, GPUs or later FPGAs – today, most miners operate out of large data centers with significant electricity infrastructure. Today, 80% of Bitcoin's hashrate is managed or controlled by 5 mining pools. These pools aggregate hashrate from many mining operations to reduce payout variance, allowing individual operations to realize a more consistent stream of revenue in exchange for their hashrate. The largest mining operations work diligently to secure low-cost electricity, use high-powered mining machines efficiently, carefully manage machine cooling and other local environmental factors, and enact complex energy hedging and curtailment strategies.

**BTC Mining Difficulty**

Source: Galaxy Research




Data: https://www.coindesk.com/tech/2020/04/26/the-rise-of-asics-a-step-by-step-history-of-bitcoin-mining/

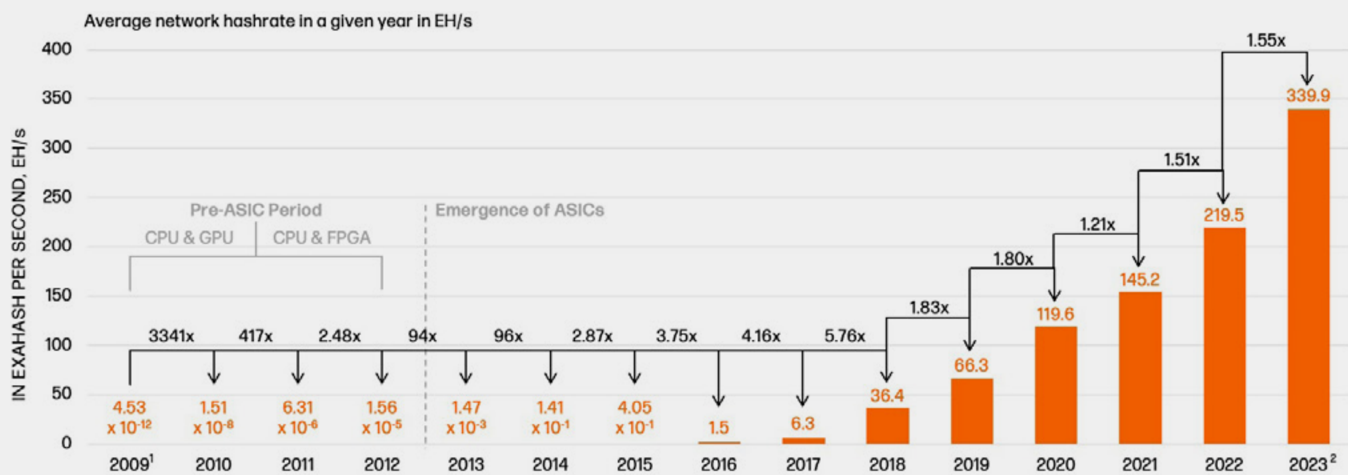
Today, mining operations are primarily large institutional data center businesses that are extremely sensitive to the marginal cost of electricity, incentivizing them to seek out the lowest cost electricity production.

Bitcoin's historical hashrate paints the picture of a network's growth is solely in energy consumption, but this view overlooks the innovation happening across the mining industry. Each transition—to GPUs, then to FPGAs, and finally to ASICs—has been characterized by a substantial increase in computational efficiency. Each new generation of machines can generate more hashes per watt of power consumed than the previous one. For example, Bitmain's latest S21 miner uses 100 times less joules per terahash than the first Bitmain miner introduced in 2013 and 20% less than the prior version introduced in 2022. This efficiency means that electricity consumption doesn't scale linearly with hashrate.

The exponential increase in mining efficiency allows the Bitcoin network to grow in terms of processing power without a proportional increase in energy consumption. This decoupling of growth from energy use is critical in improving Bitcoin's environmental footprint.

## The Historical Development of Bitcoin Network Hashrate

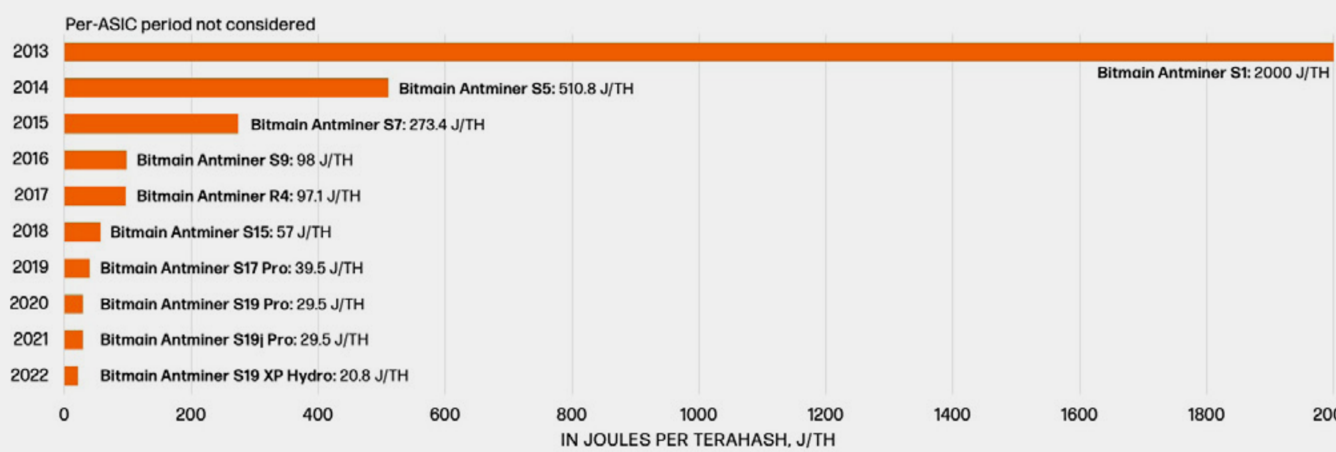
Source: Galaxy Research




Data: https://www.jbs.cam.ac.uk/2023/bitcoin-electricity-consumption/
1. from January 9, 2010
2. until August 15, 2023

## Historical Evolution of Bitcoin Mining Hardware

Source: Galaxy Research




Data: https://www.jbs.cam.ac.uk/2023/bitcoin-electricity-consumption/

# Bitcoin's Electricity Usage

There is no doubt that Bitcoin miners use significant amounts of electricity – indeed, many Bitcoin advocates would call miners' electricity consumption "a feature not a bug." In this section, we will examine the available data on Bitcoin's electricity consumption and consider the extent to which its impact is positive or negative for Bitcoin, electricity infrastructure, and the environment as a whole. For years, Bitcoin's electricity usage has been criticized. Many critics have relied on data from the internet blog *Digiconomist* to argue that Bitcoin mining uses excessive amounts of electricity. This outlet has been widely quoted in the Wall Street Journal, New York Times, and even by the White House and other U.S. government agencies, but its calculation methodology relies heavily on assumptions that have been questioned for their accuracy. Works by this outlet have been used over the years to make the common claims that Bitcoin mining consumes "as much electricity" as various nation states. A groundbreaking paper by former Galaxy Research analyst Karim Helmy and the team at Coin Metrics, *"The Signal and the Nonce"*, utilized a novel method of estimating the market share of various bitcoin mining machines to calculate a more accurate figure for the network's aggregate electricity consumption. Their research found that Digiconomist overstated the network's electricity consumption by more than 2x at some points. Even the Cambridge Centre for Alternative Finance, a widely respected research organization at Cambridge University, has both overstated Bitcoin mining's electricity consumption by 50%, and other times understated it. The point is that estimates have varied widely over time. Until Coin Metrics produced their research, there was no methodology that used on-chain data to generate a bottoms-up estimate based on the machines actually deployed on the network.

While the variance in electricity consumption estimates is due to differences in study methodology, it is undeniable that Bitcoin miners consume a lot of electricity. However, the extent to which this power consumption is good or bad – for the electrical grid and the environment – depends on more than just the **amount** of consumption. Two major factors must be considered: energy source and load flexibility.

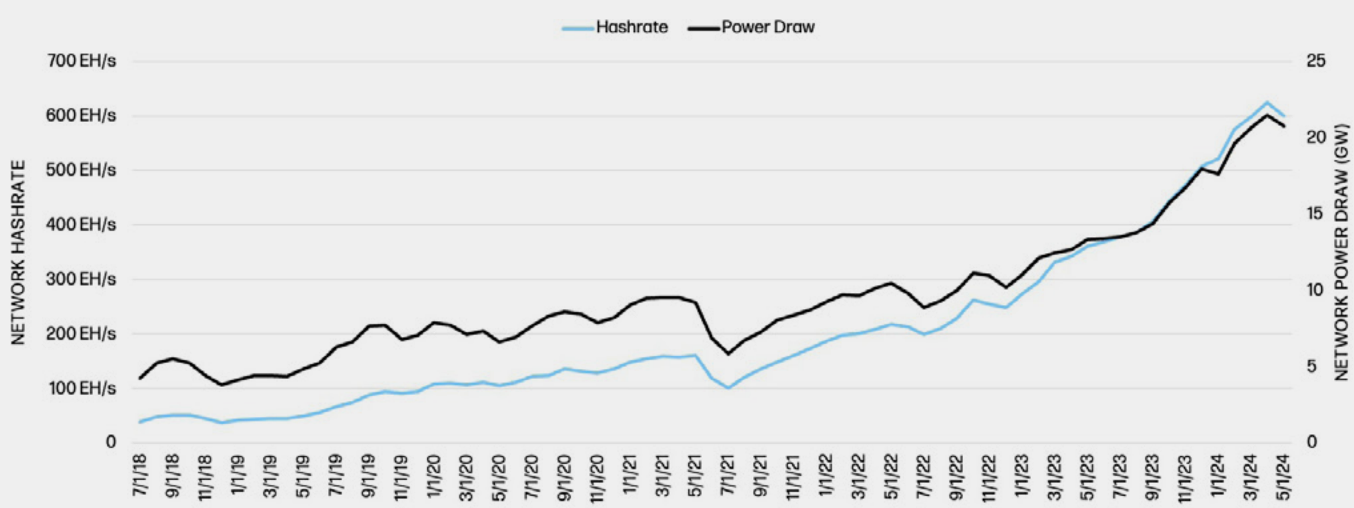
## Low Emissions & Renewable Energy Sources

Bitcoin miners do not have meaningful emissions. They do not typically emit "scope 1 emissions," meaning that mining machines don't emit smoke or carbon; rather, mining operations are more akin to data centers than factories. Claims of miner emissions rely on a form of carbon accounting that attributes the underlying emissions of energy production to the downstream electricity consumers. Bitcoin's global, distributed nature makes it difficult to get granular data on the electricity sources of Bitcoin miners. However, a combination of increased machine efficiency and relocation to regions with substantial renewable electricity generation, such as Texas wind and solar, has resulted in Bitcoin's net Scope 2 emissions being mostly flat for years, despite significant increases in hash rate and Bitcoin price.

Bitcoin miners are clustered in areas with large amounts of renewable energy: Upstate New York (hyrdroelectric), Washington

**Bitcoin Power Draw Estimates**

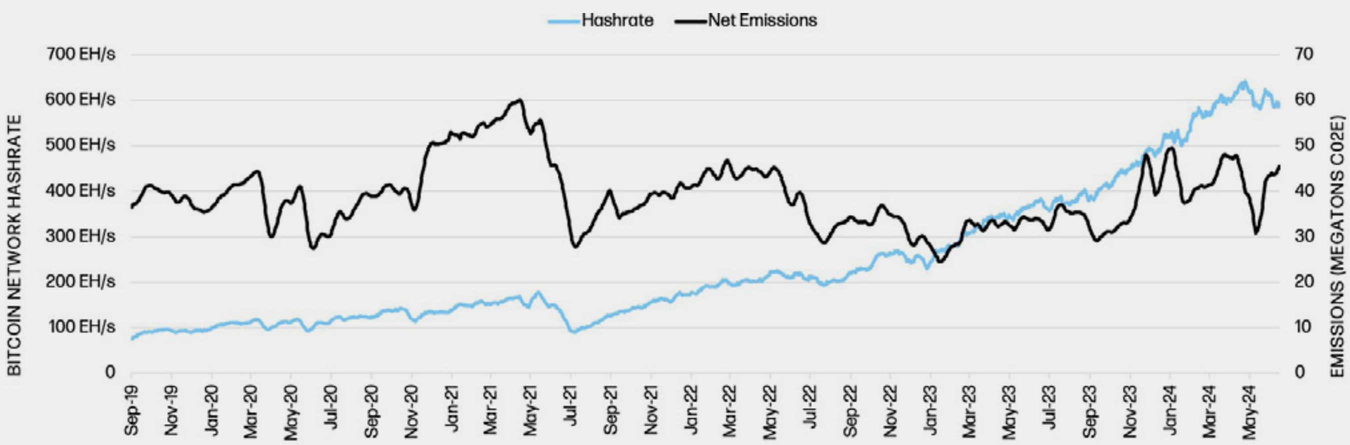
Source: Galaxy Research




Data: *The Signal & The Nonce*, Coin Metrics state (hydroelectric), Texas (wind, solar), and more. Research from Galaxy Mining indicates that Texas alone hosts 22% of the global Bitcoin mining hash rate. Ultimately, miners are economically incentivized to find the lowest cost of power, which typically exists in areas with large amounts of renewable energy penetration.

## Bitcoin Network Hashrate & Net Emissions

Source: Galaxy Research




Data: WooCharts.com

## Location of Bitcoin Miners in the U.S.

Source: Galaxy Research


Data: Company filings & press releases.

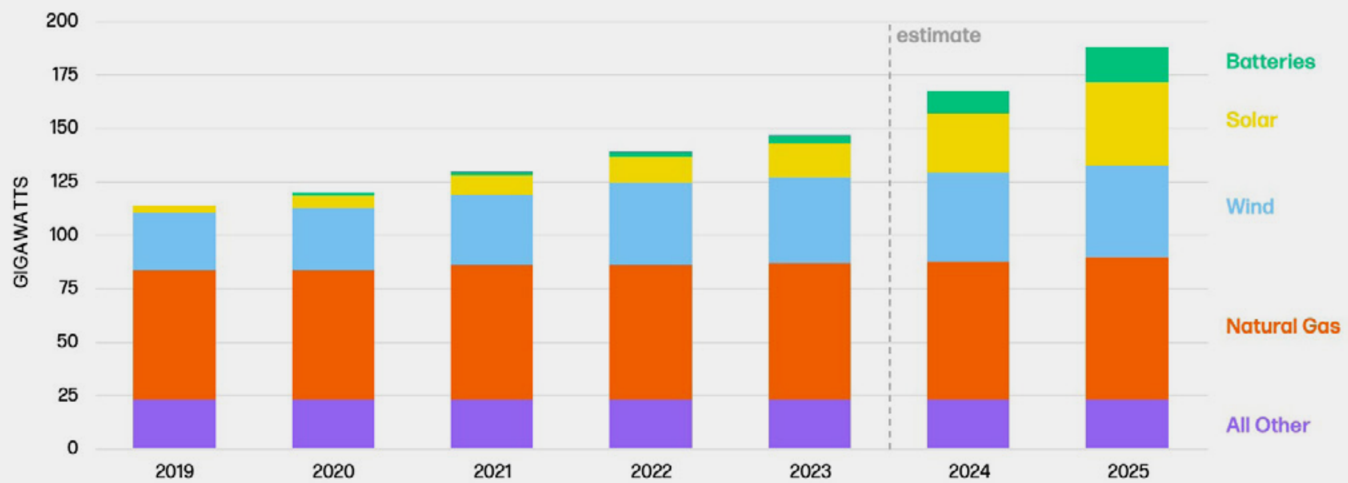
## Spotlight on Texas

Texas is a particularly interesting case study due to its grid being the freest grid market in the world, characterized by dynamic and transparent pricing, and because a substantial portion of its electricity generation comes from renewable energy sources, primarily wind and solar.

By 2025, the Energy Information Administration estimates that more than half of all Texas' electricity generation will be sourced from renewables, as the vast majority of new generation expected to come online over the coming years is wind and solar.

### Annual Texas Electricity Capacity (2019-2025)

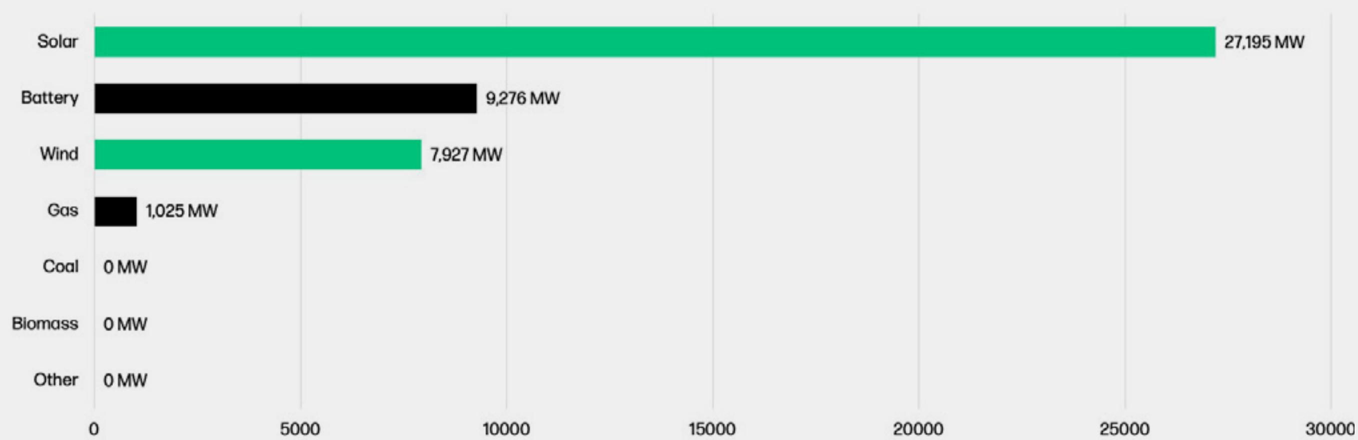
Source: Galaxy Research




Data: U.S. Energy Information Administration, Preliminary Monthly Electric Generator Inventory. Estimates include opertational installed generating capacity and planned capacity additions.

### Future Resource Coming to ERCOT's Power Grid are Primarily Renewable

Source: Galaxy Research




Data: Amelia Winger, Houston Chronicle, ERCOT November 2023 GIS Report.
Includes capacity from generators with completed security screening studies, full interconnection studies and interconnection agreements.

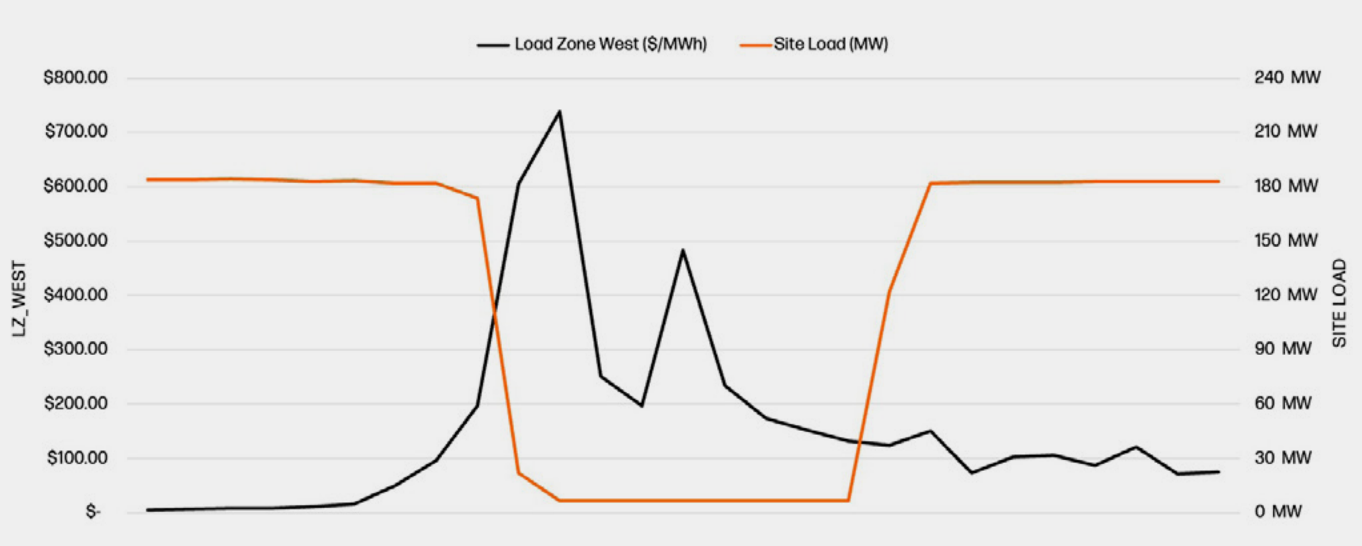
## Flexible Loads Supporting Electrical Grids

Wind and solar have extremely low emissions but they are also intermittent sources of generation. On sunny and windy days in Texas, even if grid demand is high, spot pricing for electricity can be extremely low or even negative. Conversely, on cloudy days or when there is low wind, grid pricing can be high even if grid level demand is low. In fact, even under normal conditions, electrical grids may still face stress during specific times of day, particularly in the morning and early evening when demand spikes as people wake up or return home from work. These periods of strain, whether due to a lack of available generation capacity or a spike in demand, result in high pricing on the system. This sort of new price action, caused by the abundance of wind and solar, has led to the development of numerous bitcoin mining facilities in ERCOT, effectively creating a new type of load: **large flexible loads**. Specifically, Bitcoin miners consume power when supply is high and demand is low, then turn off when the grid is stressed and prices are high, freeing up large amounts of generation capacity for other consumers. The chart below shows a specific example from Galaxy's own mining site Helios, located in ERCOT Load Zone West in Northwest Texas, during which the site turned off as electricity demand rose and restarted once prices and demand had stabilized.

There are no large demand loads – i.e., buyers of electricity – with the capability to consume vast amounts electricity and are as **flexible** as Bitcoin miners. Galaxy's site Helios can completely turn off all mining machines in as short a period as 3 minutes, an unprecedented level of **demand response** function. The flexibility of a load this size is essential for electrical grids with large amounts of intermittent energy production. In other words, while ancillary services also provide support, it is increasingly difficult for a grid to remain stable while adding large amounts of wind and solar production without the help of large flexible loads, of which Bitcoin miners are the biggest and most effective. Bitcoin miners buy energy when it is cheap, helping to create a price floor for producers, but turn off naturally when it is expensive, thus buffering price spikes and simultaneously returning capacity to the grid when others need it most. This function, along with co-location (discussed in the next section), can make renewable energy projects more reliable and their production less disruptive to the grid and its consumers. The demand response function illustrated by the Helios example above has been confirmed across the broader grid by ERCOT on several occasions, such as during Winter Storm Elliott in 2022 and Winter Storm Heather in 2024. Bitcoin miners will play an increasingly important role in absorbing and releasing excess supply from wind and solar production, providing an economical signal to spur further investments into renewable electricity generation. The advent of artificial intelligence, specifically large language models (LLM), will demand large amounts of electricity and add further stress to the grids. The data centers that operate LLMs are large loads, but they aren't flexible like Bitcoin miners. LLMs require computer power primarily for two functions: training and inference. When training, machines pour over large volumes of information to build the models. Inference is the act of querying the model for a response, such as when a user asks ChatGPT a question. While there may yet be advancements that allow LLM data centers to pause and resume operations during the training process, inference cannot be flexible without causing user downtime. Both the increase in intermittent power generation and in large inflexible loads like artificial intelligence can lead to grid instability without being paired with large flexible loads.

**Helios Curtailment Activity on Apr. 3, 2024**

Source: Galaxy Mining



## Other Examples

Bitcoin miners are becoming increasingly creative in identifying stranded energy sources or making their fleets more efficient in ways that reduce carbon emissions or support electrical grids. Some notable examples include:

- **Flaring/Methane Leak Plugging:** Bitcoin mining has an emerging role in addressing the environmental concerns associated with natural gas flaring and methane leaks. Gas flaring is the burning of excess natural gas released during oil extraction processes, typically because it's not economically feasible to capture and sell. This flaring releases carbon dioxide, a potent greenhouse gas, directly into the atmosphere. Similarly, methane leaks from oil and gas infrastructure are a significant environmental issue since methane is an even more potent greenhouse gas than carbon dioxide, especially over shorter time horizons. Bitcoin miners are beginning to utilize this otherwise wasted gas by converting it into electricity on-site to power their mining operations. This not only creates an economic incentive to capture the gas but also reduces the greenhouse gas emissions associated with flaring and leaking. By using methane that would otherwise be released into the atmosphere for electricity generation, Bitcoin mining can effectively reduce the carbon intensity of cryptocurrency mining and provide a more sustainable solution for energy usage. Moreover, this practice supports the oil and gas industry in meeting regulatory requirements to reduce flaring and methane emissions, thus contributing to overall efforts to mitigate climate change.

- **Heat Recycling:** Bitcoin mining operations generate a substantial amount of heat as a byproduct of the intensive computational processes they perform. This excess thermal energy can be captured and recycled for secondary uses, turning a potential waste product into a valuable resource. For instance, the heat generated from Bitcoin mining can be harnessed to warm residential spaces, power industrial heating processes, or even support agricultural operations such as greenhouse warming. This recycling of heat not only improves the energy efficiency of the mining operation but also contributes to a reduction in the overall energy demand from conventional, possibly fossil fuel-based heating systems. As a result, the practice of heat recapture and recycling from Bitcoin mining can reduce the carbon footprint associated with heating and contribute to more sustainable energy practices. This represents a tangible environmental benefit, reusing what would otherwise be waste heat and incorporating it into a circular economy model that benefits local communities and ecosystems by mitigating additional emissions. Efforts to implement these types of heating systems at scale are still mostly proof-of-concepts but point toward its future potential. (MIT)

- **Co-location:** Co-location in the context of Bitcoin mining refers to the strategic placement of mining operations near renewable energy sources or power plants, which can be advantageous both economically and environmentally. This arrangement allows for the direct use of excess or stranded energy that might otherwise be wasted due to transmission constraints or mismatched supply and demand cycles. For instance, a Bitcoin mining facility may be co-located with a solar or wind farm, which produces variable output depending on weather conditions. During periods of high renewable generation and low demand, excess energy can be diverted to power the mining operations, thereby ensuring that the renewable energy is not wasted and contributes to the renewable project's economics. From an environmental perspective, co-location can reduce the need for fossil fuel-based energy sources by optimizing the use of renewable energy. It also can provide a flexible load that can be quickly adjusted based on energy availability, thereby helping to balance the grid and support the integration of more intermittent renewable sources. This flexibility aids in stabilizing the grid and can reduce the need for carbon-intensive standby power sources. By using energy that would otherwise go unused, co-located Bitcoin mining operations can serve as a complementary tool for renewable energy deployment, facilitating a lower carbon footprint for the energy and cryptocurrency sectors.

# Conclusion

Bitcoin mining has become an increasingly sophisticated data center industry closely tied with the electricity sector. While Bitcoin miners consume vast amounts of electricity, they do not generate scope 1 emissions – that is, they do not actually emit carbon themselves. To the extent that Bitcoin miners are blamed for emissions, it's the underlying energy sources that actually generate them. For their part, Bitcoin mining machine fleets have become increasingly efficient over time, with some data suggesting that net scope 2 emissions have flatlined. While it is difficult to come by reliable data on the energy sources ultimately feeding the electricity that powers miners on the Bitcoin network, the available data suggests the generation sources are becoming more renewable over time.

Furthermore, particularly in areas like Texas, where Galaxy's mining operations are located, Bitcoin miners' ability to provide demand response and ancillary services are increasingly relied upon to support the growth of the renewable energy sector. Absent the growth of persistent green energy – most notably, nuclear – large flexible loads like Bitcoin miners will be increasingly important to balance the intermittent generation of wind and solar.

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