Attachment—Additional Questions for the Record

Subcommittee on Oversight and Investigations
Hearing on
"Cleaning Up Cryptocurrency: The Energy Impacts of Blockchains"
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The Honorable Frank Pallone, Jr. (D-NJ)

1. Could you explain some of the uses of the Ethereum blockchain aside from ether transactions? How does Ethereum's functionality compare to other blockchains?

Thank you very much for your question, Chairman Pallone.

Ethereum supports what are called *smart contracts*, small pieces of software that execute on blockchains and extend their functionality well beyond simple transfers of currency. For example, smart contracts are the main enabling technology behind *decentralized finance* (DeFi), meaning the spectrum of novel financial instruments being developed on blockchains. Smart contracts are also the primary vehicle for the creation and trading of *non-fungible tokens* (NFTs), digital objects representing ownership of digital collectables, artworks, and other unique assets.

Most new blockchains today also support smart contracts. Bitcoin, in contrast, does not directly support smart contracts.

The Honorable Diana DeGette (D-CO)

1. Your research on proof of work (PoW) consensus mechanisms recognized in 1999 that systems that rely on PoW are inherently wasteful of energy. We now know that PoW mining at scale produces a significant amount of electronic waste, primarily in the form of obsolete or broken application specific integrated circuits (ASICs).

    a. Why does PoW mining produce so much electronic waste?

Thank you very much for your questions, Chair DeGette.

Block production in PoW blockchains is a competitive process: A miner's success depends not on the absolute computing power of its ASICs, but the power of its ASICs *relative to other miners*. As technological advances in ASIC production occur, miners must therefore purchase new ASICs to compete successfully with other miners. This arms race means that there is a financial incentive for miners to upgrade their ASICs and discard outmoded ASICs on a frequent basis.

b. Can PoW mining occur at scale without creating significant amounts of electronic waste without also sacrificing the security of PoW blockchains?

Without a fundamental change to PoW blockchains, it is unclear how the problem of electronic waste can be eliminated. The security of PoW blockchains requires that miners compete against one another for monetary rewards. Such competition incentivizes miners to make upgrades to their ASIC equipment as technological advances occur, and therefore to produce electronic waste.

2. A common talking point among the cryptomining industry is that its operations have become increasingly more efficient. The implication is that this increased efficiency will result in decreased energy consumption over time.

a. Do you agree with this argument? Please explain.

I disagree, and the history of, e.g., Bitcoin mining, offers clear evidence that the implication is false.

It is true that ASICs are steadily growing more energy efficient according to a particular metric: *energy consumption per hash*. To put it another way, ASICs are growing faster (per unit of power) over time. In isolation, however, this fact is misleading. Faster ASICs don't confer any speed or energy benefit on a blockchain as a whole.

In fact, when there's an improvement in ASIC speed, the result isn't generally lower energy usage, but more electronic waste. The reason is that mining is a competitive process. A miner's revenue depends not on how much computation (hash power) it invests in the network, but *how much it invests relative to other miners*. When faster ASICs emerge, miners buy new ASICs and discard old ones in order to remain competitive with other miners. Faster ASICs thus play a role in the arms race that characterizes cryptocurrency mining.

If we view a cryptocurrency as a financial-transaction system, the most salient metric of energy use is *energy consumption per transaction*. Faster ASICs do not improve this metric.

Bitcoin offers a case in point. Bitcoin mining ASICs have grown progressively faster over time, i.e., energy consumption per hash has greatly *decreased* over time. *The Bitcoin network's energy consumption per transaction, however, has greatly increased.*

b. Why does the energy used for mining for PoW cryptocurrency continue to grow, while the hardware used by miners becomes exponentially more energy efficient?

As cryptocurrency mining is an arms race among miners, miners have an incentive to invest aggressively in their infrastructure and operations. Their investment takes the form of capital equipment, namely ASICs, and the electricity used to power those ASICs. As the price of a PoW cryptocurrency rises, miners can afford collectively to increase their dollar investment in these resources as they compete with one another. More energy-efficient ASICs do not diminish the overall amount of resource miners are willing to commit in order to compete.

In short, the price of a PoW cryptocurrency is a major determinant of the amount of energy consumed by miners. As cryptocurrency prices have risen, capital and energy investment in cryptocurrency mining has followed suit.

c. Given industry practice to date, is it reasonable to expect future hardware efficiency gains to lead to declining consumption at mining facilities?

As my response to Question 2a. suggests, and as the history of Bitcoin has shown, there is no reason to believe that ASIC efficiency gains will result in declining energy consumption in mining facilities.

The Honorable Michael C. Burgess (R-TX)

1. During my time as the Chairman of the Commerce, Manufacturing, and Trade Subcommittee in the 114th Congress, now the Consumer Protection and Commerce Subcommittee, I held an educational hearing about digital currency and blockchain technology.

a. How far has cryptocurrency and blockchain technology come since this hearing in 2016?

Thank you very much for your questions, Congressman Burgess.

Blockchain technology is advancing at a rapid pace, even by the standards of the technology industry as a whole. A crude but somewhat informative measure of the industry's progress since 2016 is its market capitalization, which was about $18 billion at the end of 2016 and now stands at over $1.8 trillion, i.e., has grown by a factor of one hundred. Another indicator of the technology's progress is the range of uses to which it is being put. Decentralized finance (DeFi) and non-fungible tokens (NFTs), for instance, are important application areas that scarcely existed in 2016, and the same is true of some of the most popular blockchain systems today. Nonetheless, the industry is still in its infancy. There remain major technical challenges to overcome if blockchains are to achieve the performance and functionality required to serve large communities of users. There is also enormous, as-yet-unrealized potential for blockchain technology to impact mainstream industries and create new ones.

> b. What do you see as the role of the Federal government in these technologies?

I'm not an expert on regulatory policy, but I believe that a carefully considered, clearly framed regulatory regime is badly needed to foster healthy growth in the blockchain industry.

As a separate point, I would highlight that many key advances in blockchain technology have been the clear result of past and ongoing Federal investment in scientific research, particularly through the National Science Foundation (NSF).

> c. How can the United States assist Bitcoin mining domestically in being cleaner and more productive?

Bitcoin has been a great technical and market success, but Bitcoin does not equate with blockchain technology. Accordingly, I would urge consideration of a different question: How can the United States assist *blockchain technology* in being cleaner and more productive?

I believe that a key ingredient in a cleaner blockchain industry will be policies, regulations, or market forces that recognize the negative externalities of energy-intensive activities such as proof-of-work mining in Bitcoin. Such recognition will incentivize migration toward the cleaner and more productive alternatives that much of industry is already embracing.

I would also submit that far greater opportunities for technological innovation and job creation lie in *value-added services, i.e., applications of blockchain technology* than in *merely maintaining blockchain infrastructure, e.g., in mining*. Blockchain applications extend well beyond the mere transfer of digital assets, and include innovations in finance, the arts, and other areas of activity.

I believe it's important that the United States strive to maintain its preeminence in the most technologically advanced and functionally rich realms of blockchain technology, rather than promoting Bitcoin mining in particular.