CoinShares Research

THE BITCOIN MINING NETWORK

Trends, Marginal Creation Costs, Electricity Consumption & Sources

MAY 2018 UPDATE

The Bitcoin Mining Network

- Trends, Marginal Creation Cost, Electricity Consumption & Sources

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Note: this white paper is provided subject to acceptance of the conditions contained on page 14.

Abstract

In this paper we investigate the current marginal cost of creation of bitcoin; the composition, efficiency, electricity consumption and electricity sources of the Bitcoin mining network. We also investigate trends in hashrate, hardware cost and hardware efficiency and present a 2-year extrapolation thereof. Among our findings is a market-average marginal cost of creation of $6,400 per bitcoin, as of May 11, under our current assumptions. We also show that, on an annual basis, over the last 4.5 years, the hashrate has approximately tripled, mining hardware efficiency almost doubled, and hardware costs halved. Furthermore, we find that contrary to widely cited media sources, the Bitcoin mining network is mainly powered by renewable energy, with hydro being the dominant source.

Introduction

Mining serves an essential function in the Bitcoin protocol by securing the distributed network consensus through proof-of-work. The immutability of the Bitcoin blockchain is a direct result of the cost of mining as any attacker attempting to rewrite or append fraudulent transactions to the blockchain would need to acquire and operate enough hash power to outpace the entire honest network. The combined capital and operational expenditures of such an endeavour, combined with its dubious benefit for the attacker, makes such attacks prohibitively expensive to undertake in practice.

Using provable work as a mechanism for establishing distributed consensus is still a novel and uncommon approach to systems requiring reliable synchrony between participants, such as monetary applications. Even so, over the last five years alone the Bitcoin mining industry has grown from a sector dominated by hobbyists to a multi-billion-dollar industry with individual participants whose profits match those of multinational industrial conglomerates (1).

Running a relevant Bitcoin mine is now an undertaking on the order of operating a large-scale data centre. Thousands of individual mining units often featuring multiple circuit boards containing many dozens of chips are needed to even make a dent in the Bitcoin hashrate. Mines must secure industrial-sized power supplies to run not only the mining hardware itself, but also their substantial cooling requirements. Modern large-scale mining operations often require power supplies ranging into hundreds of megawatts (MW) and the total mining network is estimated to draw multiple gigawatts (GW).

While much criticism has been levied at the energy expenditure of proof-of-work systems it is in fact this energy expenditure that keeps the system secure. There have been multiple previous attempts at quantifying Bitcoin's energy use and while some have been well-founded (2), other frequently cited attempts have been less accurate (3). In this paper we examine the current and projected size, composition and energy expenditure of the combined Bitcoin network as well as its associated costs. Using these figures, we arrive at a range of estimated marginal costs of Bitcoin creation, given a range of assumptions, before finally taking a closer look at the network's energy sources and rough geographical distribution.

Assumption Rationale

Due to the limited nature of publicly available data relating to Bitcoin mining, in the making of this paper we have been forced to adopt a range of assumptions. We consider this paper our first iteration of several where we will continue to improve on both models and assumptions. Within the limits of our knowledge we have set these assumptions as close as possible to what we believe to be the actual figures, but caution readers that no matter how well-founded these assumptions are, they are still assumptions. Where deemed valuable to the reader, we have performed sensitivity analyses to show how our calculated results are affected by varying the assumptions. The remainder of this section will shed some light on our rationales for making these various assumptions whereas full documentation and deeper explanations can be accessed in the Appendix.

First, we begin with our sampling range. We have chosen to sample all publicly known Bitcoin mining hardware with shipping dates after 1 January 2014. The year of 2014 widely considered the beginning of the industrial era of Bitcoin mining as signified by the advent of large-scale deployment of mining hardware featuring Application Specific Integrated Circuits (ASICs), designed purely for SHA-256 hashing. While we acknowledge that some Bitcoin ASICs were released before this date, widespread industrial-scale mining operations were uncommon, and even the largest mines rarely exceeded single digit megawatts (4). In line with our hardware sampling range, when extrapolating the future hashrate, hardware efficiency and hardware costs, we have calculated our regressions from data in the same time range.

Second, we have been forced to make assumptions with regards to OPEX that is not related to the pure electrical demands of running the hardware. Such OPEX non-exhaustively includes rent, cooling cost, maintenance and administration. Due to the largely private nature of most large-scale Bitcoin miners, such figures are - for obvious reasons - not publicised. In this instance we have chosen to rely on figures from comparable non-mining data centres and the educated guesses of individuals involved in the mining industry. Rather than attempting to know the unknowable, we instead perform a sensitivity analysis with a considerable input range to showcase the effect of a large assumption variance on overall marginal costs of creation.

Third, there exists no reliable source of the total amount of deployed mining hardware. We have therefore made assumptions based on a combination of various publicly available information and industry estimates, and overall worked within reason to estimate figures that correspond with the pseudo-measurable hashrate.

Finally, and relevant to all previous assumptions, we are often forced to assume that people are telling the truth. We recognise that the Bitcoin mining industry is full of unknowable information for participants residing outside of industrial entities, poorly researched opinions, and outright misinformation, sometimes even on the part of manufacturers advertising performance and total market share. In this setting it is important to keep in mind that none of the relevant ASIC manufacturers are publicly traded entities (although the main chip foundry is), and listed miners with strict disclosure requirements are only just getting their feet wet.

Thus, we have chosen the approach - to the maximum extent possible - *of don't trust, verify*. When that approach inevitably fails, we examine the information available, judge the sources on their merits and only include data that falls within a reasonable level of rationality. Again, when assumptions make significant impacts on our calculations, we perform sensitivity analyses to illuminate their effects. Since they cannot be wholly avoided we prefer instead to be perfectly clear with regards to their overall influence on results.

Based on our best estimates for market-wide electricity OPEX we have chosen $0.05/kWh as our mid-range value. On top of that we estimate an average of 30% of electricity OPEX as cooling and other (C&O) OPEX to cover all other costs including, but not limited to, rent, cooling, staffing and mining pool fees. To that we should add that we believe, and have anecdotal evidence to suggest, that 30% is at the higher end of the cost spectrum, making it a highly conservative number. Furthermore, we estimate that the average mining gear is depreciated (CAPEX horizon) over 18 months. A further discussion of the evidence to support these assumptions can be found in the Appendix.

Overall we believe the margins of error in our calculations are substantial, and we caution readers to be aware of this unavoidable fact.

Regressions and Projections

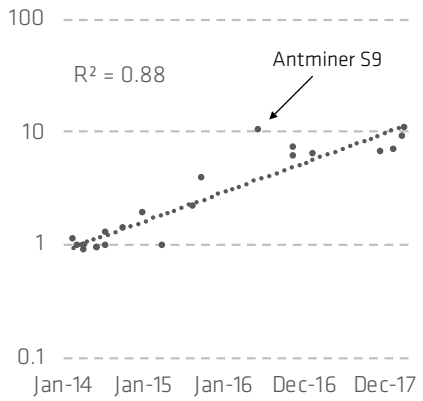
In order to enable an extrapolation of mining trends we chose three variables to regress against time: hardware efficiency measured in gigahash per joule (GH/J), hardware cost measured in dollars per terahash per second ($/TH/s), and finally the Bitcoin hashrate measured in terahash per second (TH/s). The mining efficiency scatter plot includes 22 data points of ASIC mining hardware with shipping dates later than 1 January 2014. The hardware cost scatter plot includes 21 data points, all of which are from the same hardware as used in the mining efficiency calculations. The hashrate was regressed against estimates by blockchain.info, every other day between 1 January 2014 and 1 May 2018. Further discussion of the sources and any assumptions contained therein can be found in the Source Discussion section and Appendix.

Our regressions are all exponential functions plotted on logarithmic scales [Fig 1, Fig 2, Fig 3]. Both the hardware efficiency and hashrate regression have excellent R^2 values of 0.88 and 0.96, respectively. The hardware cost regression has the least fit of the three with an R^2 of 0.63. All three show marked trends: the hashrate and hardware efficiency are both increasing, while the hardware cost is falling. Out of the three, the hashrate is experiencing the most rapid rate of change, approximately tripling every year (307%). The hardware efficiency is also growing rapidly, almost doubling every year (81%), while the investment cost, on the other hand, is almost cut in half on an annual basis (-48%).

Of considerable interest in the hardware efficiency plot is the Antminer S9, whose efficiency when first shipped in mid-2016 (~10.2 GH/J) was already at levels that have only been approached by hardware released earlier this year [Fig 1]. This significant trend-beating characteristic goes far in explaining its unmatched popularity and market dominance and is a testament to the market-leading engineering capabilities of the Chinese ASIC manufacturer Bitmain. Over the last two years, the only commercially available hardware able to match the S9 on power efficiency is the immersion-cooled solution offered by BitFury and Allied Control. However, directly comparing the two solutions is challenging as S9s are available on a per-unit basis whereas the immersion-cooled systems are only available in comprehensive multi-unit systems integrated into shipping containers costing more than $1m a piece. In addition, the S9 is cheaper on a $/TH/s-basis.

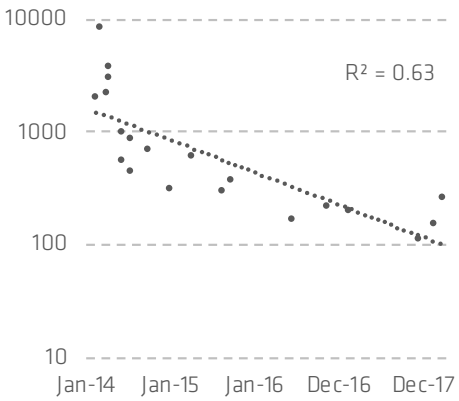
Extrapolating the trends offers an interesting peek into what the future may hold for the Bitcoin mining industry if the current trends continue to develop along their existing paths. Looking at the hashrate in May 2019 we might see figures of 81 exahash (EH) and possibly even 332 EH by May 2020. Meanwhile the average hardware efficiency may increase to approximately 18 GH/J in May 2019 and approximately 33 GH/J in May 2020. At the same times the investment cost could fall to approximately 49 $/TH/s and 26 $/TH/s, respectively.

Figure 1: Hardware Efficiency (GH/J) vs Shipping Date



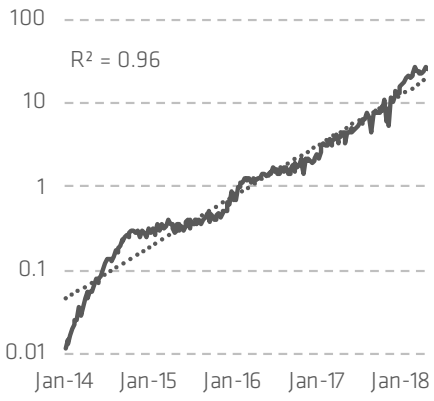
Source: Bitcoin Wiki

Figure 2: Hardware Cost ($/TH/s) vs Shipping Date



Source: Bitcoin Wiki

Figure 3: Total Estimated Bitcoin Hashrate (EH/s)



Source: blockchain.info

Marginal Creation Cost

In order to calculate a *market average* marginal cost of creation we have chosen a top-down methodology rather than the more common bottom-up approach: through a rather gruelling deep research effort we have managed to arrive at a set of fairly well-founded estimates of the total amount of mining gear on the market, their respective efficiencies and investment CAPEX. To those estimates we have added assumptions of market average electricity OPEX, a very conservative cumulative C&O OPEX and CAPEX horizon. From those figures we have arrived at total daily market-wide CAPEX and OPEX, subject to range-bound sensitivity analyses on electricity OPEX and CAPEX horizon. We then assume a steady state of bitcoin issuance of 144 * 12.5 = 1800 BTC/day and divide total daily market costs by the number of coins issued to arrive at the average marginal cost of creation. While we acknowledge that the real issuance rate is marginally higher than this due to the nearly ever-increasing hashrate, taking it into account in the model would yield differences in outputs that fall well within our existing margins of error, making it a pointless addition of complexity.

When attempting to calculate the cost of creation for Bitcoin, it is important to consider the fact that this cost is highly variable across the breadth of the industry. Mining hardware is not standardised, electricity and cooling costs vary drastically between different geographies and access to the newest, most efficient hardware is deeply preferential. Moreover, miner-manufacturers often have supreme advantages with regards to hardware investment costs because they a) have the ability to access their own hardware immediately post-production and at production cost, and b) often adjust the sales price of their externally marketed gear to reflect current trends in bitcoin prices in order to maximise their own profits and lower those of competitors.

This creates two fundamentally different competitive landscapes within the mining industry, one for manufacturer-miners and another for pure miners. When we then calculate an industry-wide average cost of creation all these factors must be taken into account with the corresponding realisation that at the same given time, some miners might be operating at razor thin margins, while others might be deeply profitable.

We have chosen to visualise this effect by using tables to show the sensitivities of creation costs to two main variables: electricity cost and CAPEX horizon (depreciation schedule) [Tab 1, Tab 2, Tab 3, Tab 4, Tab 5]. The results show that depending the electricity prices and hardware lifetime, the industry *on average* might have been approaching negative margins at the lows experienced earlier this year. For example, a generic miner having paid average market prices for hardware, depreciating said hardware over 18 months, running at electricity OPEX of 0.05 $/kWh, with extra all-inclusive C&O OPEX of 30% of total electricity cost, will have a current (as of the publishing date) cost of production of approximately $6,400 per bitcoin [Tab 3]. Varying the CAPEX assumption up or down by 20% gives mid-table values of ~$7,200 and ~$5,700, respectively [Tab 1, Tab 5]. Using a value of 20% C&O OPEX with the first set of assumptions gives a mid-table value of ~$6,200 per bitcoin whereas 40% gives ~$6,600.

Out of the mid-table creation costs, Electricity OPEX represents 33%, CAPEX represents 57%, and C&O OPEX represents 10% of the total cost.

As is evident from the tables on page 5 and figures on page 6, unsurprisingly, the cost of creation is highly sensitive to both CAPEX horizon and electricity OPEX [Fig 4]. Because our total market-wide CAPEX sum is calculated from our assumption of total amount of deployed hardware, we also show the sensitivity of creation cost to total industry CAPEX [Fig 5]. The results show that the sensitivity decreases with increasing CAPEX horizon which is again no surprise as longer CAPEX horizons allow for a higher number of days over which miners can spread their CAPEX costs.

Cost figures like these might help explain why the hashrate growth showed little sign of slowing down earlier this year, even though bitcoin prices came down more than 60% between December and February. While some miners running at the higher end of the cost spectrum were potentially struggling at and around the bottom, the market as a whole appears to have been running near or at cost during the worst of the drop. At the average prices available throughout Q1 and the first half of Q2 however, the industry seems to have been healthily profitable on average.

Table 1: Market-Wide Creation Cost (US$/BTC) at 30% C&O OPEX and -20% Below Standard CAPEX Assumption

-20% CAPEX

+30% C&O OPEX	CAPEX Horizon (Depreciation Schedule)				
Electricity OPEX	30 Months	24 Months	18 Months	12 Months	6 Months
0.01 $/kWh	$2,313	2,754	3,489	4,959	9,369
0.03 $/kWh	$3,411	3,852	4,587	6,057	10,467
0.05 $/kWh	$4,509	4,950	5,685	7,155	11,565
0.07 $/kWh	$5,607	6,048	6,783	8,253	12,663
0.09 $/kWh	$6,705	7,146	7,881	9,351	13,761

Source: CoinShares Research

Table 2: Market-Wide Creation Cost (US$/BTC) at 30% C&O OPEX and -10% Below Standard CAPEX Assumption

-10 CAPEX

+30% C&O OPEX	CAPEX Horizon (Depreciation Schedule)				
Electricity OPEX	30 Months	24 Months	18 Months	12 Months	6 Months
0.01 $/kWh	$2,534	3,030	3,857	5,510	10,471
0.03 $/kWh	$3,632	4,128	4,955	6,608	11,570
0.05 $/kWh	$4,730	5,226	6,053	7,706	12,668
0.07 $/kWh	$5,828	6,324	7,151	8,804	13,766
0.09 $/kWh	$6,926	7,422	8,249	9,902	14,864

Source: CoinShares Research

Table 3: Market-Wide Creation Cost (US$/BTC) at 30% C&O OPEX at the Standard CAPEX Assumption

Standard CAPEX Assumption

+30% C&O OPEX	CAPEX Horizon (Depreciation Schedule)				
Electricity OPEX	30 Months	24 Months	18 Months	12 Months	6 Months
0.01 $/kWh	$2,754	3,305	4,224	6,061	11,574
0.03 $/kWh	$3,852	4,403	5,322	7,160	12,672
0.05 $/kWh	$4,950	5,501	6,420	8,258	13,770
0.07 $/kWh	$6,048	6,599	7,518	9,356	14,868
0.09 $/kWh	$7,146	7,697	8,616	10,454	15,966

Source: CoinShares Research

Table 4: Market-Wide Creation Cost (US$/BTC) at 30% C&O OPEX and +10% Above Standard CAPEX Assumption

+10 CAPEX

+30% C&O OPEX	CAPEX Horizon (Depreciation Schedule)				
Electricity OPEX	30 Months	24 Months	18 Months	12 Months	6 Months
0.01 $/kWh	$2,975	3,581	4,592	6,613	12,676
0.03 $/kWh	$4,073	4,679	5,690	7,711	13,775
0.05 $/kWh	$5,171	5,777	6,788	8,809	14,873
0.07 $/kWh	$6,269	6,875	7,886	9,907	15,971
0.09 $/kWh	$7,367	7,973	8,984	11,005	17,069

Source: CoinShares Research

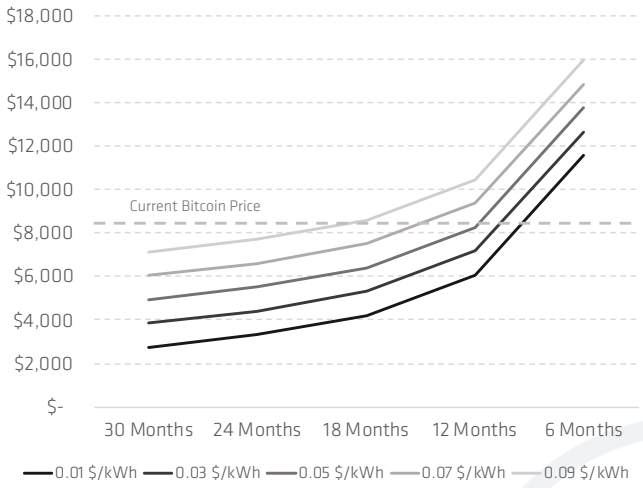
Table 5: Market-Wide Creation Cost (US$/BTC) at 30% C&O OPEX and +20% Above Standard CAPEX Assumption

+20 CAPEX

+30% C&O OPEX	CAPEX Horizon (Depreciation Schedule)				
Electricity OPEX	30 Months	24 Months	18 Months	12 Months	6 Months
0.01 $/kWh	$3,195	3,857	4,959	7,164	13,779
0.03 $/kWh	$4,293	4,955	6,057	8,262	14,877
0.05 $/kWh	$5,391	6,053	7,155	9,360	15,975
0.07 $/kWh	$6,489	7,151	8,253	10,458	17,073
0.09 $/kWh	$7,587	8,249	9,351	11,556	18,171

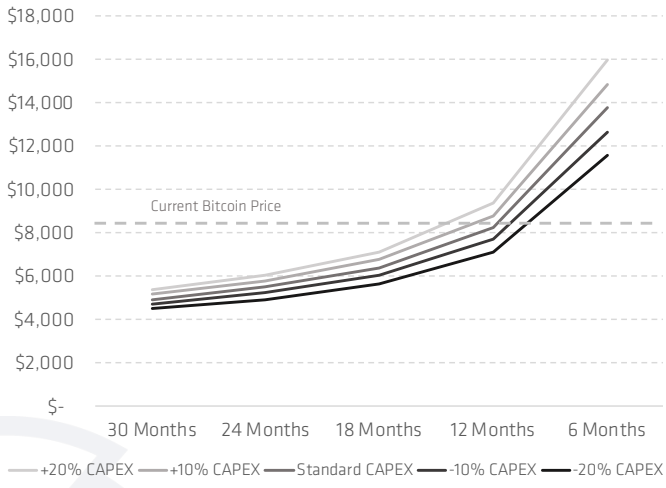
Source: CoinShares Research

Figure 4: Sensitivity of Marginal Creation Cost to Electricity OPEX and CAPEX Horizon



Source: CoinShares Research

Figure 5: Sensitivity of Marginal Creation Cost to CAPEX Assumption Size and CAPEX Horizon at 0.05 $/kWh



Source: CoinShares Research

Network Electricity Consumption

The electricity consumption of the Bitcoin network is a hot topic, with much sensationalist narrative focused on the sustainability and carbon footprint of its power sources. There are widely cited sources claiming that the Bitcoin network has an overall power demand exceeding 65 TWh on an annualised basis and that its annual carbon footprint exceeds 32 million tonnes of CO_2 (3). Our findings strictly contradict both of these figures and we believe that they rest on incorrect assumptions resulting from inadequate research.

From our combined estimates of mining market composition, we calculate the current Bitcoin mining industry to draw approximately 4 GW of power. In contrast, the IEA estimates global cumulative installed capacity (2015) at 2760 GW (5). From these figures we calculate the total power usage of the Bitcoin mining network at 0.14% of 2015 global capacity. On an annualised basis this consumption corresponds to approximately 35 TWh, less than the annual energy consumption of Luxembourg (6), a country of 585,000 people. For comparison, the banking industry in London alone employed 148,000 people in February 2017 (7).

Network Electricity Sources

Many articles have assumed that because the majority of Bitcoin mining capacity is installed in China - a country largely reliant on coal for electricity generation - the network as a whole must therefore be mostly coal-fuelled. Our findings completely contradict these claims and instead suggest that the Bitcoin mining network largely runs on hydro power.

As explored in some detail by our colleagues at BitMEX Research (8) and highlighted by financial reporters at Reuters (9), China has huge excess electricity generation capacity locked up in hydro power stations in the south and south western provinces. In most cases this capacity was originally intended to drive the Chinese aluminium industry, but with the Chinese smelting industry already dwarfing all others combined, many hydro power stations have been completed without any accompanying smelting plants leading to vast overcapacity in some Chinese provinces, particularly Yunnan and Sichuan (10) (11). Similarly, there exists large swaths of excess Chinese wind power capacity, particularly in the far west (11).

Since China lacks sufficient large scale long-distance transmission grids to transport its excess electricity to its population centres along its eastern coast, much of its excess capacity ultimately lies unused. This has led to a spectacular opportunity for Chinese bitcoin miners to take advantage of otherwise mothballed capacity for economic gain. While many local power stations were initially unable to offer electricity contracts to private buyers, some miners circumvented policies by the argument that bitcoin mining represents a form of energy recycling, somewhat akin to a battery, whereby

excess electricity otherwise wasted is instead converted into an exchangeable store of value (12). This could represent a wider global opportunity for renewable power plants struggling with periodic overproduction.

The developments mirror those observed in Quebec where Bitcoin miners have also rushed to take advantage of stranded hydro power capacity (13). Hydro is also the preferred generation source in north-western United States (14) (15), Norway and Sweden (17), whereas Icelandic mines use a mixture of hydro and geo-thermal (18).

Overall, we find that contrary to previously reported assumptions, bitcoin mining is largely driven on cheap renewable energy, dominated by hydro, with the limited permanent use of, and some seasonal migrations to, coal-based generation in certain areas of China only representing a small part of the network's total electricity demand. Because bitcoin mining is a highly mobile industry it can and will migrate to any area offering the cheapest electricity. Dams cannot be moved and as such, any installed hydro capacity is captive to its geographic location. This often makes stranded hydro plants willing to offer highly competitive electricity contracts to any willing takers in an effort to make any return on their investment. Fossil fuels are not that popular in bitcoin mining for the simple reason that they are too expensive.

Conclusion

Our total findings suggest that the Bitcoin mining industry is relatively healthy, profitable and continues to grow at breakneck speeds. The hashrate is tripling on an annual basis while the efficiency of the hardware is rapidly increasing and costs are coming down. Miners are securing access to highly competitive sources of electricity, often ones that would otherwise lie idle, and show high degrees of mobility as an industry (see the Appendix for further discussion).

In terms of prices, we find that market-average marginal costs of creation are currently significantly lower than the bitcoin price. While some miners may have felt the squeeze during the market bottom, particularly if they were latecomers in terms of the modernity of their mining gear and/or operate in areas with comparatively higher electricity costs, the mining industry appears healthy and profitable.

We also find that the industry is largely running on renewables. The cheapest electricity in the world is in many cases stranded hydro power and Bitcoin miners have shown a strong will and ability to seek out the cheapest possible sources, wherever they may be. While much of the industry has been confined to China in the last few years, we are now observing a large number of mines constructed across a much wider geographical spread.

Barring nation-level bans on mining operations like those apparently instated in China, or strong pullbacks in the bitcoin price, the industry looks poised for further growth both in terms of overall size, efficiency and geographical distribution.

Appendix A

Source Discussion

In order to arrive at our market-wide assumptions used for the calculations in this paper, we have had to dedicate a substantial amount of resources to deep research over the preceding months. As a part of this research effort we have talked to dozens of miners both large and small, dug through public records where available, and trawled a huge number of online news sites, blog platforms, forums and message boards. In this nascent space, the latter types sources are particularly invaluable as they are often the main platforms for communication between key industry players and market actors.

This research has not been easy, especially considering the global distribution and heavy Asian footprint of miners. Chinese influence is particularly strong and historically, there have been times where Chinese miners have accounted for as much as 80% of coinbases claimed. Thus, our research has extended well beyond Western news outlets, and to the best of our ability we have penetrated the Chinese news outlets to retrieve data which, to our knowledge, is not available in English.

In bringing this all together, we have produced this appendix which may not catch the interest of every reader. Those that do however, should consider the rating of strength that we have applied to the various assumptions in relation to our varying confidence in the sources. Obviously, even with these considerations in place, the reader is still advised to acknowledge the assumptions as such, particularly in the cases where we attempt to arrive at numbers, that given the realities in this nascent space, is

essentially unknowable.

Fundamental to our overall analysis is the total amount of mining gear operating in the market. Frankly, this is an unknowable figure, but thorough research can still enable reasonable approximations. We believe there is a new wave of opportunity for analysis as the mining industry matures and documents are submitted to jurisdictions like in the case of Canaan Mining (China) (19) and Hut 8 (US) (20). However, we caution that we are still miles away from anything resembling the disclosure requirements of listed companies in modern developed economies.

Part of the problem we faced is that all relevant manufacturers of mining gear are private companies with no requirement or desire to disclose any information regarding their internal business affairs. These companies will mainly show the world what they want it to see in order to maximise their own benefit. Case in point would be Chinese miner-manufacturer Bitmain who is infamous for running private mining operations under a veil of secrecy for many years prior to media disclosure, even while being recognised as the main player in the Bitcoin mining industry. Only when incentivised by the prospects of free marketing of current or future products, positive PR or reputation building can the private players be expected to reveal much about anything they do, making our jobs as researchers exceedingly difficult.

Whilst we can be reasonably sure about Bitmain's 21,000 mining units at their Ordos facility (21), we cannot be equally sure about the magnitude of the rest of their operations. In the case of GMO Mining (22), the last significant operator, we rely on reverse engineering and tinkering with information from their investor documents. This is not entirely reliable either as we have to use other assumptions to structure the information that is released by GMO and so inevitably multiplies out into further improbability.

The assumptions made regarding price are not definitive either; even in cases where prices are more or less public, such as those for Bitmain's Antminer S9, it is still hard to reliably know the full price history as we have found no public records thereof. As discussed in the breakdown in Appendix B the price of the S9 – perhaps more than most – changes frequently. In all cases, we only consider the first hand commercial market prices and do not take into account that of second hand or aftermarket sales. This will have the most pronounced discrepancy with regards to the S9 because it is the world's most popular, accessible and cost-effective miner. For example, Amazon, eBay and forum resales soared well over US$ 4,000 with the highs of Bitcoin approaching US$ 20,000. These sales are even harder to gauge and so we neglect them entirely – as they are probably of limited global scope anyway – and focus on the exchange between industrial miners and producers of miner hardware.

For a more detailed discussion of the S9 price we direct the readers to the assumption breakdown in Appendix B. When considering the costs to the manufacturer, we used Jimmy Song's article on Bitmain's production cost and scaled it up (23). This is because we believe Jimmy Song is an informed individual and his educated analysis is as good a *guess* as anyone's. Though we were surprised to find that Song recommended only 60% of the costs (US$ 300) were for the chips – as we assumed it to be higher – we went with his assumption over our own. The prices of other miners are retrieved from what is publicly available from the internet but are also not exhaustive nor definitive, as their prices just like Bitmain's – though we are sure to a lesser extent – fluctuate with a number of variables, including but not exclusive to, the price of Bitcoin.

We also rely quite substantially on advertised miner specs actually being correct. Unless there is consensus in the user market that the hardware does not match the advertised standards, we have assumed that the figures supplied by the producer of the hardware is reliable. All the assumptions regarding efficiency and hash output are thus a tempered belief that is amended to our observations of user experience. For example, on top of public forums we are also part of some private groups and in dialogue with private miners that are commanding significant hashrate. With them, we discuss specs, operating costs, capital costs as well as a wide variety of other aspects of mining. As an example of a public figure proving excellent data on forums, Bitcointalk user 'Phillipma1957' has shared a wealth of hands-on experience dealing with hardware and is considered be reliable, having verified various products over many years.

Appendix B

Specific Assumptions

(CoinShares Research Assumption Rating Strength from 0 – 10)

Mining Unit Cost in US$

Antminer S7:
US$ 1500 – 7/10

At release this unit was briefly priced at less than US$2,000 and is now priced at approximately US$500. Though there are few records of the price in between we will assume roughly an average price of US$1500 as most are likely to be bought near release time due to its current obsolescence. We arrive at the number by assuming a third of those still operating were bought at US$500 and two thirds of those still operating where bought at US$2,000.

Antminer S9 Publicly Available Units:
US$ 1800 – 7/10

This price is a function of several variables proprietary to Bitmain. One of the most pronounced observable ones is the bitcoin price. While the price has swung greatly over the time of our available data and monthly sales are not available, we consider this price to be our best guess at a volume weighted average.

We have compiled a table of the S9 price and the bitcoin price over the last seven months and, although the dataset is small, it is easy to observe that the bitcoin price alone does not set the price. Bitmain has been considered a somewhat infamous and divisive figure, especially in western sources, being actively involved in various efforts that many consider to be detrimental to Bitcoin (Bitcoin Cash, SegWit2x etc.). Considering that reputation and the timeframe, there is reason to believe that Bitmain was in fact pricing the S9 according to attempts from other players to enter the market. During this period, where the price is marked heavily marked down, Halong Mining were taking their first round of orders for their Dragonmint Miner "T1" and Ebang Technologies and Canaan mining were taking orders for their latest developments towards the end of the timeframe. The hypothesis would be that they were trying to influence the market – as has been levelled against them multiple times – in an attempt to supress the competition.

Table 6: Overview of Archived Batch Prices of the Bitmain S9 Mining Unit (24) (25)

Batch	S9 Price	BTC Price
May 18	$1,222	$9,000
Feb 18	$2,725	$9,250
Jan 18	$1,995	$13,500
Dec 17	$2,320	$16,500
Nov 17	$1,265	$8,000
Oct 17	$1,500	$5,250
Sep 17	$1,750	$4,750
Average price	**$1,825**	**$9,464**

Antminer S9 Private Bitmain Facilities:
US$ 500 - 7/10

Here we base the assumption on an article by Jimmy Song entitled "Just how profitable is Bitmain?" (23).

DragonMint T1:
US$ 1,595 – 7/10

This assumption is based on the price of batch 1. We know of no further batches.

Avalon 721:
US$ 888 – 7/10

Assuming stated price is accurate.

Avalon 741:
US$ 808 – 7/10

Assuming stated price is accurate.

Avalon 761:
US$ 1400 – 7/10

Assuming stated price is accurate.

Private Bitfury Facilities:
US$ 400,000 – 4/10

This assumption is an order of proportionally scaling Song's Bitmain supply cost (23) onto Bitfury and then doubling the per-chip cost to reflect higher costs of the full set up and the higher production costs suggested by the lower success of Bitfury relative to Bitmain.

Bitfury Publically Available Units:
US$ 1,300,000 – 6/10

This is a composite estimate of various forum posts (26) and conversations with Bitfury miners.

Bitfury x Hut 8:
US$ 1,300,000 – 6/10

See above assumption.

GMO Mining:
US$ 1,300,000 – 6/10

This assumption is resting on the fact that GMO currently has 241 PH/s (as per their Q4 investor presentation) and disclosed that they bought these miners fully assembled; considering Bitfury is one of the only industrial suppliers of fully assembled gear, and the 7.5 PH/s blockbox fits closely into 241. The price is the same as the previous two assumptions.

Total Mining Units

Antminer S7:
100,000 – 6/10

Here we assume that the total amount of S7s in the market is proportionally the same as that of Bitmain's industrial facilities, namely 1:10. Bitmain have stated that they keep S7's alongside S9's in their industrial complex' due to the reliability [specifically versus the S9]. According the interviewed remarks of working closely with them, this is 'no small luxury' and completely dependent on highly competitive electricity. Obviously, there are a lot more S7's out in the market but in most situations, they are not economical to operate.

Antminer S9 Publicly Available Units:
660,000 – 8/10

This figure is built on extensive research of forum threads and publications concerning Bitmain and other industrial miners. It is also corroborated by the remarks of an interviewed Bitmain employee stating that a production output of 30,000 units a month was the average for the year of 2017 (27).We have taken this estimate and extrapolated back and forward for the months from June 2016 through April 2018.

[30,000 * (12 + 6 + 4) = 660,000]

This we take as a conservative lower bound considering the abundance of S9's and the amount of companies with 10's of thousands of S9s. Further to it being considered conservative, if Bitmain are number 1 mining producer and Canaan are on record selling 40,000 a month (see below) then it is unlikely Bitmain were selling 10,000 less.

Antminer S9 Private Bitmain Facilities:
230,000 – 8/10

Here we base our assumption on remarks from Bitmain employees and interviews from Quartz articles on Bitmain (https://qz.com/search/bitmain, all worth reading) and Chinese news sources covering Bitmain. The Chinese sources suggest that the mine in Xinjiang is 'three times' the size of the Ordos mine of 25,000 machines; that the Xinjiang mine and the Sichuan and Yunnan mines have a migratory cycle based on the abundance of wind and solar in the dry season (Xinjiang, Northwest) (10) (11) and the hydropower of Sichuan and Yunnan in the rainy season (Southwest) (10); and lastly that they have facilities like it elsewhere in China and the world (such as in Anhui and Newfoundland (28)).

Dragonmint T1:
10,000 – 3/10

We have low confidence in this figure but we wanted to include an estimate nevertheless. There was a widespread need for a Bitmain competitor and in anticipating this, miners bought up all of the Halong mining products unseen and with a minimum order size of 5 units. At such a small batch size estimate the figure has minimal impact on overall calculations.

Avalon 721:
300,000 – 7/10

This assumption extends to the three below. Canaan mining (producers of the Avalon miners) disclosed they shipped 160,000 miners from January 2017 through to end of April 2017 (19). We have extrapolated this rate of production backwards and forwards since the release of the Avalon in August '16 to arrive at 800,000 total units. This would perhaps be an overestimate in

2016 but it is definitely a conservative estimate considering the large increase of the both the Bitcoin price and the hashrate from April 2017 and out. Since the 721 was the earliest released version, we have assigned it 300,000 of the 800,000 units.

Avalon 741:
300,000 – 7/10

See the above assumption. This model is given the same production run as the 721.

Avalon 761:
200,000 – 7/10

See the above assumption (Avalon 721). This model was only recently released, so we have allocated it 200,000 out of the total 800,000 units.

Private Bitfury Units:
112 – 7/10

This assumption is reverse calculated from Bitfury investor presentations stating 132 megawatts and subtracting off the known 'Hut 8' units leaving Bitfury's own facilities.

Publically Available Bitfury Units:
448 – 5/10

Here we use market estimates of approximately 12% of total hashrate (28 exahash) as stated by the CEO of Bitfury to reverse-arrive at 448 by using stated efficiency figures (29).

Bitfury Hut 8 Units:
57 – 8/10

This assumption is also reverse calculated as above, but because it's publicly disclosed and on Canadian news we assign them a higher confidence rating. The facilities are located in Drumheller and Medicine Hat.

GMO Mining Units:
32 – 5/10

This assumption is resting on the fact that GMO currently has 241 PH/s (as per their Q4 investor presentation) and disclosed that they bought these miners fully assembled; considering Bitfury is one of the only industrial suppliers of fully assembled gear, and the 7.5 PH/s blockbox fits closely into 241.

Hashrates and Power Efficiency per Unit

All except GMO Mining – 9/10

This represents a tempered belief in the state of the producers which will have modified only slightly if we believe the real-life specs are different (e.g. reading published reviews or forum reviews of trusted members acknowledging there to be a large disparity between the advertised spec and the testing spec).

GMO Mining – Hashrates taken from company filings (22).

Appendix C

We have assumed an average market-wide electricity tariff of 0.05 $/kWh. The basis for this figure is an estimate of the percent distribution between miners in three normalised zones of average electricity costs. The first zone represents the most highly competitive electricity prices averaged to 0.025 $/kWh. Such prices are only open to those who have access to abundant hydro power (30).

From research we know such prices probably only exist in the South West of China and the North American Continent where rivers are of such a magnitude that enormous hydro dams are able to drive electricity prices down, often generating large amounts of surplus like HydroQuebec or during the wet season in Yunnan or Sichuan (10). This tariff only applies to just over a fifth of worldwide miners as we also note that miner migration and/or price hikes occur during the dry season in China. Where the price applies on the North American continent, it seems it applies year-around, but is a case of preferential treatment which may be restricted to certain companies or have temporal limitations (31). Similar preferential treatment has been given to Bitmain – probably due to their size – in Yunnan but seems to no longer necessarily apply. This rate was reportedly as low as 0.02 $/kWh (32). Overall, with a little less than 20% of bitcoin mining on the North American continent, at the

lowest available rates and a small portion of very large industrial miners in China operating around the same levels, we assume that 22.5% of the market can access prices of 0.025 $/kWh.

The majority of miners seem to be operating at tariffs closer to 0.055 $/kWh. This is probably a more familiar electricity margin that people are used to observing around the industry. It is estimated that around three quarters of the market is operating at rates like these, but we have lowered it slightly for the ease of argument and assigned just a little less than three quarters at 72.5% of the market. It is obviously extremely hard to estimate such figures, but we observe that for example in the case of hydro in China, miners would receive different rates throughout the season and so be forced to migrate. Though we have observed miners describing behaviours like 'migratory birds' (33) we also presume that others must work out a tariff that persists throughout the year and stay in place with a slightly higher price than the highly competitive hydro prices (34). A large part of the assumption of 0.055 $/kWh comes from the observation that the majority of mining happens in China and that we consistently come across rates of between 3 (35) and 4 yuan/kWh (30). The average of this is 3.5 yuan/kWh which is 0.055 $/kWh. Bitfury reports rates of between 4-6 cents in Georgia (36) and similar rates in its facilities in Iceland and upcoming facilities in Norway. Bitfury's market research, considering their relative success, weighs heavily on our assumptions (20). Whilst their collaboration with Hut 8 in the North American continent gets 0.035 $/kWh, an average of their market research reveals a rate of 0.052 $/kWh which is close to our assumption. Prices in Iceland are similar and there is a lower bound of around 0.043 $/kWh (37) though miners will often have to pay rates that are slightly higher than this. Thus, this array of sources combined with other assumptions we deem a significant sector of the industry (72.5%) to be mining at about 0.055 $/kWh.

Lastly, there is the hobbyist tariff which is posited to be around 8 cents/kWh. As a hobbyist it is extremely hard to make a profit in the present market. To a large extent, hobbyist mining is considered to be a thing of the past, and when we are discussing the hobbyist in the present what is actually meant is *small-scale* industrial miners. These are still people mining out of what would be considered data centers in comparison to the bitcoin miners predating 2014. Both in terms of market share and the electricity tariff there is considerable variance in circumstances and it is very hard to take an average of the aggregate of various 'hobbyist' mining projects all over the world. Our estimate is that 5% of global miners are small-scale miners operating at the higher rate of 0.08 $/kWh.

Pulling this together we arrive at a very rough calculation of:

((0.225 * 0.025) + (0.725 * 0.055) + (0.05 * 0.08))

Which approximates to 0.05 $/kWh

Works Cited

1. Morris, David Z. *Fortune.* [Online] February 2018, 2018. [Cited: May 3, 2018.] http://fortune.com/2018/02/24/bitcoin-mining-bitmain-profits/.

2. Hileman, Garrick and Rauchs, Michel. *University of Cambridge, Judge Business School.* [Online] 2017. [Cited: April 26, 2018.] https://www.jbs.cam.ac.uk/fileadmin/user_upload/research/centres/alternative-finance/downloads/2017-global-cryptocurrency-benchmarking-study.pdf.

3. de Vries, Alex. Bitcoin Energy Consumption. *Digiconomist.* [Online] [Cited: May 8, 2018.] https://digiconomist.net/bitcoin-energy-consumption.

4. Brown, Patrick Cavan. Politico. [Online] March 9, 2018. [Cited: April 10, 2018.] https://www.politico.com/magazine/story/2018/03/09/bitcoin-mining-energy-prices-smalltown-feature-217230.

5. Agency, International Energy. *IEA Atlas of Energy.* [Online] 2017. [Cited: April 27, 2018.] http://energyatlas.iea.org/#!/tellmap/-1118783123/0.

6. International Energy Agency. International Energy Agency. [Online] 2017. [Cited: April 23, 2018.] http://www.iea.org/publications/freepublications/publication/KeyWorld2017.pdf.

7. TheCityUK. *TheCityUK.* [Online] February 2017. [Cited: April 27, 2018.] https://www.thecityuk.com/assets/2017/Reports-PDF/UK-based-financial-and-related-professional-Services-Enabling-growth-across-the-UK.pdf.

8. BitMEX Research. BitMEX Blog. *BitMEX.* [Online] September 15, 2017. [Cited: April 25, 2018.] https://blog.bitmex.com/mining-incentives-part-2-why-is-china-dominant-in-bitcoin-mining/.

9. Reuters. *Reuters.* [Online] June 7, 2015. [Cited: April 17, 2018.] https://www.reuters.com/article/china-renewables-hydropower/dam-waste-planning-chaos-drains-chinas-hydro-ambitions-idUSL3N0YB3UB20150607.

10. Jiansheng, Ma. *ChinaSmartGrid.* [Online] March 8, 2017. [Cited: April 13, 2018.] http://www.chinasmartgrid.com.cn/news/20170308/622441.shtml.

11. Bitcoin86. *Bitcoin86.* [Online] January 12, 2018. [Cited: May 5, 2018.] http://www.bitcoin86.com/wk/19509.html.

12. Pingwest. *Pingwest.* [Online] 2017. [Cited: April 17, 2018.] http://en.pingwest.com/insight_detail?insight_id=100.

13. Dent, Steve. *Engadget.* [Online] February 26, 2018. [Cited: May 6, 2018.] https://www.engadget.com/2018/02/26/bitcoin-mining-quebec-the-big-picture/.

14. Caruso-Cabrera, Michelle and Shah, Ratika. *CNBC.* [Online] January 11, 2018. [Cited: May 3, 2018.] https://www.cnbc.com/2018/01/11/wenatchee-washington-and-the-bitcoin-gold-rush.html.

15. Shepherd, Katie. *Willamette Week.* [Online] February 21, 2018. [Cited: May 3, 2018.] http://www.wweek.com/news/business/2018/02/21/bitcoin-miners-are-flocking-to-oregon-for-cheap-electricity-should-we-give-them-a-boost/.

16. North, Andrew. *NPR.* [Online] April 23, 2018. [Cited: May 6, 2018.] https://www.npr.org/sections/parallels/2018/04/23/597780405/how-the-tiny-nation-of-georgia-became-a-bitcoin-behemoth.

17. Steitz, Christoph and Jewkes, Stephen. *Reuters.* [Online] April 10, 2018. [Cited: May 6, 2018.] https://www.reuters.com/article/us-crypto-currencies-nordics-energy/cryptocurrency-miners-seek-cheap-energy-in-norway-and-sweden-idUSKBN1HH13L.

18. Hern, Alex. *The Guardian.* [Online] February 13, 2018. [Cited: February 8, 2018.] https://www.theguardian.com/world/2018/feb/13/how-iceland-became-the-bitcoin-miners-paradise.

18. Hern, Alex. *The Guardian.* [Online] February 13, 2018. [Cited: February 8, 2018.] https://www.theguardian.com/world/2018/feb/13/how-iceland-became-the-bitcoin-miners-paradise.

19. Wu, Dacheng and Hu, Meng. *360doc.com.* [Online] January 11, 2018. [Cited: April 22, 2018.] http://www.360doc.com/content/18/0111/23/46341144_721197317.shtml.

20. Hut 8. *Hut 8 Mining.* [Online] April 23, 2018. [Cited: April 24, 2018.] https://www.hut8mining.com/wp-content/uploads/Hut-8-Investor-Presentation-April232018.pdf.

21. Huang, Zheping and Wong, Joon Ian. *Quartz.* [Online] August 17, 2017. [Cited: May 1, 2018.] https://qz.com/1054805/what-its-like-working-at-a-sprawling-bitcoin-mine-in-inner-mongolia/.

22. GMO Internet Group. *GMO Internet Group.* [Online] May 7, 2018. [Cited: May 8, 2018.] https://ir.gmo.jp/en/pdf/irlibrary/disclose_info20180507_e.pdf.

23. Song, Jimmy. *Medium.* [Online] April 14, 2017. [Cited: April 22, 2018.] https://medium.com/@jimmysong/just-how-profitable-is-bitmain-a9df82c761a.

24. BITMAINtech. *Twitter.* [Online] January 24, 2017. [Cited: April 24, 2018.] https://twitter.com/BITMAINtech/status/823830603980079108 .

25. Bitmain. *Bitmain.* [Online] 2017. [Cited: April 25, 2018.] http://shop.bitmain.com/productDetail.htm?pid=00020170928101914177 7wvS8I1g068C.

26. phillipma1957. *Bitcointalk.* [Online] January 3, 2017. [Cited: April 24, 2018.] https://webcache.googleusercontent.com/search?q=cache:MVzsaaq9_DQJ:https://bitcointalk.org/index.php%3Ftopic%3D1737749.15+&cd=1&hl=en&ct=clnk&gl=uk.

27. 36kr. *36kr.* [Online] February 9, 2018. [Cited: April 23, 2018.] https://36kr.com/p/5119020.html?from=guess.

28. Antle, Rob. *CBC.* [Online] April 27, 2017. [Cited: April 24, 2018.] http://www.cbc.ca/news/canada/newfoundland-labrador/great-north-data-bitmain-technologies-lawsuit-1.4084925.

29. Obiko Pearson, Natalie. *Bloomberg.* [Online] February 12, 2018. [Cited: May 2, 2018.] https://www.bloomberg.com/news/articles/2018-02-12/bitcoin-chip-battle-brewing-behind-hut-8-s-canadian-listing.

30. Bitcoin86. *Bitcoin86.* [Online] May 3, 2018. [Cited: May 4, 2018.] http://www.bitcoin86.com/wk/21906.html.

31. Roberts, Paul. *Ploitcio.* [Online] March/April 2018. [Cited: April 23, 2018.] https://www.politico.com/magazine/story/2018/03/09/bitcoin-mining-energy-prices-smalltown-feature-217230.

32. Huang, Zheping. *Quartz.* [Online] January 5, 2018. [Cited: April 25, 2018.] https://qz.com/1172632/chinas-dominance-in-bitcoin-mining-under-threat-as-regulators-hit-where-it-hurts-electricity/.

33. Bitcoin86. *Bitcoin86.* [Online] February 22, 2018. [Cited: May 1, 2018.] http://www.bitcoin86.com/wk/20258.html.

34. –. *Bitcoin86.* [Online] January 12, 2018. [Cited: April 27, 2018.] http://www.bitcoin86.com/wk/19509.html.

35. Redman, Jamie. *Bitcoin.com.* [Online] 2018. [Cited: May 4, 2018.] https://news.bitcoin.com/georgia-has-become-eurasias-cryptocurrency-mining-epicenter/.

36. McQuaid, Darius. *Express.* [Online] February 17, 2018. [Cited: April 24, 2018.] https://www.express.co.uk/finance/city/920038/bitcoin-mining-latest-news-price-cryptocurrency-bitcoin-cash-litecoin-ethereum.

37. Bitfury. *Bitfury.* [Online] 2018. [Cited: May 1, 2018.]

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