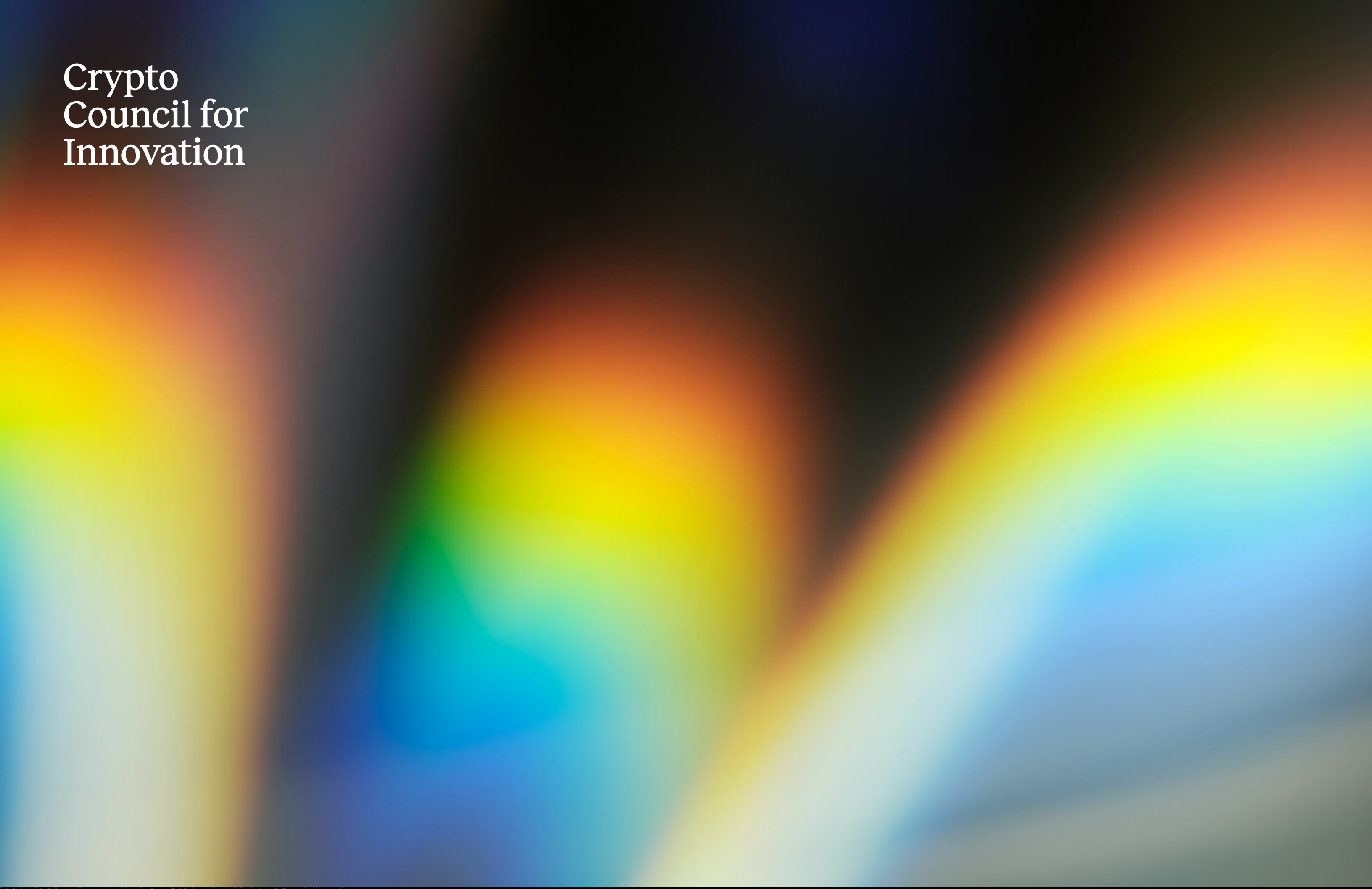

Proof of Work & Enabling the Energy Transition

Case Studies

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Source: @sean-sinclair/Unsplash

1 Executive Summary

Source: @AnnaStills/Envato

As the world transitions towards a future powered by zero-carbon energy sources, investments in energy infrastructure are critical. However, there are several challenges today that stand in the way of progress, including grid instability, energy transmission and storage, and harmful byproducts from current energy sources.

- **Grid Instability:** Renewable resources like wind and solar have a variable supply. That is, there are *"intermittency"* issues that result from the fact that these resources are sensitive to factors like time of day and weather.

- **Energy Transfer and Storage:** There is a geographic mismatch between zero-carbon energy resources and energy demand. Power generation often takes place in remote areas because these are optimal in terms of space and resources. However, energy is difficult to transfer, so it often does not reach the consumer.

- **Harmful Byproducts:** There has been an increasing awareness that byproducts of energy production, such as gas flaring, have significant negative environmental impacts. However, this has been a persistent challenge given that oil production frequently takes place in remote and inaccessible locations.

As a result, there are several challenges for projects focused on zero-carbon energy. To date, the answer to mismatches in energy supply and demand has been curtailment, which is costly and results in wasted energy. New projects are being stalled or withdrawn due to interconnection challenges – and more than 90% of requests in the US are for zero-carbon energy sources. Energy producers are being forced to sell at low or negative costs. Unmitigated gas flaring emits more than 400 million tons of CO2 equivalent emissions annually.

The need for action on the energy transition is urgent – and Bitcoin mining can be an important bridge to much-needed investments and market support. These mining operations, which are – in essence simply data centers that power the Bitcoin network – are uniquely suited to address some of these challenges due to their unique combination of flexibility, consistency, and transparency. Specifically:

I. **Flexibility:** Numerous studies have found that a flexible load on renewable-powered grids can be a key solution minimizing the mismatch of supply and demand. Bitcoin mining operations are flexible on two critical axes: (1) location and (2) demand. This means that they can access stranded sources of energy and power up and down, depending on grid conditions.

II. **Consistency:** Similarly, sustained demand at-scale is important. Typical demand for energy varies based on several factors such as time of day, population, etc. Consequently, markets for renewable energy sources can face periods of low demand, which affects their market prices and business models. Mining can serve as a consistent source of demand, reducing the need for costly curtailment.

III. **Transparency:** Bitcoin, and crypto more broadly, provide a new model for engagement with energy more broadly. The transparency of the industry means that data that can be used to inform decision-making – and, it can provide a model for greater accountability.

This paper aims to surface examples of sustainability-focused operations and provide new insights into and data behind their approaches. The case studies featured in this report represent nearly two dozen sites across the US, taking various approaches to sustainable operations. [1]

This includes:

- Utilizing flared gas as a power source to mitigate the effects of methane emissions – which has more than 80x the warming power of CO2 over a 20 year timeframe.

- Experimenting with new technology for cooling, which makes up an estimated 40% of energy consumed by mining operations.

[1] The data used in this report is timestamped 1 June 2023.

- Balancing grid instability by powering mining operations up or down within a 5-15 second timeframe.

- Building brand-new renewable energy sources, which represent more than 3 GW of added renewable energy to the grid in the long-run.

The companies in this report have made hundreds of millions of dollars of investments in sustainable infrastructure powered by local communities. They have added hundreds of jobs in areas facing the effects of industrial decline. Together, they make up almost 3,000 MW of planned and existing capacity designed to answer some of the most pressing challenges facing US grids today. Where energy mix data was available, they are powered by over 91% zero-carbon energy sources – and in some cases, have carbon negative operations.

Throughout the case studies, one thing became clear: the business models are powered by the unique properties of Bitcoin mining operations. While other use cases may follow, mining had to be the starting point to make the economics work for investing in these zero-carbon energy sources. Indeed, many of the case studies featured aim to expand their businesses to scale up environmental benefits – but these expansions are powered by the original Bitcoin use case.

While this paper does not focus on crypto, Bitcoin, or blockchain themselves, it is worth highlighting why this conversation matters beyond the energy transition. Crypto and blockchain technology are opening new possibilities for the digital economy. Creating options for individuals to interact and transact in a disintermediated manner has enormous implications for digital money, data ownership, identity, and beyond. Proof of Work, the consensus mechanism that underpins the Bitcoin blockchain was the starting point for these conversations. Its system of economic rewards design uniquely makes “cheating” expensive and incentivizes honest behavior.

This paper: (1) Provides an overview of Proof of Work, including why it matters and the features that make it well-suited to supporting a transition to a zero-carbon future; (2) Highlights case studies of the operations and business models of sustainability-focused Bitcoin mining operations; (3) Offers concluding thoughts and recommendations. We hope that these findings will illustrate potential pragmatic paths forward, given that this issue is critical to so many sectors. The paper also outlines the consequences of inaction for the US innovation and climate agendas.

2 Introduction

Source: @AlexanderLipko/Envato

As crypto increases in value and prominence, there have been discussions about the industry's energy use, environmental impact, and approach to sustainability. These are important conversations that should happen and be approached in a nuanced and evidence-based manner. This paper aims to be a starting point for Bitcoin mining and Proof of Work.

Specifically, it will examine the ways in which Bitcoin mining operations can fuel long-term markets for zero-carbon energy sources, creating a sustainable business model for wind, solar, nuclear, and flared gas. The cases examined in this report are real projects that can provide a roadmap for other projects and the financial services industry.

Importantly, this paper covers a specific subset of Bitcoin mining operations and does not necessarily reflect all such operations, although on the whole, Bitcoin mining is increasingly more sustainable than many comparable data center operations. Rather, it aims to surface examples of sustainability-focused operations and provide new insights into and data behind their approaches. The case studies featured in this report represent more than 20 sites across the US that are taking various approaches to facilitating a zero-carbon future. The companies have made hundreds of millions of dollars of investments in sustainable infrastructure powered by local communities. Together, they make up over 3,000 MW of capacity designed to answer some of the most pressing challenges facing US grids today. Cases were selected based on a focus on sustainability, data availability, and voluntary participation of case study companies.

The Bitcoin mining industry believes it is important to approach the energy policy discussion from a holistic, use-case agnostic perspective of how mining operations can be made more energy efficient overall. Getting to an accurate understanding of Bitcoin's impact requires going beyond simplified measures of energy use and accounting for the energy mix used, how it may support the market for renewables, and how the underlying technology may be used to aid climate efforts. It should also take account of the wider benefits from supporting a diversified, resilient energy grid, such as for US economic competitiveness, and for national security. The industry is interested in being a part of the solution and many participants have already invested significant resources into research and innovation on this front.

This paper proceeds in three parts: (1) Providing an overview of Proof of Work, including why it matters and the features that make it well-suited to supporting a transition to a zero-carbon future; (2) Highlighting case studies of the operations and business models of sustainability-focused Bitcoin mining operations; (3) Offering concluding thoughts and recommendations.

3 Proof of Work and its role in the energy transition

Source: @jean-beller/Unsplash

A once-in-a-generation technology and opportunity, we have already seen the immense social value of crypto and in action – quickly and transparently mobilizing funds during times of crisis, providing a lifeline in contexts of authoritarianism and instability, and in inspiring new possibilities in art, financial services, identity, and beyond. Bitcoin is a subset of the overall crypto industry and that offers a new model for both money and value exchange. The Proof of Work mechanism created to validate all Bitcoin transactions is at the heart of the energy debate, but as demonstrated by the cases, it can be an important piece of the puzzle in the energy transition.

What is Proof of Work?

Consensus mechanisms are core to enabling this trust. Other models involve a centralized intermediary managing a private ledger. These intermediaries served as "trust brokers" charging for service provision and acting as a decision-making authority around access to and incentives within the system. History has shown that these intermediaries can represent points of failure, fraud, or exploitation.

Using consensus mechanisms[2] , this responsibility is decentralized. Nodes that operate globally are responsible for agreeing to, updating, and maintaining a shared, publicly visible ledger. Through economic incentives, consensus mechanisms simultaneously disincentivize malicious behavior, by making "cheating" expensive, and incentivize honest behavior, by providing rewards to honest network operators. Each consensus mechanism has tradeoffs involved related to factors like environmental footprint, network security, scalability, concentration risk, etc. The Crypto Council for Innovation does not favor or endorse any one approach, and an evaluation of tradeoffs is ongoing and also beyond the scope of this paper.

The best-known example is Proof of Work. Under Proof of Work, nodes within the network "work" to add new records to the ledger by conducting complex mathematical computations. The quickest receives compensation called a block reward. Transaction fees represent the other form of compensation for nodes. Proof of Work is currently used by the Bitcoin network, the largest blockchain network by market cap. This enables:

I. **Openness:** Allowing anyone to join the network to validate transactions

II. **Integrity:** Providing on-chain rewards to incentivize validators to behave in line with the shared interests of the network and disincentivize fraud thereby preserving security as the network grows in size;

III. **Fairness:** The reliance on random and complex mathematical computation removes the need for human-designed governance algorithms, instead relying totally on cryptography & economic principles.

Of course, this is a simplified explanation. For those looking for more information on how Proof of Work operates, we recommend the following resources:

- Bitcoin: A Peer-to-Peer Electronic Cash System (Bitcoin White Paper)
- What is Bitcoin mining, and why is it necessary?

There are specific properties of Proof of Work, and the associated Bitcoin mining operations, that make it well-suited to enable zero-carbon energy markets.

[2] More information about consensus mechanisms can be found here: https://www.coindesk.com/learn/what-is-a-consensus-mechanism/

It is important to mention another well-known consensus mechanism is Proof of Stake (PoS). Under PoS, nodes provide tokens as collateral – known as staking – in order to participate in validating blocks on the network. In the event of dishonest or malicious behavior, the collateral can be destroyed. The Ethereum network, the second-largest by market cap, migrated to PoS in 2022. More information can be found here: https://ethereum.org/en/developers/docs/consensus-mechanisms/pos/

What are the properties of Proof of Work that enable zero-carbon energy markets?

There are currently significant challenges with next-generation energy infrastructure. These challenges are resulting in a mismatch between supply and demand – with negative impacts on new and existing projects.

The need to quickly scale up zero-carbon energy sources and associated infrastructure has been well-documented and widely recognized. States are responding in turn and investing heavily in wind, solar, nuclear, and beyond. However, the pace of adding these resources to the grid has led to several challenges.

Grid Instability

Renewable resources like wind and solar have a variable supply. That is, there are *"intermittency"* issues that result from the fact that these resources are sensitive to factors like time of day and weather. The sun doesn't always shine, and the wind doesn't always blow. So, the frequency and voltage of production is somewhat unreliable.

Breakout Box
West Texas & the ERCOT Market

There has been widespread coverage of an increase in crypto data center operations in Texas. This is, in part, because the Electric Reliability Council of Texas (ERCOT) grid has unique features that enable win-win partnerships. Texas has an isolated grid, meaning that it cannot import power from neighboring areas. This makes the ERCOT grid particularly sensitive to demand spikes and grid instability. The issue is exacerbated by the intermittency of renewables.

West Texas is a particularly relevant area – it has approximately 34 GW of power generation, but only 12 GW of transmission. For context, ERCOT West accounted fo 60% of ERCOT's total curtailments – and both wind and solar curtailments have been on the rise in the ERCOT grid as a whole. As of May 2022, ERCOT was tracking 1,017 interconnection requests totaling 199,119 MW. This includes 106,920 MW of solar and 19,544 MW of wind.

Importance of flexible loads to ERCOT
Research by energy experts found that operating flexible data centers would lead to less natural gas being built and a net-reduction of carbon emissions by 2030, when compared to a base case with no data centers and an alternative case of inflexible data centers. The research also found that "data centers can increase the resiliency of the grid by reducing demand during high-stress times (low reserves) on the grid."

The Dallas Federal Reserve suggests that expanding such demand response programs could help prevent blackouts. ERCOT estimates that these programs will "shave 2,900-4,700 MW off peak demand in the next five years."

Energy Transfer & Storage Challenges

There is a geographic mismatch between zero-carbon energy resources and energy demand. Power generation often takes place in remote areas because they are optimal in terms of space and resources. However, energy is difficult to transfer, so it often does not get to the consumer.

The difficulty of transferring and storing energy has led to grid "congestion." Subsequently, periods where there is excess supply – especially in areas that are making significant investments in renewables. Research into increasing the efficacy of transfer and storage methods is underway, but early. For now, the math on these projects isn't adding up.

New renewables projects are being stalled or withdrawn. A report from the Department of Energy found that transmission deployments fell from an average of 2,000 miles from 2012-2016 to an average of 700 miles from 2017-2021. This is happening at a time that an increasing number of projects – especially renewables projects – are seeking to connect to the grid. In fact, a recent study found that there are 1,400 GW of generation and storage capacity seeking connection to the grid. Over 90% is for zero-carbon energy sources.

In addition to the withdrawal of projects, "those that are built are taking longer on average to complete the required studies and become operational." It took 3.7 years on average for a project to come online after entering the queue – up from 2.1 years on average in the previous decade. Only 20% of wind power and 16% of solar power projects in interconnection queues have successfully connected to the grid and begun operations in the past decade.

Studies have shown that the price tag for integrating these clean energy projects will be hundreds of billions of dollars, and that interconnection represents a significant barrier for new projects. Additional work has identified a number of challenges related to the transmission construction needed for electricity system decarbonization. This includes, but is not limited to: complexity in permitting between the federal, state, and local levels, difficulties with cost allocation, and the potential for local opposition. Policymakers and regulators are taking note. In the past year, there have been new initiatives such as the Interconnection Innovation e-Xchange (i2x) and "Building a Better Grid" to specifically examine and address these issues.

At the same time, existing projects are forced to limit supply and sell energy below market cost. These infrastructure issues have meant that renewable energy produced is often unable to reach the end consumer. This results in overproduction of energy, meaning that the energy is priced below market value. Some regions have even seen negative pricing, wherein it is cheaper for energy producers to pay consumers to take generation than to curtail.

Harmful Byproducts

There has been an increasing awareness that byproducts from energy production, such as gas flaring have significant negative environmental impacts. The World Bank estimates that flaring results in more than 400 million tons of CO_2 equivalent emissions annually. The Environmental Defense Fund estimates that methane has 80x the warming power of CO_2 in its first 20 years, and that at least 25% of today's global warming is driven by methane from human actions. According to Scientific American, "While CO_2 persists in the atmosphere for centuries, or even millennia, methane warms the planet on steroids for a decade or two before decaying to CO_2."

However, this has been a persistent challenge given that oil production frequently takes place in remote and inaccessible locations. It is estimated that the cost of ending all routine flaring could be as much as $100 billion because of the challenges associated with capturing, storing, transporting, and distributing gas.

Bitcoin mining operations can be flexibly co-located with "stranded" energy sources like flared gas – offering a potential mitigation strategy for this harmful byproduct. In fact, the Cambridge Center for Alternative Finance estimates that the global gas flaring recovery potential could power the entire Bitcoin network 7.8 times.

Breakout Box The Cost of Curtailment

To-date, the answer to mismatches in supply and demand has been curtailment – which is costly and results in wasted energy. Curtailment is the practice of reducing the supply of renewable resources to stay in balance with demand.

We see this in the data. For example, California has a goal of moving state utilities towards a 50% mandate. As such, renewables projects are being built rapidly – and with it, the amount of curtailment has been on the rise. In 2015, the ISO curtailed over 187,000 MW-hours (MWh) of solar and wind generation. They curtailed 596,175 MWh – over three times as much – in April 2022 alone.

The story is the same globally. In the Sichuan, China, the hydropower produced is more than double the capacity of the power grid – meaning lots of wasted power that could power the Bitcoin network 1.3 times. In the United Kingdom, the estimated cost of curtailing wind alone hit a record high of £507 million in 2021 – up from £299 million the previous year.

The flexibility of Bitcoin mining operations provides a market for resources that may otherwise be subject to curtailment. In fact, an academic study found that deploying Bitcoin data centers at renewable power plants could reduce 50.8%-79.9% of the curtailment in CAISO – resulting in millions of dollars of profit that would have been otherwise lost.

Bitcoin mining operations offer a unique combination of flexibility, consistency, and transparency that can address these challenges.

I. **Flexibility**

Numerous studies have found that a flexible load on renewable-powered grids can be a key solution minimizing the mismatch of supply and demand. In fact, the California ISO states: "green grid reliability requires flexible resource capabilities." Bitcoin mining operations are flexible on two critical axes: (1) location and (2) demand.

Because of the interconnection and storage issues, a Bitcoin mining operation that is flexible on location can capture "stranded" energy sources. This means that energy that might otherwise be wasted or curtailed can go towards sustainably powering mining operations, providing a market where there otherwise would not have been once. Accordingly, research has found that dispatchable data centers reduce stranded power and improves grid cost and stability. This is also important for the economic and social impact of Bitcoin mining operations, as they provide jobs and local revenue in areas that are often feeling the impacts of industrial decline.

Intermittency challenges with renewable energy sources mean that flexible demand is critical as well. Bitcoin mining operations can be started and stopped in a unique manner – meaning they have an interruptible load. Recognizing this need, grids have set up demand response (DR) programs to smooth demand. Using contractual curtailment, Bitcoin mining operations can reduce their demand when power prices are surging, helping to alleviate potential pressures on the grid. In fact, the International Energy Agency found "500 GW of demand response should be brought onto the market by 2030 to meet the pace of expansion required in the Net Zero Emissions by

2050 Scenario (NZE), a tenfold increase on deployment levels in 2020."

II. **Consistency**

Relatedly, sustained demand at-scale is important. Typical demand for energy varies based on several factors, such as time of day, population, etc. Consequently, markets for renewable energy sources can face periods of low demand, which affects their market prices and business models. Research shows that renewable energy sources may not be economically viable as standalone operations but could be through integration with data centers like those used in Bitcoin mining operations.

III. **Transparency**

Bitcoin provides a new model for financial services and data centers more broadly. The transparency of the industry means that data that can be used to inform decision-making – and, it can provide a model for greater accountability.

We have seen that measuring energy use for something as complicated as money can be challenging. For example, one analysis of the banking system's energy usage looks at banking data centers, bank branches, bank ATMs, and card networks. Their assessment, which finds that Bitcoin has lower estimated energy consumption than the banking system, excludes clearinghouses and other aspects of the financial system. Overall, this is an area that has been relatively under studied to date.

"How Green is the Greenback? An Analysis of the Environmental Costs of Cash in the United States" by the Fletcher School at Tufts University found that the environmental impact of cash in the United States exceeded that of Bitcoin by a factor of almost 10 – $12.9 billion versus $1.3 billion, respectively. As the calculations highlight, cash production involves several environmental costs including water, electricity, fuel, and sludge. Importantly, these measurements do not account for the aggregate global footprint of cash, just one country. This supports conclusions from studies of the environmental impacts of cash and debit card payments in the Netherlands, which found that there were significant environmental impacts from operating the systems.

Still, academic literature has suggested that the unique combination of decentralization, interconnected autonomy, openness, and intelligence makes blockchain technology a key enabler of a variety of energy-related use cases. These include peer-to-peer energy transactions, efficiency gains in electric vehicle charging, carbon emissions certification and trading, synergy of the multi-energy system, and more.

As the Bitcoin industry develops, the financial system will become more measurable over time. Analysis of the real-time and transparent data that Bitcoin provides will support educated steps towards energy efficiency and a greener future.

How can Bitcoin mining operations serve as a “bridge” for the market?

Given the current infrastructure challenges and long-term view of crypto as a general matter, Bitcoin mining operations can serve as a critical “bridge” for the market.

While programs aim to build this critically needed infrastructure, Bitcoin mining operations are available to provide an economically aligned market for these resources. Investment in renewables is needed urgently, and the flexibility of Bitcoin mining operations can fill the void.[3]

There are two main categories of sustainability-focused operations:

- **Front of the meter:** Front of the meter approaches are grid-connected, meaning that resources are passed through an electric meter. Renewables are then purchased from the grid. These mining operations add demand for renewables to the grid.
- **Behind the meter:** Behind the meter approaches are connected to a generation facility. This includes facilities that utilize energy from on-site generation and alternative approaches such as flared gas-powered mining operations.

These approaches can be complementary; this paper includes case studies from both.

Crypto, especially Bitcoin, can be a bridge asset for early-stage investments. If the US wants to remain a leader and meet ambitious climate targets, time is of the essence. Large-scale investments and a reliable market for renewables is needed now. As this paper demonstrates, the technology and willingness are available to support this need.

This is particularly relevant given that the incentives of the network are due to change every time. The reward for mining Bitcoin halves approximately every four years – and the supply is capped at 21 million Bitcoin. These factors will affect the energy demand of Bitcoin mining operations over time.

[3] One example of investment in renewable energy is Block’s Bitcoin Clean Energy Initiative, which has a mission of investing in clean energy Bitcoin mining initiatives to help unlock innovative solutions for the industry.

Aspen Creek Digital Corporation (ACDC) and additive renewables buildouts

Aspen Creek Digital Corporation (ACDC) is data center company that focuses on new renewable buildouts to power Bitcoin data centers. Billing itself as a “power first” company, ACDC has prioritized building renewable infrastructure to support data center operations. The company plans to build more than 3 GW of wind, solar, and battery generation – equivalent to a medium-size city’s usage – by early 2025.

Notably, the company builds out more power than is used for their crypto data centers, with the intention of supplying renewable power to local communities. The company estimates it uses only two-thirds to three-quarters of the power it builds out.

For example, the three announced sites include: Speaking about this approach, CEO Alexandra DaCosta said: “If you take a step back and look at the…net-zero aspirations of the United States over the next X number of years, the fact remains that we need to be standing up far more *new* renewable energy sources than we are currently doing.”

While the company plans to expand to other use cases, Bitcoin provided an economic model for the buildouts and is a forgiving, flexible load for the intermittent renewable energy sources.

How does this compare to alternative proposals?

Policymakers and others tend to see POW as a significant source of energy consumption and ultimately, a catalyst in the climate debate. As such, many have offered various proposals for mitigating climate effects of Bitcoin mining operations. Notable examples include a Proof of Work ban and switching to an alternative consensus mechanism.

I. **Proof of Work bans will have unintended consequences.**

Recent academic research showed that actions taken by China to ban Bitcoin mining operations worsened its environmental impact, increasing its carbon intensity by 17%. This is unfortunate, given that Bitcoin mining operations' flexibility allowed them to consume excess hydroelectricity during Sichuan's rainy season.
Moreover, these efforts were ineffective in curbing this activity. New data from the Cambridge Centre for Alternative Finance showed that the quelling effects of the ban were temporary, with activity re-surging following a short gap.

II. **A transition to an alternative consensus mechanism takes research and time.**

Some have suggested that a shift to an alternative consensus mechanism is a potential avenue for reducing the environmental impact of Bitcoin mining operations.

Developer ecosystems are proceeding with caution in crafting these changes and shipping them to the main networks, whilst carefully considering the benefits and drawbacks of any such change For instance, the Ethereum network's shift to Proof of Stake was a years-long process, starting in 2015. "The Merge" involved hundreds of developers and a multi-million-dollar research and development budget. Implementing protocol-wide changes does not happen in the way that it might with centralized companies. There are rounds of community feedback, international collaborations among developers, and governance via open processes. Given the market caps of Bitcoin, caution is key to avoid devastating losses for the hundreds of millions of consumers within the ecosystem.

Moreover, the variety of consensus mechanisms in the industry is by design. The industry does not want to operate under one singular consensus mechanism for a variety of reasons, many of which stem from the pros and cons of exactly how each consensus mechanism works. Because these consensus mechanisms are relatively new in terms of technology, governance, and incentives, there are still unknown unknowns – and the multiplicity is part of understanding what works and under what conditions.

4 Case Studies

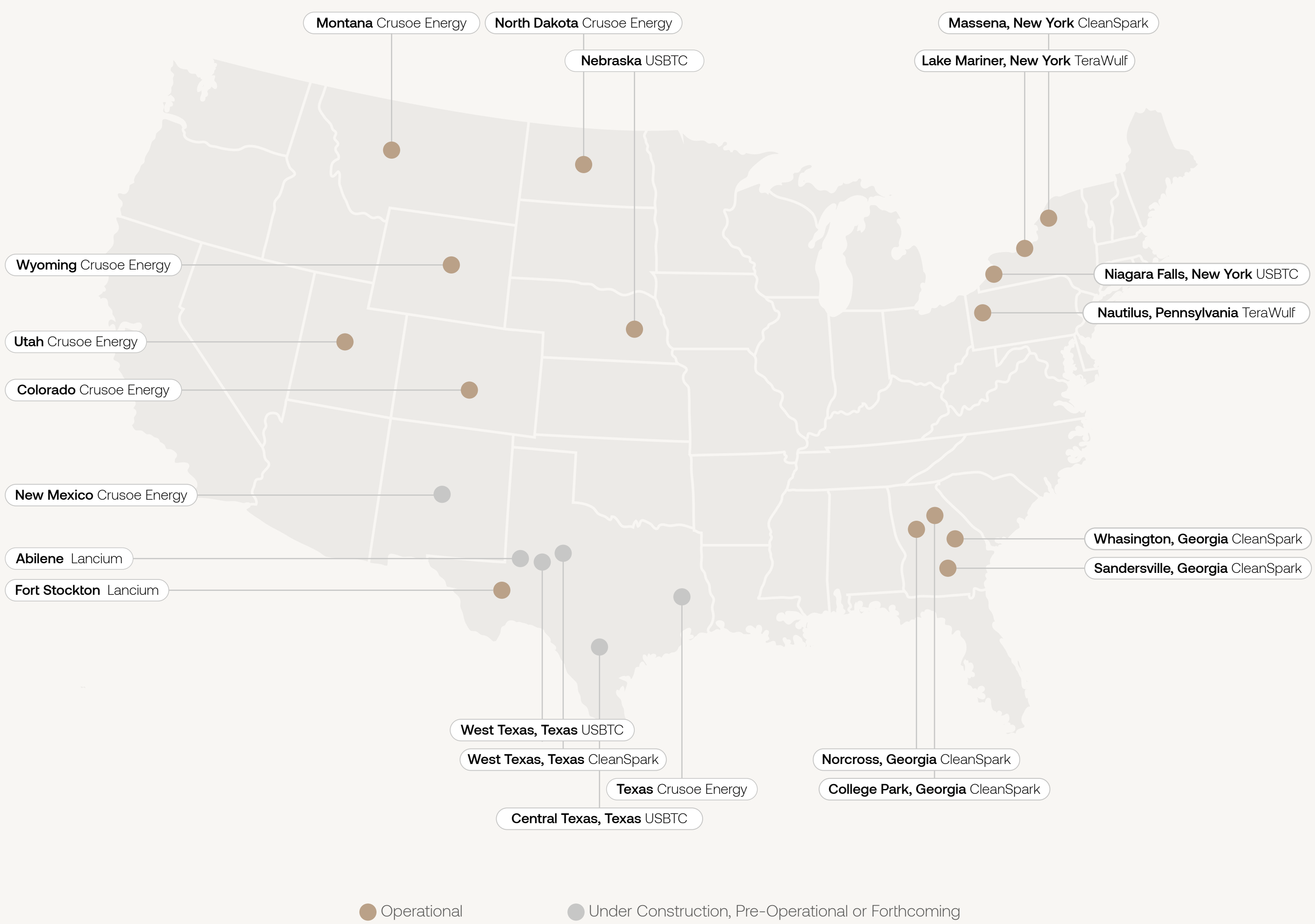
Source: @nasa/Unsplash

Overview

The case studies featured in this report represent more than 20 sites across eight states in the US, taking various approaches to sustainable operations. They are powered by varying zero-carbon sources including hydro, solar, wind, nuclear, waste flare gas, and biomass.

The companies have made hundreds of millions of dollars of investments in sustainable infrastructure powered by local communities. They have added hundreds of jobs in areas facing the effects of industrial decline. Together, they make up more than 3,000 MW of capacity designed to answer some of the most pressing challenges facing US grids today. Where energy mix data was available, they are powered by more than 90% zero-carbon energy sources, and in some cases, have carbon negative operations.

The data used in this report is timestamped 1 June 2023.



Case 1 Crusoe Energy

Flared Gas-Powered Mining Operations

Crusoe

Founded	2018
State(s) and Status	Colorado – Operational Montana – Operational New Mexico – Forthcoming North Dakota – Operational Texas – Forthcoming Utah – Operational Wyoming – Operational
Energy Challenges Addressed	Energy transmission and storage Harmful byproducts
Energy Mix*	100% Carbon-Negative Sources (Methane-Reducing)
Approach	Behind the meter

Business Data

Employees	275-300
Local jobs created	180-200 (~2/3 of company)
Business model	Bitcoin rewards Cloud computing and data center hosting

* Excludes grid power consumed at corporate offices, warehouses and manufacturing sites. 100% of grid power used is renewable, backed by the purchase of Renewable Energy Certificates (RECs) following the company's annual carbon accounting process led by Crusoe's Senior Director of ESG.

Overview

Crusoe Energy is a clean computing infrastructure company that powers its data centers using otherwise flared gas, a wasted byproduct of oil production. In oil fields across the United States, natural gas is wastefully burned in open flares where gas pipeline infrastructure is not available or when gas transportation capacity on existing pipelines is constrained or delayed. Nearly 140 billion cubic meters of natural gas is flared around the world annually, enough to power the entire Bitcoin network many times over if captured and used. The US is the sixth largest flarer of natural gas behind only Russia, Iraq, Iran, Algeria and Venezuela.

As discussed, flaring has significant negative environmental impacts, including CO2, methane, and smog-forming compounds being emitted into the atmosphere. Methane emissions are particularly concerning given that methane has more than 80x the warming power of CO2 on a 20-year timeframe. In addition to clear environmental drawbacks, flaring is wasteful and an example of commercial inefficiency, in need of a better solution.

Crusoe deploys its patented Digital Flare Mitigation® technology to capture this wasted gas and convert it into electricity used to power on-site modular data centers that are used for energy-intensive computing applications such as Bitcoin mining, artificial intelligence (AI) training, machine learning, and graphical rendering. Bitcoin mining operations were Crusoe's first use case because of the technology's energy intensity, meaning that these data centers can harness a substantial amount of the otherwise wasted gas in order to move the needle on large flaring volumes.

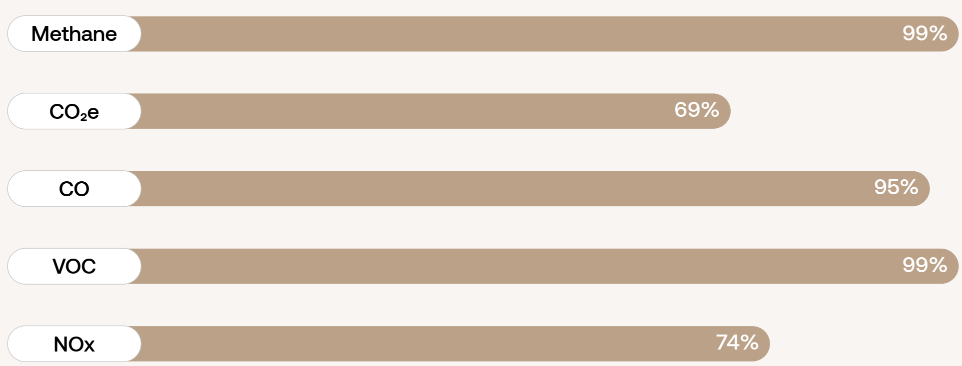
Data centers powered by flared gas provide several environmental and economic benefits. Crusoe's data centers provide a 69% reduction in CO2-equivalent (CO2e) emissions compared to the status quo of continued flaring.[4] In this way, Crusoe goes beyond carbon neutrality and delivers a carbon-reducing computing platform by eliminating methane emissions that would have otherwise persisted. Specifically, Crusoe's systems capture and eliminate 99.9% of the methane stream, converting that fuel into electricity used on-site by its modular data centers. This approach produces a 99% reduction in methane emissions relative to continued flaring. The crypto data centers also significantly reduce emissions of air pollutants like volatile organic compounds (VOCs), nitrogen oxides (NOx) and carbon monoxide (CO), which are smog-forming compounds.

Importantly, Crusoe targets stranded natural gas i.e. gas that does not have access to a pipeline. As outlined earlier in the paper, crypto data centers are location agnostic, meaning that they can co-locate with oil and gas producers. In powering these modular data centers, oil companies can monetize a resource that would otherwise be wasted, producing revenue where there would have been none. This incremental revenue contributes to state and local taxes as well as royalty revenue for land and mineral owners.

[4] Based on 20-year GWP for methane, gas composition with 93% methane, and average flaring combustion efficiency of 91.1% based on the latest research from University of Michigan (Plant, et.al., Science, Sept 29, 2022).

FIGURE 1

Relative to continued flaring Crusoe's Patented Digital Flare Mitigation® systems eliminate emissions up to



An environmental focus is at the core of Crusoe's operations. Crusoe uses a "Sustainable Project Selection Framework," which evaluates and prioritizes projects based on environmental merits. Using this framework, it chooses to invest capital in the most environmentally beneficial projects when selecting and structuring projects. This approach includes a careful focus on mitigating waste gas flaring and not incentivizing drilling that wouldn't otherwise take place on the basis of pure oil economics. Crusoe also created an executive level position to develop and administer its sustainability policies on an ongoing basis.

Operations

Crusoe co-locates its digital flare mitigation systems directly on oil well pads to convert flared gas into computing power. Each system captures approximately 300,000 cubic feet of natural gas per day, powering modular data centers with about 1.8 MW of computing load. Given that each site is different, they operate in a flexible manner and can add as many systems as needed for a given site. As of the end of 2022, Crusoe operated more than 125 data centers across Colorado, Montana, and North Dakota. The team has announced plans to expand into New Mexico, Texas, and Utah. In total, its systems have prevented more than 6 billion cubic feet of natural gas flaring since the company's founding.

Crusoe's digital flare mitigation systems include power generation, electrical and computing equipment, and the modular data centers themselves. Crusoe directly manages the transportation, logistics, installation, commissioning, and operation of its systems with a team of nearly 300 employees. Crusoe's modular and mobile design, and the data centers' ability to operate via satellite and other wireless internet connections, means the operations can be located anywhere, which is a key feature for mitigating flaring in remote locations.

Founded in 2018, the team began with a pilot in Wyoming. Crusoe created a custom-manufactured digital flare mitigation system with a modular data center that it deployed to a site that was flaring gas. The system powered 264 ASICs, which are computers designed for the computing workloads of crypto processing. Following a successful pilot, the company raised multiple rounds of venture capital funding and has scaled up its operations quickly.

On the policy and regulatory side, Crusoe follows permitting procedures as outlined by the administering states or, in the case of federal lands, the Environmental Protection Agency. Some states, like North Dakota, have created tax credits for producers that utilize flare mitigation systems. These credits provide additional incentive for operators to partner with companies like Crusoe to make productive use of stranded energy resources. In addition, Colorado provided Crusoe with a job growth incentive tax credit worth up to $3.8 million as it increases tech-based employment in the state.

Business Model

Crusoe forges partnerships with oil and gas companies looking to mitigate the environmental impacts of gas flaring. It's solution is typically provided at no-cost to operators. Partnerships noted in the press include Devon Energy, Enerplus, Kraken Oil & Gas, Exxon, and others. Crusoe's robust in-house logistics, supply chain, engineering, and operations capabilities enable DFM systems to be deployed and commissioned within one week and operated with the highest environmental and safety standards.

A key part of Crusoe's economic model is capturing flared gas that would otherwise be wasted and thus burned with zero value. Crusoe pays a nominal gas purchase price for the use of this otherwise wasted energy source and its revenue is based on Bitcoin rewards and customer fees for its Cloud and data center hosting services. Given the modular nature of Crusoe's solution, systems can be deployed based on the gas volumes produced at a particular site. Crusoe has worked with operators of all sizes to deploy digital flare mitigation systems that range from 2 MW to more than15 MW. In areas with multiple flaring well pads, Crusoe has developed a system of centralized delivery points. Operating on-site data centers is distinct from other solutions for flare mitigation, such as those that attempt to compress or liquefy gas for transportation to an end market These are expensive and only economical when the price of natural gas is high, making it a more reliable and cost-effective solution for operators.

Crusoe has also placed a large focus on job creation and skills development. Employing nearly 300 individuals, Crusoe distributed more than $30 million in annual payroll in 2022 in addition to partnering with hundreds of local vendors and contractors. Crusoe operates in many remote areas where local economies are historically driven by the commodity cycles of oil and gas. Opportunities for upskilling and entry into technology-oriented careers have generally been limited in these communities. Crusoe has created pathways to new careers in these areas through its apprentice electrician and field network engineer training programs. These provide pathways for training and mobility, and access to steady, reliable, well-paying jobs in rural communities.

At 24% non-white, Crusoe's workforce is more diverse than the oil industry, which has an average of 17% non-white employees. Additionally, unique even among technology companies, 100% of Crusoe's full time employees are equity holders in the company, and collectively share in its financial success.

Case 2 CleanSpark

Immersion cooling for renewables-powered data centers

CleanSpark

Founded	
	1987, shift to Bitcoin focus in 2020
State(s) and Status	
	Massena, New York – Operational Norcross, Georgia – Operational College Park, Georgia – Operational Washington, Georgia – Operational Sandersville, Georgia – Operational
Energy Challenges Addressed	
	Energy Transfer and Storage Grid Stability Data Center Cooling
Energy Mix	
	94% clean energy (100% targeted)
Approach	
	Front of the meter

Business Data

Employees	
	130+
Local jobs created	
	90+ at facilities in Georgia
Business model	
	Bitcoin rewards Publicly traded

Overview

CleanSpark is a publicly-traded, clean energy-focused company. Originally focused on energy and microgrids, the company was founded in 1987 and migrated to a focus on Bitcoin mining operations in 2020. As of their last disclosure, CleanSpark uses 94% clean energy and operates across the US. Its goal is to ultimately operate using 100% renewable energy.

The company invests in building mines where there is excess clean power, especially in picking up distressed assets. CleanSpark then invests in the infrastructure to re-purpose these structures into zero-carbon focused data centers.

It's mining operation in Norcross is one of the first large-scale crypto data centers to use immersion cooling as a mechanism for increasing the efficiency of miners, lowering noise, and extending the lifecycle of the hardware.

Breakout Box
Immersion Cooling

Estimates suggest that up to 40% of energy consumed by data centers – both within and outside of crypto – goes into cooling. As such, some data centers have been looking into this aspect as a mechanism for mitigating climate impacts. One such approach is immersion cooling.

Immersion cooling technology has been used by miners for almost a decade, although it has increased in popularity with crypto data centers relatively recently. Under this model, machines are immersed in flowing synthetic oil that is designed to absorb machine-generated heat. Though the machines are designed for air cooling, but CleanSpark removes the fans and opens the unit, so that the fluids can flow across the systems.

This is instead of an air-cooled approach, which uses fans. Research comparing air cooling and immersion cooling found "a reduction of about 50% in energy consumption and a reduction of about two-thirds of occupied space."

CleanSpark uses immersion cooling as a mechanism for increasing the efficiency and lifespan of hardware. The company estimates that this approach – in combination with adding software that allows the equipment to "overclock" – allows for 20% more hashpower than average rates at their Norcross facility. CleanSpark also estimates that this approach extends the life of a miner from five years to seven years.

This is also designed to reduce noise. As one journalist who visited a CleanSpark site noted, "The first thing you notice about CleanSpark's new 20MW immersion mining facility in Norcross, Georgia: It is not loud."

Watch more: CleanSpark has published behind-the-scenes videos of immersion cooling and facility operations.

Because CleanSpark aims to purchase energy where there is an excess supply, the price of energy is low compared to other data centers.

Operations

CleanSpark has four sites that it owns and operates in Georgia, plus co-locations in New York. In total, the company has approximately 67,700 operational miners that have produced more than 4,600 Bitcoin in 2022. Each site operates slightly differently due to proactive planning in partnership with local authorities and stakeholders.

The company begins with evaluating potential sites according to the power sources. Criteria include whether the site can operate with *more than 90%* renewable sources percent renewable sources, whether the site has excess power, what the projected power costs will be, and whether there are any curtailment benefits in the area.

Another axis of decision-making revolves around whether the community wants data centers there. Most sites are remote and deliberately designed to minimize impacts on local communities. In conversations with local leaders, the company emphasizes jobs and local revenue that will be created, and the ultimate decision is made from there.

Once an agreement has been made, the company is able to get operations up and running quickly. At the Washington site, it took three weeks from the Day 1 takeover to get 10,000 machines up and running. CleanSpark purchases the pods from US-based countries and plans to use local contractors and build out local supply chains for site expansions.

CleanSpark purchases energy from the grid via partners like Georgia Power and MEAG. The source of energy varies depending on the site. In Georgia, this power is largely nuclear, but includes other renewables in the mix as well.

Business Model

CleanSpark emphasizes the role of Bitcoin, low-cost energy, and market timing as key elements of its business model and strategy.

The company uses Bitcoin rewards to fund operational and capital expenditures, which is key to its growth strategy. In May 2023, the company received 609 Bitcoin, which brought the year-to-date rewards to 3,004. In the same month, the company funded growth through the sale of 471 Bitcoins, which yielded profits of approximately $12.9 million.

Moreover, because CleanSpark operates in areas of excess renewables supply, the cost of energy is lower than in other places. CleanSpark negotiates Power Purchase Agreements that vary from contract to contract. Given that crypto data centers provide consistent demand, power prices reflect long-term rates.

Finally, CleanSpark has had a specific focus on building and buying during bear markets. For example, in November 2022, CleanSpark purchased over 3,800 mining machines for $15.50 per terrahash, which is below the market average of $22.94 and significantly below the December 2021 high of $106.62. This has extended beyond equipment to the sites themselves. This includes, for instance, CleanSpark's acquisition of Mawson's Infrastructure Group's facility in Sandersville, Georgia in October 2022.

The company sees partnership with local communities as key to the success of its operations. This includes creating local jobs and re-investing in the community. For example, at a recent ribbon cutting for its Norcoss facility, CleanSpark highlighted that it had made $50 million in local investment to-date, with a planned investment of $145 million over five years. In addition, the company has created many local jobs with an average salary of $48,000 per year and granted five scholarships for computer science students seeking an associates degree at a local community college.

Case 3 TeraWulf

Fully-integrated zero-carbon facilities

Founded	2021
State(s) and Status	Lake Mariner, New York – Operational Nautilus, Pennsylvania – Operational
Energy Challenges Addressed	Energy Transmission Storage constraints
Energy Mix	91%+ zero-carbon (100% targeted)
Approach	Behind the meter and Grid Connected
Business Data	
Employees	100 (includes affiliates)
Local jobs created	200 clean energy jobs at Lake Mariner in Barker, NY
Business model	Bitcoin rewards and transaction fees Demand response / ancillary revenues Publicly traded

Overview

TeraWulf is a company with an explicit focus on sustainable Bitcoin. It uses a combination of nuclear energy, hydro-electric power, and solar to power Bitcoin mining operations. TeraWulf's facilities consume more than 91% zero-carbon energy, with the goal of utilizing 100% zero-carbon energy sources. Its target average cost of power is $0.035 per kilowatt hour, which is significantly less than the US average of $0.167 (as of September 2022).

TeraWulf achieves its mission of industrial-scale, sustainability through vertical integration. The key to their operations is controlling the sites, building its own infrastructure and mining with proprietary mining equipment. Though capital-intensive at the outset, this is intended to provide control over low-cost sources of energy. As CEO Paul Prager highlights, the aim is "taking a local commodity which cannot travel significant distances, known as electricity, and converting it into a global store of value that can be traded globally, which is Bitcoin."

TeraWulf currently has two locations: Lake Mariner in Upstate New York and Nautilus Cryptomine in Pennsylvania. The Lake Mariner facility is powered by hydro and nuclear resources, while Nautilus Cryptomine is directly connected to the Susquehanna nuclear power station. The company mined 239 Bitcoin in April 2023.

Operations

TeraWulf began mining at its Lake Mariner facility, which is located on Lake Ontario, in March 2022. The facility utilizes 91% zero-carbon energy, primarily hydro from nearby Niagara Falls. The company currently has 60 MW operational at Lake Mariner and expects to have 110 MW of digital infrastructure, 34,000 miners, and a hashrate capacity of 3.8 exahashes per second in the second quarter of 2023.

Lake Mariner is strategically located in Upstate New York where there is low cost, and often stranded, renewable resources, primarily hydro. In addition, there are more than 1 GW of additional wind and solar projects in the zone's interconnection queue – including 207 MW of solar at Lake Mariner's node.

TeraWulf's Nautilus Cryptomine facility is the first behind the meter Bitcoin mining facility in the US that is directly connected to a nuclear power plant. A partnership with Talen Energy Corporation, the site is co-located with a 2.5 GW zero-carbon nuclear facility, the Susquehanna Steam Electric Station (SSES). TeraWulf owns a 25% stake in the joint venture with 50 MW of operating capacity and the option to expand by another 50 MW

In selecting both sites, the regulatory overlay and energy supply and demand imbalance was important. For instance, New York has been supportive of the use of excess renewables. Lake Mariner has a contract with the New York Power Authority for 90 MW of power and it is partnering to bolster demand energy response capabilities. The state of Pennsylvania has been supportive of flexible loads for nuclear energy.

Business Model

TeraWulf predominantly operates as a proprietary miner, though the company will consider hosting arrangements for available digital infrastructure. The viability of its business model is through its infrastructure-first model that results in low-cost energy – and ensuring that it is not subject to gas price volatility.

FIGURE 2

Infrastructure First Model: Illustrative Annual Gross Margin

Low power cost provides downside protection, while enabling significant upside due to operational leverage

3.5 EH/s Self-Mining and 2.3 EH/s Hosting

Period Ending Global Hash Rate (1) (EH/s)	Period Ending BTC Price (2)						
	$15.000	$25.000	$35.000	$45.000	$55.000	$65.000	$75.000
200	$87	$125	$164	$202	$241	$279	$317
225	$80	$115	$151	$186	$222	$257	$293
250	$73	$106	$140	$173	$206	$239	$272
275	$68	$99	$130	$161	$192	$223	$254
300	$63	$92	$121	$150	$179	$209	$238
325	$59	$86	$114	$141	$169	$196	$224
350	$55	$81	$107	$133	$159	$185	$211

4.0 EH/s Self-Mining and 1.8 EH/s Hosting

Period Ending Global Hash Rate (1) (EH/s)	Period Ending BTC Price (2)						
	$15.000	$25.000	$35.000	$45.000	$55.000	$65.000	$75.000
200	$90	$132	$174	$216	$257	$299	$341
225	$82	$121	$160	$198	$237	$276	$314
250	$75	$111	$147	$183	$219	$255	$291
275	$70	$103	$137	$170	$204	$238	$272
300	$64	$96	$127	$159	$191	$222	$254
325	$60	$89	$119	$149	$179	$209	$239
350	$56	$84	$112	$140	$168	$197	$225

$0-$100 million $100-$200 million   +$200 million

*Note: Data table figures represent annual gross margin in $ millions and assume 98.5% miner availability. Assumptions for host economics based on an 85/15 gross margin split, pass-through of realized market power cost, and $5/MWh service fee.
(1) Period Ending Global Network Hash Rate caculated by linearly increasing the current global network hash rate (210 EH/s as of August 31, 2022)
(2) Period Ending BTC Prices calculated by linearly decreasing/increasing the current BTC price of $20k (as of August 31, 2022)

Source: TeraWulf Investor Presentation, Feb 2023

TeraWulf's facilities provide a tool to grid operators to help balance supply and demand. Its Lake Mariner facility is currently participating in demand response programs, which provide an additional source of revenue. TeraWulf estimates that participating in NYSIO's Special Case Resource (SCR) and National Grid's Commercial System Relief Program (CSRP) across 95% of hours reduces the cost of energy by approximately $6 per MWh. The Company projects that participating in future programs like the NYSIO Frequency Regulation and Operating Reserve can reduce costs by an estimated $18 per MWh. So, the flexibility of demand is mutually beneficial and supports the economics of the business model.

TeraWulf's facilities also aim to contribute to local economic growth. For instance, TeraWulf was able to hire and train those that worked for the converted coal-fired power plant at the Lake Mariner facility. A stated goal of the company is to "produce tangible, quantifiable benefits through economic development, STEM education, and employee involvement."

TeraWulf is a publicly traded company ($WULF) and has raised approximately $400 million in capital to complete the buildout of its two mining facilities.

Case 4 Lancium

Grid-connected controllable loads

LANCIUM
BALANCING ENERGY

Founded	2017
State(s) and Status	Fort Stockton – Demonstration Project, Operational Abilene – Under construction
Energy Challenges Addressed	Grid Instability Energy Transfer & Storage
Energy Mix	Data not available
Approach	Front of the meter

Business Data

Employees	~75
Local jobs created	More than 100 local jobs (Total – HQ employees)
Business model	Bitcoin rewards and transaction fees Demand response / ancillary revenues Publicly traded

Overview

Lancium is an energy technology company, focused on controllable loads. Using its proprietary technology, data centers, including Bitcoin miners, operate in a flexible manner. Data centers can ramp up or down depending on grid conditions. Its Clean Campuses are large-scale data centers located in regions with excess renewable energy generation.

These data centers are qualified as "Controllable Load Resources" (CLRs) under the protocols of the grid operator, Electric Reliability Council of Texas (ERCOT). This differs from non-CLR facilities, which typically use more manual, crude forms of adjusting energy use. For example, using a breaker to lower power needs. On the other hand, CLRs automatically respond to grid conditions. Lancium was the first company to meet ERCOT's CLR technical requirements in 2020. Its data centers can be powered up or down within 15 seconds.

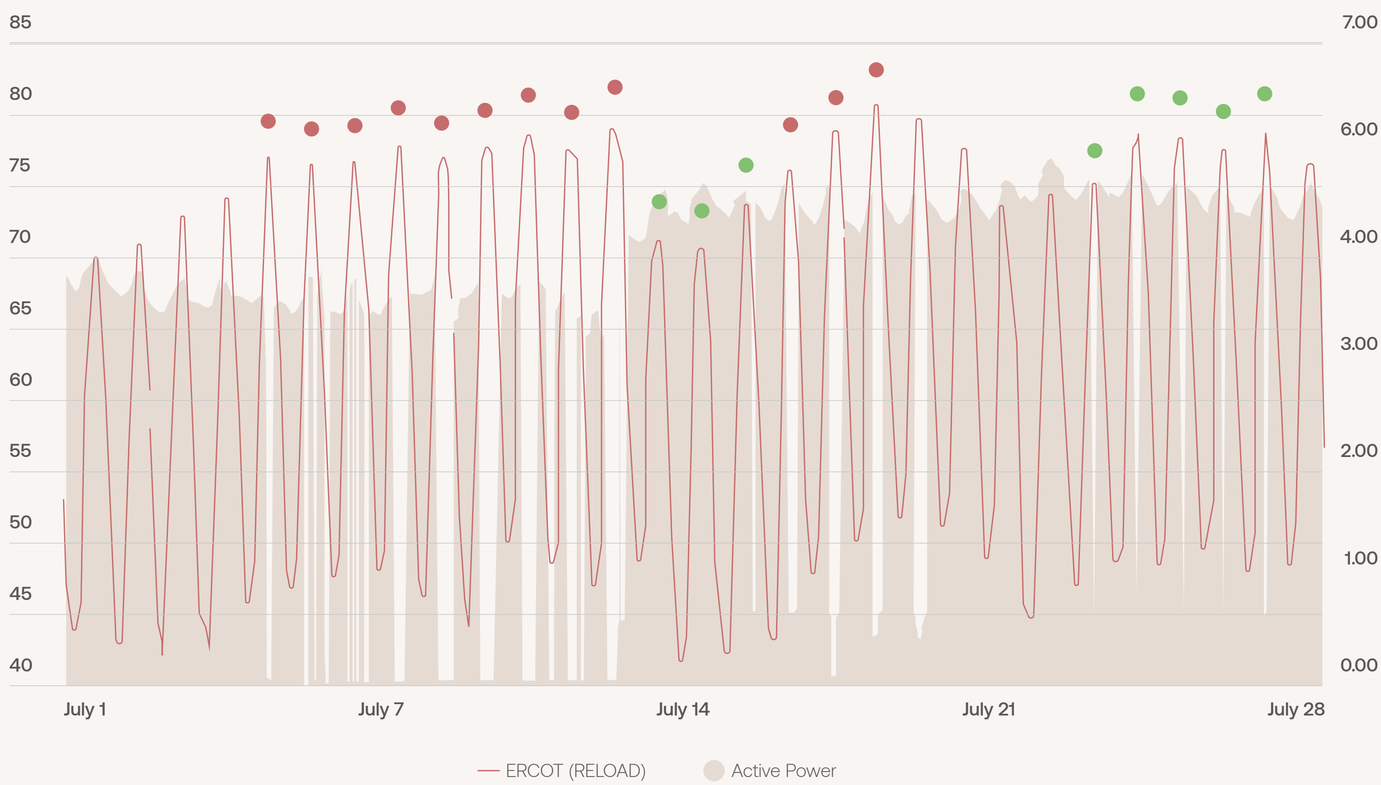
The data centers dynamically adjust power consumption based on grid conditions or energy prices. During periods of high demand, the data center operations cease. This flexibility means that, by design, the data center operations are freeing up energy for homes and businesses during periods of high demand. During times of low demand, the data centers provide grid stability ancillaries and are consistent purchasers of the energy resources. This serves as a form of insurance for the grid, in that it creates a consistent market for resources that may be under-valued otherwise.

This is not theoretical; Lancium data centers have already been consistently responding to grid conditions. For example, the figure below shows operations data for the ERCOT grid and Fort Stockton site in July 2022, which was a period that saw multiple days of record power demand. This shows the variability present in the grid and the responsiveness of crypto data centers. During periods of high ERCOT demand (red line), the Fort Stockton site reduced its demand (grey). During periods of low demand, crypto data centers were able to serve as a consistent customer for resources that may have otherwise been curtailed.

FIGURE 3

Fort Stockton Operations - July 2022

4CP Dispatch (Red Dots) and Economic Price Dispatch (Green Dots)



As highlighted throughout this report, grids that suffer from intermittency issues often rely on fossil fuel-powered Peaker Plants to provide grid stability. Using controllable loads not only facilitates renewables-powered grid stability, but operating the grid in a flexible manner can also provide energy to consumers at 50% of the market cost.

There is a significant amount of congestion in grids that are quickly ramping up their renewables production. The latest data from ERCOT shows that requests for interconnection have reached 35 GW in 2022. Higher amounts of renewables integration require a greater need for flexibility. Lancium projects exponential growth of its CLRs, as demonstrated in the Table below.

Year	Controllable Load
2019	0 MWH
2020	50 MWH
2021	100 MWH
2022	200 MWH
2023 *(projected)*	400-500 MWH

Operations

Lancium began its journey as a technology provider, helping data centers operate in a flexible manner. In 2017, a map showing energy prices indicated that there was a significant amount of negative and low-priced energy in the center of the US. This was due to a large supply of renewables. As discussed, there was a clear need for a consistent buyer of this energy that could operate in a flexible manner.

After selling their SmartResponse technology to third parties, Lancium decided to establish its own "Clean Campuses." These campuses are located in areas where there is an excess supply due to insufficient local demand and/or transmission.

The Fort Stockton campus is the first location under development. It is a more than 100,000 square-foot facility located on 110 acres in Pecos, TX. Lancium is currently testing the infrastructure and building out its Clean Campus processes, which will be scaled up at this location and others. The campus broke ground on September 15, 2021, and operations came online in 2022. The campus began participating in ERCOT's ancillary services market in mid-2022. It operated in the Texas New Mexico Power service territory.

From there, Lancium is adding a flagship location in Abilene, Texas. This location broke ground in November 2022. It will begin with 200 MW of capacity and scale up to 1 GW. With an investment over 20 years, the project is estimated to bring $993.4 million in total projected impact to the local economy. Lancium selected Texas to house its Clean Campuses because of the oversupply of renewables and due to a favorable policy and regulatory environment for flexible loads.

Shortly after breaking ground on its first Clean Campus, Lancium raised $150 million in financing. The funding round was led by Hanwha Solutions, one of the world's prominent providers of clean energy solutions.

Business Model

Lancium has three main sources of revenue:

I. Technology Licensing: Lancium licenses its SmartResponse technology so data centers can operate their loads in a flexible manner. They also provide the associate services. Though crypto was the first use case, Lancium has begun expanding to other use cases for high-throughput flexibility through its Compute business.

II. Land, Power and Controllable Loads: The Clean Campuses provide land to site large flexible loads and access Lancium's power orchestration capabilities. Customers are able to build their facilities and Lancium can provide power management solutions,based on energy prices and market signals.

III. Research and Development: Lancium is currently researching other technologies that controllable loads might apply to, such as green hydrogen production.

The business has engaged with the economic development teams within the regions, especially in Abilene. The goal is to hire full time employees from the community and stand up crypto apprenticeship programs in partnerships with local school systems. At full operation, the Clean Campuses will employ 57 full-time employees with an average salary of $67,000.

Case 5 USBTC

Wind, solar, and hydro-powered data centers

US BITCOIN CORP

Founded	2020
State(s) and Status	West Texas – Operational Central Texas – Operational Nebraska – Operational Niagara Falls – Operational
Energy Challenges Addressed	Grid Instability Energy Transfer & Storage
Energy Mix	NY: 93% zero carbon power TX: Data unavailable NE :Data unavailable
Approach	Front of the meter

Business Data

Employees	120
Local jobs created	~80 (67%)
Business model	Bitcoin rewards Selling energy to the grid

Overview

US Bitcoin Corp (USBTC) operates large-scale Bitcoin mining operations in upstate New York, Nebraska, and West Texas. USBTC prioritizes sites that offer opportunities to leverage zero-emissions energy sources and/or stabilize the power grid. As discussed, markets for renewables currently face significant challenges related to energy transport and storage, as well as grid stability. USBTC uses Bitcoin mining operations to address these challenges.

Its operations subsidize renewable and cheap electricity generation when grid prices are low. For example, in the ERCOT grid, generators are compelled to bid their electricity at their marginal cost of production. US Bitcoin operates data centers in ERCOT's Load Zone West. For context, ERCOT West accounted for 60% of ERCOT's total curtailments – and both wind and solar curtailments have been on the rise in the ERCOT grid as a whole. This consistent load on the grid during the top solar and wind hours of the day gives these generators a reliable customer for their excess energy.

Second, when grid prices are high, USBTC data centers (like many in the industry) act as a subsidy for ratepayers, general consumers, and industrial operators. In times of high demand, crypto data centers can instantly curtail operations to avoid an economic loss, simultaneously pushing unused power back into the grid for consumers to utilize. USBTC can ramp down sites or subsets of sites in approximately five seconds.

This is important because many regulated grids rely on "Peaker Plants" to provide reserve generation for peak grid demand. Peaker Plants are designed to deploy rapidly, usually within 10 minutes of a large increase in electricity demand. Due to the time-sensitive nature of their operations, Peakers Plants operate in standby mode until they are dispatched, which incurs a heavy fuel and operations readiness cost. They must be powered via natural gas, heavy fuel oil, or steam turbines and consumers pay the costs.

Instead of using fossil fuel plants for grid demand response, crypto data centers can offload this cost and be the Peaker Plants of the future by shutting down to supply the grid with excess power on demand. In fact, robust economic incentive programs such as Four Coincident Peaks (4CP), Twelve Coincident Peaks (12CP), Controllable Load Resources (CLR), and Load Resources (LR) are already in place on the ERCOT grid to incentivize this behavior from Bitcoin miners and other large industrial loads. To put this amount of power into perspective, these site shutdowns represent a grid power influx large enough to power tens of thousands of average Texan homes during the summer.

Operations

Their sites in upstate New York, Nebraska, and West Texas all operate on slightly different models, either purchasing low-cost energy from the grid and participating in demand response or working behind-the-meter with power producers as a "customer of first resort."

In New York, USBTC identified a location with abundant hydro power – a former sodium refinery that had gone largely unused since 2015. Through partnerships at the local and state level, USBTC made a brownfield investment to rehabilitate the infrastructure and put it to use for a crypto data center. The data center represented a controllable load for the New York Independent System Operator (NYISO) Zone A and the opportunity to foster local economic activity in an unutilized facility with a capacity of roughly 50MW.

In West Texas, USBTC identified a nexus point in the grid where there was a surplus of clean energy leading to grid congestion. As a result of energy transport and storage challenges, clean energy was wasted in this area. This is because the resources are stranded – meaning they would not otherwise reach cities and households. With an emphasis on wind and solar resources, the data center is a reliable buyer of renewable energy and participates in demand response for the ERCOT grid.

On the policy and regulatory side, USBTC follows permitting procedures as outlined by the administering states. Sites become operational following a load study, which allows utility partners to proactively understand the effects of miners plugging in to a given grid as an offtaker of energy

Business Model

The essence of USBTC's business model is subsidizing cheap electricity generation when grid prices are low. Energy companies are starting to notice this dynamic and are working to pair data centers with their intermittent generation sources to ensure effective capital allocation.

A key part of understanding grid impact is grasping the challenge of locating a viable economic path towards renewable grid development. Some might point out that energy storage installations, such as utility scale battery arrays, can perform both functions described above for a modern grid. It is true that batteries can purchase and store energy when the grid price is low, then subsequently sell that energy back to the grid when demand is high to compete with Peaker Plants. However, there are significant economic and regulatory barriers to entry for large battery installations. For example, when comparing a large industrial crypto data center to battery storage, the datacenter can be built from the ground up for less than 45% of the cost of a battery installation of the same size and capability. As a result, utility scale battery facilities have a much longer return on investment when compared to a crypto data center. In simple terms, the maximum profitability of a battery installation is simply the difference between the daily high and low electricity price.

If true grid stability is the goal of grid storage, profitability will compete away over time and consumers will have to subsidize their operations (much like they currently do with Peaker Plants). In contrast, profitability is decoupled from the volatility of the grid. And, due to its inherently low capital cost of construction in comparison to alternative energy storage solutions, there is a robust incentive system built in to deploy data centers like these across the grid.

USBTC partners with a number of local contractors and strives to hire locally to staff its data center operations.

5 Conclusion and Recommendations

Source: @bruno_thethe/Unsplash

This paper uses case studies to demonstrate the ways in which Bitcoin mining operations are already helping to power the energy transition. These are not speculative – the unique properties of Bitcoin mining is solving real problems with an urgency and scale that is not currently possible with other use cases.

I. **Policymakers and regulators should view Bitcoin mining operations as partners in the energy transition. This is important for both competitiveness and the climate agenda.**

Bitcoin mining companies should be viewed as partners in facilitating a transition to a zero-carbon future. As shown, they can provide valuable investment in and markets for renewables and other zero-carbon sources of energy. Beyond this, many Bitcoin mining operations are working hand in hand with local communities to create jobs and facilitate opportunities in areas that may have been negatively impacted by industrial decline.

Those who recognize the upside potential will reap the benefits in terms of infrastructure investments and contributions to local economies. Conversely, penalizing the industry without a full picture on these contributions can lead to negative consequences for US competitiveness and the climate agenda – especially with China re-claiming hashrate share within the Bitcoin network and the involvement of countries with different standards for these operations, such as Russia and Kazakhstan.

II. **Any assessment of the impacts of Bitcoin mining operations should take a contextualized and holistic approach.**

This requires taking a more detailed and nuanced view of the ecosystem. Getting to an accurate understanding of Bitcoin's impact requires going beyond simplified measures of energy use and accounting for the energy mix used, how it may support the market for renewables, and how the underlying technology may be used to aid climate efforts, as well as support related goals from a resilient energy supply, such as US economic competitiveness, and national security. The industry is interested in being a part of the solution and has already invested significant resourcing into research and innovation on this front.

Breakout Box
Crypto & Carbon Markets

Though outside of the data center scope of this paper, academic research has also suggested that the unique combination of decentralization, interconnected autonomy, openness, and intelligence makes blockchain technology a key enabler of a variety of energy-related use cases. These include peer to peer energy transaction, efficiency gains in electric vehicle charging, carbon emissions certification and trading, synergy of the multi-energy system, and more. Once again, these are not theoretical propositions. Initiatives like "regenerative finance" – or ReFi – are working to bring these climate-focused projects to life. For instance, the Climate Collective mapped over 250 projects spanning carbon credits, biodiversity, energy markets, waste management, and beyond.

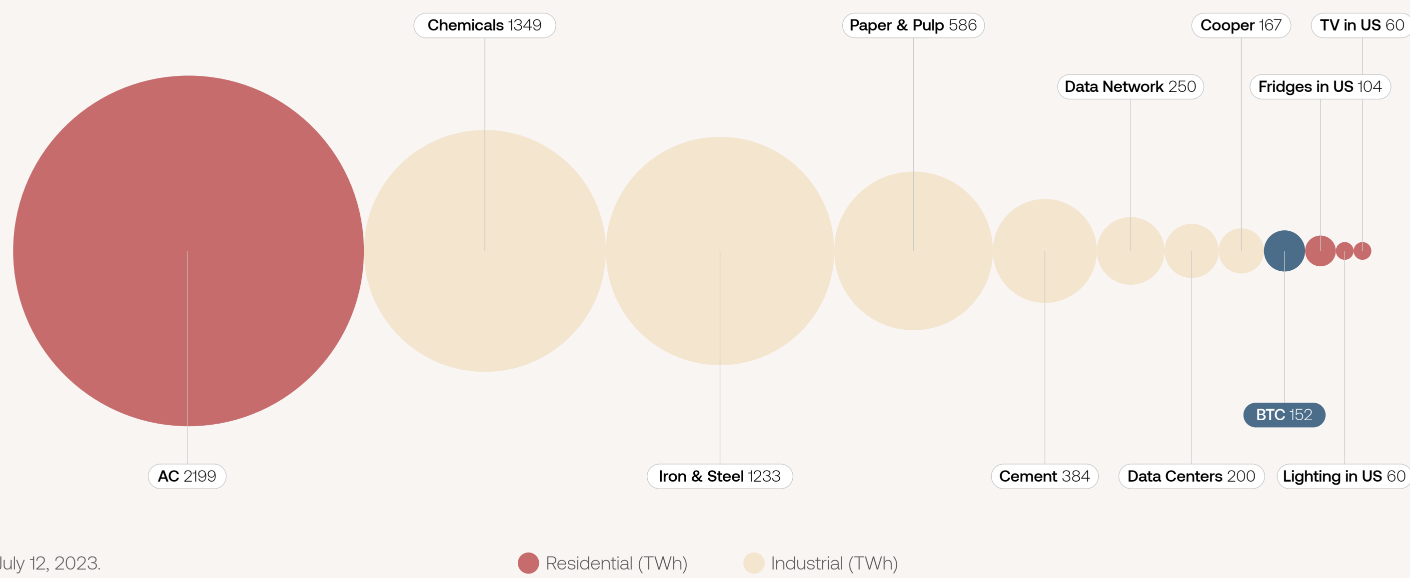
For example, Bitcoin and blockchain technology are the underlying infrastructure for a range of uses and applications – currencies, payments networks, digital art, decentralized financial services, digital identity, and more. As one industry expert highlights, "We must remember that credit card payments still rely on existing, emissions-heavy infrastructures like the ACH, Fedwire and SWIFT, as well as the military and diplomatic strength of the US government… Comparing Bitcoin and the traditional banking system [is] like comparing the emissions of the entire coffee industry with a single cafe."

Moreover, there is limited data on the climate implications of other assets or financial services. The financial system runs on a complex network of offices, technology, data centers, and more, which all consume energy. There are also many physical elements involved in the traditional financial system. Where research has been done, there are indications that cash and banking systems have more significant environmental impacts than Bitcoin.

The comparison becomes starker when comparing Bitcoin mining operations to traditional commodities mining.

Precious and industrial metals, oil and gas, and agricultural goods all have well-documented environmental impacts. The CBECI offers comparisons to industrial use cases as well, with areas like chemicals, iron and steel, and paper and pulp dwarfing the footprint of Bitcoin. Industries such as mining for gold and diamonds have well-documented effects on the environment beyond energy consumption.

FIGURE 5
Impact comparison



As of July 12, 2023.

III. **It is important to study examples to better understand what works – and what does not.**

As discussed, there have been several policy and technology proposals put forward regarding this issue. However, there has been little rigorous investigation of potential long-term implications for climate impact and beyond – for instance, security, competitiveness, and economic impacts. It is important, then, to thoroughly study Bitcoin mining operations and the potential consequences of policy proposals.

Existing examples may provide a starting point.

There are a variety of incentives including energy costs, policy and regulatory considerations, and practical matters like available space and climate. The US leads data center operations globally, making up 37% of the global hashrate. Across the country, states are making moves to attract Bitcoin mining operations. In 2021, 33 states and Puerto Rico had pending crypto resolutions and 17 enacted legislation or adopted resolutions. Two states have taken notable steps to attract Bitcoin mining operations in particular: Georgia and Texas.

Georgia holds the largest hashrate share in the United States, 30.8%. The growth in the state has been driven by access to low-priced nuclear and solar power as well as friendly regulation. Incentives to attract Bitcoin mining operations to the state have included a solar program allowing companies to offset emissions with renewable energy credits and providing day-ahead power prices.

Texas has been more widely discussed in popular discourse. While it doesn't currently have the largest hashrate share, it is the fastest-growing state for Bitcoin mining operations and is currently home to the largest facility in the United States. Located in Rockdale, Texas, Whinstone is North America's largest Bitcoin mining operations, operating 24 hours a day and employing a staff of more than 120. Facilities that were once housed elsewhere, especially in China, have made large-scale moves to Texas. There is no set recipe, but this has been achieved through a combination of bottom-up and top-down efforts from both industry groups and vocal support from government officials.

On the other hand, research has shown that actions taken by China to ban Bitcoin mining operations worsened its environmental impact – increasing its carbon intensity by 17%. Moreover, these efforts were not effective in curbing this activity. New data from the Cambridge Centre for Alternative Finance showed that the effects of such a ban were temporary, with activity re-surging following a short gap.

Conclusion

As the conversation around the energy transition picks up – and is more critical than ever – it is important to consider different approaches to catalyzing investments in infrastructure. This paper outlines how the Bitcoin mining industry has already taken action, with case studies of zero-carbon operations.

These examples include:

- Utilizing flared gas as a power source to mitigate the effects of methane emissions – which has over 80x the warming power of CO2 over a 20 year timeframe.
- Experimenting with new technology for cooling, which makes up an estimated 40% of energy consumed by mining operations.
- Balancing grid instability by powering mining operations up or down within a 5-15 second timeframe.
- Building brand-new renewable energy sources, representing more than 3 GW of added renewable energy to the grid in the long term.

Representing almost two dozen sites across the US, these companies provide a roadmap for utilizing the unique features of Bitcoin – namely, flexibility, transparency, and consistency – to address some of the pressing challenges that the country's energy grid faces today. As the Bitcoin mining industry continues to grow, these examples of sustainable operations can pave the way for financial services and data centers more broadly.

Where the incentives are aligned and Bitcoin mining operations are viewed as partners, these significant investments in infrastructure – including around grid stability, energy storage, and cooling technology – and in communities – by providing jobs and opportunities to hundreds of individuals and local contractors.

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Alexander Neumueller
Cambridge Center for Alternative Finance

Ben Kelner
Crusoe

Brendan Malone
Paradigm

Catherine Mulligan
Imperial College London

Cully Cavness
Crusoe

Dan Swislow
Block

Eleni Stylianou
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Emily Meyers
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Isaac Holyoak
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Shaun Connell
Lancium

Sigal Mandelker
Ribbit Capital

Taylor Monnig
CleanSpark

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Case Studies

Questions?
Please email us at: info@cryptoforinnovation.org

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