Table Of **Contents**

2024 POLICY REPORT

HOW BITCOIN MINING'S FLEXIBILITY REDUCES CARBON EMISSIONS

PRESENT AND FUTURE ENERGY IMPACTS OF AI AND BITCOIN MINING

Bitcoin Policy Institute

Executive Summary

The rapid rise of bitcoin mining, and more recently, the computing required for artificial intelligence (AI), have both raised alarm regarding their consumption of electricity and their emissions. Yet, the energy and emissions impacts of these two forms of computation are vastly different. In this report, we explain and document those differences, outline the challenge of meeting the coming electrical demand, and make recommendations to policymakers for how best to meet it.

Bitcoin Mining and AI are Different

- We explain bitcoin mining's basic design parameters as a kind of energy-intensive lottery that secures a distributed network and fairly distributes new bitcoin. Those design parameters cause it to be a flexible, scalable, portable, location-agnostic, and price-sensitive consumer of electricity. That, in turn, dictates its relentless search for waste energy, whether mitigating flare gas in remote oil fields or co-locating with solar and wind installations. Bitcoin miners, like dung beetles, subsist on waste.
- For contrast, we compare AI computing to locusts, which feed on valuable crops: their power usage is mostly inflexible, location-dependent, scale-dependent, and price-insensitive. AI data centers add to peak demand, requiring additional peak generation from grids.
- Estimates of AI server electricity usage (20-125 TWh) range widely, but AI could already use more than double the power of the bitcoin network (48 TWh), and has a steeper rate of growth.
- Caveats: We see AI eventually evolving to be more like bitcoin mining in the future as compute loads are shifted to the cheapest power source. We note, too, that in brief periods of bitcoin price appreciation, bitcoin mining can behave in a locust-like way, when mining is profitable on all available electricity.

Documenting Bitcoin Miners' Flexibility

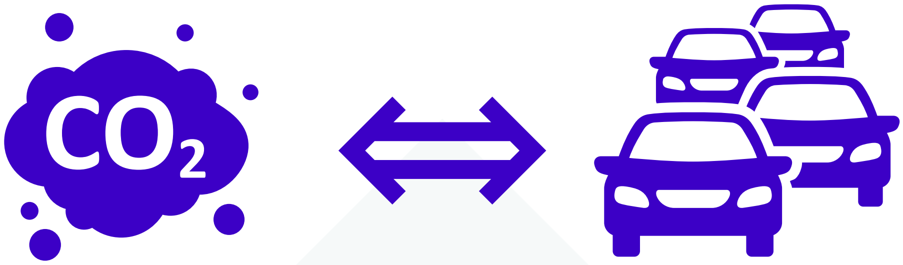
- Bitcoin miners often tout their ability to turn their machines off whenever electrical grids are stressed, but until now, the extent of miner flexibility has not been independently substantiated. We gathered detailed power usage data from 10 bitcoin mining companies in the US and Canada and found that they curtailed power usage between 5% and 31% of the time.

Flexibility Matters for Carbon Emissions

- We used marginal emissions factors from RESurety and WattTime to compute the amount of carbon dioxide emissions avoided when a bitcoin mining facility reduced its power demand, relative to a constant-uptime data center. Over three months, the miners we studied reduced their carbon dioxide emissions by 13.6 kilotons. If our sampled miners are representative of the network, the marginal impact of miner flexibility is equivalent to avoiding 4.4 million tons of carbon dioxide annually, or taking more than 956,500 cars off the road.

Policymakers Should Encourage Flexibility and Enable New Generation

- We need informed and differentiated policy that encourages both bitcoin mining and AI to evolve to more flexible patterns of energy use, such as rate structures that reward demand response and reflect scarcity and abundance in pricing. We also need transmission and interconnection reform, which would allow power generation projects to meet the coming demand.

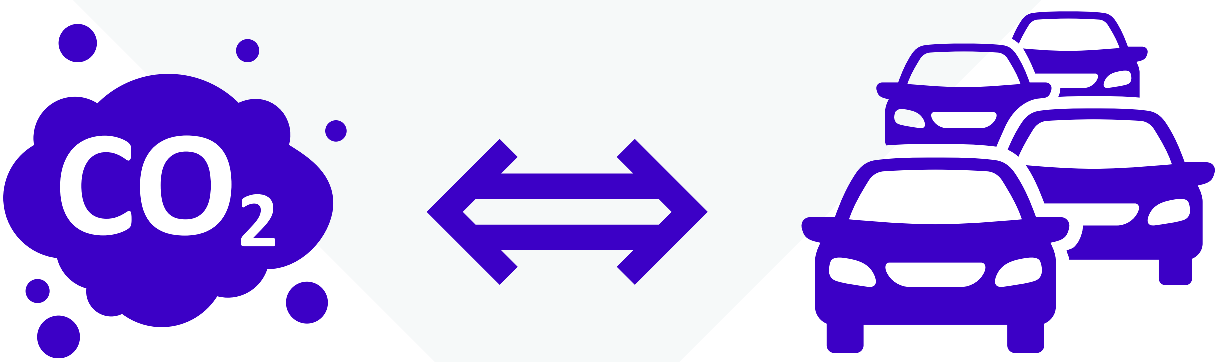


13.6 kilotons CO_2 avoided

2,951 cars off the road

For 8 mining facilities during July, August, and September 2023.

Bitcoin mining's flexibility reduces carbon emissions.



4.4 million tons CO_2 avoided

956,521 cars off the road

Assuming the entire network has similar flexibility as the facilities in our study in similar grid conditions.

Annual emissions. Based on data collected from the Bitcoin mining industry in the United States and Canada, the CBECI, and the EPA.

All data centers are not created equal

Fifteen years after its invention, bitcoin mining remains poorly understood. Most policymakers now know that what we call “mining” is actually a kind of computation performed in data centers. They know that bitcoin mining uses a lot of energy, currently 0.22% of all primary energy in the world [1]. What they do not understand is the difference between bitcoin mines and other kinds of data centers, either the traditional data centers that process our emails and video streaming, or the burgeoning new data centers powering artificial intelligence. For most regulators, a data center is simply a data center. But we think this is a dangerous conflation of two things that are in fact very different, and our report aims to explain why.

The locust and the dung beetle

We use, as a guiding metaphor, two species of insects: the locust and the dung beetle.

Traditional data centers, and particularly the new AI data centers, are locusts. Just as locusts descend onto a farmer’s crop, eating everything in sight, traditional data centers consume power on their own terms. Their contracts require 99.99% uptime, so they cannot turn off their machines when grids are under stress, such as during a heat wave. Their profit margins support paying high prices for power, so they outcompete local buyers. They require special water-intensive cooling and low-latency internet connections to major metropolitan areas. This means the data centers are coming like swarming locusts, and they will consume as much energy as those grids can produce, raising prices and increasing emissions.

> **“This impact of curtailing operations on emissions has been ignored by every estimate of bitcoin mining emissions to date; those estimates have wrongly conflated the dung beetle with the locust.”**

Bitcoin mining, on the other hand, is a dung beetle, which uses animal waste both as a food source and as a breeding chamber. We call mining a dung beetle because the design parameters of bitcoin make mining unprofitable on all but the cheapest energy in the world. (Few miners can operate profitably above $0.05/kWh, and most are paying far less.) Miners can also move to any location in the world without impacting their profits, and they can turn their machines on or off in mere seconds. That cluster of features means miners are engaged in a relentless world-wide search for waste energy. That search for waste energy takes many forms, such as mitigating methane gas in remote oil fields (which is otherwise simply burned in a flare stack), or co-locating with solar and wind installations to absorb excess power. When a bitcoin mining data center is connected to a grid, its machines will simply turn off whenever power is scarce and expensive, and turn back on when power is abundant and cheap. **So, while bitcoin mining consumes large amounts of power, just like the lowly dung beetle, it uses primarily what others leave behind.**

Bitcoin miners have long described themselves as electricity-cost-sensitive, uniquely-flexible consumers of power—in other words, as dung beetles. Academics have written papers about what such flexibility could, in theory, achieve. Adding a dung beetle does not necessarily require more generation infrastructure to meet peak demand, but adding a locust does. And the addition of highly-flexible data centers could, in theory, even reduce total grid emissions [2]. But until now, the flexibility of bitcoin miners had not been substantiated with real-world data. We knew that bitcoin miners could operate like dung beetles, but we did not know whether they actually did so, or whether they were acting like locusts themselves.

Different not only in theory, but in practice.

We collected real-world energy-usage data directly from ten bitcoin mining companies to see whether the reality of mining's flexibility matches its rhetoric. We then analyzed that data to determine how much emissions are avoided relative to a traditional, inflexible, data center.

What we found was that miners are, in fact, acting like dung beetles and behaving flexibly. We found that the Bitcoin mining facilities in our study turned off their computers between 5% and 31% of the time, whenever electricity prices were expensive or when grid operators signaled them to.

We also found that this flexibility matters. Using our data together with marginal emissions factors from WattTime and ReSurety, we analyzed the emissions impacts of miners turning down their machines when and where they did so. Consuming energy like a dung beetle, it turns out, generates far fewer emissions than consuming like a locust. The bitcoin miners who provided us data avoided 13,577 tons of carbon dioxide over 3 months, compared to a typical data center that does not power down at all. This is the equivalent to keeping 2,951 cars off the road every year. If the entire Bitcoin network behaves like our participants, under similar grid conditions, then the network is avoiding over 4 megatons of carbon dioxide annually, equivalent to keeping more than 956,500 cars off the road for one year. This impact of curtailing operations on emissions has been ignored by every estimate of bitcoin mining emissions to date; those estimates have wrongly conflated the dung beetle with the locust.

In short, AI and Bitcoin have different characteristics, and we believe policy should be crafted with an understanding of those differences. We suspect that AI will become less locust-like and more dung-beetle-like over time, as the industry becomes more competitive, and especially as model training becomes parallelized and distributed. But at present, we see only nascent evidence of flexibility in AI compute.

In what follows, we more deeply explain the nature of these two species of energy consumer and estimate their current and future energy usage and relative emissions. We conclude by offering policy recommendations that would allow grids to meet the coming demand and capitalize on Bitcoin mining's unique, dung-beetle-like characteristics.

Bitcoin Mining 101
What is Bitcoin Mining?

The Bitcoin network is essentially a distributed ledger. Instead of a single ledger–held by a bank, for instance–the bitcoin protocol creates thousands of copies of the ledger on anyone's computer who is running the Bitcoin software. Not only is this ledger massively distributed, it is also complete: it is a public record of the history of all bitcoin transactions.

What keeps all the thousands of copies of the ledger in agreement is bitcoin mining. Mining not only coordinates all copies of the ledger, protecting it from attacks of various kinds, but also issues new bitcoin.

But what is bitcoin mining, and how does it coordinate the copies of bitcoin's ledger?

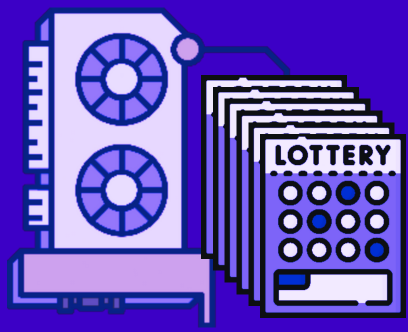
Mining is a competition best imagined as a lottery. Each mining computer is like a lottery ticket generator. The more machines you have, the more tickets produced, and the more chances you have at winning the mining lottery. Currently, the bitcoin network runs through a trillion, million lottery tickets every second.

When a miner "wins" the lottery, everyone on the network can quickly verify that their ticket is a winner, and the network grants the winning miner the right to publish new batches of transactions, called blocks, to the shared ledger. Winning the lottery is lucrative because the miner who publishes a batch of transactions can collect fees attached to those transactions (~5% of miner revenue) and also receives a prize for being the winner, which is called the block subsidy (~95% of miner revenue). The block subsidy is how all new bitcoin are distributed.

Unlike a typical lottery, the prize decreases: every four years, bitcoin's block subsidy is cut in half. It is now 3.25 bitcoin per block, down from 50 bitcoin per block in 2009.

Bitcoin's protocol also controls how fast blocks are added to the blockchain. The protocol decreases the probability of a single ticket winning if blocks are found faster than 10 minutes on average and increases the probability of winning if blocks are being found slower than 10 minutes, ensuring a reliable stream of new transactions, and a steady issuance of new bitcoin.

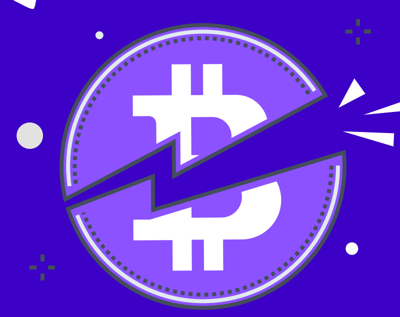
Bitcoin Mining Is Like a Lottery



Each mining computer is like a lottery ticket generator.

The more tickets you generate, the more likely you'll win the reward.

But... If participants guess right too fast, the lottery gets harder.



And... The reward gets cut in half every four years.

So... You have to get more efficient to stay in the game.

Bitcoin Mining 101
From Lottery to Unique Power Consumer

This dung-beetle-like pattern of consumption manifests in the real world in a variety of ways.

- **Buyers of first and last resort for wind and solar.** Unlike other consumers of power like homes or factories, bitcoin miners can be buyers of electrical power that is stranded, i.e., not physically connected to users who need it. So, miners can be "buyers of first resort," basically anchor tenants for new solar and wind farms in advance of full grid connection. Miners can also be "buyers of last resort," who will take the leftover power when generators are producing too much. For instance, on a windy, sunny day when solar panels and wind turbines are producing more than the connected marketplace needs, miners can use that excess [3]. Because renewables require buyers of their power, mining can actually incentivize the build out of renewable power generation. And in fact we often find bitcoin mining operations in areas where there is excess wind and solar power, either co-located at a wind or solar farm, or in an area of an electrical grid where lots of renewable energy is stranded due to transmission constraints.
- **Using stranded hydroelectric power on-site.** In other cases, bitcoin miners are setting up in places like Kenya, where hydropowered mini-grids are struggling due to a lack of demand [4] Recently, Marathon Digital Holdings, a US-based and publicly traded Bitcoin mining company, signed a deal to monetize and invest 80 million dollars into Kenya's stranded green energy [5]
- **Curtailing in two ways.** Most on-grid bitcoin miners shut down their machines whenever electricity prices are too high to mine profitably. This is called price-responsive curtailment. But we are also seeing miners participating in grid insurance programs known as demand response, where miners voluntarily shut down their equipment when grid operators require them to do so under a contractual agreement [6]. Demand response prevents grid blackouts and improves reliability by allowing grid operators to control whether miners are operating, or not, at any given time. Both of these behaviors mean that miners are typically offline during peak demand, returning power to the grid when it is most needed.
- **Mitigating methane emissions.** Other bitcoin mining companies are targeting wasted or inefficiently combusted methane gas at landfills and in oil and gas fields [7] Some of these methane miners are also able to mitigate emissions, either by capturing methane that is currently vented, or by improving on flare stacks' poor inefficient combustion.

- **Electrifying heating.** The drive to stay competitive is also forcing mining companies to re-use their wasted heat for other purposes such as municipal heating, distilling water, or providing heat for direct air capture of carbon [8].
- **The exceptions.** Of course, the search for cheap energy does not always result in support for renewable energy, balancing electrical grids, or reducing greenhouse gas emission mitigation. In some cases, bitcoin mining companies have chosen to set up alongside natural gas or coal plants. But as profit margins have narrowed, only the cheapest energy is now profitable to use for mining, and such energy use tends to be benign, if not beneficial.

All of these behaviors are predictable, and as outlined above, downstream from bitcoin's unique and essential nature. Mining is an incentive structure that naturally pushes towards dung beetle behavior. It uses large quantities of energy, but in a way that is rarely harmful, and often helpful.

Apart from direct market forces, some companies such as The Sustainable Bitcoin Protocol are using financial products to incentivize greener energy use. On the policy side, states like New York have limited the co-location of Bitcoin mining with fossil fuel plants [9]. Other states, like Ohio, are creating new rate structures that would seriously limit the demand from mining on their grid [10]. We do not make any value judgements about these policy choices, but given the emerging mix of market and policy incentives, the combination of bitcoin mining's low profit margin and its unparalleled flexibility will ultimately drive bitcoin mining toward excess clean energy.

In the next section, we'll delve deeper by doing a comparative analysis of bitcoin mining and AI, to explore how the similarities and differences will impact demand for power, grid reliability, and greenhouse gas emissions.

AI Data Centers 101: **Characteristics**

We have introduced the dung beetle—Bitcoin mining—and explained how its design features drive it towards energy-scavenging behavior. Now it is time to meet the locust: AI data centers. Most of what we will say about AI data centers applies to traditional data centers as well, whether they are providing email services, streaming videos, or enabling ecommerce. But we chose to highlight AI data centers due to their rapid growth. While traditional data centers, at least until 2022, were only expanding moderately due to improvements in efficiency, the International Energy Agency predicts 10x the power usage in 2026 compared to 2023 for AI [11]. It is this rapid growth that has sparked alarm among utilities, regulators, and in the media [12].

Properties	Bitcoin Mining	AI
Cost-sensitive	Only operates on the cheapest power.	Less sensitive to electricity costs.
Location-agnostic	Latency is not an issue.	Latency can be an issue, especially for inference.
Temporally-agnostic	Computations are worth the same regardless of time of day.	Computations are not always worth the same and may be time-dependent.
Operationally flexible	Can power on and off without effecting the network.	Cannot easily power on and off machines without special software to manage workloads. Training workloads are more flexible than inference.
Scaleable	Can profit with one machine or thousands at a site.	Large scale models require multiple GPUs.

Two kinds of computing are required to support the forms of artificial intelligence that are experiencing growth. Training refers to the processing of vast amounts of information to build a machine-learning model. Inference refers to the kind of computation that processes a query from a user—for instance, someone typing a prompt into ChatGPT or Midjourney—and yields an answer or an image, using the machine-learning model. Currently, both training and inference primarily use GPUs, which have extremely high power density. By density, we mean that traditional data centers have an average density of 5-10 kilowatts per rack, whereas AI servers now require 60 or more kilowatts per rack [13].

We showed that bitcoin mining is cost-sensitive, location-agnostic, time-independent, flexible, and scalable. AI compute differs, at least to some degree, across all of these dimensions.

Cost-sensitivity. First and foremost, profit margins for AI compute, at least presently, are much higher than profit margins for bitcoin mining. While the newest bitcoin mining machines generate only $0.17-$0.20/kWh of revenue, Nvidia GPUs generate $3-$5/kWh, a 17-to-25-fold difference [14]. Those high profit margins means that even if an AI facility were able to turn off their GPUs in a time of high electricity prices, it would not be profitable to do so unless electricity prices were extremely high. Every moment a GPU is not running, it is foregoing substantial revenues and simultaneously depreciating.

Location-dependency. High profit margins also mean the price of electricity is not necessarily the deciding factor on where to locate AI facilities. Instead, AI facilities face other constraints. For instance, there may be geopolitical constraints on where sensitive data is stored. More importantly, for inference, low latency is important so that queries may be answered quickly. Thus, inference must be located near the population-dense areas they serve.

Flexibility. In-principle, training tasks could be flexible. Computational load could shift in time and space to find the power that is cheapest. And there is nascent evidence that AI has that capability, in that the firmware used by bitcoin miners to dial up and down their power usage has been adapted to support AI. However, we yet to find direct evidence that AI computation is actually powering down. Inference is on-demand and location-dependent. It is difficult to see how it could be highly-flexible beyond reducing power usage for non-computational equipment like cooling.

Scalability. In-principle, at least some forms of AI compute should be capable of being distributed across smaller computing clusters. For now, we informally hear from industry participants that 10MW is the minimum scale companies are looking for.

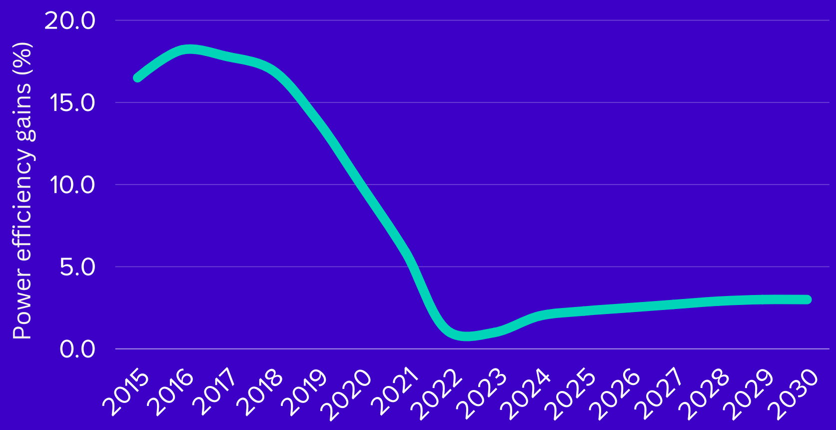
Such is the nature of the locust: cost-insensitive, location-dependent, largely-inflexible, and scale-dependent.

In what follows, we review the best estimates of how much energy each of these kinds of computation use —both present and future—after which we will review the projected growth of new electrical generation to meet that rising demand, and finally, analyze the extent of bitcoin mining's flexibility and the impact of that flexibility on emissions relative to inflexible consumers.

Efficiency Trends

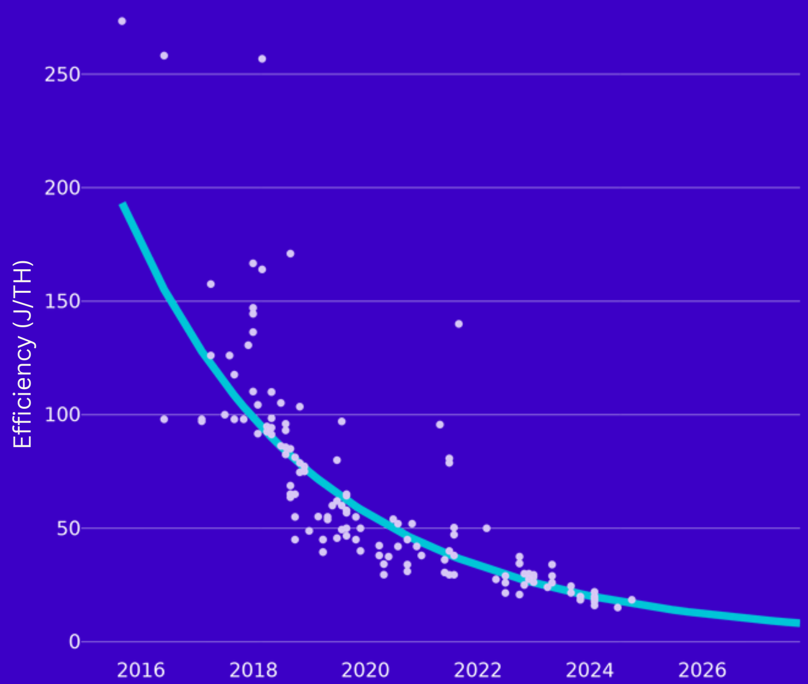
Efficiency Flattens

Data center efficiency gains--mostly from improved power usage efficiency--were projected to meet demand at least in the early 2020s, but updated estimates from Goldman Sachs and LBNL show that these efficiency gains stopped around 2018, likely due to the unexpected advancements in AI technology.



Source: Goldman Sachs, 2024.

Efficiency gains need to be more innovative than chip improvements to be able to offset increased energy demand.



Source: ASICminervalue.com

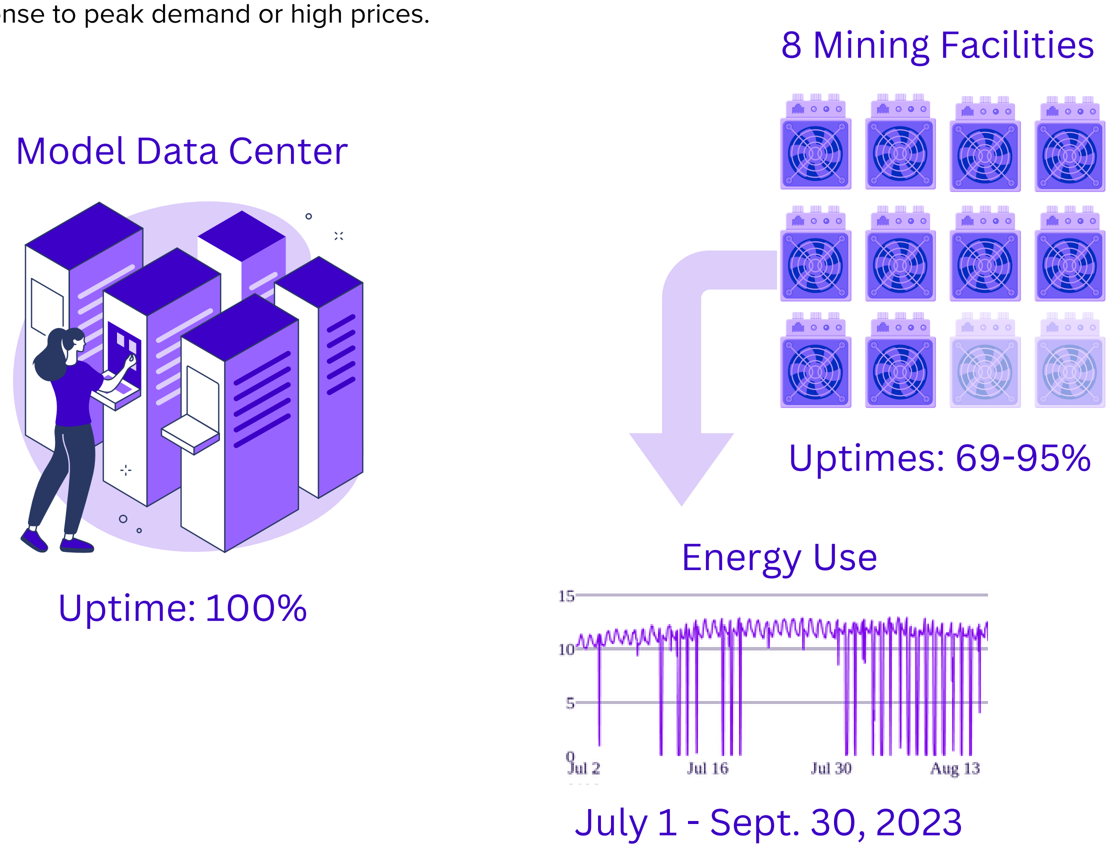
Slowing Chip Efficiency Gains

Machine efficiency trends have slowed over the last five years. However, there is still some modest room as machines move toward 3-nm chips. Samsung and Block have both announced that they are producing a 3-nm ASIC chip for bitcoin mining. Other manufacturers are also introducing 4-nm chips while most machines currently use 5-nm chips. Chips used for AI are also following a similar trajectory.

Our Study:
Data and Method

To better understand how data center and Bitcoin mining load flexibility impacts emissions and stable grid operations, we collected data from 10 Bitcoin mining companies across the United States and Canada. We knew that Bitcoin miners had the theoretical ability to turn on and off quickly, and that there was anecdotal evidence of this in news reports, but until now, little to no data has been produced to definitively demonstrate this.

Using marginal carbon dioxide emission factors from RESurety and WattTime, we computed the amount of carbon emissions avoided when a Bitcoin mining facility reduced its power demand specifically in response to peak demand or high electricity prices [23]. We then compared this to our data center model, which we assumed to be a firm load, meaning, it never reduced its power in response to peak demand or high prices.



Our Study: **Analysis**

Miners behave flexibly.

During our flexibility analysis, using a time window of July 1 - September 30, 2023, we found that Bitcoin miners powered down machines 5-31 percent of the time. This high variability is likely more to do with the type of power contract they have than the capabilities of the facility. Anecdotally, some Bitcoin mining operators have lamented that they would like to provide load flexibility, but the pricing structures where they are located do not make this possible.

Miners turn down during extreme weather events.

To explore Bitcoin mining's support for the grid during times of stress, we selected data from three Bitcoin mining facilities that overlapped with the January 2024 Texas winter storm that jeopardized grid reliability with unusually high demand. Our results show that these mining facilities were able to power down - either based on signals from the grid operator, or solely in response to high prices that were above the mining facility's break even price. Bitcoin mining's ability to pay for power generation at times when the grid is not strained, yet turn down during those peak events, improves the grid's overall reliability.

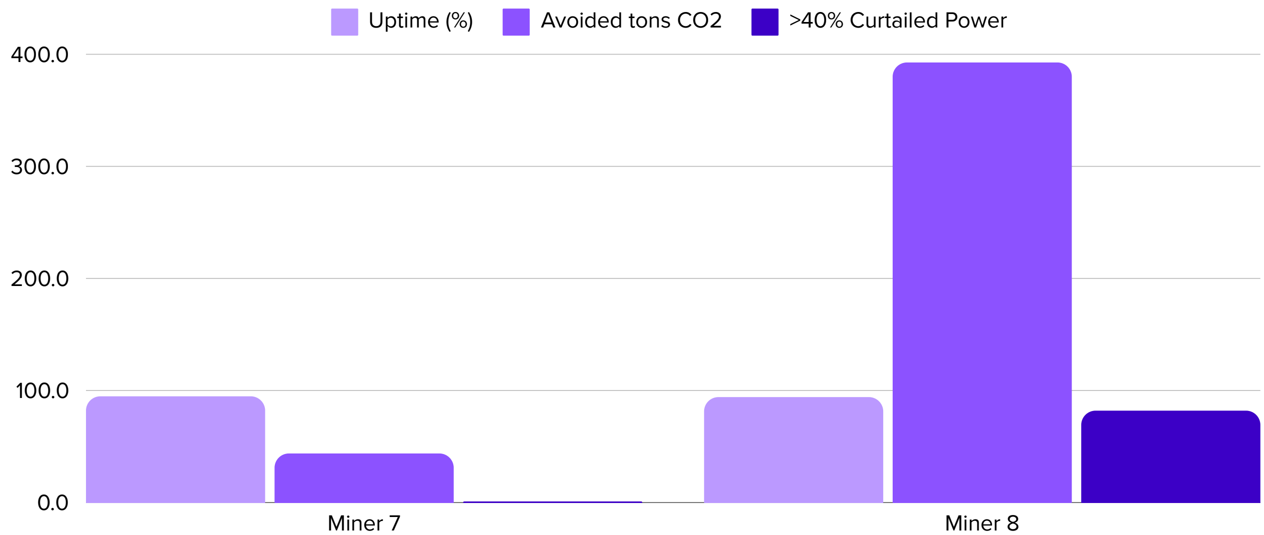
Bitcoin miners' flexibility results in substantial avoided emissions.

Over three months, the miners we studied reduced their CO2 emissions by 13.6 kilotons. If our sampled miners are representative of the network, the marginal impact of miner flexibility is equivalent to avoiding 4.4 million tons of CO2 annually, or taking more than 956,500 cars off the road.

The extent of flexibility matters.

We also found that the degree to which miners power down matters for the total emissions avoided, in addition to the frequency with which they power down. For example, we had two miners, labeled Miner 7 and Miner 8 in our study figures, that had similar uptimes of about 94 percent. Yet, Miner 7 avoided only 43.8 tons of carbon emissions, while Miner 8 avoided 392.7 tons. Our study found that Miner 7 reduced its power more than 40 percent once during our three-month window, while Miner 8 reduced power consumption by the same amount for a total of 82 times.

The key takeaway from our study is that demand-side flexibility is important for both avoiding additional emissions and for maintaining grid reliability, especially in light of the expected rapid rise in demand from data centers over the next several years. Bitcoin mining is not only capable of providing this flexibility, but is actually doing so.



The Future of Flexible Consumption

Bitcoin mining has pioneered the use of computation as a large, highly-flexible load. Mining is driven to flexibility by the bitcoin protocol itself, which forces miners to seek out the cheapest power in the world, and incentivizes them to curtail power usage whenever power is expensive. But in principle, flexibility should be possible for other kinds of computational tasks. Though we have little evidence of it at present, AI training servers may be able to provide a similar kind of flexibility in the future, given that they do not need to be near large cities and their workloads can be interrupted or shifted.

In fact, all data centers could potentially provide demand response services if they enlist their backup generators whenever grids call upon them to do so. However, using diesel generators in this way would increase marginal emissions for the grid overall. Data centers could bring their own electrical generation to the table, using their own low-carbon microgrids to support utilities during peak demand. There are higher capital expenses for operating this way, but demand response programs often pay participants to power down or provide power back to the grid, so there are incentives that might offset these higher expenses to make it worthwhile. Companies like Verrus are building data centers with battery microgrids to be able to provide this kind of flexibility and plan to have their first flexible data centers ready in 2026 or 2027 [24].

A final qualification must be made. While bitcoin's incentives ultimately drive it to the cheapest energy, during periods of upward price volatility, it can be profitable to mine bitcoin on very expensive power. These periods are short-lived, because, as noted above, mining profits incentivize the production and deployment of more mining computers, and that, in turn, shrinks margins for all miners, until once again only those with the cheapest energy can survive. But such periods do happen, as when China banned bitcoin mining during a bitcoin price spike, and a global pandemic interfered with supply chains. During that period, bitcoin mining was profitable on expensive power, and so, while bitcoin mining had the ability to be flexible, it did not necessarily behave flexibly. Such inflexible behavior could recur under similar conditions.

Energy Use:
Bitcoin & Data Centers

Current Energy Use

For our report, we chose to use the preliminary results from Lawrence Berkeley National Laboratory's (LBNL) upcoming report to estimate present and future growth for data centers and AI servers in the United States. The group producing this report uses industry data to inform their energy models. Their estimate for 2024 suggests US data centers will use 375 TWh while AI servers will make up about 47% of that total. They project similar future growth will come from the AI industry through 2027 [15].

According to the Cambridge Bitcoin Electricity Consumption Index (CBECI), as of July 6, 2024, United States Bitcoin mining's energy consumption is estimated to be 139.81 TWh [16]. This number fluctuates, depending on the amount of energy consumed on a daily basis. Since we are not able to get daily or even monthly estimates for data centers, we can only compare across years. Last year, US Bitcoin mining facilities used an estimated 121.13 TWh, while US data centers used 100-325 TWh, and US AI servers were estimated at 20-125 TWh [17].

It may come as a surprise to find that Bitcoin mining's energy use is likely much lower than that of data centers. We believe that the reason for this distortion is due to Bitcoin mining's rapid and unexpected growth in 2021, after China banned Bitcoin mining. At its peak, Bitcoin mining in China was estimated to represent about 72.98% of the total network's mining facilities [18]. Bitcoin miners moved quickly and, in hindsight, sometimes recklessly, as they searched for new locations to power their machines. CBECI data shows an estimated 375.5% increase in US-based Bitcoin mining from 2020 to 2021 [19]. The similar recent spike in demand for generative AI may result in news reports giving outsized attention to the risk from AI energy use, as they did with Bitcoin.

Projected Energy Use

Estimating energy use is challenging. Forecasting future energy use is even more so. Computing is subject to unpredictable technological breakthroughs that can drastically change the trajectory of energy use trends from year-to-year. Bitcoin mining is no exception, especially when the additional factor of a volatile cryptocurrency is considered. Unfortunately, we do not have robust estimates for future energy usage from recent industry or academic studies. Thus, for the sake of having some kind of educated guess to compare to, we decided to include an estimate for Bitcoin mining in our figures. However, our estimates should be seen as a guide for what could be, and not as a strict reality, as this is an extremely simplified estimate of network growth. There are many other factors to consider that could impact projected energy use.

Using our projections for Bitcoin mining, and LBNL and Goldman Sachs' projections for data centers, we expect data centers to likely outpace Bitcoin mining growth. Our educated guess puts Bitcoin mining at about 160 TWh in 2027, while LBNL estimates about 240 TWh for AI servers and about 540 TWh for the data center industry as a whole (excluding cryptocurrency mining) [20]. Goldman Sachs, on the other hand, has somewhat more modest estimates for 2027 with around 70 TWh for AI servers, and about 280 TWh for data centers (excluding cryptocurrency mining) [21]. Overall (see Appendix 1), industry reports project increases to be between 48% and 186% for future energy use for data centers, mostly attributed to growth in AI and generative AI applications.

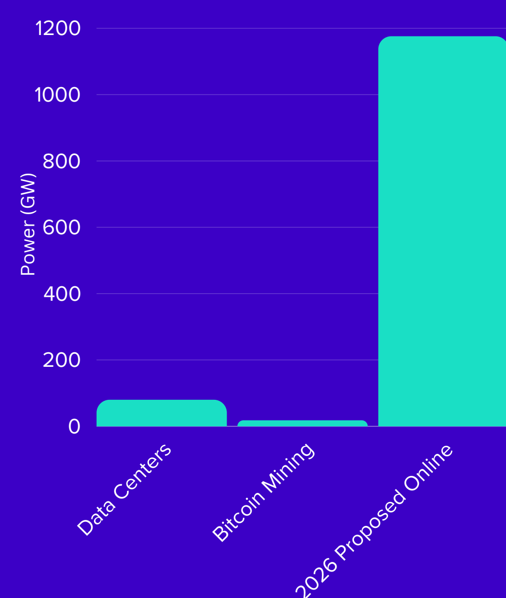
AI has recently experienced a maturation in technology with generative AI, which will likely drive a spike in demand until adoption of this new technology stabilizes. As a result, we think that an accelerated increase in demand for power that outpaces Bitcoin mining is reasonable, at least in the United States. The current influx of capital into the AI market means that Bitcoin mining will struggle to compete against competitors that can pay more for the same electricity. However, this trend may not last forever, depending on the market dynamics for AI. Still, energy use largely remained steady in its growth prior to the April 2024 halving, and according to Luxor's Hashrate Index, because of increased competition, Bitcoin mining's revenues per unit of compute is near its lowest since 2017 [22].

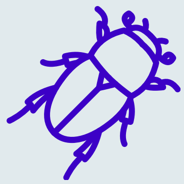
Given these projections, the power usage of both Bitcoin mining and AI will continue to capture headlines. We believe, however, that policymakers and other stakeholders should pay more attention to how these new data centers are using power than to the absolute amounts of power they use. In the following section, we explain why, presenting our original research on the degree of actual flexibility of bitcoin miners and analyzing the impact of that flexibility on emissions.

Interconnection Queues Can Meet Increased Demand

Data centers and Bitcoin are 6.3% of proposed new operational generation capacity.

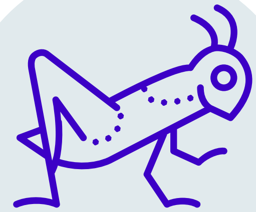
The high-end estimate for data centers (including AI) is about 80 GW by 2027, while our estimate (outlined above) for Bitcoin mining suggests 18 GW by 2027. Combined, this represents 6.3 percent of the total generation capacity with a proposed operational date by the end of 2026. Indeed, the Berkeley Lab report shows growth in active generation projections have a remarkably similar exponential trend to data center demand.





48 TWh

2023 Bitcoin Energy Use

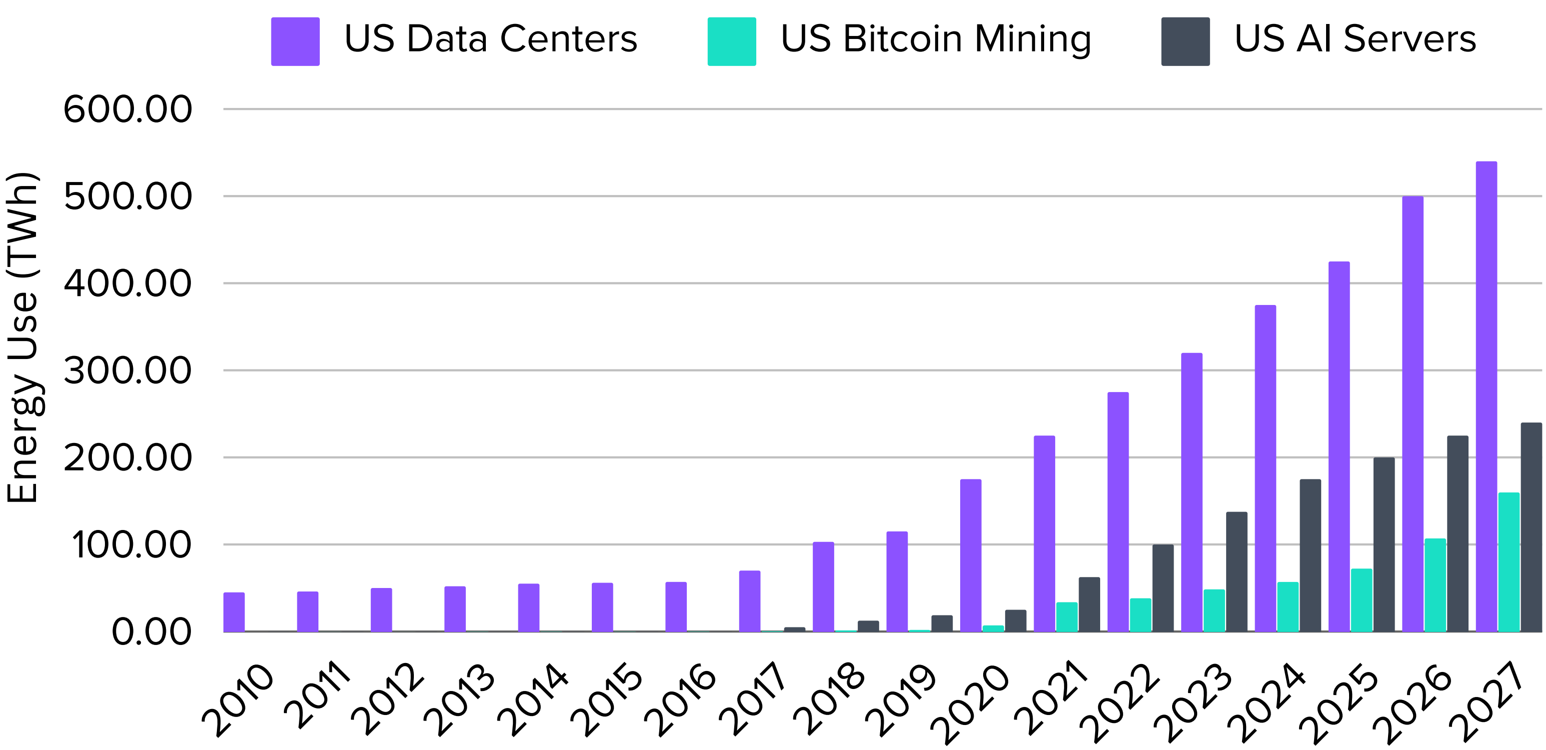


20-125 TWh

2023 AI Servers Energy Use

100-325 TWh

2023 Data Center Energy Use



Based on data from CBECI, Lawrence Berkeley Lab, Goldman Sachs, Minerasicvalues.com, and Coinshares hashrate projections.

Policy Recommendations

Developing sound policy for an industry that is rapidly changing and reinventing itself is challenging. Below, we outline some suggestions to help stakeholders make better decisions that incentivize grid reliability, reduce emissions, and spur innovation.

Set price structures that incentivize flexibility.
We caution local policymakers and grid operators that have control over rate structures to not assume that data centers, and in particular, Bitcoin mining, are firm loads. As we demonstrated, Bitcoin mining is a highly flexible load. Given the right structure, Bitcoin miners can optimize their flexibility to help grid operators avoid power interruptions and also avoid emissions that would have been produced had they maintained constant uptimes. As such, we recommend ensuring that data centers of all kinds that provide demand-side flexibility, coordinate with grid operators to make forecasting smoother.

Reform transmission rules and reduce interconnection queue wait times.
Even with the highest growth projections for data centers, there is more than enough power generation waiting in the interconnection queues (new energy generation projects waiting to be connected to the grid). Only 6.3% of the promised power would need to come online by 2027 to meet the coming demand [25]. Most of the active capacity in the interconnection queues have proposed online dates between 2025 and 2028, right on time to match increased data center construction. The biggest challenge is making sure that these generation projects are seen through to completion.

Berkeley Lab's study showed that power development projects are approaching a median duration of 5 years from interconnection request to commercial operation for projects completed in 2022-2023. Support for reforms to decrease wait times, like those outlined in recent Federal Energy Regulatory Commission (FERC) order 2023, and for the solutions outlined in the Department of Energy's (DOE) interconnection innovation eXchange (i2X), are necessary to improve interconnection delays [26]. Such reforms guarantee that the available capacity can be online in time to meet the projected new demand. We also urge state-level stakeholders to ensure that the federal level rule changes are implemented.

Encourage the integration of computation and generation.
Increasing numbers of Bitcoin mining companies are incorporating AI and high performance computing into their facilities. Likewise, Microsoft, Meta, Google, and Amazon are the first data companies to become power companies as well, investing in new generation projects. Data centers will continue to grow in size: 1GW centers will be commonplace [27]. To be able to supply enough power to these sites, new power generation will likely have to be commissioned. Or, for loads that can provide high flexibility, we will see more renewable energy companies dedicating a percentage of their power to these compute centers to boost baseline revenue. Policymakers should encourage these activities because they will ultimately accelerate the build out of clean energy.

Exercise caution with energy estimates.
We recommend a cautionary principle around regulating with limited data or based on poorly developed studies. As we showed in our report, estimating energy use is difficult, but forecasting years into the future is an even more colossal task. Extreme predictions of growth have a track record of being mistaken, and lawmakers should treat them as highly provisional [28].

Appendix A

Energy Estimates Methodology

The best estimates of energy use are "bottom up" and tell us information about the number of machines or servers in use, efficiency trends for these devices, and for cooling the facilities that house them. However, collecting these data is time-consuming, so most estimates rely on simplistic "top down" assumptions and historical trends, which often mislead the public.

We looked at a number of data center energy estimates going back to 2008. We found the data to be sparse, with gaps across multiple years between stated estimates. For example, for the best estimates, we only have data for 2000, 2005, 2010, 2015, and 2018. Methods used for other less reliable estimates often overstated energy use. In 2024, challenges with estimating energy use are still prevalent. We pulled multiple industry reports and academic papers published from 2023 through the present and found similar problems to those discussed in Mytton et al. (2022) [29].

For Bitcoin mining, we rely on a continuous estimate going back to the beginning of the network from the Cambridge Bitcoin Energy Consumption Index (CBECI) [30]. Their model has limitations—which they themselves document thoroughly— but remains the most reliable estimate to date. CBECI is able to make continuous estimates because Bitcoin's protocol provides an indirect metric known as hashrate, which is the total computing power of the entire bitcoin mining network. Hashrate can be derived from the frequency of block times and the difficulty of mining a single block, and together with machine and facility energy efficiency, can then be used to estimate energy use at granular time scales. We suspect that Bitcoin mining has received outsized attention in the United States media partly because of this transparency. There is no similar, publicly-available measure of all active computing power in data centers.

For our estimate, we relied on Coinshares' estimate of future hashrate growth, which they estimated using a power curve, assuming steep appreciation in bitcoin's price [31]. We then assumed that for the next three years, network efficiency will approximate an 80-20 weighted mix of machines currently profitable at $0.05/kWh, while accounting for linear efficiency gains every year.

For future energy use estimates, we relied on LBNL's preliminary results from their upcoming 2024 Report to Congress on U.S. Data Center Energy Use which were presented at Data Center World 2024 [32]. We also compare these to estimates from Goldman Sachs [33]. We chose these estimates because both use earlier bottom-up estimates as a foundation, and both include continuous annual estimates across multiple years.

We also compared AI growth estimates from LBNL, Goldman Sachs, the IEA, Schneider Electric, Semianalysis, Boston Consulting Group, Morgan Stanely, McKinsey, and Newmark Consultancy Group [34]. While each report uses different methods for estimating their growth projections, what all reports have in common is that they show a sharp increase in demand between 2023 and 2030.

Appendix B

Meeting the Demand

New Power Generation Will Likely Be Mixed
AI and Bitcoin mining are not the only rising sources of demand. Electric vehicles continue to add load to our grids, as do new manufacturing facilities, and the production of green hydrogen. In western Texas, which has the highest concentration of bitcoin mining in the US, data centers will represent 45 percent of new demand growth, Bitcoin mining will account for 20 percent, and the remaining demand will come from green hydrogen projects [35]. So how will grids respond?

Goldman Sachs estimates that 60 percent of new data center demand will be met with natural gas and 40 percent with renewable energy. Several utility companies project major investments in natural gas, as well. The 2024 interconnection queue report from Lawrence Berkeley Lab shows 79 GW of natural gas in the queues compared to approximately 1,480 TW of solar, wind, and storage. Connection delays mean that a smaller percentage of these will come online, but based on the amount of generation in the queues, there is more than enough potential low-carbon generation, storage, and natural gas, available to meet the rise in demand from AI and Bitcoin mining.

Flexibility and Grid Planning
Utilities are modeling new demand as load that will use power 24/7, which will require natural gas to power the grid. During peak hours, natural gas peaker plants will have to turn on to meet new demand. However, this can be avoided if data centers, like Bitcoin miners, can operate flexibly. As noted above, Bitcoin mining has the ability to turn on and off within seconds and use that ability to participate in demand response programs and, depending on their power contract, power off based on electricity price.

Traditional data centers have shown signs of developing flexibility. In the last year, we have seen corporations like Google providing demand response using proprietary technology that shifts workload geospatially and temporally, But this is still not an industry standard. Tier IV Data centers are expected to have 99.995 percent reliability, meaning that power should not go down for more than 26.3 minutes out of the year.

To guarantee this uptime, most data centers keep diesel generators as backups. Data centers do not yet have the same flexibility capabilities that Bitcoin mining does, but this is likely to change over the coming years, as more data centers build micro-grids that can be used as virtual power plants to provide power back to the grid during times of peak demand.

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About the Authors & BPI

The Bitcoin Policy Institute is a non-partisan, non-profit think tank researching the impacts of Bitcoin and other emerging monetary networks. Established as a 501(c)3, BPI provides educational resources to policymakers while empowering more than a dozen Fellows from across the country to conduct original academic research on cryptocurrency and technology policy issues.

Margot Paez
Fellow

Margot Paez is a PhD candidate at the Georgia Institute of Technology. She is the recipient of BPI's Bitcoin and Energy Graduate Fellowship, and recipient of the Human Rights Foundation's Bitcoin Development Fund grant that supports sustainable energy development research using Bitcoin mining in the Global South. She is the first researcher to successfully collect data from the Bitcoin mining industry and present it before policymakers in Washington D.C.

Troy Cross
Fellow

Troy Cross is Professor of Philosophy and Humanities at Reed College where he teaches courses on the philosophy of religion, color, and the philosophy of mind, as well as lecturing in the humanities program. Prior to coming to Reed in 2010, he held positions at Yale and Merton College, Oxford. Cross's philosophical research interests center on foundational issues in metaphysics and epistemology, but has also been involved in bitcoin since 2011, cultivating interest in a number of bitcoin-related issues in that time, most of all, the question of bitcoin mining's present and future environmental impact.

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