Square

Bitcoin is Key to an Abundant, Clean Energy Future

In this memo, we aim to explain how the Bitcoin network functions as a unique energy buyer that could enable society to deploy substantially more solar and wind generation capacity. This deployment, along with energy storage, aims to facilitate the transition to a cleaner and more resilient electricity grid. We believe that the energy asset owners of today can become the essential bitcoin miners of tomorrow.

Highlights

Bitcoin mining presents an opportunity **to accelerate the global energy transition to renewables** by serving as a complementary technology for clean energy production and storage.

Solar and wind are now the least expensive energy sources in the world, but are hitting deployment bottlenecks primarily because of their intermittent power supply and grid congestion.

Bitcoin miners as a flexible load option could potentially help solve much of these intermittency and congestion problems, allowing grids to deploy substantially more renewable energy.

By deploying more solar and wind, **these generation technologies will likely fall even further down their respective cost curves**, bringing them closer to zero marginal cost energy production.

ABOUT THIS MEMO

The Bitcoin Clean Energy Initiative has developed this short research paper as a starting point to share our vision for how bitcoin mining - in conjunction with renewable energy and storage - is especially well suited to accelerate the energy transition. To complement this work, ARK Invest has contributed an open source model that demonstrates how bitcoin mining could augment these renewable + storage systems to supply a larger percentage of a grid's baseload energy demand for comparable or lower cost unit economics. This work is merely the beginning of what we hope will be a fruitful exploration of solutions to help usher in an abundant, clean energy future.

A UNIQUE ENERGY BUYER

Bitcoin miners are unique energy buyers in that they offer highly flexible and easily interruptible load, provide payout in a globally liquid cryptocurrency, and are completely location agnostic, requiring only an internet connection. These combined qualities constitute an extraordinary asset, an energy buyer of last resort[1] that can be turned on or off at a moment's notice anywhere in the world.

Energy asset owners are the entities which own the power production plant once it is in commercial operation.

Bitcoin Clean Energy Initiative (BCEI) is a project launched by Square in December 2020 to promote the use of clean energy in Bitcoin mining. Learn more about its origin here.

Interruptible load is an end use of electricity, like mining bitcoin, which can be turned on or off quickly and easily.

1. *Special Report: Energy Backed Money*, Satoshi Energy.

RENEWABLE ENERGY IS NOW THE CHEAPEST ENERGY

The Levelized Cost of Energy (LCOE) for solar and wind has fallen 90% and 71%,[1] respectively, over the last decade. The *unsubsidized* costs of solar and wind energy are now 3-4 cents / kWh and 2-5 cents / kWh, respectively. Certain individual projects have had even lower costs. For context, the average LCOE for fossil fuels such as coal or natural gas is ~5-7 cents / kWh. This means that solar and wind are *already* at a lower price point than coal and natural gas. Solar and wind energy also just reached cost parity[2] with both geothermal and hydroelectric, which at around 3-5 cents / kWh are inexpensive, but geographically limited.

There will always be inexpensive individual sites for different power sources like hydro or geothermal, but on the whole, solar and wind are now the lowest cost and most scalable. What's more, we believe they will only continue to get more affordable over time. We believe this is especially true for solar, a semiconductor technology, which has consistently declined in price by 20-40%[3] per doubling of cumulative capacity deployed.

LCOE by Energy Source

In Price per kWh

Hydro	~.01 – .04	**Nat. Gas**	~.04 – .07
Wind	~.02 – .05	**Geothermal**	~.05 – .10
Solar	~.03 – .04	**Coal**	~.06 – .07

All but Hydro, Lazard. *Hydropower,* IRENA – International Renewable Energy Agency.

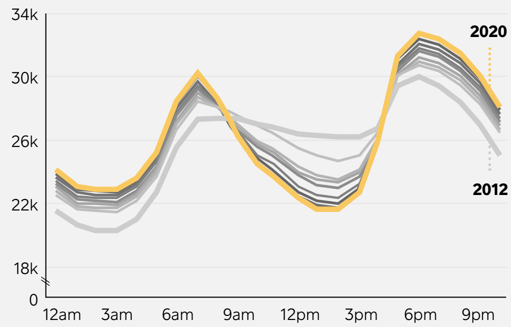
TEMPORAL SUPPLY & DEMAND MISMATCH AND GRID CONGESTION

Solar and wind energy, however, both suffer from one major deficiency versus more expensive baseload power like natural gas or nuclear: intermittency. In the energy industry, this results in what is known as the "duck curve."[4]

NREL Duck Curve

Net load in Megawatts, January 11

Years 2012-2020 represented



Ten Years of Analyzing the Duck Chart, NREL.

In essence, the sun shines during the day, but not at night. Wind is more unpredictable, but tends to blow more heavily at night. Energy supply, therefore, is either abundant or non-existent. Demand, however, peaks around the late afternoon or early evening when people arrive home and turn on appliances, at which time neither solar nor wind are abundantly available. The end result is significantly more power than society typically needs for a few hours per day and not nearly enough when demand spikes. This same challenge also plays out seasonally as the sun shines more during the summer and the wind blows more during the winter. These deficiencies are further exacerbated by grid congestion,[5] which is similar to highway traffic and frequently occurs because solar and wind projects are often built in rural areas with lots of sunlight and wind but little nearby load (i.e. end power users) and transmission capacity. Because of these challenges, there are >200 GW[6] of delayed solar and wind capacity currently in just three U.S. grid interconnection queues. These are solar and wind projects which have developers and financing readily available, but which grids physically cannot accommodate.

Increased transmission capacity and energy storage will be critical to solving these problems, especially as Lithium Ion batteries continue to fall down their cost curve. For the moment, though, utility-scale batteries are still too expensive to deploy universally. After they've fallen another 80% in cost, they will still face physical limitations around their useful lifespan and for how long they can store energy without dissipation. They will, however, be the most critical technology in storing inexpensive mid-day solar power for evening peak demand.

Levelized Cost of Energy (LCOE) is the total lifetime cost of building and operating a power plant divided by the total amount of energy it produces (measured in cents / kWh).

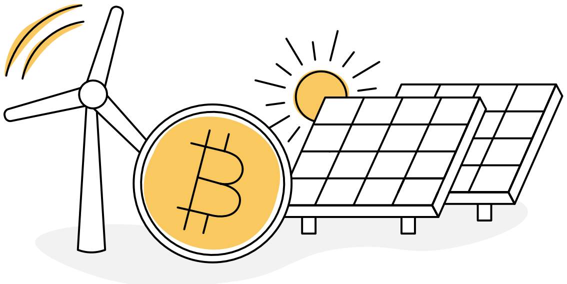
Semiconductor technology the basis of modern electronics and computing which has historically fallen in cost as its production capacity increases (e.g. see Moore's Law).

Intermittency is when an energy source is not constant. For example, in the case of a solar farm, it only produces when the sun shines.

Grid congestion is when a grid's transmission lines have reached the maximum capacity for how much electricity can flow through them at any given moment.

Transmission capacity the rate at which electricity can be moved from a power plant (e.g. a solar farm) to a load center (e.g. a city).

1. *Levelized Cost of Energy and Levelized Cost of Storage – 2020,* Lazard.
2. *Levelized Costs of New Generation Resources in the Annual Energy Outlook 2021,* U.S. Energy Information Administration.
3. *Solar's Future is Insanely Cheap (2020),* Ramez Naam.
4. *Ten Years of Analyzing the Duck Chart*, NREL.
5. *Transmission congestion & constraints: Market impediment or opportunity?* NRG Editorial Voices.
6. *New data tool from Berkeley Lab Tracks Proposed Projects in Interconnection Queues,* Berkeley Lab.



BITCOIN MINING IS AN IDEAL COMPLEMENT FOR GENERATION + STORAGE

Bitcoin miners, on the other hand, are an ideal complementary technology for renewables and storage. Combining generation with both storage and miners presents a better overall value proposition than building generation and storage alone. As mentioned above, there will always be physical limitations to how much energy can be cost effectively stored without dissipation. However, the daily intermittency challenge can be met almost entirely with just a few hours of storage capacity.

By combining miners with renewables + storage projects, we believe it could:

1 Improve the returns for project investors and developers, moving more solar and wind projects into profitable territory.

2 Allow for the construction of solar and wind projects even before lengthy grid interconnection studies are completed (as bitcoin miners can offtake the energy until selling to the grid becomes possible).

3 Provide the grid with readily available "excess" energy for increasingly common black swan events like excessively hot or cold days when demand spikes (e.g. the early 2021 outages in Texas).

Note that this "excess" energy will also be quite useful as society's electricity demands increase with the proliferation of electric vehicles and the electrification of all devices. In a sense, the unlimited appetite of miners allows them to eat whatever remains of the "duck's belly." Given these benefits, we believe it makes logical sense for utility-scale storage developers to augment their current battery offerings with bitcoin miners.

LONG TERM IMPLICATIONS

We believe there are two large implications if bitcoin mining becomes normalized as an energy buyer of last resort. First, the amount of solar and wind energy on the grid could increase dramatically. As noted above, there's currently >200 GW of delayed solar and wind capacity in the interconnection queues of just three U.S. electricity markets. For context, that's approximately double the amount of solar and wind capacity currently installed there.

As society starts deploying more solar and wind, we believe it should bring their LCOE even further down their cost curves, making the next batch of solar and wind even more affordable. If the LCOE falls, it could potentially unlock profitable new use cases for that electricity like desalinating water, removing CO_2 from the atmosphere, or producing green hydrogen. Some experts in the field expect that the marginal cost of producing new electricity will actually approach zero.[1]

The second major potential impact could be a sizable transformation and greening of the bitcoin mining industry. It's estimated that there's only 10-20 GW[2] of mining capacity worldwide today. Deploying miners at even 20% capacity with the above mentioned 200GW of delayed solar and wind projects on U.S. grids alone could result in 40 GW of new mining capacity, effectively dwarfing the entirety of the existing global market. Note that while many of these projects would likely be built "behind the meter" to utilize otherwise curtailed solar and wind power whenever possible, they would likely still mine with grid electricity during other periods when profitable to do so, so it wouldn't be entirely green from day one. But if solar and wind become even less expensive and constitute an increasingly large portion of baseload power, the ultimate trend would continue moving quickly toward renewable dominated hashrate. We believe deploying such a large amount of new, geographically diverse hashrate would also have the second order consequence of strengthening the security of the Bitcoin network, potentially further entrenching bitcoin as a sound currency for all.

Dissipation is the process of losing some stored energy as heat, also known as "heat loss".

Black swan events are low probability, high impact events like severe winter storms or heat waves.

Utility-scale storage is large batteries deployed by utilities with storage capacity ranging from a few megawatt-hours (MWh) to hundreds of MWh.

Interconnection queues are projects awaiting approval to supply energy to transmission grids.

Behind the meter refers to using energy directly at the generation site without traveling through the grid.

Hashrate is the total computational power securing the Bitcoin network.

1. *Zero Marginal Cost Energy*, Max Webster. Dec 2020.
2. *Cambridge Bitcoin Electricity Consumption Index.*

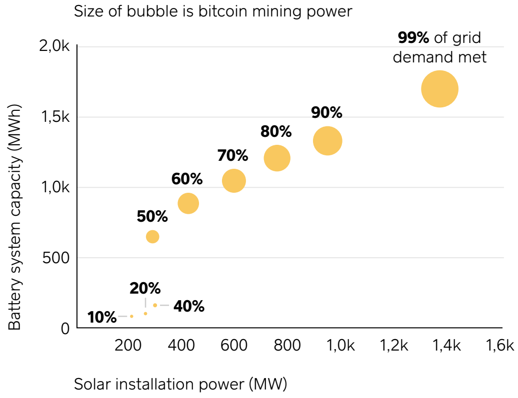
ARK INVEST

With real-world data, we (ARK Invest) demonstrate that bitcoin mining could encourage investment in solar systems (solar grids + batteries), enabling renewables to generate a higher percentage of grid power with potentially no change in the cost of electricity.

Without bitcoin mining, solar - an intermittent energy source - could supply only 40% of grid power before utilities would face the need to fund significant investments with higher electricity prices. With bitcoin mining integrated into a solar system however, energy providers - whether utilities or independent entities - would have the ability to play the arbitrage between electricity prices and bitcoin prices, as well as potentially sell the "surplus" solar and supply almost all grid power demands without lowering profitability.

The graph above illustrates the impact that bitcoin mining could have on the adoption of solar systems. Assuming a constant cost of electricity, it traces what percentage of power solar could provide to the grid. The y-axis is the power generated by solar, the x-axis is battery capacity. The size of each circle is proportionate to the size of the bitcoin mining operation. At each point, the solar system provides a different percentage of the grid's needs. As bitcoin mining scales, the solar system increases in size and provides a higher percentage of the grid's needs. Increasing bitcoin mining capacity could allow the energy provider to "overbuild" solar without wasting energy. In the bottom left of the chart, in the absence of bitcoin mining, renewables can satisfy only 40% of the grid's needs. In the top right of the chart, including solar, batteries, and bitcoin mining can satisfy 99% of the grid's demand.

Bitcoin mining could encourage investment in solar systems, enabling renewables to generate a higher percentage of grid power with no change in the cost of electricity



Our model demonstrates that integrated bitcoin mining could transfigure intermittent power resources into baseload-capable generation stations. It suggests that the addition of Bitcoin mining into power developers' toolboxes should increase the overall addressable market for renewable and intermittent power sources. All else equal, with bitcoin mining, renewable energy could provision a large percentage of any locality's power economically. As a follow-on effect, cost declines associated with scaling renewables should most likely accelerate, leaving them even more economically competitive at equilibrium.

WE PROVIDE AN OPEN-SOURCE VERSION AND MORE DETAILED BREAKDOWN OF THE MODEL AND ITS ASSUMPTIONS HERE[1].

Baseload-capable generation refers to the ability to meet the minimum level of demand on an electrical grid over a span of time.

1. *Solar Battery Bitcoin*, ARK Invest GitHub.

NEXT STEPS

There are still some important remaining questions about how the above vision could play out. We see at least three meaningful business opportunities:

1 **Energy Management Software and Services**
Energy management companies that specialize in both storage and mining could build software to decide in real-time the best use for a newly created electron: whether to use it, store it, or mine it. They could also provide key asset management tools and analytics to monitor project performance.

2 **Energy/Miner Marketplaces**
Managed marketplaces could emerge to connect project developers, miners, and financiers. One key challenge would be solving the current creditworthiness threshold requirements for existing miners.

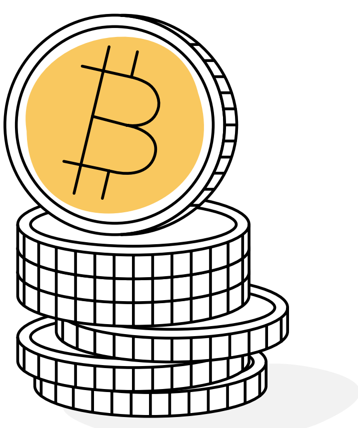
3 **ASIC Manufacturing**
New chip foundries could be built to meet the expected surge in demand. Samsung and TSMC are leading the way with recent announcements of new North American plants. We also expect to see continued hardware and firmware improvements to increase the durability of mining equipment optimized for interruptible power usage.

Call to Action

The bitcoin and energy markets are converging and we believe the energy asset owners of today will likely become the miners of tomorrow. Utility executives, sustainable infrastructure funds, and grid-scale storage developers are well-positioned to expedite this future by aligning their strategic roadmap and deploying large scale investments into the emerging synergy between bitcoin mining and clean energy production.

We plan to follow up with more research explorations and additional resources focused on the intersection of bitcoin and clean energy.

CONTACT BITCOIN-ENERGY@SQUAREUP.COM



Application Specific Integrated Circuit (ASIC) is a computer chip that's customized to perform one function. In this case, ASICs are specialized to mine and secure the Bitcoin network by performing a hash function called SHA-256.

Taiwan Semiconductor Manufacturing Company (TSMC) is a Taiwanese multinational semiconductor contract manufacturing and design company.