MATH5314 Final Project

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1 Introduction

The rise of blockchain technology has brought about never-before-seen transparency in financial systems, offering unique opportunities to analyze network activities and market behavior. On-chain analysis—the study of blockchain data to understand transaction patterns and asset movements—provides critical insights into market sentiment, supply dynamics and user behavior[1, 2]. This report examines the power of on-chain analysis, helping investors, analysts, and stakeholders better understand market movements, trends and network health.

To conduct this analysis, it is essential to briefly assess the current state of the cryptocurrency market. Market sentiment, often captured by tools like the Fear and Greed Index[3], reflects the emotions driving investor decisions. Periods of extreme fear often signal opportunities, while greed can indicate market overheating. By evaluating sentiment metrics alongside on-chain data, we can uncover patterns that drive cryptocurrency price action and market participation.

At its core, on-chain analysis extracts valuable data directly from blockchain transactions. Unlike traditional financial analyses, on-chain data is transparent, immutable, and real-time, offering unique insights into network health, investor behavior, and economic fundamentals. Two important questions need to be addressed before starting the analysis:

- **What is on-chain analysis?** On-chain analysis involves examining blockchain transaction data, wallet activities, and other publicly available information to identify trends.
- **Why is on-chain analysis important?** It allows us to answer critical questions about market dynamics: Are long-term holders (LTH) accumulating or selling? Are short-term investors (STH) realizing profits? What is the market's cost basis, and are we near a potential cycle top or bottom?

This report will explore crucial on-chain metrics that collectively form the foundation for understanding market behavior. Analysis will be conducted on supply dynamics, market cycle indicators, and network health to identify signals and trends that may not be visible through traditional market analysis alone. Each metric and dataset will be explained in detail, ensuring clarity for both new and experienced readers.

2 Data Dictionary - Important Terminology

All the metrics introduced in the following data dictionary 2 table will be introduced and visualized examined in the following sections[1].

Term	Definition and Importance
Hash Rate	The computational power used to mine and process transactions on a blockchain network. A higher hash rate indicates more mining power securing the network.
Difficulty	The current estimated number of hashes required to mine a block.
Miner	Bitcoin's security is maintained by miners, who are rewarded in BTC for supplying computational power, validating transactions, mining new blocks, and adding them to the blockchain.
LTH (Long-Term Holder)	A wallet or address that holds a cryptocurrency for a period exceeding 155 days. LTHs are considered strong hands, less likely to sell during market volatility.
STH (Short-Term Holder)	A wallet or address that holds a cryptocurrency for 155 days or less. STHs are more likely to react to short-term price changes and market volatility.
Market Value to Realized Value Ratio	A ratio comparing the current market value of a cryptocurrency to its realized value. High MVRV suggests overvaluation, while low MVRV indicates undervaluation and accumulation.
Realized Price	It is calculated as the total value of all bitcoins based on their last on-chain transaction price, divided by the total bitcoins in circulation. It represents the average price at which all bitcoins were acquired, serving as an "average cost basis" for the network.
Realized Profit	Realized Profit denotes the total profit (USD value) of all moved coins whose price at their last movement was lower than the price at the current movement.
Network Health	A collective measure of blockchain metrics such as hash rate, difficulty, transaction volume, and unique addresses. Indicates the stability, security, and activity of the blockchain.
Transfer Volume	The total value of assets transferred on the blockchain over a specific time frame. Reflects overall activity and liquidity in the blockchain network.
Mining Efficiency	A measure of how effectively miners convert computational power into mined blocks and profits. Helps evaluate the profitability and sustainability of mining operations.
Block Reward	the amount of Bitcoin miners receive for successfully mining a new block and adding it to the blockchain. Initially set at 50 BTC per block, this reward undergoes a process called "halving" approximately every four years (or 210,000 blocks). Halving reduces the reward by half, ensuring Bitcoin's supply is limited and follows a deflationary issuance schedule. Currently, the reward is 3.125 BTC per block.
Cost of Production	The estimated cost for miners to produce one unit of cryptocurrency, often based on electricity cost and hash rate. Understanding this helps identify miner behavior, sell pressure, and breakeven points.

3 Supply Dynamics & Holder Behavior

3.1 LTH & STH Supply and Realized Profit

In this section, we will apply several metrics introduced before to help us gain insights into the market's supply dynamics, investor behavior, and how these factors influence price cycles. All the plots are generated on the online Bitcoin dashboard glassnode, which is an online real time tracking system, provided charts for many different metrics. Most of the metrics we introduced in the data dictionary are from this platform, first we will introduce the idea of Long-Term Holders (LTH) and Short-Term Holders (STH).

Long-Term Holders are defined as keeping possession of their coins for periods of time, from several months to years, in this report an approximate threshold is defined as 155-day holding period, after which dormant coins becoming increasingly unlikely to be spent [4]. They will accumulate bitcoin during periods of relatively low prices, and often seen as more conviction-driven investors, tend to retain their coins for extended periods, providing a stable "bedrock" of supply. As the market matures and prices move higher, LTH supply often keep stable or declines slightly, as some long-term investors choose to take profits or reposition their holdings.

In contrast, the number of Short-Term Holders will typically increase during bullish phases, as newcomers and speculative traders flock into the market for quick gains [4]. When prices are rising, STH supply tends to increase, which results in elevated short-term optimism. Conversely, when uncertainty or price corrections emerge, these short-term players often exit, causing STH supply to contract.

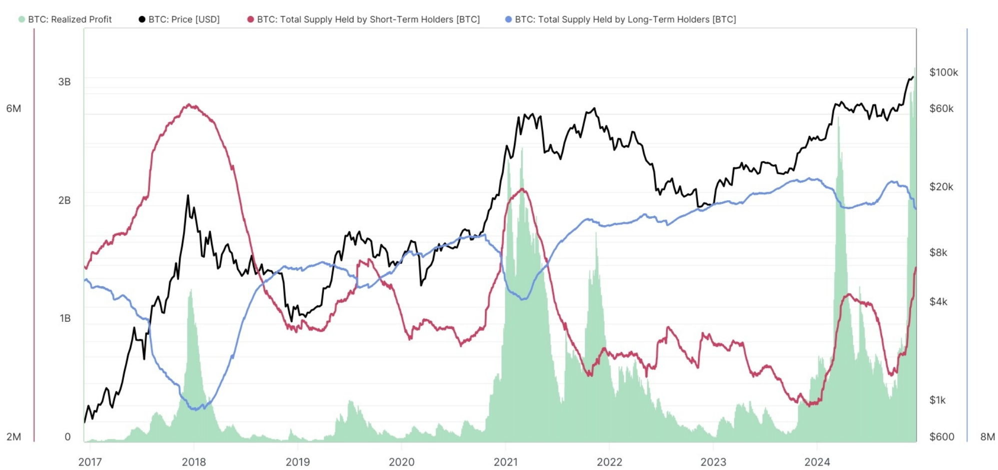


Figure 1: STH LTH

The chart 1 presented shows several key metrics from 2017 to right now, allowing us to visualize how different segments of Bitcoin holders and their profit-taking behavior interact with market price movements, including Realized profit, Bitcoin Price, Long-Term Holder Supply, and Short-Term Holder Supply.

The black line, representing Bitcoin's price, serves as a baseline to which we compare with the other indicators. Surrounding this price trend, the two key supply metrics are also mentioned here: the blue line for Long-Term Holders (LTH) and the red line for Short-Term Holders (STH). LTH supply generally increases when prices are decreased, reflecting the steady hands of conviction-driven investors who accumulate and maintain their holdings irrespective of short-term changing. Over time, this creates a foundation of coins locked away by those anticipating future growth. In contrast, STH supply tends to increasing rapidly during bullish phases as newcomers and speculators surge into the market, promised by the promise of quick gains and riding the wave of upward momentum.

However, these same short-term participants are often the first to exit when the market falters, causing STH supply to contract. Meanwhile, the green shaded area representing Realized Profit offers a standard measure of how frequently and aggressively holders are willing to sell at a profit. When Realized Profit spikes, it suggests that many are capitalizing on favorable prices, consisting of market tops marked by widespread optimism. Conversely, when Realized Profit remains decreasing, it may indicate a period of disinterest, more participants quit the market as they think it is less possible to realize gains.

3.2 Market Cycle Indicators

Figure 2: MVRV_Score

This graph 2 presents the relationship between the price of Bitcoin (black line), its realized price (green line) and the market value to realized value ratio shown in orange[5] . The MVRV ratio quantifies Bitcoin's market value relative to its realized value, providing insights into market valuation. Notably, during significant price increases, the MVRV ratio spikes, indicating that Bitcoin is overvalued relative to its historical cost basis. For example, peaks above the 3.2 red line signify historically overheated markets, often preceding sharp corrections or bear markets. These moments align with speculative frenzy phases in past bull runs, such as in 2013, 2017, and 2021.

On the lower end, when the MVRV ratio approaches or dips below the 0.8 blue line, Bitcoin is considered undervalued, reflecting market bottoms. Such periods historically correspond to ideal buying opportunities, where prices trade below the average cost basis of holders. The yellow (2.4) and green (1.0) thresholds act as intermediate benchmarks. The oscillating ratio between 1.0 and 2.4 reflects neutral to mild optimism, often observed during the accumulation phases. This cyclical movement of the MVRV ratio, combined with the realized price, highlights clear patterns of market tops and bottoms, making it a valuable tool for timing investment strategies.

3.3 Network Health

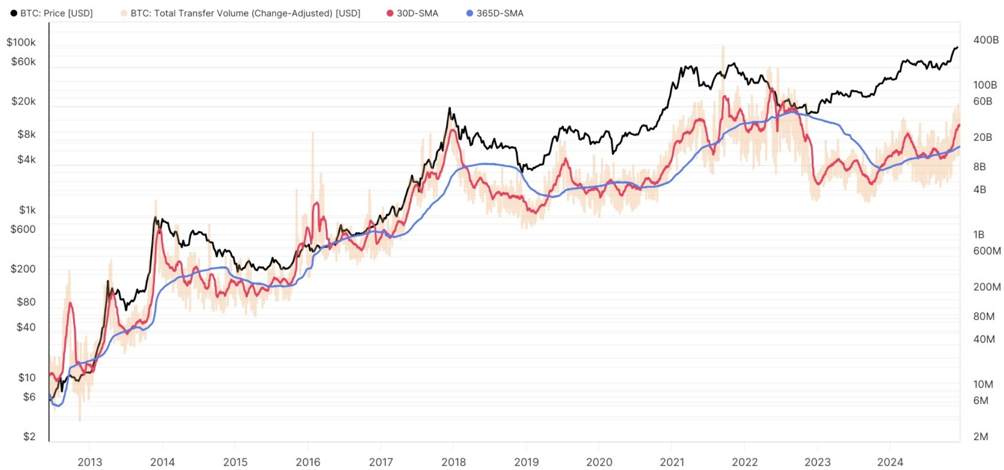


Figure 3: Transfer Volume Momentum

This graph 3 provides a comparative analysis of the price of BTC (USD), the total transfer volume (change-adjusted), and its corresponding simple moving averages for 30 and 365 days (SMA). The black line represents the BTC price, while the golden line reflects the transfer volume on the blockchain network, showing the total transactional activity on-chain. The transfer volume exhibits significant spikes during major market cycles, particularly during bull runs, highlighting increased activity when Bitcoin reaches peak speculative phases. These spikes indicate heightened transaction movements, often caused by profit-taking, large holder transfers, or increased adoption during periods of market excitement.

The two moving averages, 30D-SMA (red) and 365D-SMA (blue), serve as smoothing tools to identify trends within the transfer volume. The 30-day SMA reflects short-term activity, reacting quickly to spikes and dips, whereas the 365-day SMA provides a longer-term trend line, smoothing out volatility. Notably, when the 30D-SMA crosses above the 365D-SMA, it often aligns with significant BTC price increases, signaling increased network usage and investor engagement. Conversely, when the 30D-SMA declines below the 365D-SMA, it frequently precedes price corrections, suggesting reduced market activity and potential cooling periods. This relationship highlights the strong connection between BTC price momentum and on-chain transaction dynamics, making transfer volume a valuable indicator for understanding market sentiment.

3.4 Mining Pulse: A Window into Miner's Behavior

So far, we've explored key on-chain metrics, like MVRV, LTH vs STH supply, and transaction momentum to reveal investor behavior and network activity. Let's shift our perspective to the mining side of the market. A helpful tool for this view is the "Mining Pulse."

the Mining Pulse[6] measures how quickly or slowly new Bitcoin blocks are being found relative to the ideal 10-minute target. More specifically, it tracks the deviation between the 14-day average block interval and that 600-second goal:

Negative Mining Pulse: These indicate block times faster than the 10-minute target. Generally, this happens when network hash rate is increasing more quickly than the Difficulty Adjustment can compensate, pushing blocks out at a pace faster than intended. It's often a sign of miners expanding their operations, adding new hardware, or otherwise boosting collective hash power.

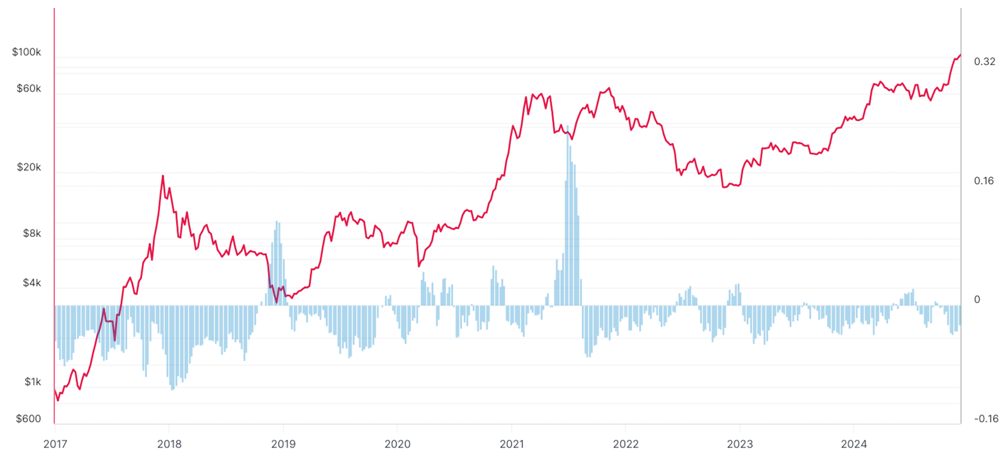


Figure 4: Mining Pulse

Positive Mining Pulse: These indicate block times slower than the 10-minute target. This usually means some miners are turning off their machines, or the network hash rate is decreasing quicker than Difficulty Adjustments can react. Block production slows down, signifying a contraction or some level of stress in the mining ecosystem.

The Mining Pulse is more than just a technical curiosity; it's a window into miner sentiment and economics. Because miners have to balance electricity costs, hardware investments, and market conditions (Bitcoin's price), changes in hash rate, and thus in the Mining Pulse, often line up with where miners perceive profitability. This is where the relationship of the Mining Pulse aligns with the Cost of Production6 chart, which will be introduced in the next section.

4 The Fusion of On-Chain & Off-Chain Data Analysis: Estimating Bitcoin's Cost of Production

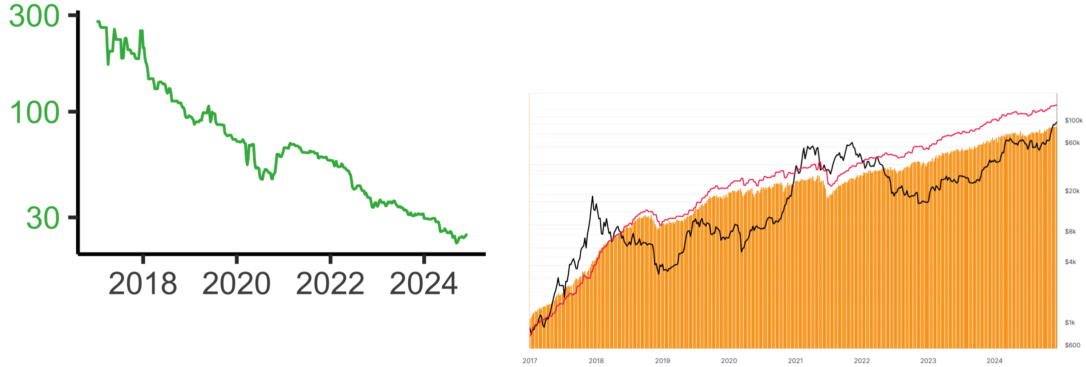
In the preceding sections, we've explored a rich tapestry of On-Chain metrics. Now, we shift our perspective to include a critical piece of the Bitcoin puzzle that can't be fully understood from on-chain data alone: the cost of producing each Bitcoin.

The cost of production for Bitcoin refers to the estimated financial outlay required by miners to secure the network and generate new bitcoins. Miners expend significant resources, mostly electricity, to power specialized hardware (ASICs) that solve computational puzzles. As a reward, they earn newly minted bitcoins (the block reward2) plus transaction fees.

4.1 Capturing Energy Efficiency: The Hardware Factor

To arrive at a meaningful estimate of Bitcoin's cost of production, we need reliable, real-world data about the mining environment. One critical input is energy efficiency, essentially how much electricity is needed to perform a given unit of computational work (hashing).

The Cambridge Centre for Alternative Finance provides a Bitcoin mining hardware efficiency index[7], illustrating how state-of-the-art ASIC machines have become dramatically more efficient over time. This continuous improvement5(a) reduces the energy (and thus cost) per unit of hash rate. These mining hardware efficiency improvements mean miners can produce more hash power5(b) with less energy, reducing their



(a) Bitcoin Mining Hardware Efficiency

(b) Bitcoin Network Hash Rate and Difficulty

Figure 5: Isolation Forest

cost per Bitcoin mined. However, this also increases competition as more miners enter the network, pushing up the network difficulty5(b).

4.2 Putting the Pieces Together: A Simple Formula

While there are many variations in calculating cost of production (some models add overhead costs or regional electricity price differences), the essence can be broken down into a straightforward conceptual formula[8]:

$$\text{Cost per BTC} \approx \frac{(\text{Hash Rate} \times \text{Avg Efficiency}) \times \text{Electricity Cost per kWh}}{\text{Avg Block Reward} \times \text{Blocks per Day}} / 70\%$$

In the formula shown above, we assume an average electricity price of \$0.05/kWh[9] globally, and we treat electricity as 70% of total production costs, implying other overhead (rent, salaries, maintenance) makes up the remaining 30%. In reality, the cost of production will differ from miner to miner depending on their electricity contracts, hardware generation, and operational scale. Nonetheless, this aggregated viewpoint gives us an industry-wide baseline. It's like saying: On average, how much does it cost to "create" one new bitcoin given today's energy prices and hardware efficiencies?

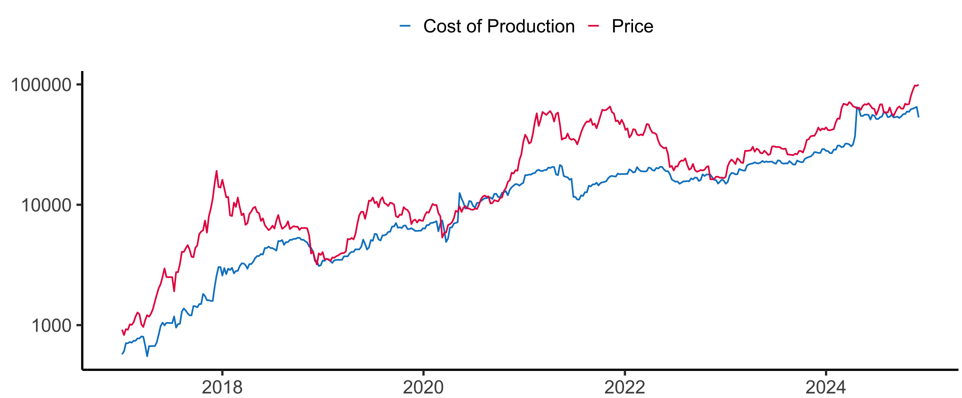


Figure 6: Estimated Cost of Production of A Single Bitcoin

From our estimated cost of production chart,

- **If Price <Cost of Production**: Struggling miners may turn off their machines, causing hash rate5(b) to decline. The network adjusts difficulty downward, blocks return to 10-minute intervals, and eventually the supply-demand balance restores. When Bitcoin's price approaches this cost, It signals potential miner capitulation. Historically, these periods have aligned with market bottoms, presenting opportunities for long-term investors.
- **If Price >Cost of Production**: Healthy profits encourage more miners to join, increasing the hash rate5(b), and thus strengthening the network's security. This scenario often corresponds with stable or upward-trending markets, as miners become net accumulators or have the luxury to sell fewer coins to cover expenses.

The Cost of Production is more than a theoretical concept; it's a fundamental driver of Bitcoin's market dynamics. It acts as a price floor where miners' profitability is tested. By incorporating On-Chain data (block rewards, hash rate, difficulty) with off-chain factors (electricity costs, hardware efficiency), we've painted a clear picture of the economic forces underpinning Bitcoin.

4.3 Aligning With the Mining Pulse

An especially important connection lies in how cost of production and the Mining Pulse move in together. When Bitcoin's market price dips near or below miners' production cost6, profit margins evaporate, forcing less-efficient mining rigs offline. This action reduces overall hash rate5(b), increases block times, and pushes the Mining Pulse4 into positive territory (slower blocks). Conversely, as the price climbs comfortably above production cost6, miners expand by adding new machines. The increasing hash rate5(b) speeds up block times, pulling the Mining Pulse4 into negative territory (faster blocks).

Thus, both metrics reflect real-time adjustments in miner behavior, and reinforce each other's signals about broader market profitability.

5 Conclusion

In this report, we have explored the complicated dynamics of on-chain data and its application in understanding cryptocurrency markets. Most of the visualization work are realized by the online dashborad, which is one professional and widely-used real time data monitoring tool. Beginning with an introduction to on-chain analysis, we highlighted its transparency, real-time insights, and utility in evaluating market sentiment, supply dynamics, and network health. Key metrics such as Long-Term Holder (LTH) and Short-Term Holder (STH) supply, realized profit, and the Market Value to Realized Value (MVRV) ratio were crucial in uncovering trends across market cycles. These metrics provided valuable context for distinguishing between speculative behaviors and long-term accumulation patterns.

We also examined network health through indicators such as transfer volume momentum and mining pulse, providing insight on transactional activity and miner behavior. By integrating these insights with off-chain factors like the cost of Bitcoin production, we demonstrated a complete approach to understanding market dynamics. This combination of data offers not only a robust framework for investment strategies, but also serves broader applications in regulatory compliance and anti-money laundering efforts.

Ultimately, the analysis highlights the critical role of on-chain metrics in bridging data-driven insights with real-world implications, empowering stakeholders to navigate the evolving cryptocurrency landscape with confidence and precision.

6 Beyond the Markets — The Power of On-Chain Data

Our journey through On-Chain metrics has revealed not just market insights but a gateway to broader applications. Beyond guiding investment decisions, these transparent, ledger-based On-Chain datasets serve as a powerful tool in fields like anti-money laundering and criminal activity detection.

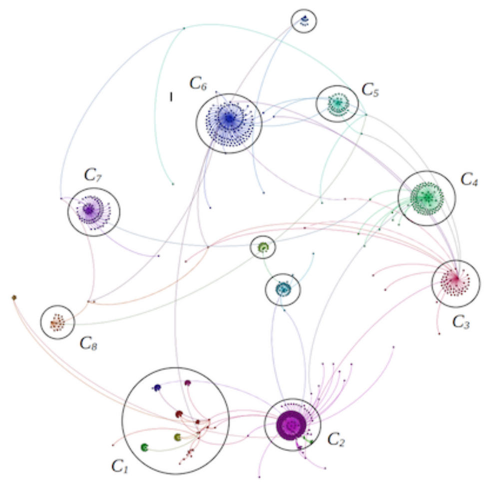


Figure 7: Clusters of Addresses Illuminate Hidden Relationships and Money Flows

The graph shown here is a clustering analysis[10] of On-Chain data, where transaction flows are visualized to uncover hidden patterns and relationships within a network. Each cluster represents a distinct group of addresses, and their interconnected flows provide a powerful lens for spotting ransom payments, laundering paths, or illicit fund transfers. For example, this approach has been successfully applied to analyze ransomware like CryptoLocker, where researchers tracked ransom payments, mapped their network structure, and identified connections to money laundering services.

On-Chain data allows analysts, regulators, and stakeholders to interpret the complex narratives behind transactions. Whether you're monitoring markets, combating crime, or ensuring regulatory compliance, blockchain data remains a cornerstone for visibility, accountability, and intelligence.

7 Team Contribution

- Kewei Zhang: Section 3.1, text revise
- Junyu Chen: Section 3.2, 3.3
- Wenzhe Zhang: Section 3.4, 4, 6
- Max Guthrie: Section 1, 2, 5

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