# THE INTELLIGENT MINER

## THE DEFINITIVE BOOK ON BITCOIN MINING

NABS EDITION

## LUXOR TECHNOLOGY

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# Preface

**The future of Bitcoin mining is intelligent.** In one of the most hyper-competitive and zero-sum industries in the world, miners making binary decisions will be outcompeted.

Our research shows **Intelligent Mining** will result in at least **8–14% more profitability** than binary mining. Intelligent Miners will attract capital, acquire the ones left behind, and forge the future of this industry.

Navigating this new paradigm requires an understanding of the key inputs to mining profitability: hashrate and energy. We cover the fundamentals of these evolving markets and the opportunities they create, but they are only part of the picture. Success also requires mastering the operating system of machines, the coordination of fleets and facilities, and the financial infrastructure that underpins sustainable growth.

The integration of all these factors is what we call Intelligent Mining. It starts with understanding the markets, evolves into a strategy, and demands operational excellence to execute.

The binary miner speculates at full throttle, always at the mercy of Mr. Hashprice. The Intelligent Miner operates with a system — shifting gears, embracing volatility when it pays, and stepping back when it doesn’t. This book is about that system: how to thrive through cycles, extract more value per joule of energy, and build Bitcoin mining businesses that dominate the competition.

# Part I: The Markets That Power Bitcoin Mining

In this section, we cover two crucial markets essential for mining: hashrate and energy.

## Hashrate Markets

Hashrate is the compute commodity used in bitcoin mining. It measures the number of cryptographic computations (i.e., *hashes*) performed per second by bitcoin mining computers — hence the name. Hashrate is one of the most dynamically evolving digital commodity markets in the world.

Hashrate represents the instantaneous productive capacity of mining computers. In this sense, it is analogous to electrical energy measured in megawatt-hours (MWh), e.g., 1 petahash per second. Understanding this market is foundational to Intelligent Mining, as it defines the output miners monetize to generate revenue.

| Metric | Scale | Example |
|---|---|---|
| **Terahash per second (TH/s)** | 1,000,000,000,000 ($10^{12}$) | A single machine |
| **Petahash per second (PH/s)** | 1,000,000,000,000,000 ($10^{15}$) | Forward hashrate contracts, mid-sized mining facilities |
| **Exahash per second (EH/s)** | 1,000,000,000,000,000,000 ($10^{18}$) | Large-scale miners |
| **Zettahash per second (ZH/s)*** | 1,000,000,000,000,000,000,000 ($10^{21}$) | The Network |

**After Zetta, it's Yottahash (YH/s = $10^{24}$)*

## Mining Pools & Pricing Hashrate

At the foundation of hashrate markets are mining companies and mining pools — over-the-counter (OTC) markets where miners sell hashrate to mining pools. Around a dozen mining pools aggregate computational power from tens of thousands of mining companies and pay out block rewards based on hashrate contribution. Pool payout methods have evolved over time, from legacy proportional payment systems to transparent and consistent payouts.

Modern mining pools offer multiple payment schemes, with *Full-Pay-Per-Share (FPPS)* emerging as the industry standard. Luxor's FPPS formula calculates the theoretical intrinsic value of hashrate by combining block rewards (subsidy + transaction fees) and network difficulty over a past 144-block (24-hour) window. Pools will offer miners a slight discount to this value, in exchange for taking on the volatility associated with finding actual blocks. This forms the basis for *hashprice* — the basic metric for mining economics.

## Hashprice

Hashprice is the value miners earn from selling their hashrate to a pool. It reflects the expected value of a standardized unit of hashrate production over time, much like how electricity is priced in dollars per megawatt-hour ($/MWh). It was introduced as a concept to the market by Luxor in 2020.

Luxor's **Bitcoin Hashprice Index** quantifies the expected revenue from one petahash per second per day (PH/s/Day): a petahash per second (PH/s) of hashrate operated over a 24-hour period. In practice, this is roughly the output of ten Bitmain Antminer S19J Pro machines running continuously for one day. Hashprice is denominated in both Bitcoin (BTC) and U.S. dollars (USD).


Bitcoin-denominated hashprice is composed of three inputs: newly issued bitcoin from the network's block subsidy (currently 3.125 BTC per block, post-2024 halving), transaction fees paid by users of the Bitcoin network (highly variable and based on network activity), and network difficulty representing the intensity of mining competition on the network (algorithmically adjusts every 2,016 blocks).

Dollar-denominated hashprice includes a fourth factor, bitcoin price. Together, these inputs create a complex volatility profile: hashprice can swing 20–30% within a single difficulty epoch and undergo dramatic shifts during major network events.

Hashprice has become the main metric for bitcoin mining revenue because it distills its drivers into a single, standardized measure. Luxor's Bitcoin Hashprice Index serves as a reference point for the real-time spot market value of hashrate, similar to real-time 'index' pricing for electricity.

By monitoring Bitcoin Hashprice Index, operators can optimize fleets, manage risk, and benchmark performance against the broader mining market; moving beyond crude estimates toward data-driven, dynamic decision making.

**Spot vs. Fixed Hashprice**

Like other commodities, hashrate can be hedged through Luxor's Forward Market. Forward hashrate contracts lock in a hashprice over fixed terms, typically ranging from 1–12 months. These agreements establish predictable revenue streams, enabling stable earnings and precise cash flow forecasting for miners. As a result, hedged mining operations become more attractive to lenders and equity investors who value certainty in project financing.

However, forward contracts also carry tradeoffs. Miners may forgo upside during periods when spot hashprice outperforms fixed rates, creating opportunity costs. Forward market participation also requires posting collateral, which ties up capital that could otherwise be deployed.

Many miners adopt a mixed strategy, combining hedged and spot hashprice exposure to balance revenue certainty with upside exposure.


*Note: The fixed hashprice shown is illustrative, and based on the average mid-market rate from forward contracts listed on Luxor's order book between August 1, 2024 and August 31, 2025 (excluding intra-month contracts).*

## Energy Markets

Bitcoin mining computers require energy to run, and lots of it. Energy markets represent the primary input cost for mining operations, with electricity typically accounting for 60–80% of total operating expenses. Understanding these markets is critical for Intelligent Mining, as power pricing structures and grid participation opportunities dramatically impact real-time mining profitability and strategy. Unlike traditional industries where energy is simply a cost center, bitcoin miners can leverage their *flexible demand characteristics* and become active grid resources, transforming energy consumption from a passive expense to a revenue opportunity (depending on operational characteristics, jurisdiction, and local energy market dynamics).

### Power & Grid Access

Miners engage with wholesale power markets in various ways, but not all operations are exposed to grid market dynamics. Many miners operate on the fringes or entirely outside organized wholesale markets, sourcing power directly from generators through colocation arrangements or producing it themselves off-grid.

These approaches can unlock low-cost power from stranded or under-utilized generation while providing a natural hedge against spot power price volatility. However, they generally lack responsiveness to real-time market signals and opportunities to participate in grid ancillary services, which is where we will focus.

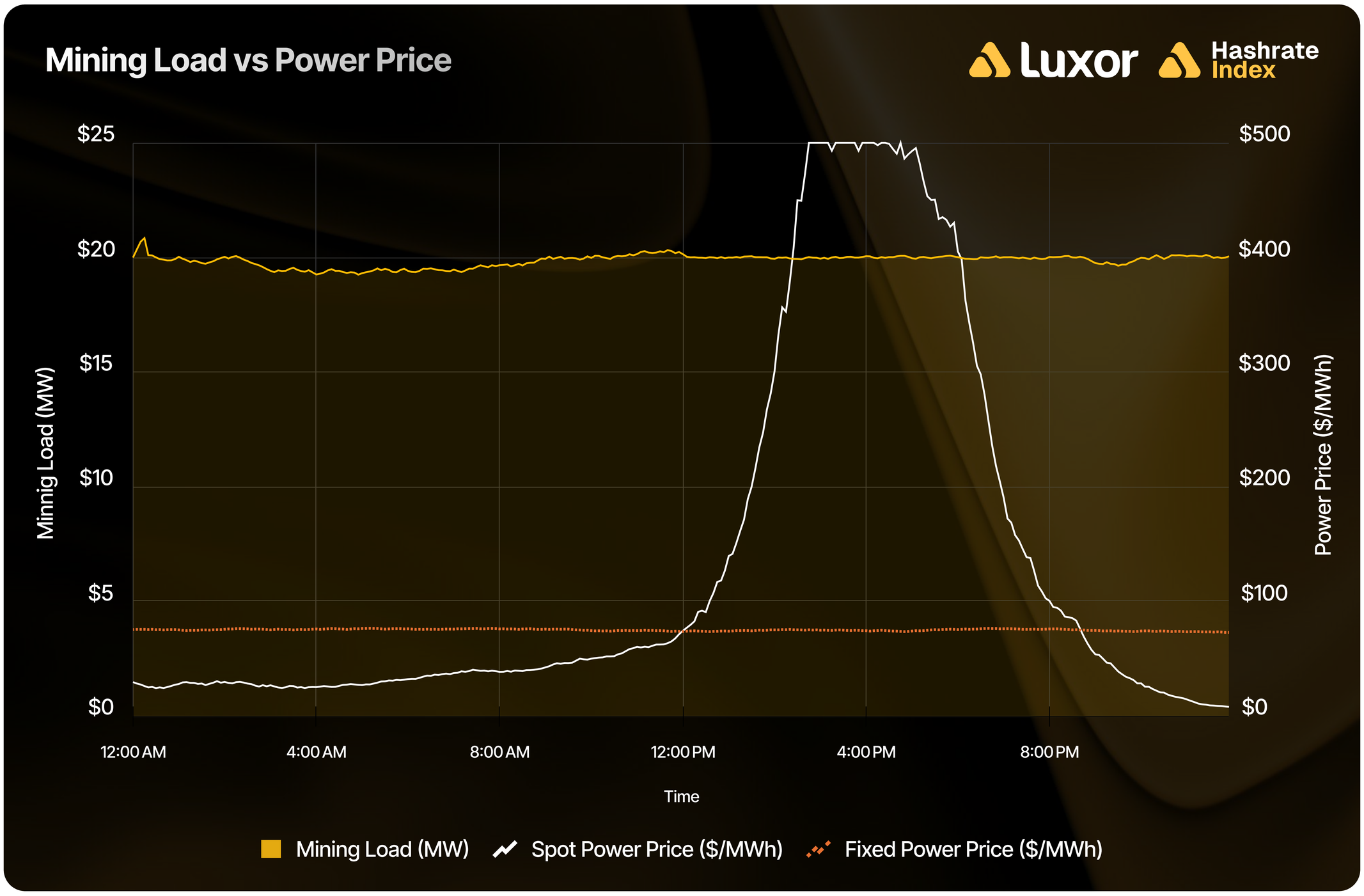
Grid-tied power markets are governed by institutional frameworks which enable wholesale electricity trading and grid participation. In deregulated markets like Texas' ERCOT, bitcoin miners typically access electricity through *Retail Electric Providers (REPs)*, which purchase power in wholesale markets and resell it to end customers while handling billing, customer support, and energy delivery logistics. For more sophisticated operations, miners can work directly with or become *Qualified Scheduling Entities (QSEs)* — the financial interface with ERCOT that manages bids and offers for power and ancillary services in wholesale markets.

**Spot vs. Fixed Power Prices**

The choice between fixed and real-time spot (or ‘index’) electricity pricing will prime a mining operation's risk profile and strategic flexibility. Fixed-price power purchase agreements (PPAs) provide predictable energy costs over contract terms, typically ranging from 1–10 years. This enables precise financial modeling and reduces cash flow volatility. Banks and investors prefer these predictable cost structures for project financing, and mining operations remain simplified with minimal need for price monitoring or dynamic load management.

However, fixed pricing comes with tradeoffs. Miners may end up paying above-market rates during low spot-price periods, and PPAs will also often require collateral commitments that tie up capital.

As shown below, a mining facility under a fixed-price PPA may choose to continue operating uninterrupted during periods of extreme spot power price spikes.

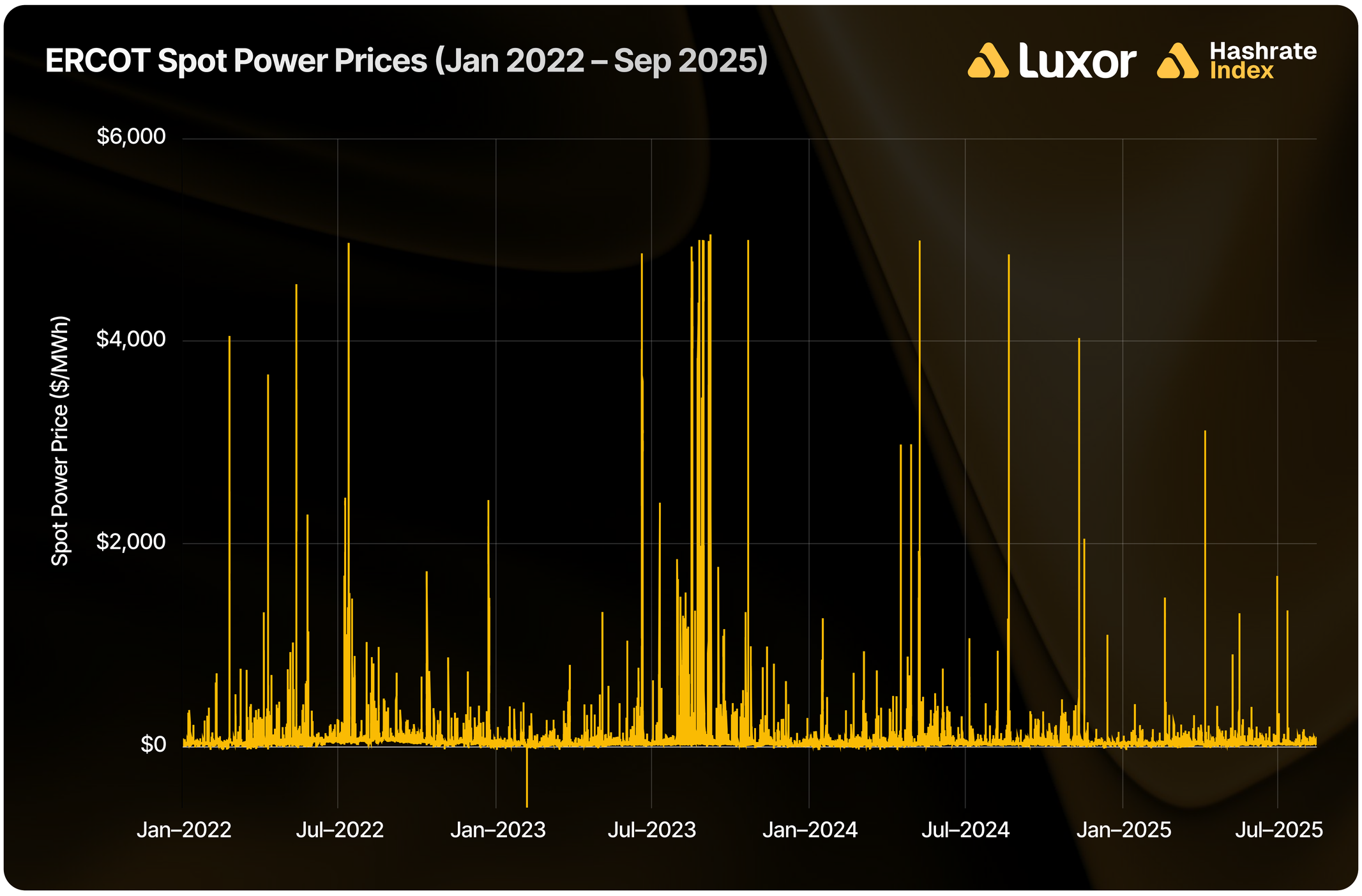



At first glance, it seems intuitive that a fixed-price miner with a PPA should simply keep operating during extreme spot price spikes. After all, their cost of power remains fixed and predictable. However, this view ignores the *opportunity cost* of not engaging with real-time signals. In reality, a PPA miner who chooses to mine straight through high-price intervals is leaving money on the table. Selling power back to the grid often generates more profit than hashing, especially during scarcity events. Sell-back optionality is embedded into most PPAs by default; it is always in a miner's best interest to maximize for interval-by-interval profits regardless of power price structure.

A more sophisticated expression of a fixed-pricing strategy is the *hashspark spread*, inspired by the natural gas industry's spark spread. By pairing a cost power hedge (fixed-price PPA) with a revenue hashprice hedge (Luxor's fixed pool payouts), miners can effectively lock in operating margins. This transforms an otherwise volatile financial profile into one that is predictable, with both input costs and output revenues known in advance.

Spot-price power exposes miners to real-time electricity rates, creating both opportunity and risk. Spot prices can swing dramatically within a single day, spiking to thousands of dollars per MWh (during peak demand) and collapsing to zero — or even turning negative — when supply outstrips demand.

As shown below, ERCOT's spot electricity market is among the most volatile in the world, with both scarcity spikes and periods of ultra-low or negative pricing occurring frequently:




**Load Zone South, Locational Marginal Prices with Adders ($/MWh)*

Spot-price structures unlock a spectrum of marginal economics. High volatility enables power price optimization by capitalizing on low-cost periods and negative pricing events, though this requires sophisticated monitoring and automated response systems. The operational complexity increases significantly, but so does the profit potential.

A miner's optimal power price choice ultimately depends on risk tolerance, operational sophistication, and local market conditions. Fixed-price miners choose certainty and predictability, whereas spot-price miners prefer to maximize profits at the margin. The operational complexity is higher for the latter — requiring monitoring, telemetry, and rapid response capable of precision load adjustments — but so is the upside. Advanced miners increasingly favor variable pricing structures that enable dynamic load management and grid participation, viewing the additional complexity as an opportunity for competitive advantage rather than a burden.

## Ancillary Services & Grid Programs

Ancillary services markets enable miners to become valuable grid resources. These markets compensate participants for providing services that maintain grid stability and reliability, creating entirely new revenue streams that can exceed mining profits, especially during certain market conditions.

*Frequency regulation services* allow miners to provide rapid response to grid frequency deviations by adjusting their power consumption within seconds. Bitcoin mining operations prove particularly valuable for this service because they can interrupt their power consumption without affecting long-term production significantly. Automated systems can also respond faster than traditional generation resources. Compensation rates often exceed mining revenues during high-demand periods, creating clear economic incentives for active participation.

*Grid balancing services* enable miners to provide upward and downward balancing by increasing or decreasing power consumption to match supply and demand in real-time. Mining loads prove ideal for these services due to their rapid response capabilities without the startup costs and delays associated with traditional generation resources.

*Demand response programs* compensate miners for reducing power consumption during peak-demand periods or grid emergencies. Miners receive capacity payments for maintaining curtailment availability, energy payments when actually curtailing load, and also benefit from avoided costs during high-price periods. The stackable nature of these revenue streams can result in total compensation that exceeds mining revenue during curtailment events.

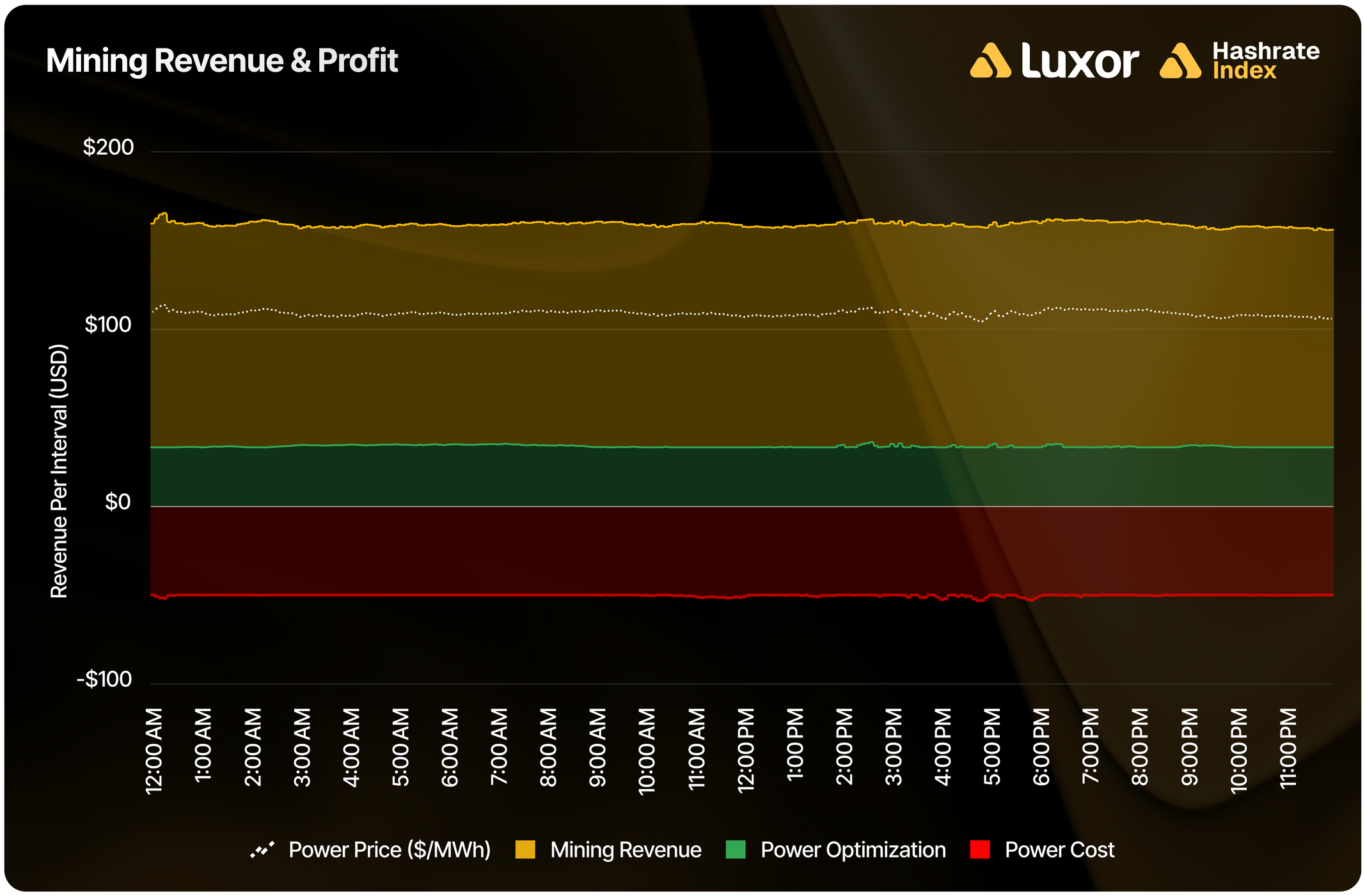
*Demand charge optimization* through transmission cost allocation mechanisms like ERCOT's Four Coincident Peak (4CP) creates additional strategic considerations. 4CP currently allocates transmission costs based on a customer's peak demand during the four highest system-wide demand hours of summer (June–September), with charges applied throughout the following year. Miners can significantly reduce their annual transmission costs by curtailing operations during these critical peak periods, lowering overall energy bills, but must remain nimble as program features evolve.

Companies such as Luxor Energy help miners directly enroll in ancillary services and demand response programs. Luxor Energy delivers a signal to miners so that they can automatically curtail and get paid to consume less power.

## Towards Intelligent Energy Consumption

The modern miner's evolution toward Intelligent Mining requires active participation in energy markets, venturing beyond rudimentary cost minimization. Real-time optimization involves dynamic decisions between mining and alternative revenue streams (curtailment, power resale, ancillary services) based on continuously volatile spot price signals and market conditions. This approach treats mining operations, energy contracts, and grid service opportunities as an integrated portfolio rather than separate revenue & cost centers.

Instead of relying solely on hashrate production, modern miners are developing multiple income streams which provide a *margin of safety* while creating profit centers that often exceed mining revenues during optimal market conditions.




*Mining Profit = (Hashrate × Hashprice) + Power Optimization – (Power Consumption × Power Price)*

Integrated solutions become crucial for deploying automated systems that can respond accurately to these opportunities, within seconds or minutes. The speed of response often determines winners; conditions can change dramatically within short time intervals. Miners who master this game stand to transform from passive price takers to active market participants.

This transition from static to dynamic represents one of the most significant competitive advantages currently available to modern miners. However, sophisticated hashprice and energy optimization techniques require more than just strategic thinking. They demand technology.

The ability to accurately **read signals, rapidly respond** within seconds, **modulate machines** and power consumption across the fleet, and **coordinate complex calculations** across a portfolio of revenue streams — all while respecting facility constraints — depends entirely on the underlying technology stack that makes Intelligent Mining possible.

Let’s dig in.

## The Tech Stack Turning Signals Into Decisions

### Firmware (Operating System)

Firmware represents the starting point to transform mining hardware from basic binary machines into responsive rigs capable of active participation. Firmware serves as the “brain” or operating system for mining machines, managing operations such as ASIC chip frequency, voltage regulation, fan speeds, and thermal management. It is software installed directly on each individual machine's control board, enabling control and customization for various conditions.

Manufacturer-installed stock firmware provides basic operational modes with limited options. These systems typically offer simple on/off functionality with predetermined performance profiles optimized for maximum hashrate output under standard conditions. Advanced third-party firmware solutions like LuxOS unlock granular control over machine performance parameters. These systems enable operators to adjust frequency settings, voltage levels, and thermal profiles to optimize for a range of goals — whether it's maximizing hashrate, minimizing power consumption, or finding profitability sweet spots in between.

Advanced firmware provides several critical capabilities for Intelligent Mining. *Performance profiling* allows custom configurations that balance hashrate output against power consumption based on changing market conditions. *Thermal management* enables automatic adjustments based on ambient temperature, humidity, and other environmental conditions. Most importantly for grid participation, advanced firmware enables *rapid response* capabilities, allowing machines to ramp performance up or down within seconds.

Individual machine intelligence is powerful, but it's not enough. Firmware systems must integrate with a higher-level management platform to enable fleetwide coordination. This allows individual machine capabilities to respect facility-level constraints while maintaining the flexibility to respond and reap the benefits of current market conditions and grid services.

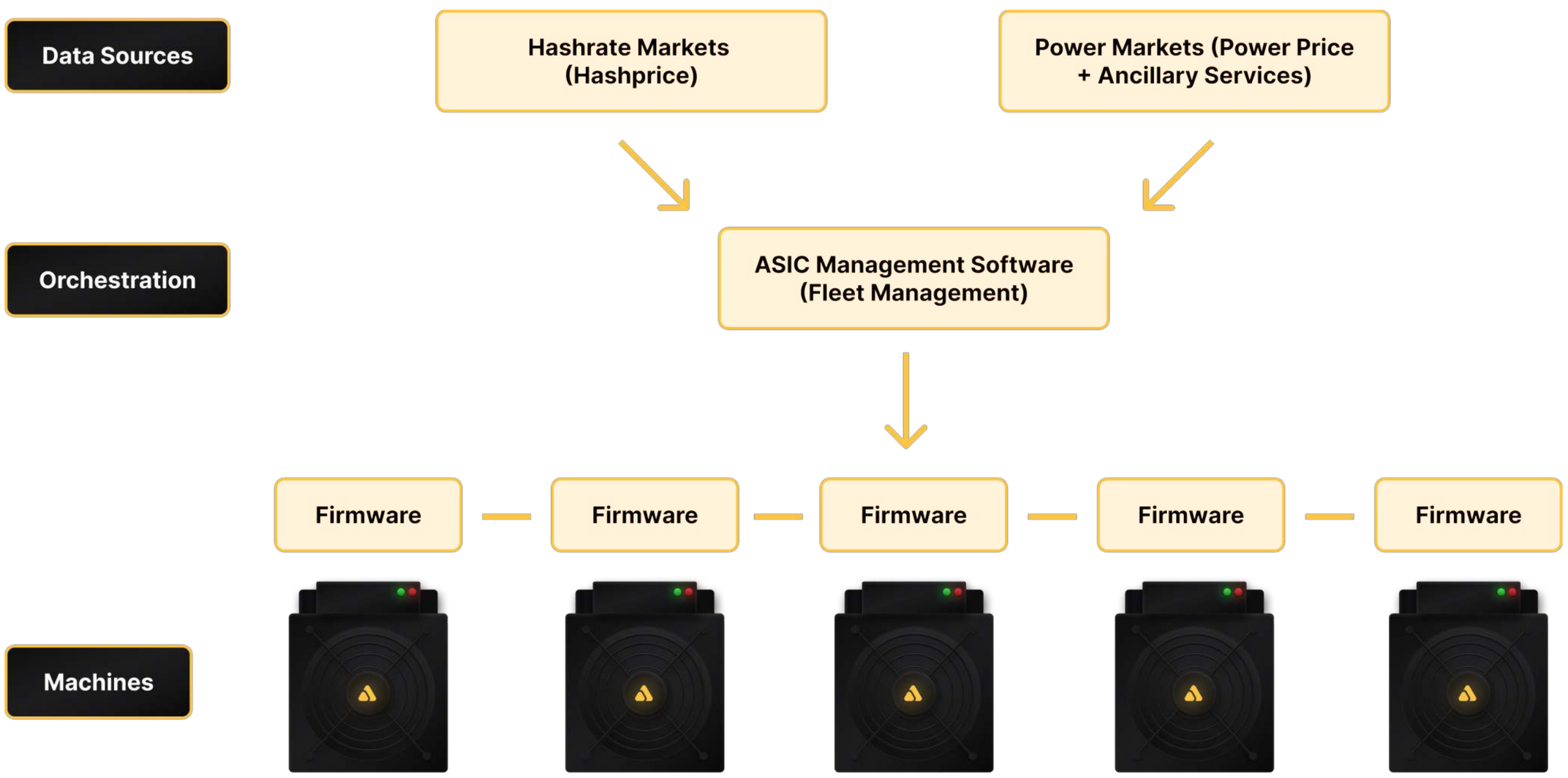
### Fleet Management Software

Fleet management software orchestrates coordination across entire mining facilities. This telemetry layer receives and processes external market signals, then directs thousands of machines through automated decision-making systems, typically deployed as lightweight agents running on on-site servers.

Fleet management systems handle three primary functions. *Configuration management* enables bulk operations (e.g., firmware updates, performance profile adjustments, pool switches etc.) across entire fleets at once. *Automation* handles routine maintenance tasks like machine reboots and failover management, reducing operational overhead and human error. *Real-time monitoring* tracks individual machine performance, environmental conditions, and other operational parameters across the facility.

Large-scale mining operations require sophisticated orchestration when managing thousands of machines simultaneously. Each machine may require a unique performance setting based on hardware characteristics and in-field history. Fleet management software must track and optimize for individual variations while achieving site-wide operational objectives and responding to external market signals in real-time.

Advanced fleet management platforms integrate with a suite of external systems to enable grid services participation. Direct connections to energy market platforms provide real-time pricing data, whereas grid operator interfaces enable participation in demand response programs and ancillary services. Hashrate market integration allows automated hedging and derivatives trading. In combination, these building blocks transform mining facilities from passive electricity consumers into dynamic decision makers capable of actively deploying Intelligent Mining strategies.



# Part II: Intelligent Mining

## Chapter 1: The Binary Era is Over

### The On/Off Status Quo

Imagine purchasing a car that can only operate in one gear. Whether you're climbing steep hills, cruising on highways, navigating stop-and-go traffic, or driving through severe weather conditions, your vehicle will be locked into the same speed and fuel consumption profile. Such a car would be functional but dramatically suboptimal — burning excessive fuel in city driving, struggling on inclines, and providing poor performance across varying conditions. This analogy describes the current state of bitcoin mining operations using stock firmware.

The mining industry has been unintentionally limited to single-gear thinking since inception. This didn't emerge from technological constraints or strategic choice, but rather from the evolutionary path of development in bitcoin mining hardware and software. In the early days, when individuals could mine profitably with CPUs & GPUs under residential power rates, the concept of variable performance seemed unnecessary. Mining was profitable or it wasn't — machines were on or they were off — and the industry developed around this binary paradigm.

As mining evolved into more sophisticated operations dominated by industrial-scale data centers consuming megawatts to gigawatts of electricity, this ‘on/off’ mentality continued to persist despite a radical change in operational and financial considerations. Hardware manufacturers focused on maximizing peak hashrate performance, viewing their products as specialized computers that should run at full capacity whenever operational. Firmware development reflected this philosophy: stock operating systems were designed without considering dynamic hashrate and power markets. The result was an entire industry built on the premise that mining machines have binary states: running at full speed or shutdown on idle.

This mindset made sense in mining's early era when energy was cheap, competition was less fierce, and market dynamics were simpler. However, as the industry matured, competition increased, and margins compressed, the hidden costs of all-or-nothing operations became apparent.

Binary miners cannot efficiently respond to spot energy price fluctuations. They systematically miss out on revenue maximizing opportunities during low-price periods, and lack the ability to operate profitably during high-price periods, being forced to curtail instead. Single-gear fleets cannot participate in lucrative ancillary services markets that require rapid performance adjustments, leaving a significant amount of money on the table.

Perhaps most critically, on/off miners operate without a margin of safety. Like a speculator, they exist at the mercy of external conditions. If energy costs spike or hashprice drops, these miners are forced to head into a loss or come to a complete stop. The consequences only compound and loom larger during periods of increased market volatility.

Just as the automobile industry has innovated over time, bitcoin mining is now turning the corner into its next stage of evolution. The binary era is over. **The race car era** — where gears shift with precision — **has begun.**

## Chapter 2: The Race Car Revolution

### The Spectrum of Performance & Profitability

The race car revolution begins with a recognition that bitcoin mining ASIC machines can operate across a spectrum of performance levels optimized for specific conditions.

Advanced third-party firmware solutions like LuxOS install a sophisticated “multi-gear transmission” into your mining fleet, providing **precise control** over **performance parameters**. Taking this simple step transforms a fleet’s operational profile from **‘On/Off’ to ‘0–100’**.

Taking the quintessential mining machine, Bitmain’s Antminer S19j Pro, as an example: running LuxOS unlocks the ability to operate this model in frequency ranges anywhere between **375MHz to 625MHz**, producing hashrate outputs ranging from **~70 TH/s to ~120 TH/s**, while consuming proportionally varying amounts of power.

| Miner Model Inputs | |
|---|---|
| **Miner Model** | S19j Pro |
| **Hashrate (TH/s)** | 100 |
| **Power (W)** | 2950 |
| **Efficiency (J/TH)** | 29.5 |

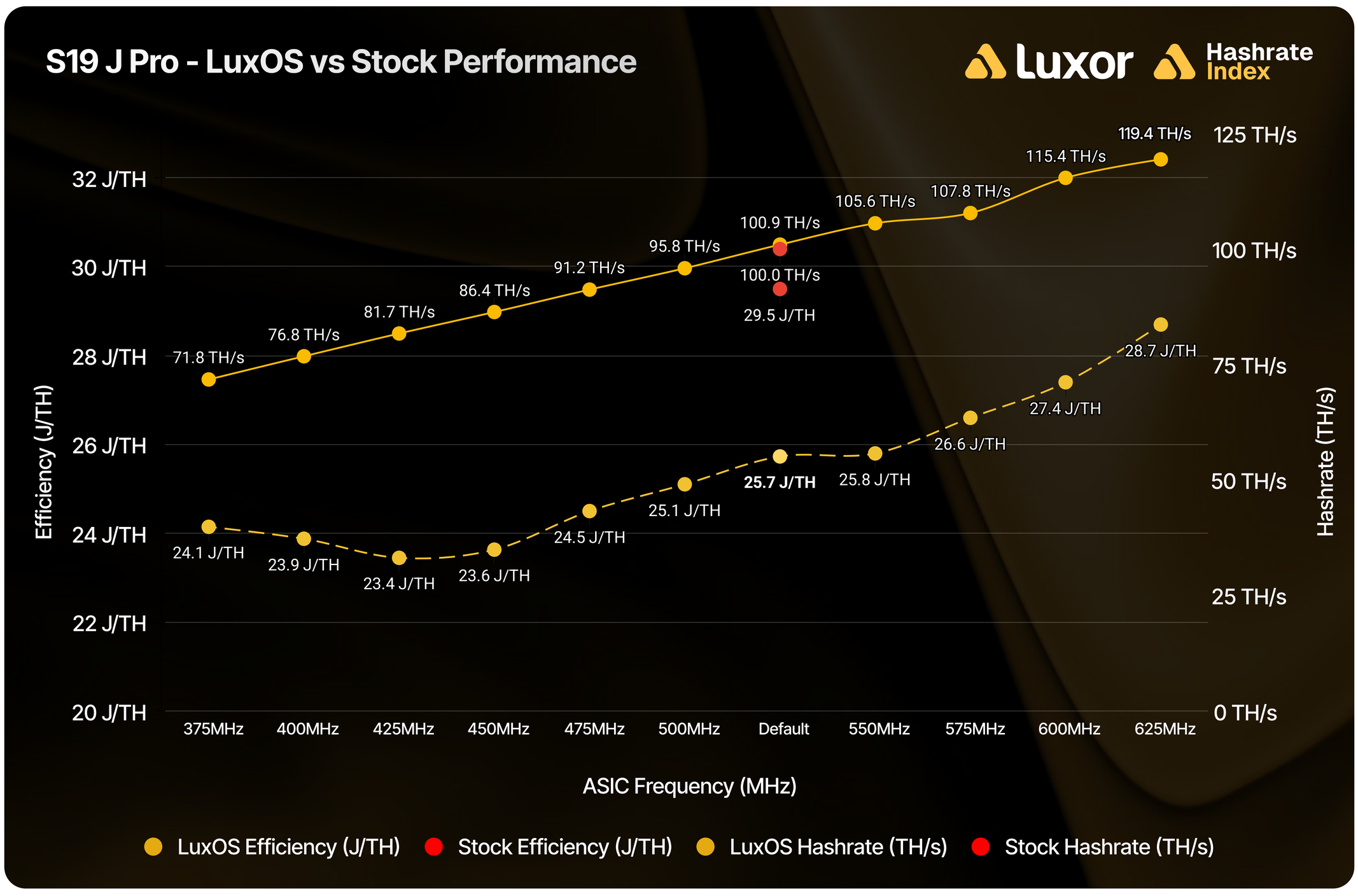
| Step | Profile (MHz) | Power (W) | Hashrate (TH/s) | Efficiency (J/TH) | Efficiency Gain (%) | Hashrate Gain (%) |
|---|---|---|---|---|---|---|
| **-6** | 375MHz | 1733 | 71.8 | 24.1 | 22.17% | |
| **-5** | 400MHz | 1834 | 76.8 | 23.9 | 23.54% | |
| **-4** | 425MHz | 1916 | 81.7 | 23.4 | 25.81% | |
| **-3** | 450MHz | 2041 | 86.4 | 23.6 | 24.83% | |
| **-2** | 475MHz | 2235 | 91.2 | 24.5 | 20.40% | |
| **-1** | 500MHz | 2406 | 95.8 | 25.1 | 17.51% | |
| **0** | default | 2597 | 100.9 | 25.7 | 14.65% | 0.94% |
| **1** | 550MHz | 2724 | 105.6 | 25.8 | 14.34% | 5.60% |
| **2** | 575MHz | 2723 | 107.8 | 25.3 | 16.79% | 7.80% |
| **3** | 600MHz | 3159 | 115.4 | 27.4 | 7.77% | 15.40% |
| **4** | 625MHz | 3424 | 119.4 | 28.7 | 2.87% | 19.40% |

*Note: While this table displays 11 different preset profiles, LuxOS offers 25 by default. Steps shown spanning from -4 to +2 are considered as a ‘safe zone’ for operations, providing balance between efficiency, performance, and hardware safety. Miners can venture beyond this range at their discretion. Exercise caution and remain attentive to your equipment and conditions.*

There are many ways to increase profitability through LuxOS. The first is through *AutoTuning* — a proprietary algorithm that calibrates groups (domains) of ASIC chips to their optimal frequency. Rather than applying uniform settings across an entire hashboard, autotuning adjusts performance per domain, ensuring that every joule delivers the maximum possible hashrate.

When the machine is in **default AutoTune** mode (not overclocking or underclocking), a **direct increase in efficiency by ~15%** is observed. When optimizing for **maximum hashrate**, moving to a heavy overclock step (+4) will **increase hashrate by ~19%.** If optimizing for **best efficiency** instead, moving to a heavy underclock step (–4) will **improve efficiency by ~26%.**

This stark contrast in performance profile reveals two things at once. First, the flaw in status-quo thinking: the binary miner assumes that maximum hashrate output equals maximum profitability. Second, that peak performance often occurs at frequencies well below maximum settings, as demonstrated by the S19 J Pro's hashrate and efficiency curves.



Consider the performance profile of the machine across its operational range under LuxOS. At the –3 profile (450 MHz), the machine produces 86.4 TH/s — roughly 85% of maximum hashrate — while drawing 2041W of power, only 69% of maximum consumption. Efficiency improves to 23.6 J/TH, a 20% improvement over stock. This illustrates the **non-linear relationship between power and hashrate**: power draw rises steeply at higher frequencies, while hashrate scales more linearly. As a result, **efficiency "sweet spots"** emerge at mid-range profiles (–3 to –5), where miners capture the majority of hashrate output at significantly lower energy cost.

This efficiency gain becomes economically significant when electricity represents 60–80% of total operating costs. The ability to **operate in "efficiency gear" during high-price intervals** preserves profitability by sacrificing some hashrate production for an outsized improvement in efficiency.

A car locked in a single gear may move, but it cannot adapt to terrain or traffic. Firmware equips the miner with the full range of gears, enabling adjustments for the road ahead. Instead of getting randomly stuck at red lights, the Intelligent Miner adapts. During high-energy-cost intervals, they underclock, cutting costs while still hashing. When hashprice weakens, they avoid losses by gradually gliding down. If energy prices become cheap or negative, they adapt by kicking into heavy overdrive and maximizing hashrate. Meanwhile, The binary miner continues to oscillate between full-speed ahead and frequent run-ins with red STOP signs.

## Chapter 3: Dynamic Gear-shift Strategies

### How to Ride Real-time Power Markets

The race car revolution extends beyond just the ability to change gears. Becoming truly price-responsive means dynamically adjusting between performance modes in response to real-time signals, which requires turning manual shifting into automatic. Real-time telemetry between integrated firmware and fleet management layers allow Intelligent Miners to calculate profitability across both sides of the mining margin: hashprice (revenue) and energy (cost), ensuring that each individual machine in the fleet operates at its precise sweet spot at every single interval.

Locking in either side of the miner's operating margin smooths outcomes and creates certainty, but hedging does not replace the need to **respond to spot economics**. Operators must always make the most of the moment — failing to continuously optimize fleet performance simply leaves money on the table. In reality, **profit maximization is occurring at the margin**, within each spot-power-price interval. The opportunity cost of ignoring spot power price signals can be just as damaging as direct operating losses.

The table below shows how a binary miner responds to fluctuating power prices, holding all else equal. At a **$40** per PH/s/day **hashprice**, the binary miner running a fleet of S19j Pro's **turns off** at **power prices above $60** per MWh and beyond, in order to avoid operating at a loss.

**Bitmain Antminer S19j Pro (100TH) Profitability - $40 Hashprice**

| **Binary Mining** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Power Price ($/MWh)** | $30 | $35 | $40 | $45 | $50 | $55 | $60 | $65 | $70 | $75 |
| **Miner Profitability ($/Day)** | $1.88 | $1.52 | $1.17 | $0.81 | $0.46 | $0.11 | $(0.25) | $(0.60) | $(0.96) | $(1.31) |
| **Miner Setting (On/Off)** | On | On | On | On | On | On | Off | Off | Off | Off |

The table below shows how an Intelligent Miner would respond to the same scenario. At a $40 per PH/s/day hashprice, the operation would simply "shift gears into efficiency mode" and **continue to run** the fleet of S19j Pro's at **power prices above $60** per MWh, until it reaches **shutdown at $75** per MWh. In this case, the change in gears is a down-shift, otherwise known as **underclocking** — the process of running a machine's individual ASIC chips at a lower frequency and/or voltage versus stock settings. By dialing frequency down, the chips perform fewer hashes per second, reducing total hashrate output (TH/s).

However,  power draw falls proportionally more than hashrate, which means lower joules per terahash, improving efficiency (J/TH) as a result. This allows the Intelligent Miner to **continue hashing and squeeze out additional revenue** as it slowly declines to a stop, when necessary. Meanwhile, the binary miner is stuck in a loop between hard stops and restarts, covering less ground.

**Bitmain Antminer S19j Pro (100TH) Profitability - $40 Hashprice**

| **Binary Mining** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Power Price ($/MWh)** | $30 | $35 | $40 | $45 | $50 | $55 | $60 | $65 | $70 | $75 |
| **Miner Profitability ($/Day)** | $1.88 | $1.52 | $1.17 | $0.81 | $0.46 | $0.11 | $(0.25) | $(0.60) | $(0.96) | $(1.31) |
| **Miner Setting (On/Off)** | On | On | On | On | On | On | Off | Off | Off | Off |
| **Intelligent Mining** | | | | | | | | | | |
| **Power Price ($/MWh)** | $30 | $35 | $40 | $45 | $50 | $55 | $60 | $65 | $70 | $75 |
| **Miner Profitability ($/Day)** | $2.35 | $2.02 | $1.70 | $1.37 | $1.04 | $0.76 | $0.52 | $0.28 | $0.05 | Off |
| **Optimal Miner Setting (OC/UC)** | OC | OC | OC | OC | OC | UC | UC | UC | UC | Off |
| **Optimal Miner Setting (TH/s)** | 108 | 108 | 108 | 108 | 108 | 86 | 86 | 82 | 82 | Off |

The other side of the coin is where it gets even more interesting. When hashprice is elevated or energy costs are extremely low, Intelligent Miners can **shift up into "performance mode**" by overclocking machines beyond stock settings. Advanced firmware unlocks frequencies of **up to ~130% of stock levels**, increasing hashrate output (albeit at the cost of higher power consumption and additional cooling requirements). This overdrive capability allows for **maximizing revenue** during windows of opportunity, while maintaining the flexibility to pull back down as conditions change.

At a **$50** per MWh **power price**, the binary miner running a fleet of S19j Pro's **turns on** at **hashprices above $35** per PH/s/Day and beyond, in order to operate profitably.

**Bitmain Antminer S19j Pro (100TH) Profitability - $50/MWh Power Price**

| **Binary Mining** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Hashprice ($/PH/s/Day)** | $30 | $35 | $40 | $45 | $50 | $55 | $60 | $65 | $70 | $75 |
| **Miner Profitability ($/Day)** | $(0.54) | $(0.04) | $0.46 | $0.96 | $1.46 | $1.96 | $2.46 | $2.96 | $3.46 | $3.96 |
| **Miner Setting (On/Off)** | Off | Off | On | On | On | On | On | On | On | On |

The Intelligent Miner would respond by “shifting gears into performance mode” and **overclocking** the fleet of S19j Pro’s at **hashprices above $35** per PH/s/Day and beyond. By dialing frequency up, the individual ASIC chips perform more hashes per second, increasing total hashrate output (TH/s).

**Bitmain Antminer S19j Pro (100TH) Profitability - $50/MWh Power Price**

| **Binary Mining** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Hashprice ($/PH/s/Day)** | $30 | $35 | $40 | $45 | $50 | $55 | $60 | $65 | $70 | $65 |
| **Miner Profitability ($/Day)** | $(0.54) | $(0.04) | $0.46 | $0.96 | $1.46 | $1.96 | $2.46 | $2.96 | $3.46 | $3.96 |
| **Miner Setting (On/Off)** | Off | Off | On | On | On | On | On | On | On | On |
| **Intelligent Mining** | | | | | | | | | | |
| **Hashprice ($/PH/s/Day)** | $30 | $35 | $40 | $45 | $50 | $55 | $60 | $65 | $70 | $75 |
| **Miner Profitability ($/Day)** | $0.15 | $0.57 | $1.04 | $1.58 | $2.12 | $2.66 | $3.20 | $3.74 | $4.28 | $4.82 |
| **Optimal Miner Setting (OC/UC)** | UC | UC | OC | OC | OC | OC | OC | OC | OC | OC |
| **Optimal Miner Setting (TH/s)** | 82 | 86 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 |

The economic impact of Intelligent Mining becomes apparent when considering the range of market conditions miners can face. During periods of negative energy pricing, miners with advanced firmware can shift into overdrive, effectively being paid to consume electricity while producing additional bitcoin. This flexibility transforms the economics of mining operations. Instead of binary profitability decisions based on fixed performance assumptions, Intelligent Miners optimize their operations continuously across changing market conditions. The result is higher profitability, reduced risk, and the ability to actively participate in energy markets as flexible demand resources.

**Binary Mining**

| Power Price ($/MWh) | Hashprice ($/PH/Day) $30 | $40 | $50 |
|---|---|---|---|
| $60 | Offline | Offline | Stock |
| $50 | Offline | Stock | Stock |
| $40 | Stock | Stock | Stock |

**Intelligent Mining**

| Power Price ($/MWh) | Hashprice ($/PH/Day) $30 | $40 | $50 |
|---|---|---|---|
| $60 | Underclock | Underclock | Underclock |
| $50 | Underclock | Underclock | Overclock |
| $40 | Overclock | Overclock | Overclock |

## Layering on Ancillary Services

Intelligent Mining doesn't stop at responding to hashprice and spot power. Sophisticated participation means tapping into grid programs and ancillary services — where miners get paid for how and when they consume electricity.

Programs like ERCOT's 4CP transmission charge optimization, demand response, and ancillary services markets reward flexible loads for curtailing, underclocking, or even overclocking at specific times. In many cases, the compensation from these programs can exceed the value of hashing itself — paying miners hundreds of dollars per MWh.

The core principle here is **revenue optionality**. Every megawatt has multiple layers of potential value. Energy can drive SHA-256 hashing directly, it can be sold back into the grid during scarcity events, and it can also be monetized through ancillary services — often while hashing continues in parallel. Intelligent Miners treat energy not just as a cost center but as a revenue center, continuously evaluating which option generates the highest return.

Successfully executing on this requires operational excellence. Grid signals must flow directly into firmware and fleet management layers so that machines can curtail or ramp within seconds. Decision logic must also account for market conditions: at extreme hashprice highs, mining is likely dominant; in weak or flat periods, grid programs may deliver superior economics.

These power market programs are ultimately economic incentives to strengthen the grid — reducing peaks, absorbing excess renewables, and making the system more resilient. Miners who participate are not only improving their own economics, but also contributing to the sustainability and long-term growth of the grids they rely on.

As the mining industry matures and margins compress, the winners will be those who stack every available revenue stream, layering ancillary services on top of real-time mining optimization. Miners who master both will inevitably leave peers in the dust.

## Chapter 4: The Intelligent Mining Playbook

### The Future is Infinitely Variable

We've made it to the finish line, tracing a path from binary on/off mining to an integrated optimization solution, unlocking real-time responsive mining. However, this is not where the race ends. If anything, it opens onto a new track: one where Intelligent Miners don't just react to current conditions, but anticipate future ones.

Most of today's optimization strategies revolve around present-state economics: what is the hashprice now? What is the power cost during this interval? These are powerful levers, and as we've seen, they create meaningful profit uplift versus binary mining.

The next frontier is in forecasting: shifting from reaction to prediction. Firmware, fleet management, and derivatives unlock the ability to optimize a mining fleet at every point, not just the extremes. Hashprice and power markets are never static; they fluctuate by the minute, sometimes by the second. Intelligent Miners can respond accordingly:

- A forward-looking miner may monitor the forward hashrate curve, mempool activity, and estimates for incoming difficulty adjustments to forecast changes in hashprice and blockspace demand.

- In deregulated energy markets like ERCOT, there is alpha in forecasting power prices ahead of time. Short-term forecasts may enable miners to avoid uneconomic intervals before they happen, or to stay online when transient spikes would otherwise trigger premature curtailment, reducing unnecessary wear-and-tear while capturing more cumulative profit.

- A forward looking miner with a forecast or view can use energy markets, such as the Day-Ahead Market (DAM) to lock in pricing and avoid real-time volatility (or benefit from it). This results in increased operational certainty, and potentially higher operational profit with quality forecasting.

The point is to **remain agile** across all possible states. Mining economics are converging toward perfect competition: margins will thin, volatility will increase, and capital will consolidate. Miners who make every watt and hash count by treating their machines as infinitely variable instruments will define the next era of Bitcoin mining.

# Chapter 5: Conclusion

## Why Intelligent Miners Will Win

The age of binary mining is closing. The industry is entering an era where those who continuously optimize fleets against moves in hashprice and power markets will be the only ones to not only survive, but thrive.

Several trends reinforce this outcome:

1. **Margins will continue to compress**
Bitcoin mining is a near-perfectly competitive industry. As more efficient fleets enter the network and difficulty climbs higher, profit margins will inevitably continue to compress, and running machines on a simple on/off basis will no longer be viable. Miners with stronger margins will attract capital and high valuations.

2. **Industry consolidation will accelerate**
Profitable and well-capitalized miners are already attracting new investment, acquiring distressed assets, and scaling operations. In the coming years, consolidation will be led by those who demonstrate operational excellence — the Intelligent Miners who consistently maintain profitability and resilience across market cycles. These consolidators will set the pace for the industry.

3. **Hashprice volatility will intensify**
With every halving, the fixed subsidy shrinks, and transaction fees represent a larger share of miner revenue. This dynamic will only make hashprice more volatile. Surviving in such an environment requires the ability to dynamically respond to swings in both blockspace demand and power prices — something binary miners are structurally incapable of doing.

**Binary mining produces structurally worse outcomes than Intelligent Mining.** While binary operators cycle between full-throttle and shutdown, Intelligent Miners continuously adapt — underclocking to preserve margins when power costs rise, overclocking to capture upside when energy is cheap or negative, and curtailing when the price is right. Over time, this difference will compound into survival for the Intelligent Miner and extinction for the binary one.

If you are ready to **move beyond binary** and to **master volatility**, reach out to us at Luxor. We can help establish your Intelligent Mining operation across the full stack.

— Happy Hashing!

## Miner Case Studies

### Case Study #1 — Miner facing Spot Hashprice & Power

A miner operating in ERCOT West Texas Load Zone with full exposure to both spot hashprice and spot power. This operator makes no use of hedges, embracing volatility on both sides of the margin. We compare performance from January 2022 through August 2025 for a 1 EH/s fleet of the Antminer S19j Pro (100 TH/s) under two scenarios: Intelligent Mining and binary mining.

### Case Study #2 — Miner facing Fixed Hashprice & Spot Power

A miner in ERCOT West Texas Load Zone with hedged hashprice exposure via rolling 6-month non-deliverable forward (NDF) contracts (USD-denominated), but unhedged power exposure to real-time spot electricity prices. This profile reflects an operator that secures predictable revenues while remaining flexible on the cost side. We compare post-halving performance from May 2024 through August 2025 for a 1 EH/s fleet of the Antminer S21 (200 TH/s) under Intelligent Mining and binary mining scenarios.

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⚠ *Disclaimer: The profitability figures in these case studies reflect gross margins relative to electricity costs only. They exclude other major expenses such as hardware capex, infrastructure buildout, labor, operations & maintenance, depreciation, and financing costs. In practice, once these factors are included, net margins are significantly lower. These simplified case studies are designed to isolate and illustrate the impact of Intelligent vs. binary mining decisions.*

*In addition, these figures exclude revenue upside opportunities from ancillary services and other alternative revenue streams.*

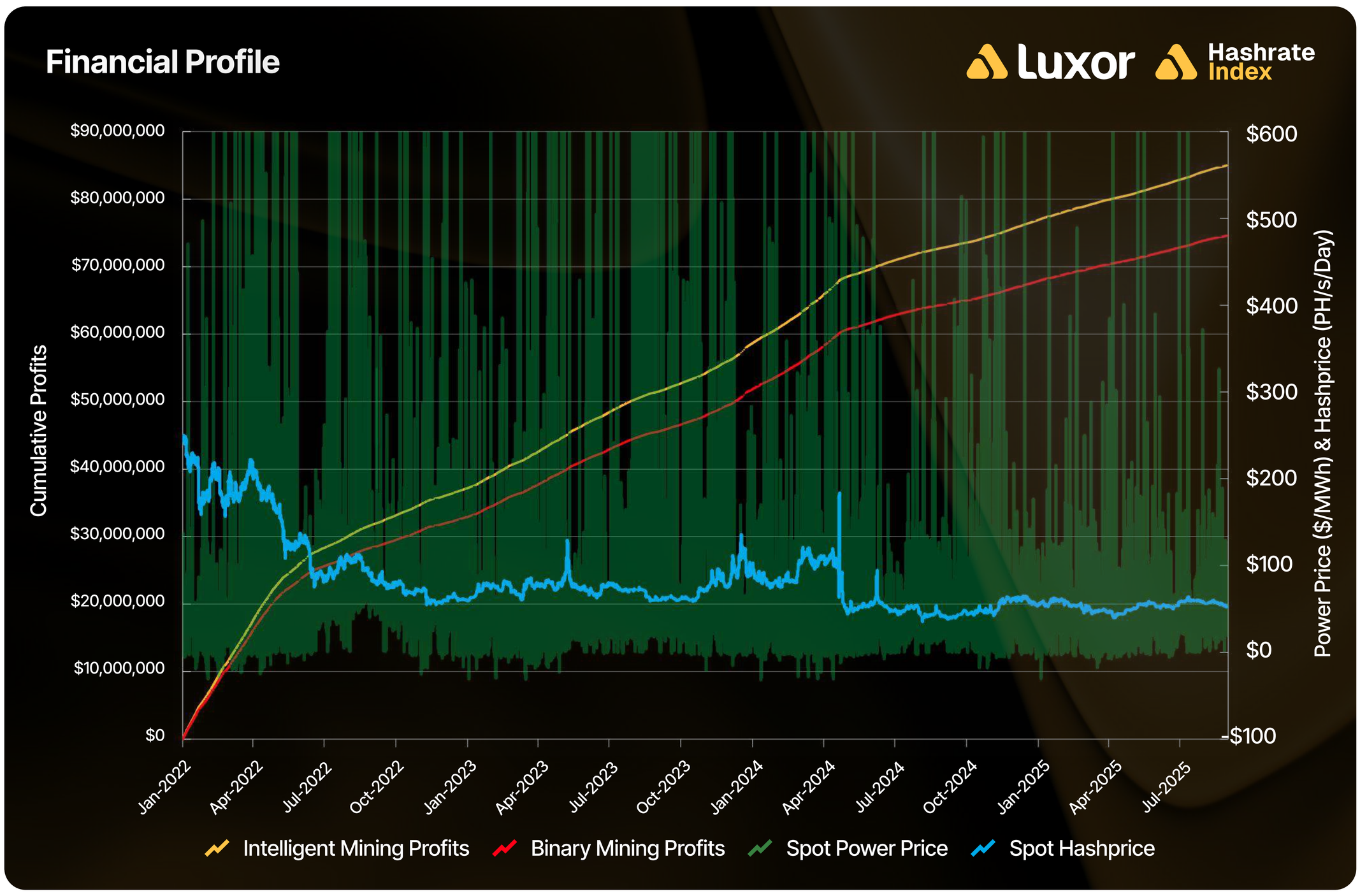
## Case Study 1: Spot Hashprice & Power

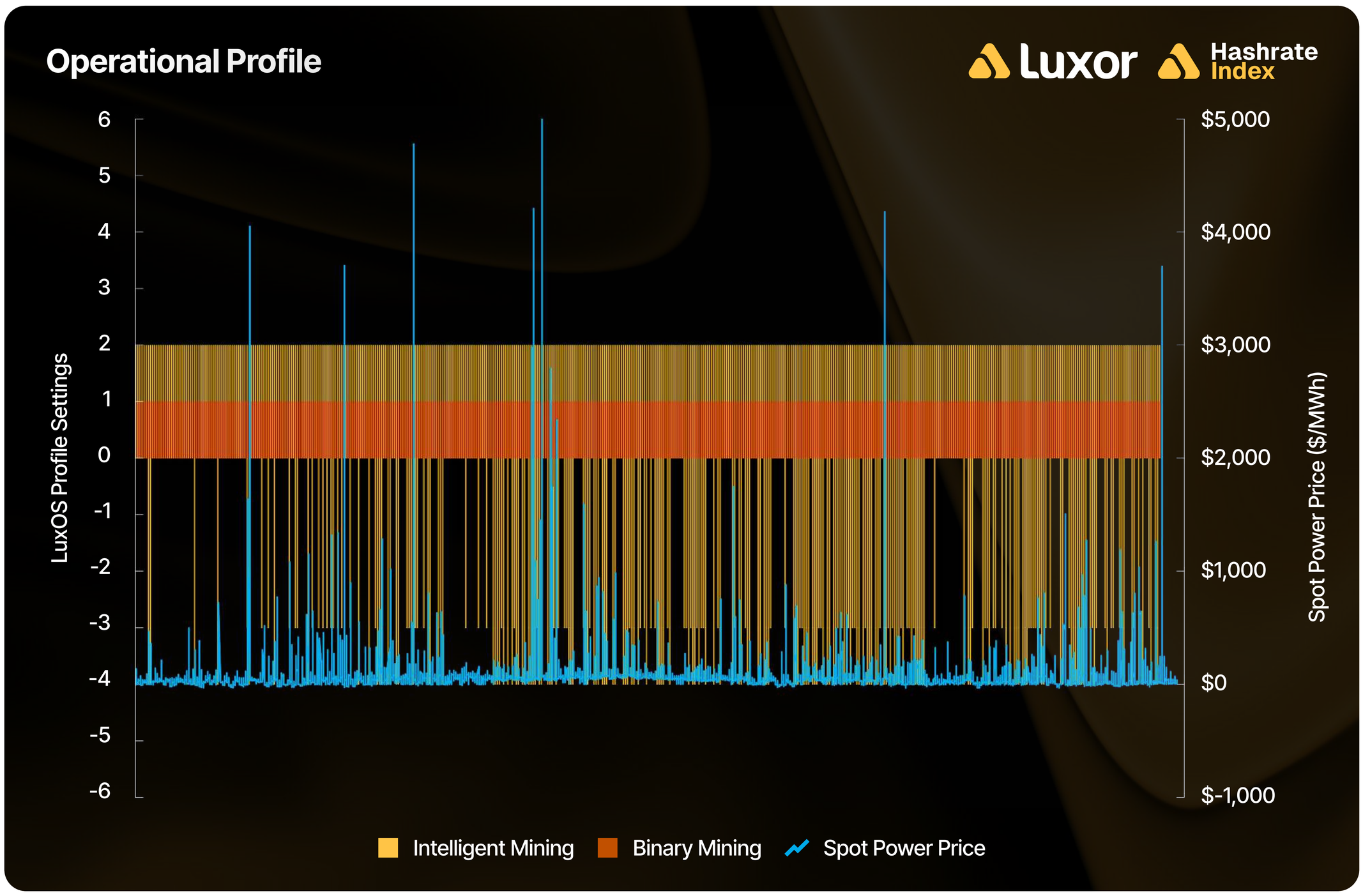
### Profile

1 EH/s miner operating in **ERCOT West Texas Load Zone**, fully exposed to both **real-time hashprice** and **real-time power.** The fleet consists of **10,000 Antminer S19j Pros (100 TH/s)**, deployed from **January 2022 – August 2025.**

### Results

| Metric | Intelligent Mining | Binary Mining |
|---|---|---|
| **Total Revenue ($)** | $112,604,202 (+9.5%) | $102,823,293 |
| **Total Cost ($)** | $27,539,358 (-2.3%) | $28,373,003 |
| **Gross Mining Profit ($)** | $85,064,844 (+14.0%) | $74,629,098 |
| **Gross Profit Margin (%)** | 75.54% (+2.96 pps) | 72.58% |
| **Average Hashprice ($/PH/s/Day)** | $81.56 | |
| **Average Power Price ($/MWh)** | $50.85 | |
| **Average Hashrate (EH/s)** | 1.021 EH/s (+10.1%) | 0.927 EH/s |
| **Total Power Consumed (MWh)** | 826,687 MWh (-5.9%) | 879,196 MWh |
| **Uptime (%)** | 95.62% (+2.29 pps) | 93.33% |
| **Curtailment Intervals** | 5,627 (-33.4%) | 8,571 |






## Insights

1. **Efficiency gains compound:** By continuously autotuning and profile switching, Intelligent Mining **reduced power consumption** by over **52,500 MWh** compared to binary mining, while delivering over **10% more average hashrate.**

2. **Reduced curtailment:** Intelligent Mining required **33% fewer curtail intervals**, keeping machines online longer while still avoiding unprofitable operations. As a result, overall **uptime improved by 2.5%.**

3. **Margin expansion:** Tighter cost control and higher hashrate performance improved profit margins by **2.96 percentage points.**

4. **Snowball effect:** Over four years, Intelligent Mining outperformed binary mining by **14% in cumulative profit**, demonstrating how disciplined intra-interval optimization can compound into competitive advantage over time.

## Conclusion

For miners exposed to the volatility of ERCOT's West Texas zone, binary on/off strategies leave significant money on the table. Intelligent Mining turned this risk into opportunity, delivering more hashrate, lower costs, higher uptime, better efficiency, and ultimately stronger margins.

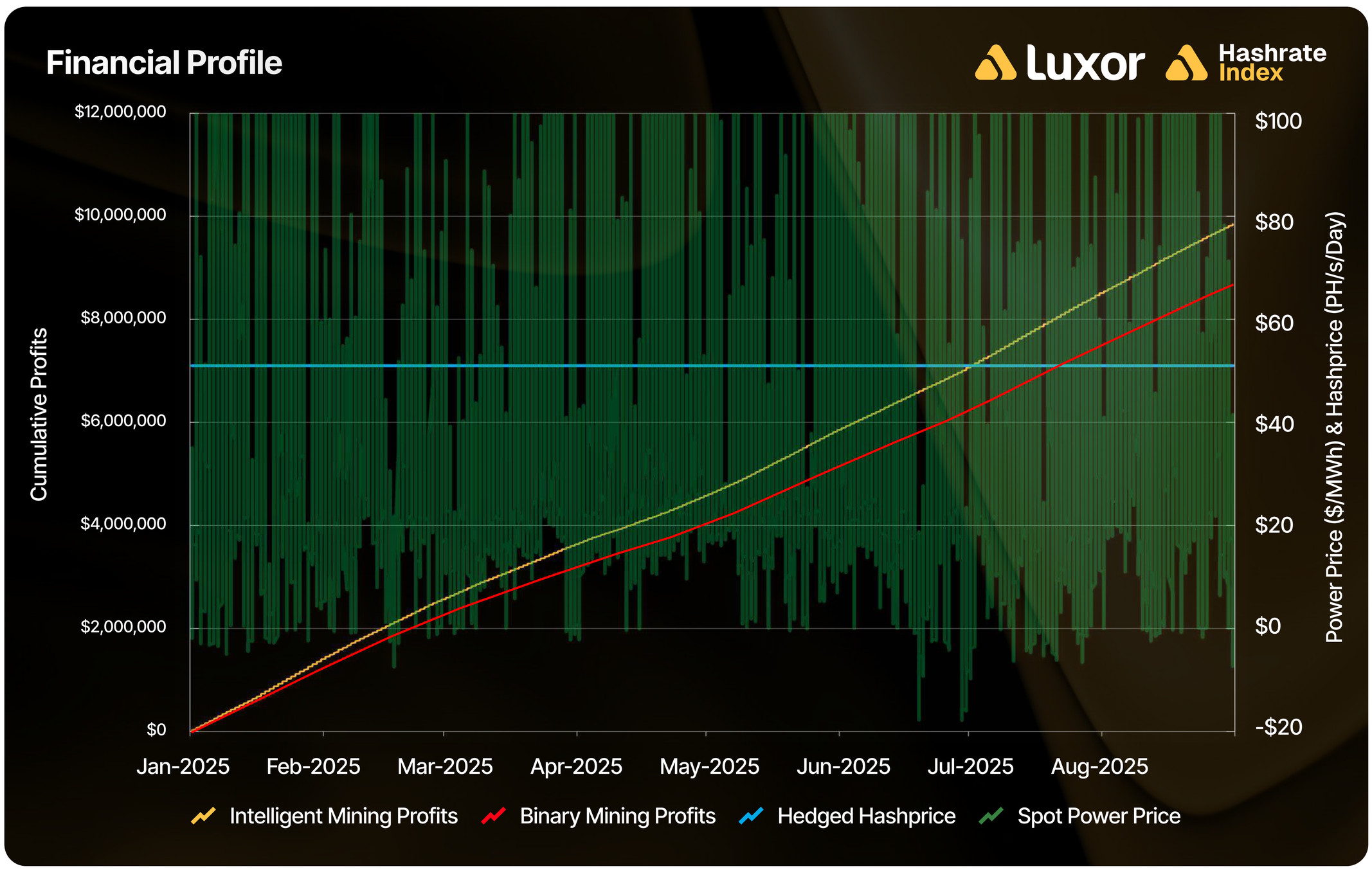
## Case Study 2: Fixed Hashprice & Spot Power

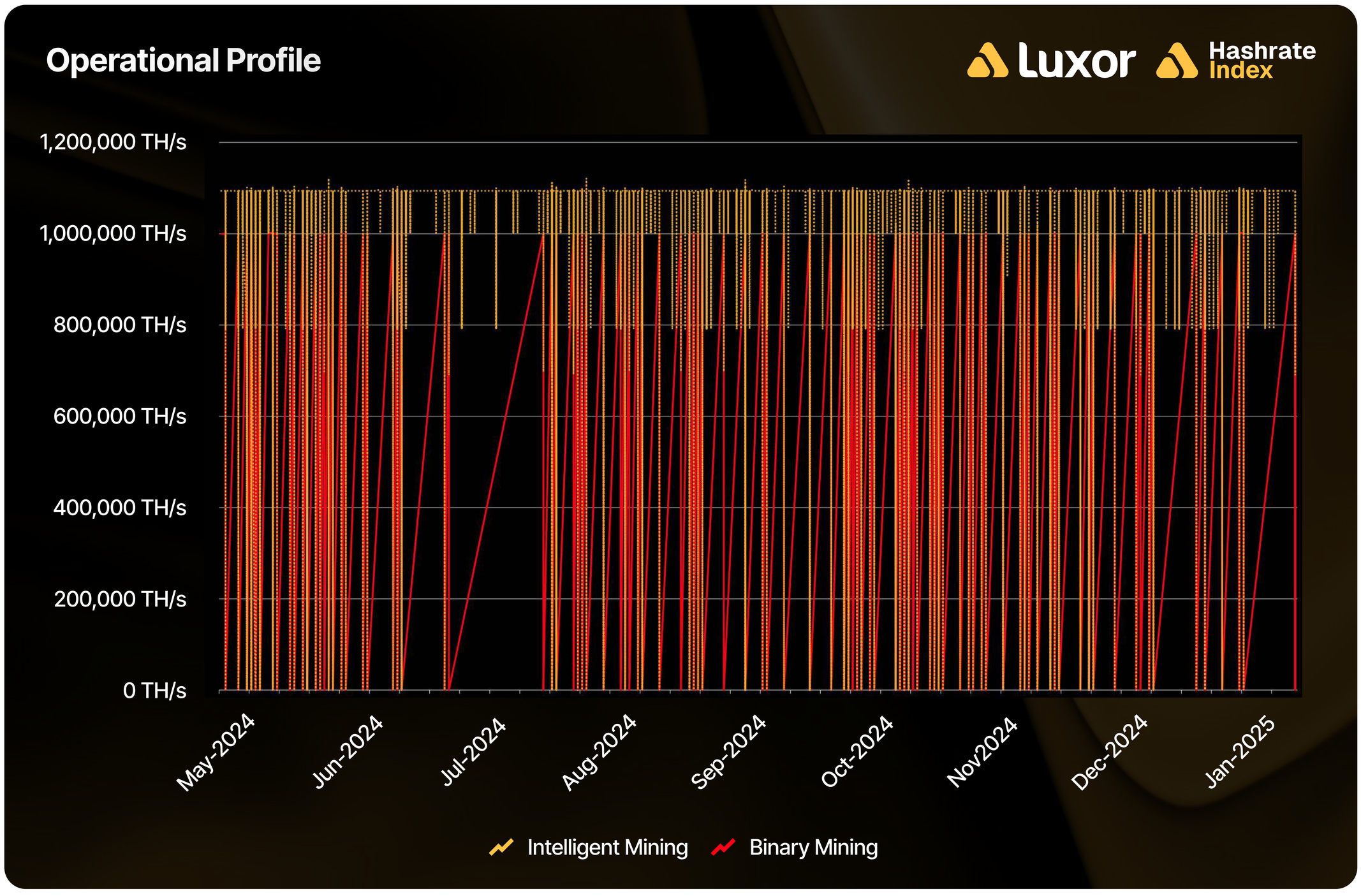
### Profile

1 EH/s miner operating in **ERCOT West Texas Load Zone**, hedging hashprice via rolling 6-month contracts (USD-denominated) while remaining exposed to **spot power price**. The fleet consists of **5,000 Antminer S21 units (200 TH/s)** deployed from **May 2024 – August 2025.**

### Results

| Metric | Intelligent Mining | Binary Mining |
|---|---|---|
| **Total Revenue ($)** | $26,363,596 (+8.6%) | $24,273,875 |
| **Total Cost ($)** | $7,438,663 (+10.5%) | $6,732,224 |
| **Gross Mining Profit ($)** | $18,924,933 (+7.9%) | $717,773,365 |
| **Gross Profit Margin (%)** | 71.8% (-0.5 pps) | 72.3% |
| **Average Hashprice ($/PH/s/Day)** | $51.00 | |
| **Average Power Price ($/MWh)** | $39.68 | |
| **Average Hashrate (EH/s)** | 1.059 EH/s (+8.6%) | 0.975 EH/s |
| **Total Power Consumed (MWh)** | 225,358 MWh (+12.7%) | 199,903 MWh |
| **Uptime (%)** | 97.97% (+0.45 pps) | 97.52% |
| **Curtailment Intervals** | 948 (-18.1%) | 1,162 |






## Insights

1. **Revenue uplift:** Intelligent Mining generated **$2.1 million additional revenue (+8.6%)**, as a result of higher uptime and increased hashrate from overclocking.

2. **Efficiency vs. power tradeoff:** Power costs climbed **~10.5%** as Intelligent Mining consumed ~12.7% more MWh. Yet, the revenue uplift outweighed these higher costs, driving **$1.4 million in additional profit (+7.9%)**. Counterintuitively, overclocking next-gen machines like the S21 can expand overall profitability even if margins compress. Overclocking burns more power but still delivers higher absolute profit.

3. **Curtailment precision:** Intelligent Mining encountered ~18% fewer curtailment intervals, avoiding unnecessary downtime while still responding to unprofitable prices.

4. **Capitalizing on cheap:** There were **2,769 intervals when prices fell to zero or below.** Intelligent mining exploited these windows by overclocking, squeezing out extra hashrate while the hedged hashprice guaranteed stable revenue.

## Conclusion

For miners hedging hashprice but riding real-time power, Intelligent Mining is decisive. Despite drawing more power, it delivered higher uptime, stronger hashrate, and nearly 8% more profit than binary operations. Hedged or unhedged: real-time fleet optimization turns volatile markets into opportunities, ensuring miners capture every possible edge.

## Resources

1. https://docs.luxor.tech
2. https://hashrateindex.com
3. Gridstatus.io
4. The Intelligent Investor

## About Luxor Technology Corporation

Luxor Technology Corporation is a Bitcoin mining software and services company that offers a suite of products catered toward the mining and compute power industry. Luxor's suite of software and services includes an Antminer ASIC Firmware, an ASIC Marketplace, a Bitcoin mining Pool, an Hashrate Derivatives Desk, and Hashrate Index a bitcoin mining data platform.