Will AstroForge Collapse the PGM Market?

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AstroForge seeks to mine platinum group metals (PGM) from asteroids. Asteroid reserves appear to be unlimited, and at current market price the gross margin of asteroid mining would be very high. It is natural to ask: when AstroForge successfully demonstrates economic space mining of PGM, will they cause the PGM market to collapse? We answer the question with a non-steady system dynamics model of the PGM market. We find that the market price for PGM will eventually drop towards the much lower cost of asteroid mining, but only after the entire supply has shifted off-world. In the meanwhile, huge fortunes will be made. And everybody on Earth will benefit from new applications of lower-price PGM.

INTRODUCTION

Platinum Group Metals (PGMs) serve as the backbone for both current industrial standards and the burgeoning green energy transition. Traditionally, the automotive sector has been the primary consumer of these materials, utilizing approximately 90% of global PGM supply in the production of catalytic converters to mitigate harmful exhaust emissions [1]. However, as the global economy pivots from internal combustion engines to electric and hydrogen-based platforms, the demand profile is shifting. The hydrogen energy sector, which relies on PGMs for the production and utilization of hydrogen fuel, is projected to become the largest end-market for platinum by 2040 [2]. Beyond these sectors, PGMs remain indispensable in electronics, chemical processing, and high-end jewelry.

The PGM "basket" is dominated by palladium and platinum; annual production is summarized in Table I. Production remains concentrated: in 2023 and 2024, global output reached 208 and 190 metric tons of palladium, and 179 and 170 metric tons of platinum, respectively. Total terrestrial reserves are estimated at roughly 100,000 metric tons, with the vast majority localized in Russia and South Africa's Bushveld Complex [1]. Despite these reserves, the industry faces a structural deficit. Demand consistently outstrips supply [3] and is forecast to grow at a Compound Annual Growth Rate (CAGR) of 4.72% through 2031, driven largely by the green energy mandate [4].

This supply–demand imbalance has kept PGM prices high, yet terrestrial mining operations are struggling to remain profitable. Commodity market volatility has compressed average gross margins to single digits, with an estimated 25% of producers operating at negative margins below certain spot prices [6]. These economic pressures are exacerbated by physical constraints: as existing mine shafts reach greater depths, the costs associated with refrigeration, reefing, and power requirements climb exponentially [4, 7]. We are approaching a geological "event horizon" where the energy and capital required for extraction may soon exceed the market value of the metals themselves.

Asteroid mining presents a transformative solution to these terrestrial limitations, offering superior ore grades and virtually limitless volume. While terrestrial "high-grade" ores typically yield 4 to 10 parts per million (ppm), analysis of iron meteorites suggests metallic asteroids contain PGM concentrations ranging from 100 ppm to as high as 187 ppm [8]. The scale of this resource is difficult to overstate: a single metallic asteroid approximately one kilometer in diameter could contain more PGMs than have been harvested in all of human history, plus all known remaining Earth-based reserves [9]. The valuation of such a single body reaches into the trillions of dollars [10].

Beyond economics, moving extraction off-planet offers a significant environmental and social dividend. Terrestrial mining is synonymous with ecological degradation, including acid mine drainage and the contamination of water tables with arsenic and lead [10]. Asteroid mining eliminates these local environmental impacts and bypasses the "not in my backyard" (NIMBY) opposition and land-use conflicts associated with tailings dams [11]. Furthermore, the transition to highly automated space-based mining could reduce global reliance on dangerous artisanal mining practices often linked to human rights abuses in developing nations [10].

Leading this transition is AstroForge, a commercial pioneer aiming to decouple PGM supply from Earth's terrestrial constraints. By targeting metallic asteroids with projected profit margins of roughly 85%—a stark contrast to the 7% margins seen in terrestrial mines—AstroForge is attempting to prove the economic case for deep space resources [12]. Their strategy favors high-frequency, low-cost iteration; the company's initial spacecraft were developed for approximately \$3.5 million, a fraction of the \$95 million typically required by govern-

TABLE I. Summary of PGM mine production (kg/y) and reserves (kg). Source: [1, 5].

	Mine production				
	Palladium		Platinum		PGM reserves
Country	2023	2024[e]	2023	2024[e]	
United States	10,300	8,000	3,040	2,000	820,000
Canada	16,100	15,000	5,170	5,200	310,000
Russia[e]	87,000	75,000	21,000	18,000	16,000,000
South Africa	74,900	72,000	125,000	120,000	63,000,000
Zimbabwe	15,900	15,000	19,200	19,000	1,200,000
Other countries	4,200	4,200	5,710	4,600	N/A
World total	208,000	190,000	179,000	170,000	>81,000,000

World resources: PGMs are estimated to total more than 100 million kilograms. The largest resources and reserves are in the Bushveld Complex in South Africa.

ment space agencies. Following the 2025 launch of their first deep space vehicle, *Odin*, the company is currently preparing its 2026 DeepSpace-2 mission. This mission aims to execute the first private landing on a celestial body beyond Earth's gravity well to provide definitive ground-truth validation of PGM concentrations [13].

The natural question is: if AstroForge—and presumably other follow-on ventures—successfully demonstrates that asteroid mining of PGM is viable, will the PGM market inevitably collapse? In a recent podcast, AstroForge addressed this very topic. The answer given was "no", but the rationale was weak. This is understandable, since most economic textbooks [14] treat supply and demand curves with equilibrium arguments, qualified by "short term" and "long term." But the transition dynamics are exactly what we are interested in. In this note we attempt to answer the question by developing a non-steady system dynamics [15] model of the PGM market. We expect that "yes", the PGM market will collapse. Total market profit will increase by about a factor of eight before collapsing to less than half the initial value. The asteroid miners will be the winners in the profit run-up, and the terrestrial miners will be the losers. And to the extent that PGM enables new technologies (electronics, electric cars, *etc.*), we will all be the winners.

THE BUSINESS OF ASTEROID MINING

AstroForge's operational roadmap for mining Platinum Group Metals from asteroids follows a sequential process of target validation, magnetic anchoring, photonic extraction, and refined material return. This architecture is designed to avoid the prohibitively high costs of returning waste rock to Earth or the technical complexities of mechanical drilling in microgravity.

The process begins with the identification of Near-Earth Asteroids (NEAs) exhibiting metallic spectral signatures. Because ground-based observations cannot definitively confirm the presence of high-concentration ore bodies, AstroForge's plan utilizes precursor missions to validate targets. The company's roadmap involves sending scout spacecraft—such as the *Odin* and *DeepSpace-2* vehicles—to rendezvous with candidate asteroids. *DeepSpace-2* is specifically designed to attempt the first commercial landing on a body outside Earth's gravity well to verify the surface composition and ensure the target is indeed a PGM-rich metallic body rather than a "rubble pile" or non-metallic rock [12, 13, 16]. The mission architecture utilizes high-energy launch trajectories, such as Trans-Lunar Injection (TLI), and leverages lunar gravity assists to slingshot the vehicle toward the target asteroid in deep space [16].

Upon arrival and matching rotation with the asteroid, the mining vehicle faces the challenge of securing itself in a microgravity environment where standard drilling forces would push the spacecraft away from the surface. AstroForge addresses this by targeting "M-type" (metallic) asteroids, which are composed primarily of iron and nickel, and using spacecraft equipped with landing legs featuring switchable "clamping" magnets. These magnets allow the vehicle to adhere firmly to the iron-rich surface of the asteroid, providing a stable platform for extraction operations without complex mechanical gripping systems [17, 18].

Once anchored, the extraction system utilizes high-power lasers to vaporize and eject regolith from the asteroid's surface into a collection system with minimal physical resistance. Returning raw asteroid material to Earth is economically unfeasible due to the low density of PGMs within the bulk iron-nickel matrix. Therefore, the AstroForge model relies on in-situ refining—separating the valuable PGMs from the lower-value iron and nickel waste slag in deep space. This process concentrates the ore, aiming to produce a material (similar to a "doré bar") with a purity of approximately 60% or higher [18].

The final phase involves returning only the concentrated high-value materials to Earth. The mining vehicle essentially functions as a return capsule; the refined

PGMs are loaded into the body of the spacecraft, which is equipped with a standard heat shield. The vehicle flies back to Earth and performs an atmospheric reentry, protecting the payload until it reaches the ground for recovery and final sale on the terrestrial market [18].

MODELING THE MARKET TRANSITION TO ASTEROID PGMS

Once AstroForge demonstrates that it is possible to recover PGM from asteroids at eighty percent gross margin, profit motive will inspire other companies to do the same. Increased supply will indeed start to reduce prices, but as long as some terrestrial sources remain the market price will stay high enough that asteroid mining will enjoy healthy margins. Asteroid reserves are practically unlimited, so investment can continue until essentially all terrestrial demand for PGM is supplied off-world. Eventually commodity dynamics will drive the gross margins once again down to equilibrium values, around ten percent.

A PGM market dynamic simulation can be created to get a sense of the trajectory from terrestrial to all off-world mining. Three representative points in the trajectory are considered to bound the relevant parameter ranges:

1. **Initial conditions**, representative of the PGM market today, when all mining is terrestrial. Market efficiencies have driven the gross margin down to $\mathrm{gm} = 0.1$.

2. **Peak conditions**, during the transition between terrestrial and off-world mining when gross margin peaks. The costs are reflective of off-world mining, yet the market price has not yet fallen. The average margin is reflective of the new technology: $\mathrm{gm} = 0.8$.

3. **Final conditions**, when all mining has moved off-world. Once again market efficiencies have driven the gross margin down to $\mathrm{gm} = 0.1$.

For simplicity, it is assumed the market demand remains constant at all three points. The relevant market variables and their symbols are collected in Table II, and the governing relations are

$$R = Q \cdot P, \tag{1}$$

$$E = Q \cdot C, \tag{2}$$

$$\Pi = R - E, \tag{3}$$

$$\mathrm{gm} = \frac{\Pi}{R} = 1 - \frac{C}{P}, \tag{4}$$

$$P = \frac{C}{1 - \mathrm{gm}}. \tag{5}$$

TABLE II. Market variable definitions.

Description	Symbol	Units
Market volume	Q	ton/y
Market price	P	M$/ton
Cost	C	M$/ton
Market revenue	R	M$/y
Market expenses	E	M$/y
Market profit	Π	M$/y
Gross margin	gm	—

Table III presents a "back of the envelope" sketch of the trajectory of market dynamics. Market profit peaks at eight times the initial value before falling to less than one quarter the original value.

Expanding the model into a dynamic simulation using System Dynamics allows us to capture the market transitions from terrestrial to off-world mining, depicted in Table III, but with higher fidelity.

Simulating PGM Supply Capacity

Figure 1 presents a stock and flow model of the PGM supply, categorized by cost as low, medium, or high. The bulk of the terrestrial supply—in South Africa and Russia in today's market—is assumed to be a Medium Cost Supply (MC). The MC stock capacity, median cost, and standard deviation of cost are all assumed fixed. The High Cost Supply (HC) is characteristic of the PGM supply found elsewhere terrestrially, such as in the United States. HC capacity is much smaller than MC, and the median costs are higher, but also fixed. In this model, the off-world asteroid mining is considered Low Cost Supply (LC) and is variable based on the flow generated by asteroid mining entities such as AstroForge. LC capacity is a new supply stock which starts small and grows through investment attracted by high gross margins relative to an industry norm, as represented. The LC median cost and standard deviation of cost are assumed fixed.

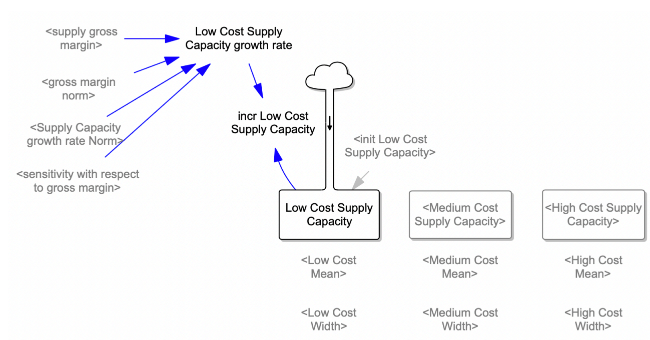

FIG. 1. Model of the Low Cost Supply Capacity of PGMs from asteroid mining.

TABLE III. Back-of-the-envelope sketch of trajectory of market dynamics.

Description	Symbol	Units	Initial	Peak	Final
Market demand	Q	ton/y	400	400	400
Market price	P	MUSD/ton	60	60	11
Average gross margin	GM	—	0.1	0.8	0.1
Average cost	C	MUSD/ton	54	12	10
Market revenue	R	MUSD/y	24,000	24,000	4,444
Market profit	Π	MUSD/y	2,400	19,200	444
Steady?			Yes	No	Yes

The market's natural push to maximize the gross margin [Eq. (4)] will continuously push cost C lower. The current terrestrial-only market favors the Medium Cost supply in Russia and South Africa over the High Cost supply elsewhere. Likewise, as the Low Cost supply capacity increases due to increased asteroid mining, the favored supply will move from MC to LC.

The structure of the dynamics of the LC capacity can be described with a Causal Loop Diagram, as presented in Figure 2.

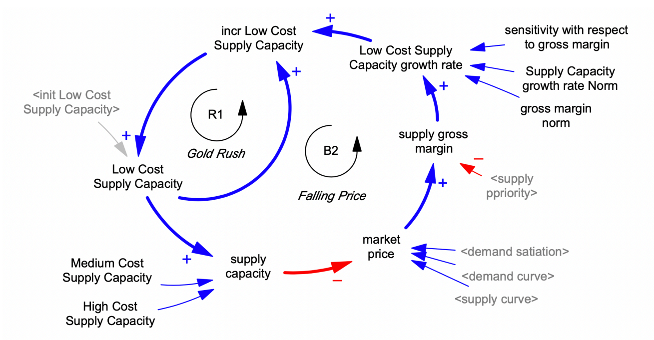

FIG. 2. Asteroid PGM mining supply causal loop diagram.

AstroForge's demonstration of low-cost, unlimited mining of PGMs kicks off reinforcing feedback loop R1 *Gold Rush*: the initial gross margin is much higher than the industry average, which attracts exponentially growing investment. Eventually the low cost supply capacity is large enough to start to depress the market price, which triggers a balancing feedback loop B2 *Falling Price*, which reduces the growth rate of investment. The attractiveness of investment is proportional to the spread between the gross margin of the low cost capacity and the industry norm.

Solving for PGM Market Price

To solve for the market price of PGMs as the supply shifts from terrestrial to off-world mining, we use the built-in Vensim function `FIND_MARKET_PRICE` to satisfy the allocation of supply to demand. This is a non-trivial—but solved—problem. To quote from Ventana [19], a good allocation formulation must satisfy six properties:

1. **Conservation of Matter.** The amount received by the demanders (summed across all demanders) must equal the amount provided by the suppliers (summed across all suppliers).

2. **Nonnegative.** All quantities allocated must be positive or zero.

3. **Conservation of Intent.** No supplier shall provide more than it desired to supply and no demander shall receive more than it has chosen to demand. (Less, however, is possible.)

4. **No Loopholes.** Under conditions of adequate supply, each demander should receive its stated demand. Under conditions of adequate demand, each supplier should supply its stated supply.

5. **Clear Differentiation.** When there is insufficient supply, extremely low-priority demanders should receive little or nothing and extremely high-priority suppliers should receive everything or almost everything. Conversely, when there is excess supply, extremely unattractive suppliers should provide little or nothing and extremely attractive suppliers should provide the bulk of the demand.

6. **Continuity.** Small changes in priorities, supply, and demand should cause small changes in the resulting allocations. Smoothness, which requires that small changes cause only small changes in the derivative of the allocations, is also often desirable.

With some adjustment and manipulation, allocation logic can be made to pass properties 1 through 4, but satisfying property 5 is very hard. The formulation in Vensim satisfies all six.

The many-to-many allocation problem takes the demand preferences of one or more consumers and the supply preferences of one or more providers and matches these [20]. We discuss this as finding the price at which the supply, summed across all providers, equals the demand, summed across all consumers. If one is working with true supply and demand curves, that price is the standard market clearing price. We first find the price that clears the market with FIND_MARKET_PRICE, then compute the amount supplied by the different providers using SUPPLY_AT_PRICE and the amount demanded by the different consumers using DEMAND_AT_PRICE.

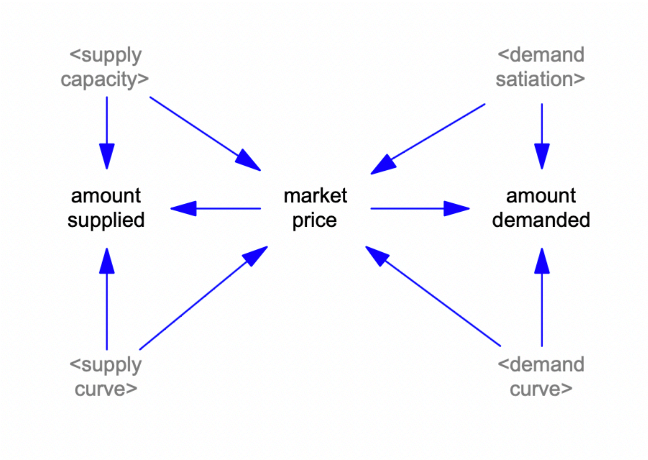

FIG. 3. Solving many-to-many allocation [20].

RESULTS

Using the System Dynamics model, an example scenario trajectory is presented in Figure 4. After the first demonstration of economic mining of PGM on asteroids (low cost supply, LC) at $t = 0$, the appeal of high margins attracts increasing investment resulting in exponential growth of capacity (top left panel). Capacity growth starts to slow when supply is sufficient to start to depress market price (bottom right panel). The declining price has first impacted the thin margins of the US PGM mines (high cost supply, HC), reducing the market share (top right panel). Continued investment in low cost supply continues large enough to take market share from the bulk terrestrial PGM mines (medium cost supply, MC). Declining market price stimulates an increased demand (bottom center panel). Eventually the market price drops down near the cost of the low cost supply, the investment rate drops, and the low cost capacity stabilizes (top left panel). Growth of a new, low-price market segment (lower left panel) means the ultimate supply quantity is much larger than the initial quantity.

DISCUSSION

The potential for AstroForge to disrupt the Platinum Group Metals market rests on its ability to successfully launch deep-space vehicles, intercept metallic asteroids, and return refined materials to Earth. If successful at a sufficiently low cost point, the company will enter a market where prices are currently anchored to expensive terrestrial operations, ensuring a projected gross margin of approximately 85%.

Our simulation model highlights that this "Gold Rush" phase is a product of non-steady-state dynamics. As AstroForge demonstrates the economic viability of asteroid mining, the high returns will inevitably attract competition from other commercial aerospace entities. This influx of capital triggers the Reinforcing Loop (R1), leading to exponential growth in Low Cost Supply (LC) capacity.

As this supply reaches the market, it will systematically displace terrestrial sources based on their cost structures:

- **High-Cost (HC) Suppliers.** Initial price declines will first impact thin-margin operations, such as those in the United States, causing them to lose market share early in the transition.
- **Medium-Cost (MC) Suppliers.** Continued investment in asteroid mining will eventually take market share from the bulk of terrestrial production currently localized in South Africa and Russia.

Ultimately, the Balancing Loop (B2) will take effect as supply abundance depresses market prices. The simulation reveals that while asteroid PGM mining is exceptionally lucrative in the short term, the market will eventually reach a new equilibrium. In this final state, market prices will drop toward the actual cost of off-world extraction, and gross margins will compress back to industry norms of roughly 10%.

The strategic takeaway is clear: the window for outsized profits is finite. The key to the PGM "gold rush" is to be an early mover and capitalize on terrestrially-anchored prices before the market corrects for the coming era of asteroid-sourced abundance.

CONCLUSION

The transition from terrestrial to space-based extraction of Platinum Group Metals represents more than a technological milestone; it is a fundamental shift in the global economic landscape. As this analysis demonstrates, the successful deployment of AstroForge's mining architecture will likely initiate a non-steady market transition where terrestrial operations are ill-equipped to survive.

Our system dynamics model suggests that the PGM market will undergo two distinct phases:

1. **The Gold Rush Phase.** Early movers will capitalize on the vast delta between the low costs of asteroid mining and the high, terrestrially-anchored market prices. During this window, market profits are projected to peak at eight times their initial value.

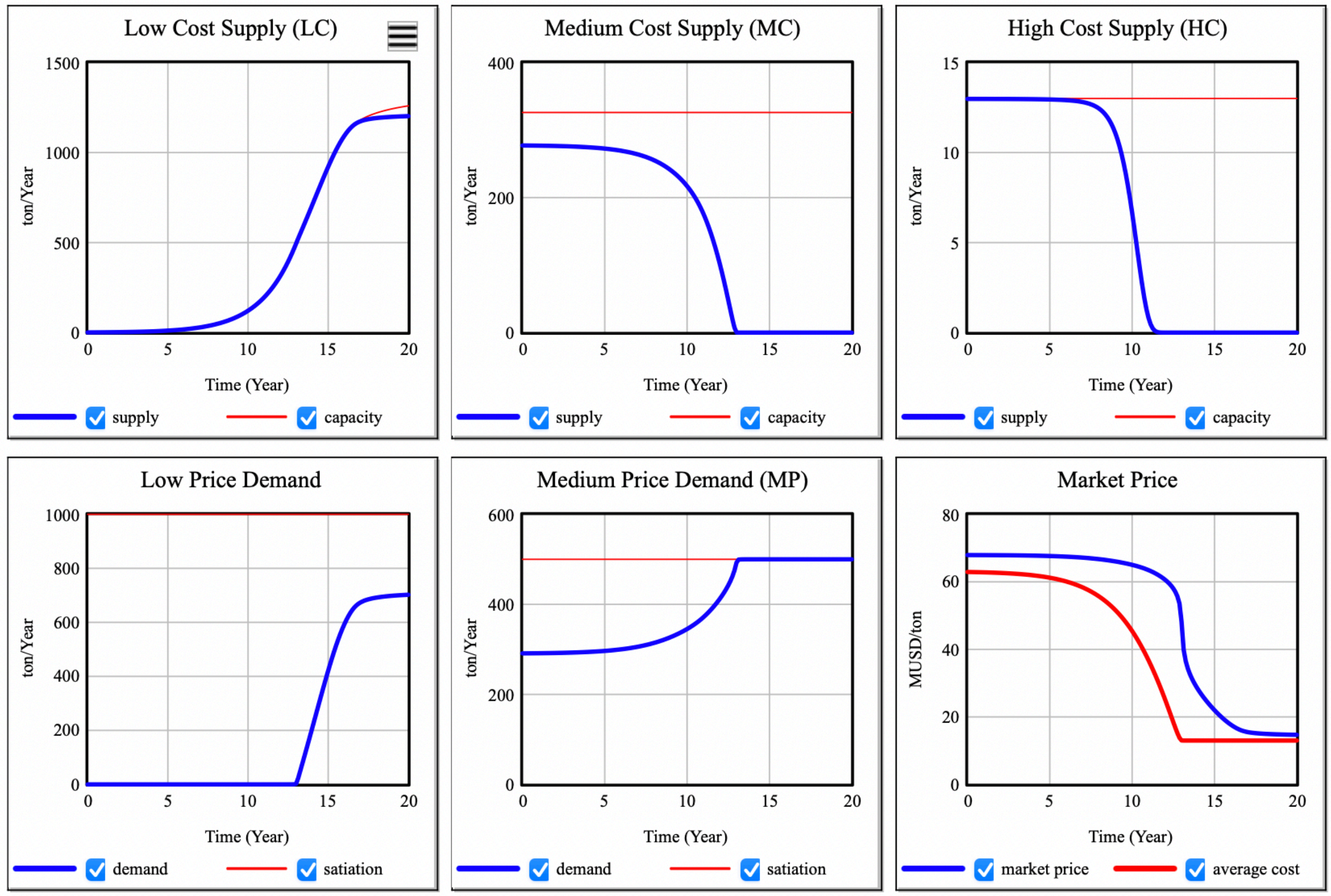

FIG. 4. Example scenario trajectory of PGM demand, supply, and market price as supply moves from terrestrial to asteroid mining.

2. **The Equilibrium Collapse.** As asteroid-sourced supply eventually displaces terrestrial capacity, the market price will decouple from Earth-based mining costs and drop toward the lower cost of off-world operations. While this "collapses" the traditional market price, it stabilizes at a new steady state where gross margins return to industry norms of approximately 10%.

The implications of this shift extend beyond the balance sheets of aerospace firms. The displacement of terrestrial mining offers a significant environmental and social dividend, potentially ending the ecological degradation and human rights concerns associated with deep-shaft and artisanal mining. Furthermore, the resulting abundance of low-cost PGMs will likely catalyze a new era of industrial innovation, particularly within the green energy and hydrogen sectors.

Ultimately, the "collapse" predicted by our model is not a failure of the market, but its evolution. While terrestrial miners face a geological and economic "event horizon," the rest of the global economy stands to benefit from an era of virtually limitless resources. For AstroForge and its successors, the message is clear: the greatest rewards belong to those who can bridge the gap between Earth and the asteroids before the market corrects for the coming abundance.

[1] U.S. Geological Survey, *Platinum-Group Metals*, 2020 Minerals Yearbook.

[2] M. Flaherty, "Viewpoint: PGM demand from hydrogen sector to rise," *Argus Media*, 20 Dec. 2024.

[3] S. Zhang *et al.*, "Supply and demand of platinum group metals and strategies for sustainable management," *Renewable and Sustainable Energy Reviews* **204**, 114821 (2024).

[4] Mordor Intelligence, *Platinum Group Metals—Market Share Analysis, Industry Trends & Statistics, Growth Forecasts (2026–2031)*, 12 Jan. 2026.

[5] U.S. Geological Survey, *Mineral Commodity Summaries 2025—Platinum-Group Metals*, `https://pubs.usgs.gov/periodicals/mcs2024/mcs2024-platinum-group.pdf`.

[6] E. Sterck *et al.*, "Platinum essentials," World Platinum Investment Council, 14 Dec. 2023.

[7] J. Jacobsen, "Deeper mines are tantalising but costly," *Mining Magazine*, Mar. 2022.

[8] T. Abbasi, *Investigating Economic Potential of Asteroid Mineral Resources: A Case Study on Platinum and Water*, M.S. thesis, McGill University (2018).

[9] S. D. Ross, "Near-Earth asteroid mining," Space Industry Report, Caltech, 14 Dec. 2001.

[10] K. Yarlagadda *et al.*, "Asteroid mining: A review," (2022).

[11] M. Sonter, "Near earth objects as resources for space industrialization," *Solar System Development Journal* **1** (2001).

[12] AstroForge, "Unlocking deep space resources through asteroid mining," `https://www.astroforge.io` (2026).

[13] C. Snowden, "Odin't: A complete debrief of our deep space mission," AstroForge, 6 Mar. 2025.

[14] R. S. Pindyck and D. L. Rubinfeld, *Microeconomics*, 7th ed. (Pearson/Prentice Hall, Upper Saddle River, NJ, 2009).

[15] J. Sterman, *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Irwin/McGraw-Hill, Boston, 2000).

[16] "Episode 42," *Roid Rage* podcast, AstroForge.

[17] "Episode 49," *Roid Rage* podcast, AstroForge.

[18] "Episode 45," *Roid Rage* podcast, AstroForge.

[19] Ventana Systems, Vensim Help, "Requirements of a realistic allocation logic," `https://www.vensim.com/documentation/24320.html`.

[20] Ventana Systems, Vensim Help, "Many-to-many allocation," `https://www.vensim.com/documentation/24340.html`.